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Numerical Simulation of Piled-Raft Foundation in Cohesionless Soil using ABAQUS

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Abstract

Due to rapid growth in infrastructure sector, the construction of high-rise buildings is becoming very popular among all the countries. Engineers face significant issues with high rise buildings, particularly in terms of structural and foundation aspects. Many old design approaches can't be used with certainty since they involve extrapolation far beyond the domains of existing experience, hence structural and geotechnical engineers are being compelled to use more advanced analysis and design methodologies. The current study is an attempt to predict the bearing capacity and settlement behavior of piled-raft footing when embedded into cohesionless deposit. The numerical analysis has been carried out to examine the effect of numerous key parameters of pile and raft such as pile length (10, 15, 20 m), pile diameter (0.3, 0.4, 0.5 m), pile number (16, 20, 24), pile spacing (2D, 3D, 4D) (where "D" is diameter of the pile), raft thickness (0.4, 0.5, 0.6 m), and angle of internal friction of soil (25°, 30°, 35°) on load-settlement behavior of the piled- raft foundation using ABAQUS software. A constant spacing between the piles, i.e. 3D was used throughout the analysis. The results of numerical investigation revealed an improvement in bearing capacity and a reduction in settlement value on increasing length, diameter and number of piles and also with increasing angle of internal friction. The current study not only increases the bearing capacity of the foundation but provides a cost-effective foundation technique to engineers.

1. Introduction

Conventional piled-raft foundation assumes that the loads are entirely taken by the piles and the effect of raft on load sharing mechanism is totally ignored. Since the raft is in immediate interaction with the soil and thus bears a large percentage of the load, this concept is extremely conservative. Number of researchers, through experimental and numerical analysis, examined the behavior of Piled-Raft Foundation (PRF hereafter), and it was observed that as compared to traditional methods, piled-raft foundation proves to be economical and more reasonable. Clay-based piled-raft foundation was examined and it was found that fraction of total load carried by the pile at failure was virtually constant and equivalent to unity with the piles beneath the raft having the same capacity as a freestanding pile group [1]. The slippage at the pile-soil interface and the pile designs greatly influence the growth of settlement and pile loads for a piled-raft. It was also discovered that the coefficient of the pile groups within a piled-raft and unpiled raft at failure for both stiff and soft clay were nearly equal to 1.0, indicating that the fraction of the load taken by the raft at the failure was not greatly dependent on the pile designs [2]. It was observed that rafts with lower raft-soil stiffness ratio and higher pile group to raft width ratio were found to be successful in reducing the average settling ratio [3]. For the case of piled-raft foundations in sand, the performance of piled-raft foundation in sandy soil was examined and analyzed that the pile spacing and pile number define the maximum settlement of piled-raft foundation. The raft thickness has negligible

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impact on total settlement [4]. It was found that for unpiled raft foundation, the load carrying capacity improves with the increase in size, whereas the raft thickness has negligible impact on load carrying capacity. It was also observed that in case of piled-raft system, the total load carrying capacity strengthens with the increase in raft size, pile number, pile length and pile diameter [5]. For a given number of piles, as the raft-soil stiffness improves; the load carrying capacity of the raft slightly decreases [6]. It was shown that in all situations, the soil underneath the raft played a key role in bearing the imposed loads in piled-raft foundation. The length to width ratio has a considerable impact on the pile with raft group, and the maximum settlement of the pile with slab footing does not exceed 5% of the raft width in all circumstances [7].

Computer based methodologies, which comprise of the following main approaches, have lately appeared to be effective tools for facilitating the design of such foundation systems: Method employing a strip on spring approach, method employing a plate on spring approach, boundary element method, and numerical analysis using Finite Element Method. ABAQUS 3-D analysis was done to investigate the behavior of piled-raft foundation in soft soils and was observed that the settlement decreases as the pile raft coefficient increases [2]. The behavior of piled-raft foundation using PLAXIS software was observed and found that the pile number and settlement are inversely proportional to each other [8]. The performance of piled-raft in clayey soils was analyzed focusing on raft size and pile length. From the analysis it was found that with the increase in pile length, the maximum settlement decreases [9]. A numerical study on PRF embedded in sandy soil using software PLAXIS was conducted and from the study it was observed that the governing factors affecting the performance of PRF are pile length, pile number, pile spacing, and raft thickness. It was also noticed that with the increase in the pile number and pile length, the load carrying capacity of the piled raft increases considerably while a significant decrease in the magnitude of settlement was noticed [10]. The various aspects of PRF were analyzed and main focus on numerous parameters like settlement, raft-soil behavior, bending moment, soil stress, and axial stress on pile etc. was done and it was found that PRF considerably reduces the total and differential settlement. Also in case of high rise buildings, PRF improves the bearing capacity of foundation. It was also revealed that differential and total settlement can be lowered by increasing the number of piles under raft. In the raft-soil contact behavior, the contact pressure increases with the increase in the raft width. Also with the increase in spacing to diameter ratio, bending moment increases [11]. A FEM software PLAXIS 2D was used to examine the performance of PRF in silty soil and clayey soil under uniform static loading. It was investigated that with the help of PRF total and differential settlement can be reduced significantly. The effect of number of piles and spacing was also studied and it was concluded that by increasing the number of piles and spacing between them kept constant, logarithmic decrement in total and differential settlement can be observed [12]. In the current study, a numerical analysis using FEM based software ABAQUS is used to understand the load-settlement behavior of piled-raft foundation embedded in sandy deposit. The novelty of this research lies in its contribution to the understanding of piled-raft foundation behavior in cohesionless soil for high-rise buildings. It showcases the application of advanced numerical methods and provides practical implications for optimizing the foundation design, ultimately benefiting the infrastructure sector with cost-effective and reliable foundation techniques.

2. Numerical Modeling of Piled-Raft Foundation

2.1. Finite element model

In the current study, a three-dimensional finite element modeling of the piled raft foundation, subjected to a downward displacement of 10% of the pile diameter was carried out using ABAQUS software package. The soil-structure interface was simulated using the master-slave concept in which pile and raft surfaces were treated as master surface and the soil in contact with foundation elements represented the slave surface. The pile head was firmly fixed to the raft without any sliding at the contact. To assure slippage and frictional behavior between the interfaces, the surface-to-surface concept was applied [13-14]. The Mohr-Coulomb elasto-plastic model was chosen as it requires low soil input parameters. Figure 1 shows the Mohr-Coulomb failure criterion and is expressed as shown in Equation 1:

$$\tau = c + \sigma * tan\phi \tag{1}$$

where τ = shear stress
c = Cohesion
ϕ = Angle of friction

2.2. Mesh pattern and boundary condition

The soil and raft elements were modeled as 8 nodal hexahedral brick elements for mesh refinement, and the circular pile as a triangular prism element. Past research on the finite element approach demonstrated that the mesh pattern and element size have a significant impact on the results, so consideration should be given while generating the mesh [14]. For improved accuracy, a fine mesh was used around the structural elements, whereas farther away from the piled-raft, a coarser mesh was used (Figure 2).The boundary conditions at the bottom of the soil were held constant at all degrees of freedom and were restrained from both lateral and vertical translations. The boundary condition of y-z plane was set to XSIMM that means the symmetry about the x-plane was constant. All three displacements around this axis were equal and zero. The x-y plane was set to ZSIMM, which means that the symmetry around the plane z remained constant. Furthermore, the Encastre boundary condition was applied to the bottom surface of the model, restricting movement in all directions.

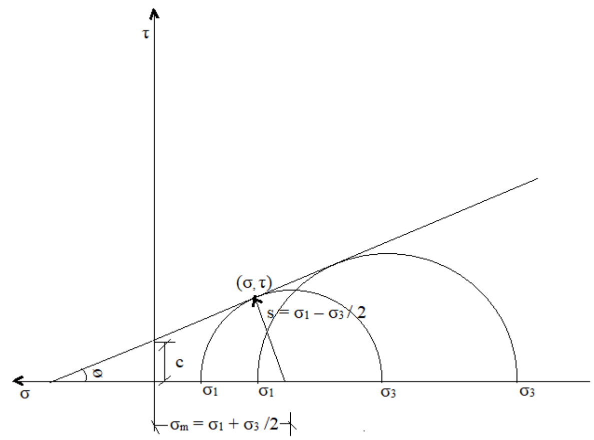

Figure 1. Mohr-Coulomb failure model.

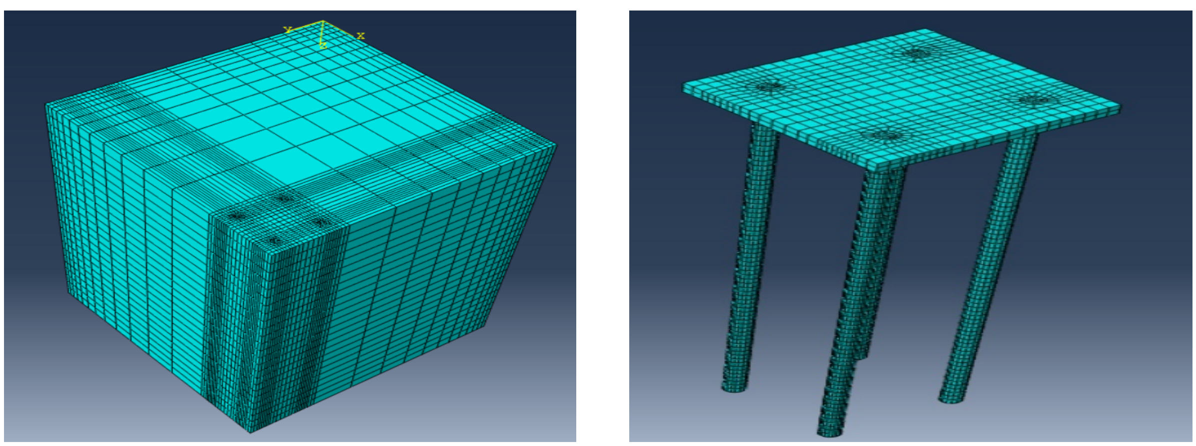
Typical soil element **Typical piled-raft element**

Figure 2. Typical soil and piled-raft element.

2.3. Analysis outline

The numerical modeling was carried out in various steps for different components. The model was brought to an equilibrium condition under geostatic stress field or gravity loading in the first step, prior to the pile installation. The pile was installed in the second step, and the model was brought back to equilibrium by inducing self-weight in the entire model. Owing to the complexity of modeling the pile installation process, the model was assumed to be in a stress-free state at the start of the analysis, and the impact of the pile installation was ignored. Following the first two procedures, a displacement value of 10% D (where D is the diameter of the pile) was provided at the top of the raft in a downward direction to evaluate the influence of displacement on load-settlement characteristic.

2.4. Soil and piled-raft property

The piled-raft foundation consisted of a soil continuum and a group of pile supported by a raft. The soil in the study was considered as sandy soil having modulus of elasticity (E) as 60×10^6Pa and mass density of 2000kg/m^3. On the other hand, the modulus of elasticity of piled-raft was considered as 2.059×10^6 Pa with mass density of 2400kg/m^3.

The length of the pile was varied between 10m, 15m, and 20m with diameter ranging from 0.3 to 0.5m to observe the behavior of piled-raft foundation against settlement and load carrying capacity. The soil continuum and piled-raft dimensions were taken as (20×25×20) m and (5×5) m respectively. The various variables considered in the numerical simulations of piled-raft foundation are tabulated in Table 1 and Table 2.

Table 1. PRF geometrical configurations

Length of PRF (m)	Diameter of PRF (m)	Raft thickness (m)	Spacing (m)
10	0.3, 0.4, 0.5	0.4, 0.5, 0.6	2D, 3D, 4D
15	0.3, 0.4, 0.5	0.4, 0.5, 0.6	2D, 3D, 4D
20	0.3, 0.4, 0.5	0.4, 0.5, 0.6	2D, 3D, 4D

Table 2. Properties of soil and Piled-raft

Material	Properties	Values
Soil	Mass Density (Kg/m^3)	2000
	Young`s Modulus, E (Pa)	60×10^6
	Poisson`s ratio, μ	0.35
	Angle of internal friction, ϕ (˚)	25˚, 30˚, 35˚
	Undrained Cohesion, C_u (Pa)	1
	Dilation angle, ψ (˚)	20
Piled-raft	Mass Density (Kg/m^3)	2400
	Young`s Modulus, E (Pa)	2.059×10^6
	Poisson`s ratio, μ	0.2

3. Numerical results

The load-settlement responses of PRF subjected to the downward displacement are discussed in this section. The bearing behavior of piled rafts is thoroughly investigated as a function of pile length, pile diameter, pile number, pile spacing, raft thickness, and angle of internal friction. Figure 3 shows the displacement diagram of a PRF subjected to displacement. The improvement in the efficiency of piled rafts is expressed using a non-dimensional factor, called the bearing capacity enhancement (BCE). This factor is defined as the ratio of the bearing capacity of piled raft to the bearing capacity of un-piled raft at the same settlement level. The BCEs are plotted against the key geometric parameters influencing the performance of piled raft foundations at 25 mm and 50 mm settlements of the raft center.

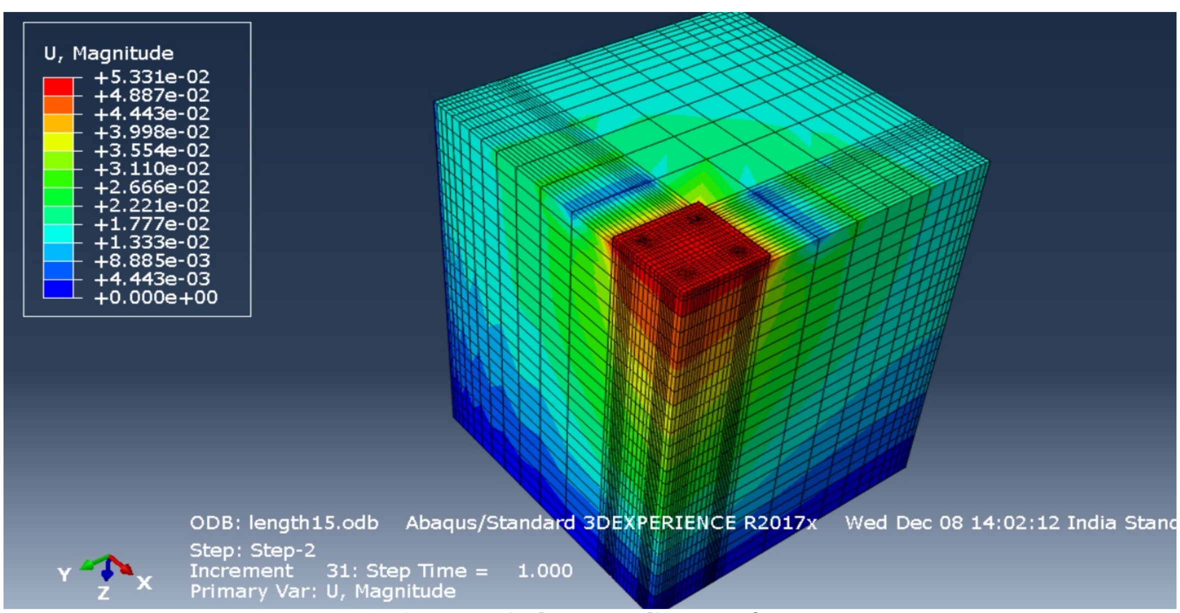

Figure 3. Displacement diagram of PRF.

3.1. Effect of length on load-settlement behavior

To analyze the load- settlement behavior of PRF, different length values, as given in Table 1, were considered and corresponding load-settlement was calculated by applying a prescribed displacement of 10% of pile diameter. The load-settlement characteristics of un-piled raft has also been calculated and presented in Figure 4(a). The results were analyzed for varying pile length (10 m, 15 m, and 20 m) keeping all other parameters constant (No. of piles = 24, spacing = 3D). The angle of internal friction of soil was kept constant as 30° and the thickness of pile raft was kept as 0.5m. From the load settlement curve, it was noticed that for a constant pile diameter of 0.3 m, the maximum load carrying capacity for 10m length of pile was 600 kN; for 15m pile length was 1190 kN; and, for 20 m pile length was 1560 kN. It is clearly observed from Figure 4(a) that with the increase in the pile length, the value of maximum load carrying capacity of the PRF increases. The percentage increment in the load carrying capacity of PRF for 0.3 m diameter was 98% on increasing length from 10m to 15m, and 70% when the length was increased to 20m. Figures 4(b and c) represent the load-settlement curve for various L/D ratios at 0.4m and 0.5m diameter respectively. For a constant diameter of 0.4 m diameter, the percentage increment in maximum load carrying capacity was 40% on increasing length from 10 m to 15 m, while a percentage increment of 70% was noticed when pile length was increased to 20m (Figure 4b). Similarly, for a constant diameter of 0.5m diameter, the percentage increment in maximum load carrying capacity was 25% on increasing length from 10m to 15m, while a percentage increment of 66.67% was noticed when pile length was increased to 20 m (Figure 4c).

From the results of numerical analysis, it was observed that the increase in the load carrying capacity on increasing length keeping other parameters constant may be attributed to the fact that longer piles penetrate deeper into the soil layers, resulting in a larger interface area between the pile and the soil. This increased interaction allows the piles to mobilize more resistance from the surrounding soil, effectively distributing the applied load over a larger area and improving the foundation's bearing capacity. Furthermore, as the pile length increases, the amount of shaft friction also increases. This is especially significant in cohesionless soils, where the frictional resistance between the pile and the surrounding soil plays a crucial role in bearing capacity. Similar results were obtained in the past in case of PRF embedded in sandy soil deposit [15-18].

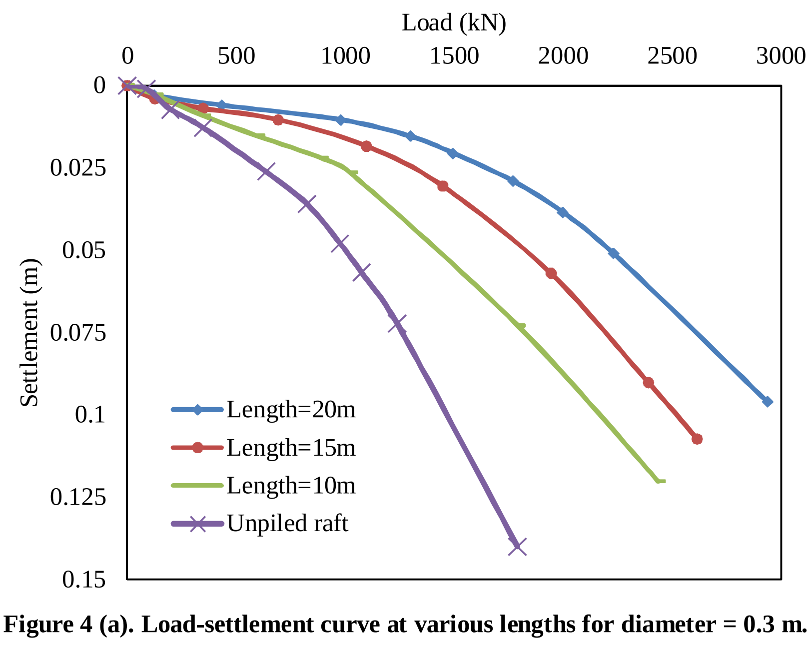

Figure 4 (a). Load-settlement curve at various lengths for diameter = 0.3 m.

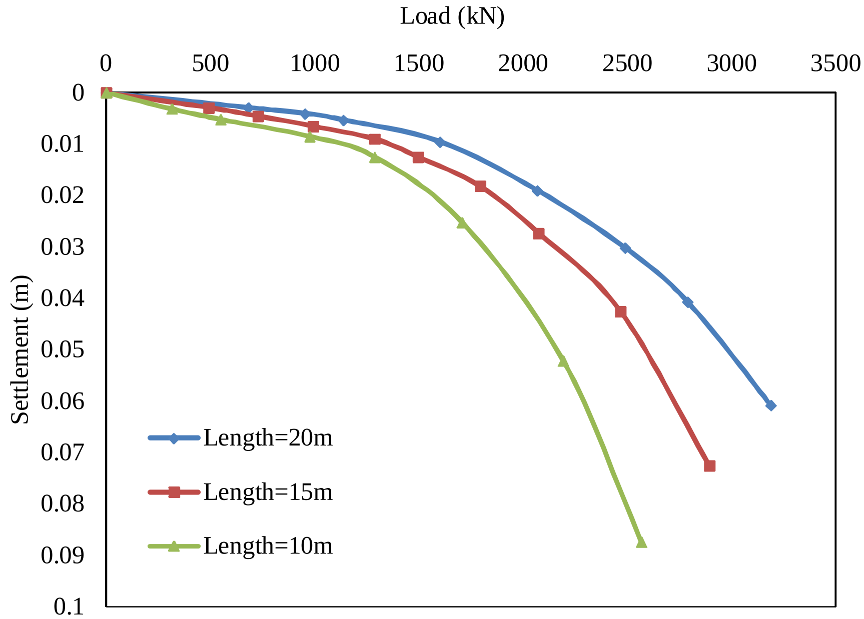

Figure 4 (b). Load-settlement curve at various lengths for diameter = 0.4 m.

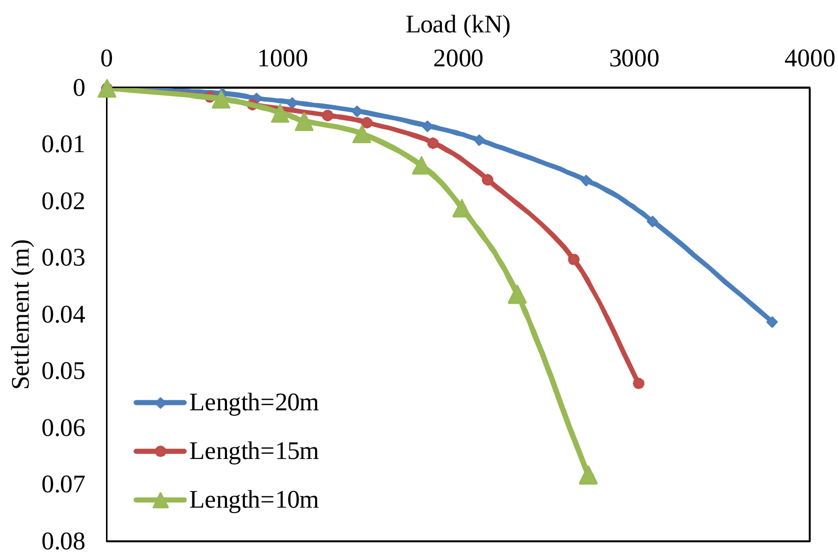

Figure 4 (c). Load-settlement curve at various lengths for diameter = 0.5 m.

Figure 5 presents the variation of bearing capacity ratio (BCR) for various pile lengths for a constant spacing of 3D for 24 numbers of piles. It is clear from graphical representation that on increasing the pile length, the bearing capacity ratio goes on increasing irrespective of the settlement value. It may be noticed from Figure 6 that bearing capacity value for higher settlement values is lower for all length values. For length values between 10 m to 20 m, the BCR value was 1.8 for settlement value of 50 mm; however, the value declined to 2.16 for settlement value of 25 mm.

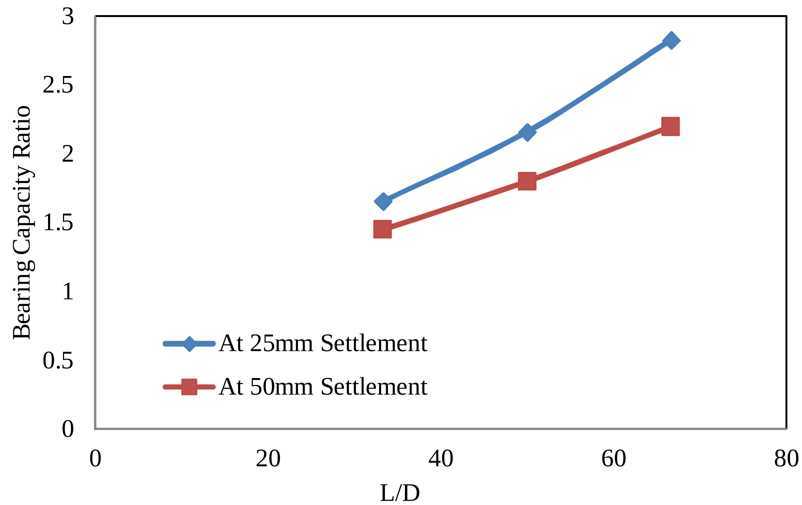

Figure 5. Bearing capacity ratio with various pile lengths.

3.2. Effect of pile diameter on load-settlement behavior

In order to determine the influence of pile diameter on load- settlement behavior of piled-raft foundation, the diameter was varied as 0.3m, 0.4m, and 0.5m while keeping other parameters constant ($\phi = 30°$, raft thickness= 0.5 m and spacing = 3D, No. of piles = 24). Based on all the results, it was concluded that with the increase in pile diameter, the settlement decreases while the load carrying capacity increases. The percentage increment in the value of load carrying capacity for 10 m pile length was around 60% and 85.7% for pile diameter increased from 0.3 m to 0.4 m and then to 0.5 m, respectively (Figure 6a). For pile length of 15m, the percentage increase in load carrying capacity 62.79% and 97.67% for pile diameter increased from 0.3 m to 0.4 m and then to 0.5 m, respectively (Figure 6b). Similarly, for pile length of 20 m, the percentage increase in load carrying capacity 33.3% and 67% for pile diameter increased from 0.3 m to 0.4 m and then to 0.5 m, respectively (Figure 6c).

The increase in load carrying capacity may be due to the interconnection between the large surface area of the pile (when diameter is increased) and the surrounding soil which enables the pile to carry additional load safely. The similar results on increasing pile diameter for PRF were observed in the past [5, 13, 19].

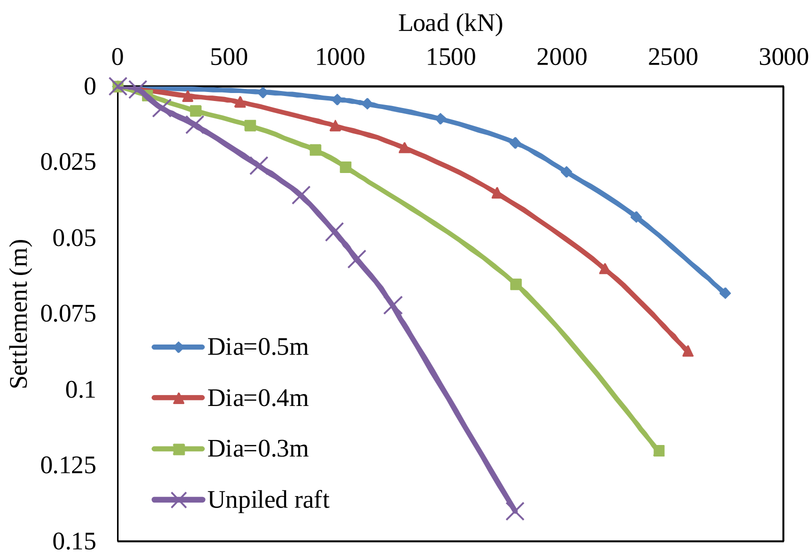

Figure 6 (a). Load-settlement curves for varying diameters having L = 10 m.

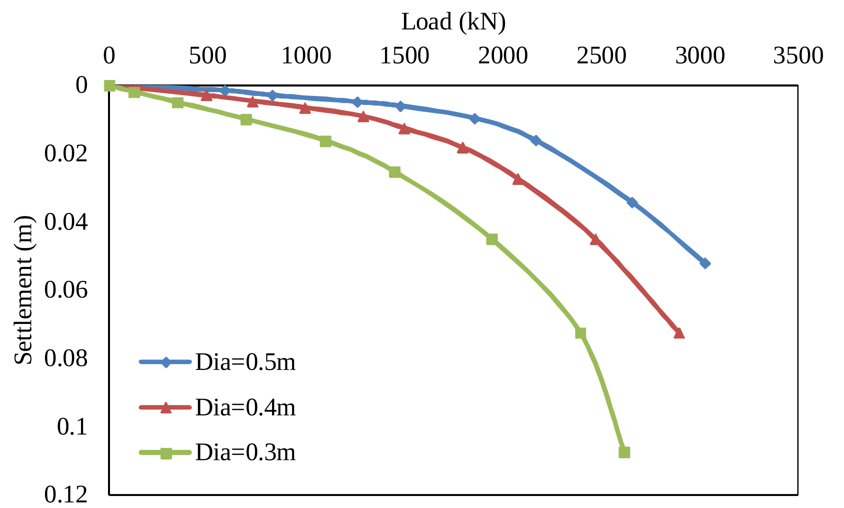

Figure 6 (b). Load-settlement curves for varying diameters having L = 15 m.

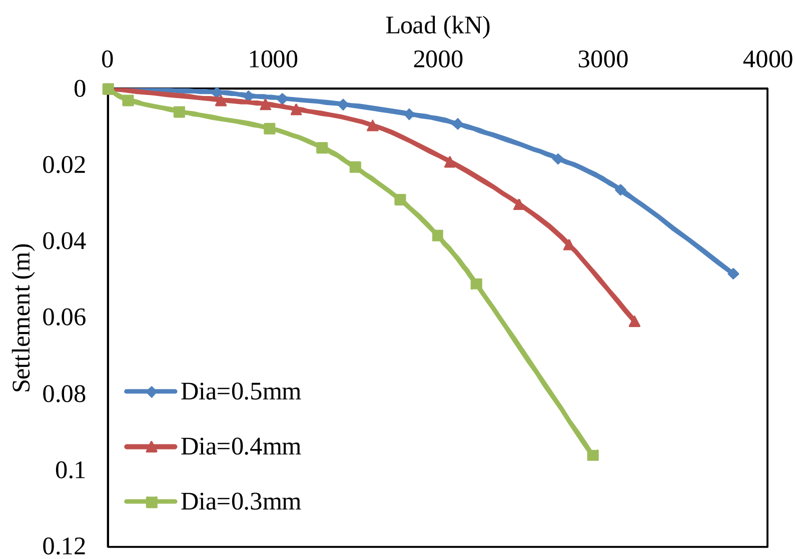

Figure 6 (c). Load-settlement curves for varying diameters having L = 20 m.

Figure 7 presents the variation of bearing capacity ratio (BCR) for different pile diameters with a constant spacing of 3D for 24 numbers of piles. It is clear from graphical representation that on increasing diameter, the bearing capacity ratio goes on increasing irrespective of the settlement value. It may be noticed from Figure that bearing capacity value for higher settlement values is lower for all pile diameters. For diameter ranging from 0.3 m to 0.5 m, the BCR value was 2 for settlement value of 50 mm; however, the value declined to 2.33 for settlement value of 25 mm.

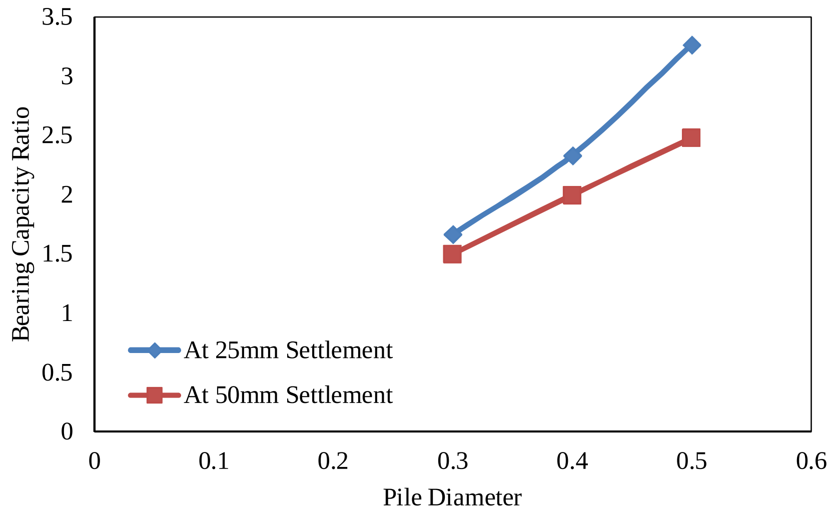

Figure 7. Bearing capacity ratio with various pile diameters.

3.3. Effect of number of piles on load-settlement behavior

In order to examine the effect of number of piles on load-settlement behavior of pile-raft foundation, the piles were adjusted in group of 16, 20, and 24 numbers keeping other parameters constant ($\phi = 30°$, raft thickness = 0.5 m and spacing = 3D). Based on the results, it was analyzed that as the pile number increases, the settlement value reduces while the load carrying capacity improves. The percentage increase in the load carrying capacity of PRF for 10m pile length was found to be 20% when the pile number was varied between 16 to 20 and 83.3% when the pile number was increased to 24 (Figure 8a). For 15 m pile length, the percentage increase was about 33.3% when the pile number was increased from 16 to 20, while the percentage increment was 91.6% when the pile number was increased to 24 (Figure 8b). For 20 m pile length, the maximum load carrying capacity was found to be 27.27% when the pile number was changed from 16 to 20, and 90.9% when the pile number was increased to 24 (Figure 8c).

This is due to the fact that with more piles in the foundation system, the applied load from the superstructure is distributed among a larger number of piles. This load-sharing effect helps in reducing the individual load on each pile, allowing each pile to carry a smaller portion of the total load. As a result, the bearing capacity of each pile is less likely to be exceeded; contributing to an overall increase in the bearing capacity of the piled-raft foundation. Further, increasing the number of piles provides greater flexibility in the design of the piled-raft foundation. It allows engineers to optimize the pile arrangement and configuration to achieve the desired bearing capacity and settlement performance based on the specific site conditions and project requirements. Similar results were obtained on the influence of pile number on PRF embedded in sandy soil in the past [4, 16, 20-22].

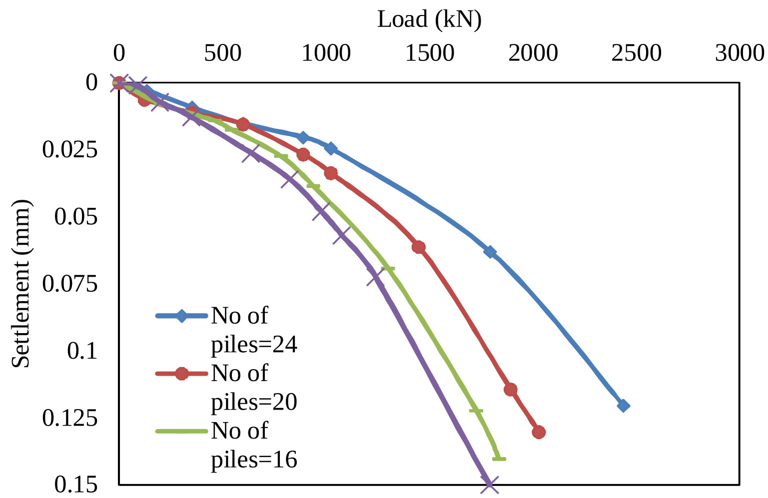

Figure 8 (a). Load-settlement curve for different number of piles with length 10 m and 0.3 D.

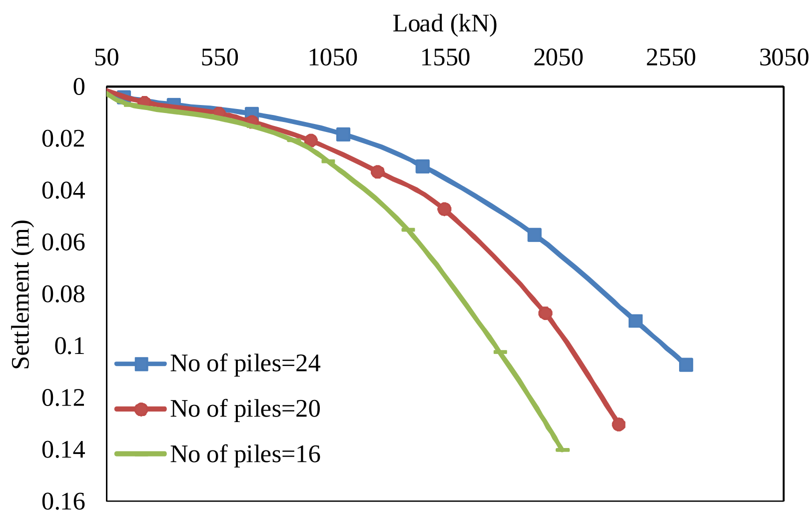

Figure 8 (b). Load-settlement curve at different number of piles with length 15 m and 0.3 D.

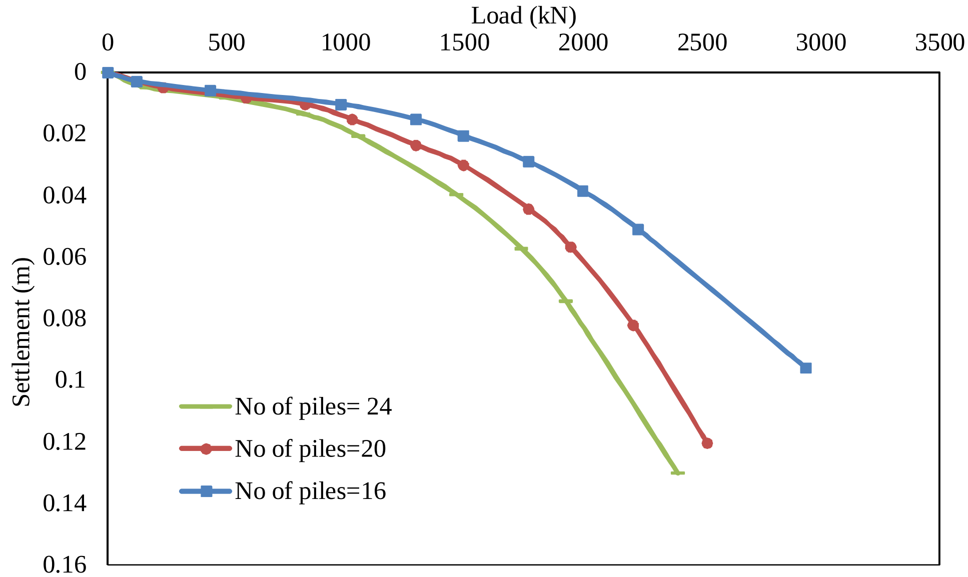

Figure 8 (c). Load-settlement curve at different pile numbers with length 20 m and 0.3 D.

Figure 9 presents the variation of bearing capacity ratio (BCR) for different pile numbers with a constant spacing of 3D. It is clear from graphical representation that on increasing the pile number, the bearing capacity ratio goes on increasing irrespective of the settlement value. It may be noticed from Figure that bearing capacity value for higher settlement values is lower for all pile numbers. For pile number increasing from 16 to 24, the BCR value was 1.38 for settlement value of 50 mm; however the value declined to 1.36 for settlement value of 25 mm.

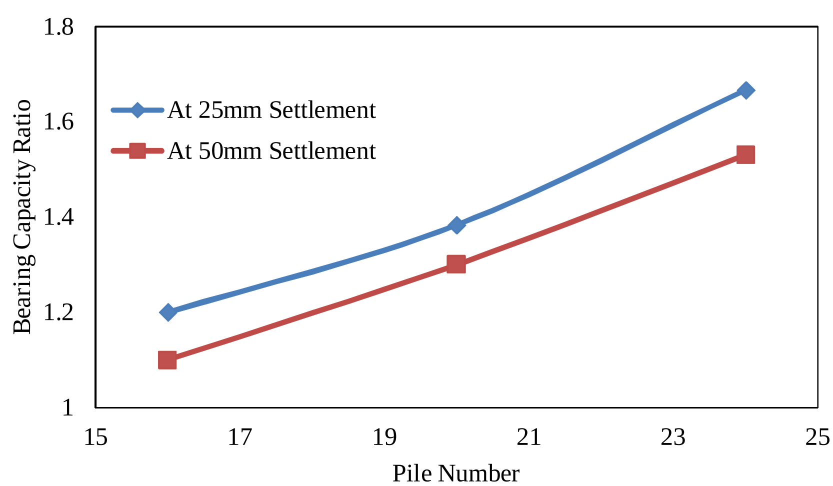

Figure 9. Bearing capacity ratio with different pile numbers.

3.4. Effect of pile spacing on load-settlement behavior

In order to determine the influence of pile spacing on load- settlement behavior of piled-raft foundation, the spacing was varied as 2D, 3D, and 4D while keeping other parameters constant (ϕ = 30 °, raft thickness= 0.5m, diameter of the pile = 0.3 m, and No. of piles = 24). Based on all the results, it was concluded that with the increase in the pile spacing, the settlement decreases while the load carrying capacity increases. The percentage increment in the value of load carrying capacity for 10m pile length was around 40% and 96% when the pile spacing increased from 2D to 3D and then to 4D, respectively (Figure 10a). For pile length of 15m, the percentage increase in load carrying capacity was 28.57% and 57.14% when pile spacing increased from 2D to 3D and then to 4D respectively (Figure 10b). Similarly, for pile length of 20 m, the percentage increase in load carrying capacity was 27.7% and 66.7% for pile diameter increased from 0.3 m to 0.4 m and then to 0.5 m, respectively (Figure 10c).

This is due to the fact that the capacity of the piles reduces due to the overlapping of pressure bulbs. The pressure bulbs of the piles overlap when the pile spacing is reduced, resulting in an increase in stress in that zone. As a result, the raft settles more, resulting in a reduction in the load carrying capacity of the piled raft system. As pile spacing increases, the likelihood of pressure bulbs overlapping each other decreases, which results in an increase in the load carrying capacity of the piled raft system. Figure 11 (a, b) depicts a typical plan view of pressure bulbs of piles below the pile tip for pile spacing of 2D and 4D, respectively. It is observed that the pressure concentration is highest in the centre of the pile tip and decreases gradually in the radial direction. In Figure 11 (a), the circles showing the extent of pressure bulbs of the piles overlap with each other as the spacing between the piles is smaller, i.e. 2D. As a result, increased pressures build in the overlapped zone, causing the raft to settle more. However, in Figure 11 (b), the circle indicates that the pressure bulbs do not overlap as the spacing between the piles is greater, i.e. 4d. The pressure bulb of each pile forms individually as the space between the piles increases, leading to a large mobilization of the load capacity of pile. As a result, the piled raft system with higher spacing between piles has a higher load carrying capacity than the system with smaller spacing between piles, i.e. under the raft. The fact behind this is that as the pile spacing increases, the distance between adjacent piles becomes larger. This results in larger pile caps, which are the foundation elements that transfer the load from the superstructure to the piles. Larger pile caps spread the load over a wider area of soil, reducing the intensity of stresses on the soil and increasing the bearing capacity. Moreover, when piles are closely spaced in a pile group, they tend to interact with each other, which can affect their individual load-bearing capacity. As the spacing between piles increases, the interaction effects diminish, and each pile can function more independently, thus increasing its capacity to carry loads.

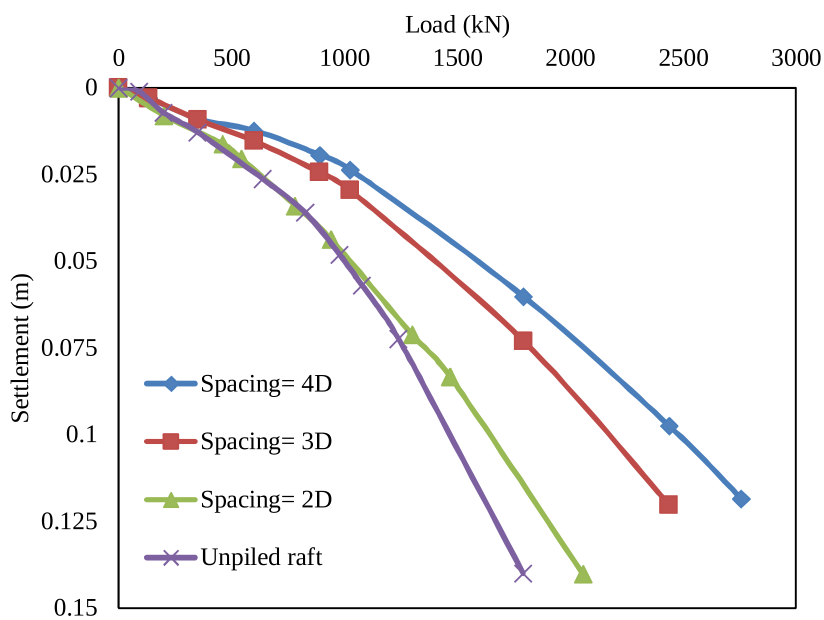

Figure 10 (a). Load-settlement curve at different spacing with length 10 m and 0.3 D.

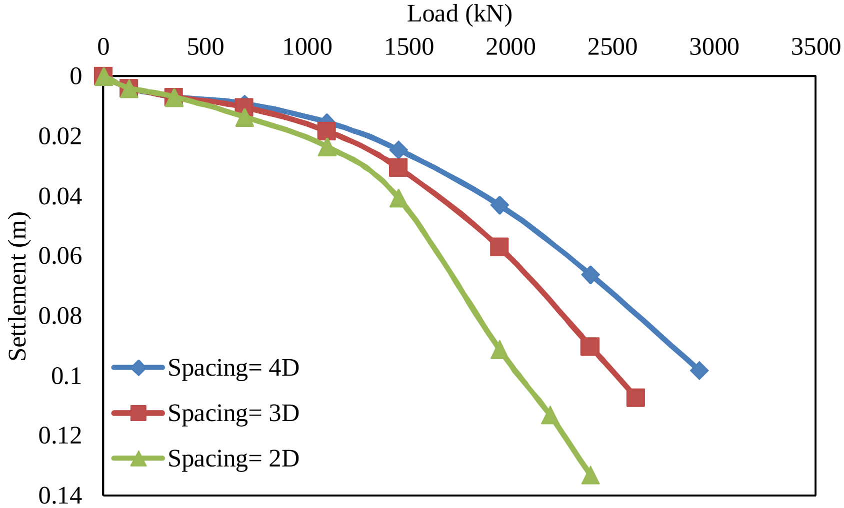

Figure 10 (b). Load-settlement curve at different spacing with length 15 m and 0.3 D.

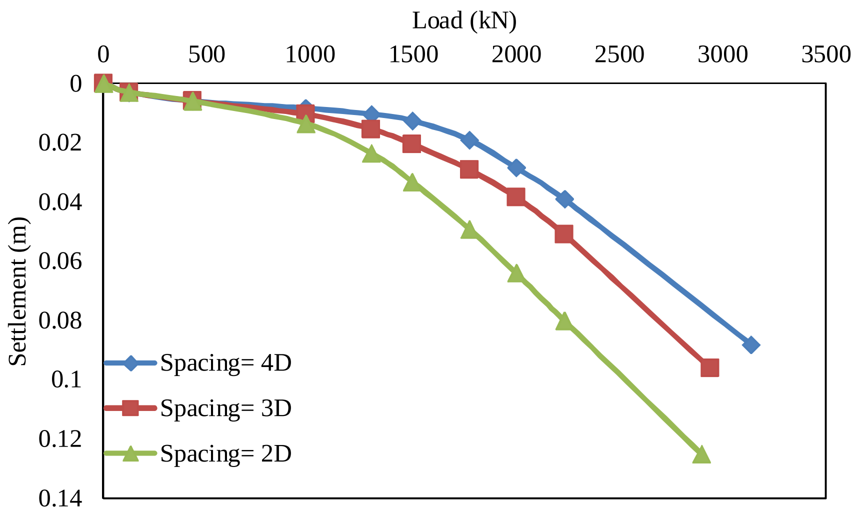

Figure 10 (c). Load-settlement curve at different spacing with length 20 m and 0.3 D.

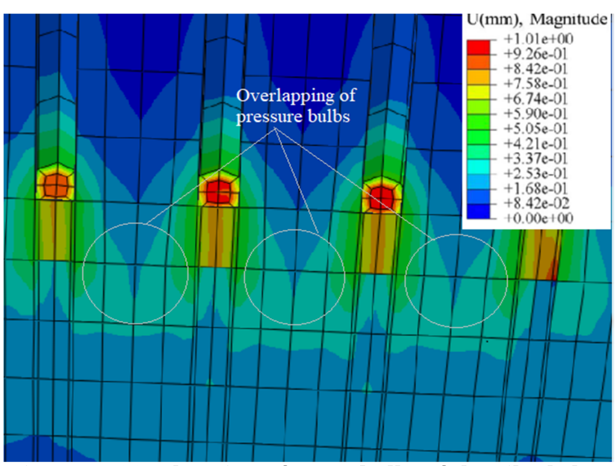

Figure 11 (a). Plan view of stress bulbs of the piles below the pile tip at S = 2D.

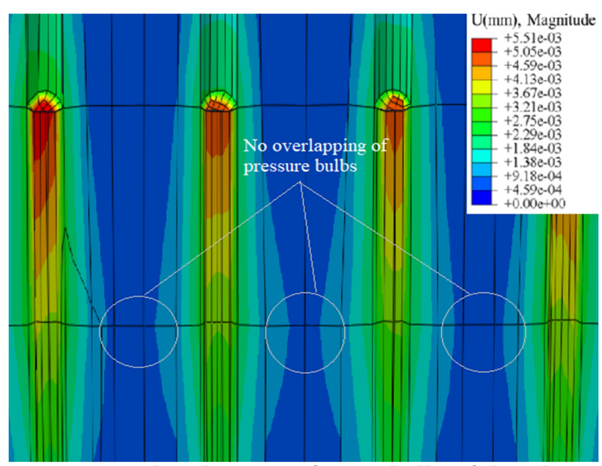

Figure 11 (b). Plan view of stress bulbs of the piles below the pile tip at S = 4D.

Figure 12 presents the variation of bearing capacity ratio (BCR) for different pile spacing with a constant diameter of 0.3m. It is clear from graphical representation that on increasing the pile spacing, the bearing capacity ratio goes on increasing irrespective of the settlement value. It may be noticed from figure that bearing capacity value for higher settlement values is lower for all values of pile spacing. For pile spacing increasing from 2D to 4D, the BCR value was 2.14 for settlement value of 50 mm; however the value declined to 2.15 for settlement value of 25 mm.

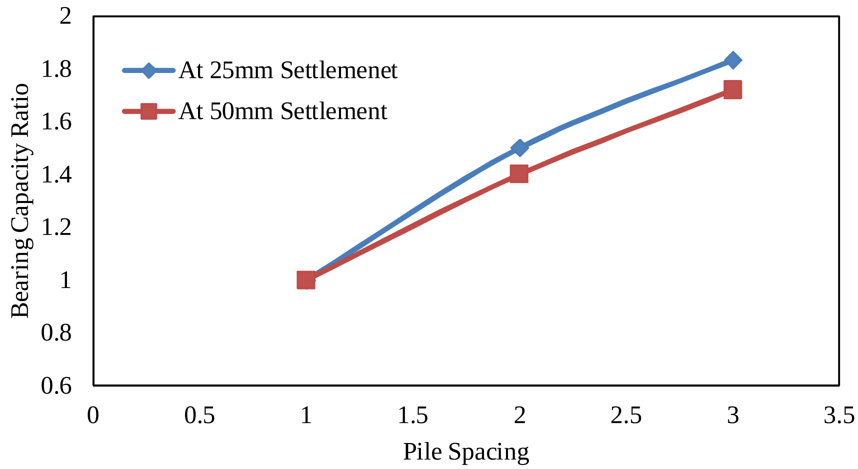

Figure 12. Bearing capacity ratio with different pile spacing.

3.5. Effect of raft thickness on load-settlement behavior

To analyze the effect of raft thickness on the load-settlement characteristic of PRF, the raft thickness was varied between 0.4 m, 0.5 m, and 0.6 m while keeping other parameters constant (ϕ = 30°, number of piles = 24 and spacing = 3D). From the findings, it was concluded that with the increase in raft thickness, the load carrying capacity improves while the settlement decreases. For10m pile length, the percentage increase was observed to be 30% when the raft thickness changed from 0.4, to 0.5m, and 88.9% when the thickness was increased to 0.6m (Figure 13a). For 15 m pile length, the percentage increase was observed to be 51% for raft thickness varying between 0.4 m to 0.5 m, while the percentage increment was found to be 88.9% when the raft thickness was further increased to 0.6m (Figure 13b). For 20 m pile length, the percentage increase was found to be around 30% when the raft thickness increased from 0.4 m to 0.5 m, and 77.7% when the thickness was increased to 0.6 m (Figure 13c).

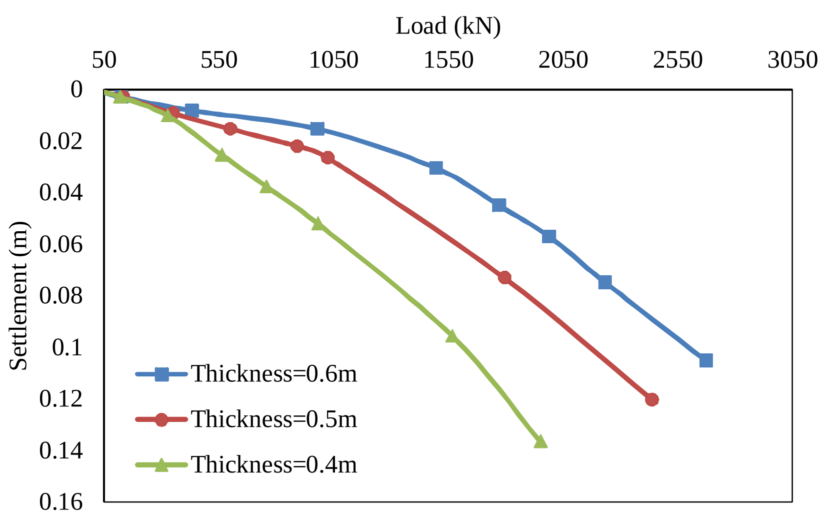

Figure 13 (a). Load-settlement curve at different raft thickness with length 10 m and 0.3 D.

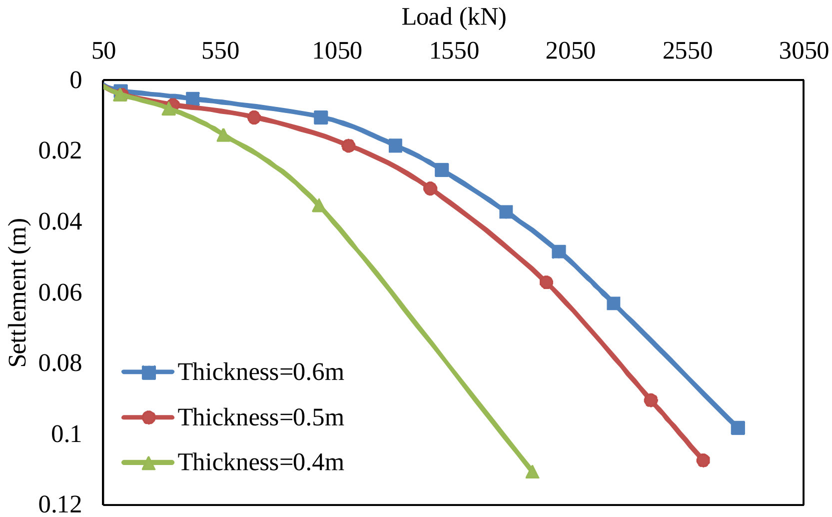

Figure 13 (b). Load-settlement curve at different raft thickness with length 15 m and 0.3 D.

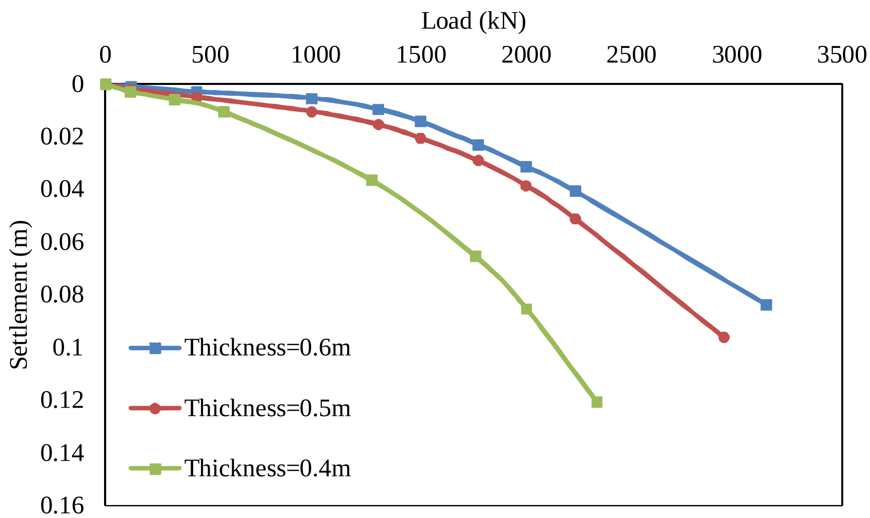

Figure 13 (c). Load-settlement curve at different raft thickness with length 20 m and 0.3 D.

Figure 14 presents the variation of bearing capacity ratio (BCR) for different raft thickness with a constant spacing of 3D for 24 numbers of piles. It is clear from graphical representation that on increasing the raft thickness, the bearing capacity ratio goes on increasing irrespective of the settlement value. It may be noticed from Figure that bearing capacity value for higher settlement values is lower for all pile numbers. For raft thickness increasing from 0.4m to 0.6m, the BCR value was 2.2 for settlement value of 50 mm; however the value declined to 2.66 for settlement value of 25 mm.

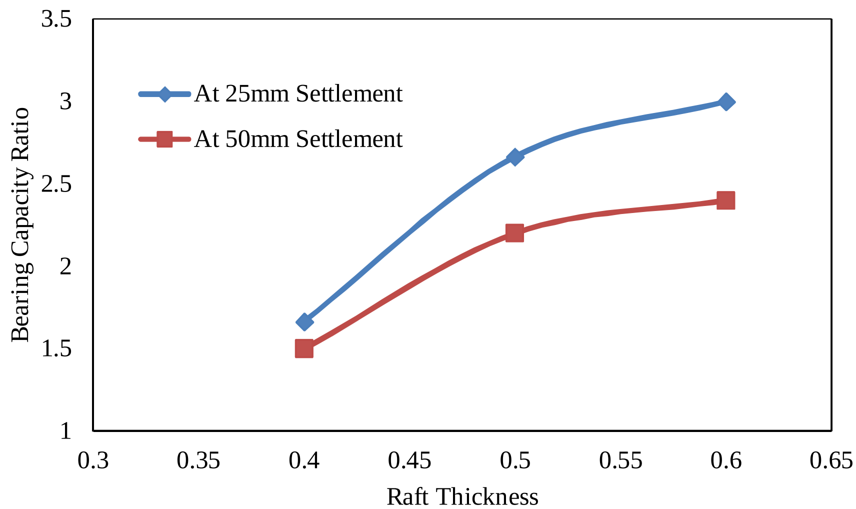

Figure 14. Bearing capacity ratio with varying raft thickness.

3.6. Effect of angle of internal friction on load-settlement behavior

From the study, load-settlement characteristic of piled-raft foundation was examined by ranging the angle of internal friction of soil from 35° to 25° while keeping other parameters constant (raft thickness = 0.5 m, number of piles = 24 and spacing = 3D). From the findings it was concluded that as the angle of friction changed from 35° to 25°, the value of settlement goes on decreasing while load carrying capacity increases. The percentage increment in the load carrying capacity of PRF for 10m pile length was observed to be 50% for frictional angle ranging between 25° to 30° and 83% when the frictional angle increases to 35° (Figure 15a). For 15 m pile length, the maximum load carrying capacity was found to be 27.7% for frictional angle ranging from 25° to 30°, and 81% when the frictional angle changes to 35° (Figure 15b). For 20 m pile length, the maximum load carrying capacity was found to be 50% when the frictional angle changed from 25° to 30°, and 91% when the frictional angle increases to 35° (Figure 15c).

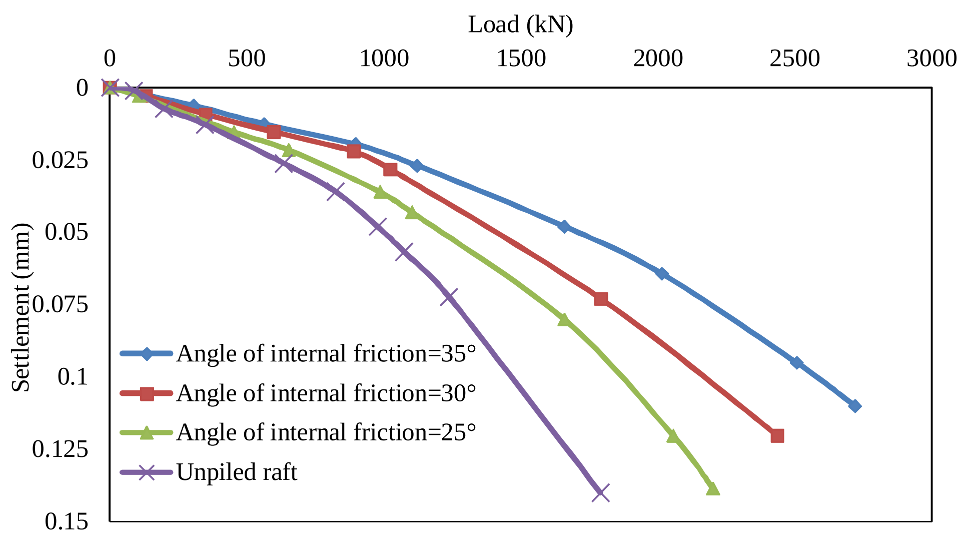

Figure 15 (a). Load-settlement curve at different angle of internal friction with length 10 m and 0.3 D.

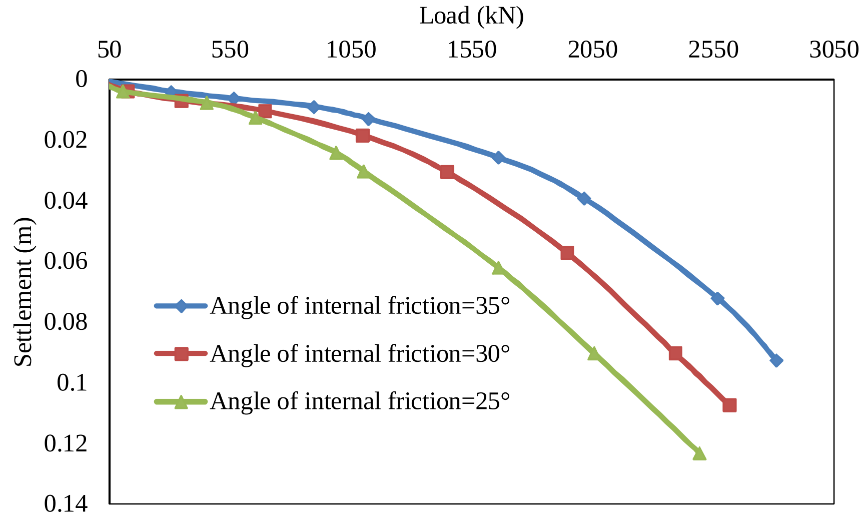

Figure 15 (b). Load-settlement curve at different angle of internal friction with length 15 m and 0.3 D.

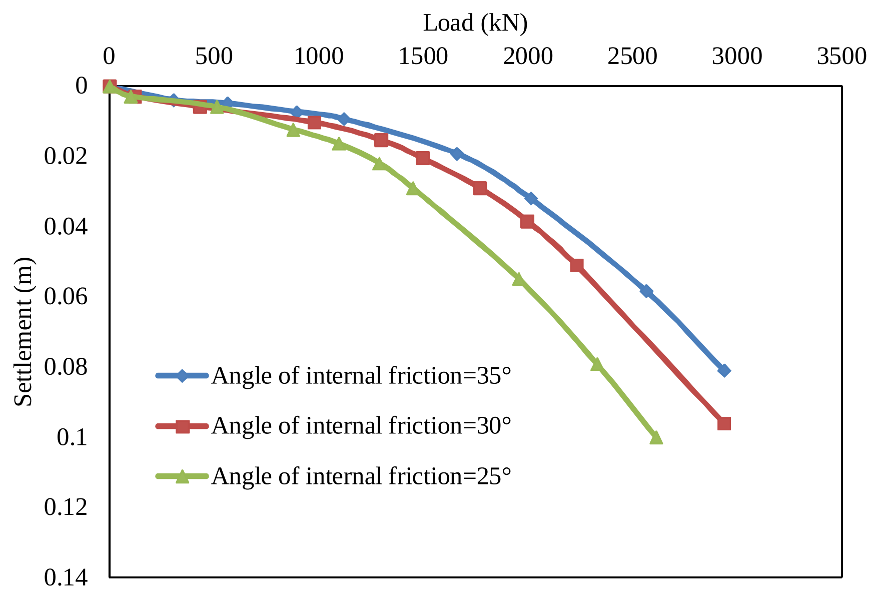

Figure 15 (c). Load-settlement curve at different angle of internal friction with length 20 m and 0.3 D.

Figure 16 presents the variation of bearing capacity ratio (BCR) for different angle of internal friction with a constant spacing of 3D for 24 numbers of piles. It is clear from graphical representation that on increasing the frictional angle, the bearing capacity ratio goes on increasing irrespective of the settlement value. It may be noticed from Figure that bearing capacity value for higher settlement values is lower for all pile numbers. For internal friction increasing from 25° to 35° the BCR value was 2.2 for settlement value of 50 mm; however the value declined to 2.66 for settlement value of 25 mm.

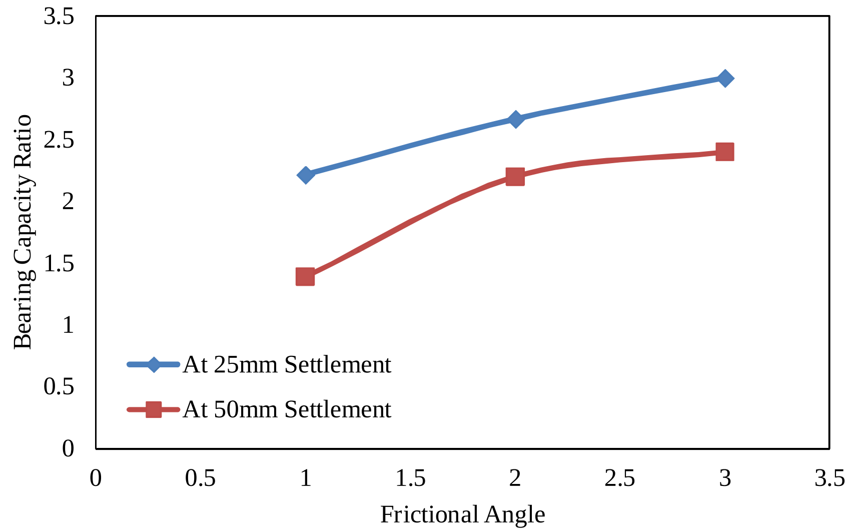

Figure 16. Bearing capacity ratio with varying angle of internal friction.

3.6. Load sharing between piles and raft

In a piled raft foundation, the load coming from the superstructure is distributed to the soil by the bearing actions of both the raft and the piles. Many geometric parameters, such as pile spacing, pile length, pile diameter, pile numbers, and raft thickness, influences the load sharing between raft and piles. The load shared by piles and raft is shown as a percentage of the total external load imposed. For a PRF with pile length of 10 m, 15 m, and 20 m at pile spacing of 3d, simulations were carried out on a raft with dimensions of 5 m × 5 m. With increased raft settlement, it may be seen that pile load sharing reduces and raft load sharing increases. The majority of the applied weight is carried by the piles during the initial minor settlement of the raft. The percentage of the load shared by pile of length 10m is 69.38% while raft shares 30% of the total applied load (Figure 17a). The piles share for 15m pile length is found to be 67.8% of the total applied load while that of raft share is around 32% (Figure 17b). The percentage of the load shared by pile of length 20 m is 62.12% while raft shares 37% of the total applied load (Figure 17c).

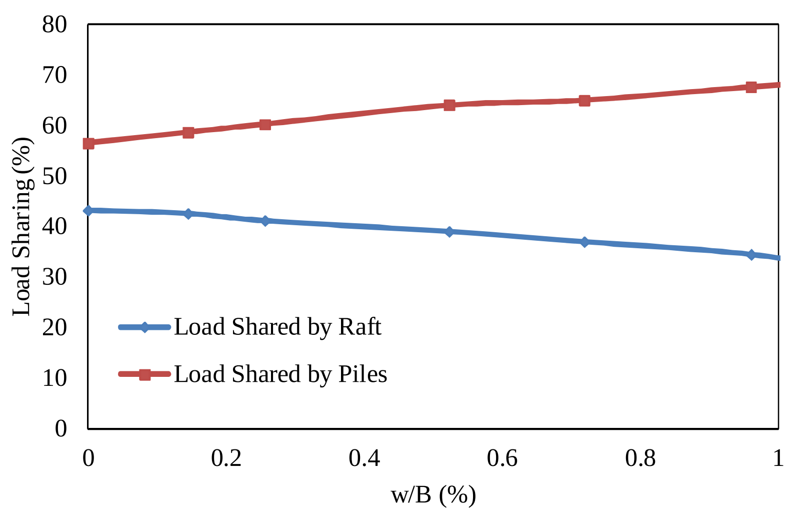

Figure 17(a). Variation of pile-raft load sharing proportion with L = 10 m.

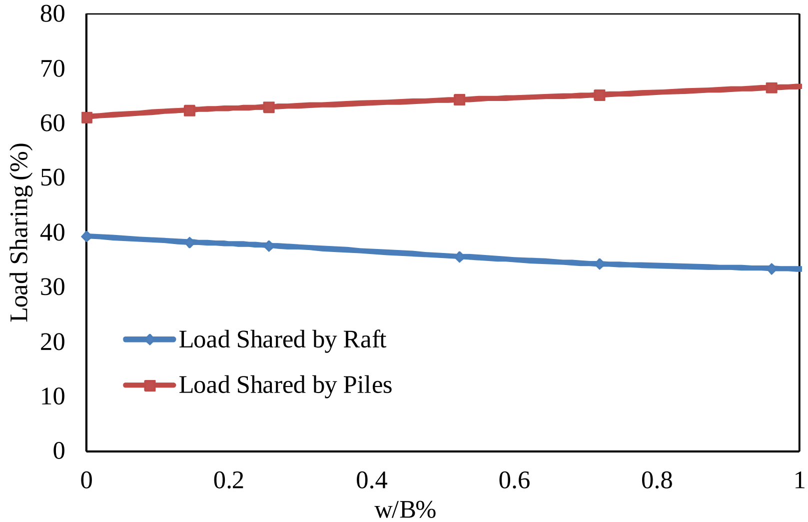

Figure 17 (b). Variation of pile-raft load sharing proportion with L = 15 m.

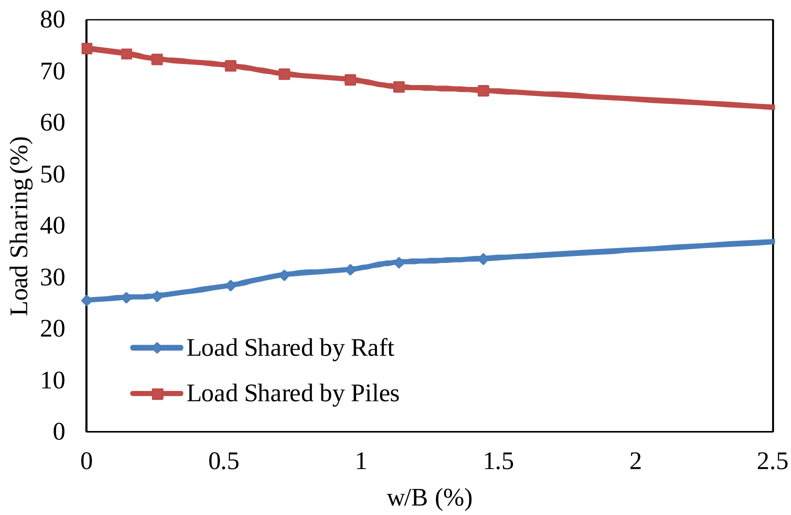

Figure 17(c). Variation of pile-raft load sharing proportion with L = 20 m.

4. Conclusions

3D FEM numerical simulation was conducted on sandy soil to examine the load-settlement behavior of PRF. The primary factors like pile length, pile diameter, pile number, raft thickness, and frictional angle of soil that governs the performance of piled-raft were varied to observe the impact on the behavior of PRF. The following conclusions can be drawn from the current research:

1. By installing piles in raft foundation, not only the structure becomes cost-effective but maximum and differential settlement can be reduced to a considerable extent while the load carrying capacity increases significantly. PRF proves to be effective in cohesionless soils.
2. It was found that various key parameters like pile number, pile length, pile diameter, raft thickness, and angle of internal friction of soil plays a key role in the performance of piled-raft foundation.
3. From the findings it was revealed that with the increase in pile number, the settlement reduces to a certain number and then becomes constant while the load carrying capacity increases. Based on the permissible settlements, the desired number of piles in a piled raft foundation system must be considered for an economical design.
4. By increasing the pile diameter and pile length, the value of settlement decreases and load carrying capacity increases.

5. In a PRF, by increasing the pile spacing, the piles share more load than the raft due to less interactions between the piles. The piles interact with each other through overlapped stress fields at smaller spacing, resulting in a lower load carrying proportion by the piles than the raft.
6. From the study it was also revealed that with the increase in various parameters like pile length, pile number, pile diameter, raft thickness and angle of internal friction, the bearing capacity enhancement was found to increase.

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شبیه‌سازی عددی پایه رافت شمعی در خاک بدون چسبندگی با استفاده از ABAQUS

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چکیده:

با توجه به رشد سریع در بخش زیرساخت، ساخت و ساز ساختمان های بلند مرتبه در بین همه کشورها محبوبیت زیادی پیدا کرده است. مهندسان با مشکلات قابل توجهی در ساختمان‌های مرتفع، به ویژه از نظر ساختاری و فونداسیون مواجه هستند. بسیاری از رویکردهای طراحی قدیمی را نمی‌توان با قطعیت استفاده کرد زیرا آنها شامل برون‌یابی بسیار فراتر از حوزه‌های تجربی موجود هستند، از این رو مهندسان سازه و ژئوتکنیک مجبور به استفاده از روش‌های تحلیل و طراحی پیشرفته‌تر هستند. مطالعه حاضر تلاشی برای پیش‌بینی ظرفیت باربری و رفتار نشست پای قایق انباشته هنگام تعبیه در نهشته بدون چسبندگی است. تجزیه و تحلیل عددی برای بررسی تأثیر پارامترهای کلیدی متعدد شمع و کلک مانند طول شمع (10، 15، 20 متر)، قطر شمع (0,3، 0,4، 0,5 متر)، تعداد شمع (16، 20، 24)، فاصله شمع (2D، 3D، 4D) (که در آن "D" قطر شمع است)، ضخامت کلک (0,4، 0,5، 0,6 متر)، و زاویه اصطکاک داخلی خاک (25 درجه، 30 درجه، 35). درجه) بر رفتار بارگذاری - نشست پی پیلینگ با استفاده از نرم افزار ABAQUS. یک فاصله ثابت بین شمع‌ها، یعنی 3D در سراسر تجزیه و تحلیل استفاده شد. نتایج بررسی عددی حاکی از بهبود ظرفیت باربری و کاهش میزان نشست در افزایش طول، قطر و تعداد شمع‌ها و همچنین با افزایش زاویه اصطکاک داخلی است. مطالعه حاضر نه تنها ظرفیت باربری فونداسیون را افزایش می‌دهد، بلکه یک تکنیک پی سازی مقرون به صرفه را در اختیار مهندسان قرار می‌دهد.

کلمات کلیدی: فونداسیون قایق شمعی، ته نشینی، تحلیل عددی، ظرفیت حمل بار.