EFFECT OF PILE LENGTH ON THE BEHAVIOR OF PILE RAFT FOUNDATION

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ABSTRACT: This study investigates the influence of pile length on settlement and straining actions of a piled raft foundation and load-sharing mechanism between piles and the raft. Finite element analysis using PLAXIS 3D and SAP 2000 was conducted to study key parameters such as settlement, bending moment, shear force, and load distribution. It can be observed from the results that with an increase in pile length from 8m to 12m, the settlement reduces by 42%,, while further extension to 14m and 16m results in diminishing returns with reductions of 12.7% and 9.97%, respectively. Regarding bending moment, an increase in pile length from 8m to 12m decreases it by 4.7%, while extending from 12m to 16m results in an additional 5% reduction. Similarly, the raft shear force decreases by 5.26% when pile length increases from 8m to 12m, with marginal reductions beyond that. The load-sharing analysis reveals that at 8m pile length, the raft carries 38% of the total load, which reduces to 22% at 12m and 14m, and 19% at 16m, demonstrating the increasing reliance on piles for load-bearing. The study highlights the optimal pile length for maximizing settlement reduction and efficient load distribution, offering practical guidance for foundation design improvements.

Keywords: (Pile length, Settlement,Bending moment, Shear force, Load distribution)

1. INTRODUCTION

.Piled raft foundations are an advanced geotechnical solution in which the load-carrying capacity of piles and rafts interacts synergistically to effectively transfer structural loads to subsurface strata. This hybrid system is particularly useful in optimizing foundation performance, especially in cases where sole raft foundations may be inadequate due to excessive settlement or inadequate bearing capacity. Design and behavior of piled raft foundations are based on several important parameters:Pile Length and Diameter: The diameter and length of piles are essential in determining the capacity of the load and settlement of the foundation. Piles are longer, since they extend deeper into competent strata, causing higher stability and lower settlements. Similarly, pile diameter increase enhances the contact area between the pile and the soil, enabling better load transfer and further minimizing settlement issues.Raft Thickness: Raft thickness plays a significant role in determining the overall stiffness of the foundation system. A thicker raft can distribute loads more evenly and reduce differential settlements within the structure. But the raft thickness must be balanced to avoid excessive material consumption and self-weight, which could adversely affect the foundation performance. Soil Characteristics: The soil properties and type below the foundation play a significant role in determining the design and performance of piled raft systems. Variations in soil stiffness, density, and stratification necessitate comprehensive geotechnical investigations toin form design decisions. Understanding load behavior plays a key role in the estimation of settlement behavior and long-term foundation stability., the American Society of Civil Engineers (ASCE) has also developed simplified design methods for piled raft foundations, which are highly effective tools at preliminary design levels.These methods enable simple estimation of load sharing between piles and raft, enabling engineers to design the foundation system with respect to performance as well as cost. Thus successful use of piled raft foundations involves a holistic understanding of the relationship between structural members and geotechnical conditions.

By exercising diligent consideration of matters like pile diameter, raft thickness, and soil type, and by strict adherence to current American standards and codes, engineers are able to successfully design foundations that are both strong and efficient in a way that ensures the strength and safety of the structures to be supported. The objective of the research is to study the effect of increase in pile length and its penetration into dense ground on piled raft foundation behavior. The objective of the research is to determine the effect of the increase in pile penetration in high-strength soil on the piles and raft load distribution, and to study its effect on the foundation behavior regarding settlement, bending moment, and shear force. By finite element analysis, the research seeks to determine the pile length that is optimum in that it achieves enhanced stability and minimized settlement as well as less pressure on the raft and improved load distribution between the raft and piles.. Ultimately, this study contributes to the development of foundation design strategies in strong soil conditions, enhancing structural performance and leading to more efficient and safer engineering designs in construction

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1.1 Novelty Statement

Previous studies have looked at the behavior of piled raft foundations under static loading using finite element modeling. The investigation in this research goes a step further by systematically analyzing the effect of different pile lengths (ranging from 8 m to 16 m) on the contact/noncontact mechanism between raft and soil. Furthermore, the integration of PLAXIS 3D and SAP2000 provides a dual analytical approach addressing both geotechnical and structural aspects, offering deeper insights into stress distribution and enhancing design efficiency compared to traditional methods.

2. RESEARCH SIGNIFICANCE

The current research contributes a critical knowledge gap to the geotechnical engineering discipline by providing a detailed analysis of the effects of pile length on the behavior of piled raft foundations. Although most previous studies have focused on general design and behavior of piles raft foundations, only a small number of studies have examined the performance and effect of incremental increases in length on the settlement, bending moments, shear forces, and load distribution controlling parameters at the contact surface. The findings of this research builds the research record with a parametric analysis and detailed finite element modelling (Plaxis 3D and SAP 2000) to improve the understanding of how the length of the piles influences the global behaviour of the foundation system. The value of this research study is potential guidance for optimizing design of piled raft foundations and possibly reducing settlements and optimizing load distribution. By quantifying the effect of varying pile lengths, this study provides engineers with evidence-based recommendations that can be applied in practice. These findings offer practical implications for designing more stable, cost-effective, and efficient foundation systems, especially in geotechnical challenging environment, the study's findings extend beyond theoretical knowledge. They provide valuable insights that can be applied to real-world projects involving piled raft foundations, such as high-rise buildings, bridges, and large-scale infrastructure projects. The research is expected to be particularly beneficial for engineers working in regions with complex soil conditionsincorporating 110 piles, each with a fixed diameter , offering them data-driven solutions for optimizing foundation performance. This research makes a significant contribution to the field by improving our understanding of pile-soil-raft interactions and their impact on foundation stability. It provides new avenues for future studies on foundation design and helps refine engineering practices for more reliable and sustainable foundation systems. Using finite element modeling through PLAXIS 3D and SAP 2000, this study provides a detailed analysis of how pile-soil-raft interactions affect the overall structural efficiency. The results show that more pile length reduces settlement, enhances load distribution, and increases the foundation's stability. The results advance the field of geotechnical engineering by providing useful modification strategies for foundation design, allowing for cost-effective construction and efficient designing processes. The research will help engineers who are designing piled raft foundations over a range of soil conditions to successfully increase performance and safety.

2.1 CASE OF STUDY

The current study examined using a three-dimensional finite element model utilizing PLAXIS 3D (version 2013) and SAP 2000 to analyze the theoretical effect of pile length on piled raft foundations. Proposed Model . The present case was set up for a particular site in a government project in Egypt. Fig(1) shows the borehole profile at the study site, showing a multilayered soil profile that is modelled as a semi-infinite elastic, homogeneous and isotropic material. The analysis consists of a piled raft foundation system Piled raft foundation in contact with soil Piled raft foundation without contact with soil. Specifications and variations of key parameters are shown in tables (1)- (3). Pile lengths (L_p = 8m,12m, 14m and 16m) for two main cases (D = 0.6 m) and a spacing of (S_p = 5D), The 14 m and 16 m section lengths were selected to examine the performance of the piled raft system at larger depths where the soil stiffness increases whereby could observe the point of diminishing returns whereby additional length does not produce settlement reductions in any economically viable way and thus inform us about the best design length.. To guarantee a uniform load distribution beneath the raft and to also eliminate any local punching shearing effects, it was decided to use 110 piles at 0.6m and 5D spacing. This approach meets the Egyptian Code for Soil Mechanics and Foundation Design (1995) (Part 4, 2001) and is consistent with on-site John experience practical applications for medium to large foundations projects. .The soil properties presented in Tables 2 were derived from actual site investigation data from a governmental project in Egypt. These properties represent the stratigraphy of medium-stiff and stiff clayey soils typical of the study location. All parameters were verified according to the EgyptianCode for Geotechnical Works (2001) and usedconsistently throughout the analysis

Table1.Investigatedcases ofstudy

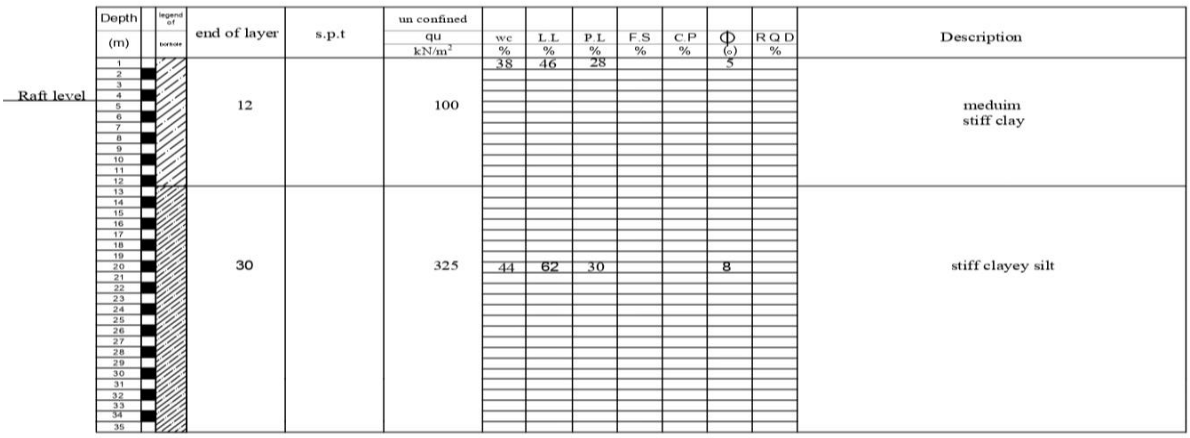
N0.	Number ofpiles	pile diameter (m)	The contact of the raft with the soil	Length Of the piles (m)	Pile spacing	Raft Thickness (m)
1				8		
2	110	0.6	Rested on the soil	12	5D	1.5
3				14		
4				16		
5			Un Rested on the soil	8		
6	110	0.6		12	5D	1.5
7				14		
8				16		

Table 2.PropertiesofSoil Layers

Description	Unit weight (kN/ m3)	Youngsmodulu (kN/m2) Es	Poissn ratio, υ	Cohesin (kN/m2) C	Friction angle Ø	Dilatanc angle Ψ
Meduim stiff black clay	16	4000	0.35	70	5	0.00
Stiff clayey silt	17	17000	0.30	120	20	0.00

Table3.piles and raft parameters

Parameters	Pile	Raft
MaterialBehavior	Elastic	Elastic
Material type	Concrete	Concrete
Diameter of pile(m)	0.6	-
Raft thickness (m)	-	1.5
density(kN/m3)	25	25
young'smodulusEs (kN/m2)	24*10^6	24*10^6
Poisson ratio(υ)	0.2	0.2



RQD = Rock quality designation.
= Unit weight of soil.
qua = Unconfined compressive strength or pocket penetrometer.
L.L = Liquid Limit.
P.L = Plastic Limit.

FS = Free swell.
CP = Collapse potential under stress of 200 kg/m2
SPT = Blows of standard penetration test /30 cm.
= Angle of internal friction.
A.F.S = Axial free swell (under seating load of 10 kn/m2).

Fig 1.Borehole for the model

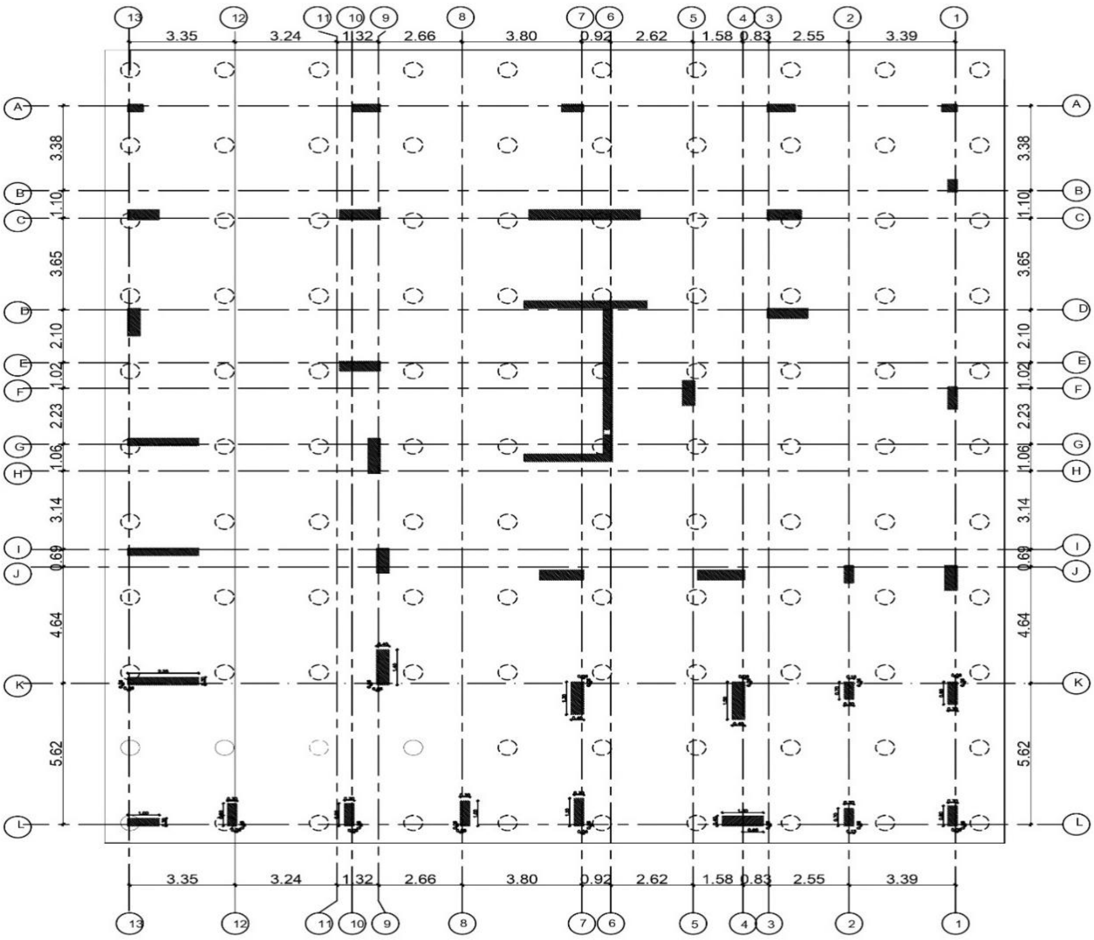


Fig.2.Plane of piled raft foundation

3. PARAMETRIC STUDY

This section reviews how pile length may affect important structural and geotechnical parameters of piled raft foundations, including: piled raft foundation settlement the bending moment in raft Shear Force in the raft Load distribution between piles and raft

3.1 Finite Element Methodology

Finite element software package of PLAXIS 3D version 2013 have been adopted for the finite element modelling within this study. This allowed the use of embedded piles consisting of beam elements that satisfy the primary goal of portraying the interaction with soil and modelling the raft principally as a plate element. Soil is modelled employing the Mohr-Coulomb model (MC). SAP 2000 has been adopted for the calculations of straining actions in the raft such as bending moment and shear force in the raft. Piled raft simulation was achieved by assigning springs (horizontal and vertical) at the nodes of the piles and area springs at the membrane of the raft. Modulus of subgrade reaction (ks) were calculated utilising Vesic's Theory. $ks = q/\ \delta$.A mesh size of 0.5 meters was adopted in the PLAXIS 3D modeling, following recommendations from the PLAXIS 3D Reference Manual (2013), which balances computational efficiency and result accuracy. Convergence was verified by reducing the mesh size by 20%, resulting in displacement and stress variations of less than 5%, thus confirming the numerical stability and reliability of the model.

3.2Finite Element Results

The results derived from the selected cases are presented in Figures 3 to 10, illustrating various scenarios and their corresponding outcomes Figure (4) illustrates settlement for rested piled raft with pile length 16m. Figures (5A and 5B) present the axial force on the pile for both the case of rested pile raft and un-rested piled raft. Figure (6) provides the bending moment on the raft for rested piled raft foundation with pile length 16m. Figure (7) provides the shear force on the raft for rested piled raft foundation with pile length

16m.Fig (8) shows settlement for un rested piled raft wit pile length 16mFig (9) show the bending moment on the raft for un- rested piled raft foundation with pile length 16m.

Fig (10) show the shear force on the raft for unrested.

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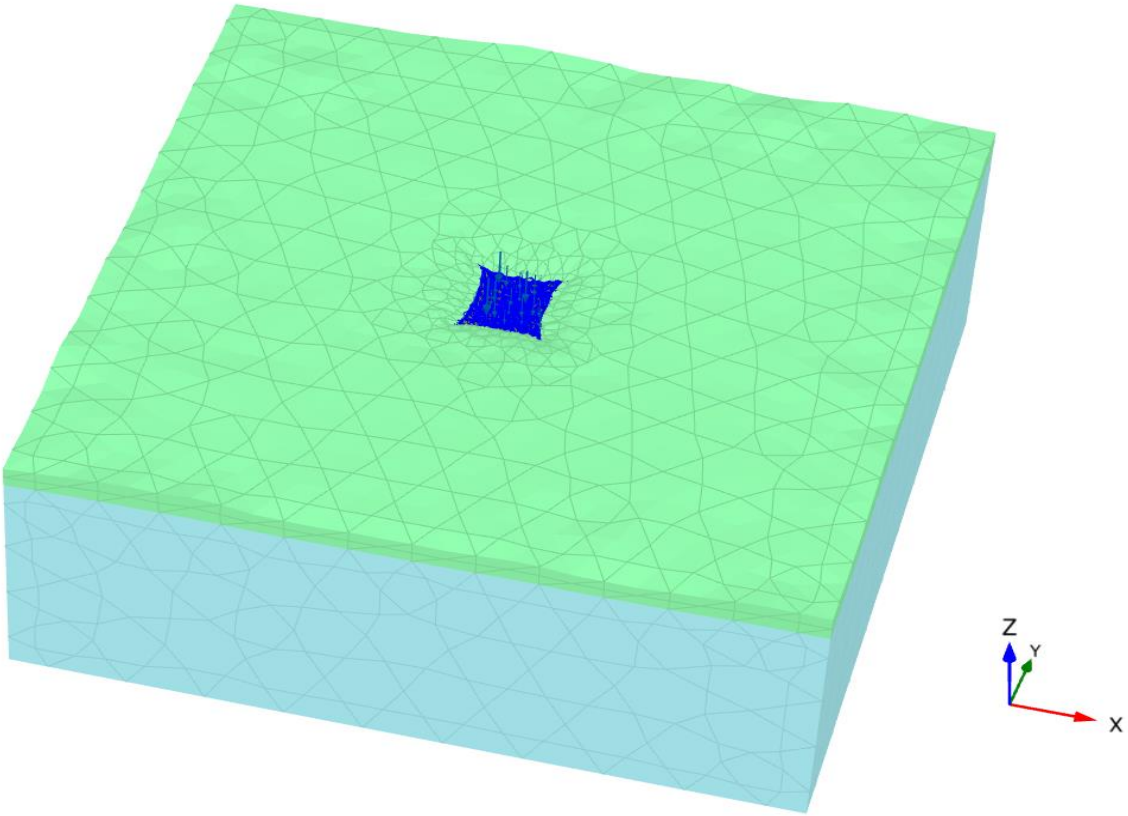


Fig. 3 deformed mesh of piled raft foundation rested in the soil with pile length 16m

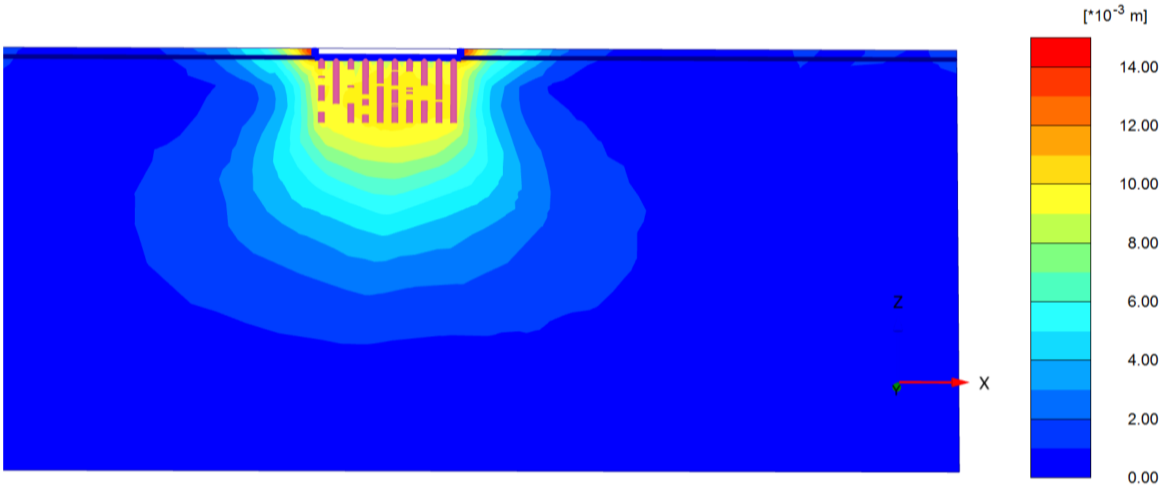


Fig .4 The vertical displacement for piled raft foundationwith pile length 16m

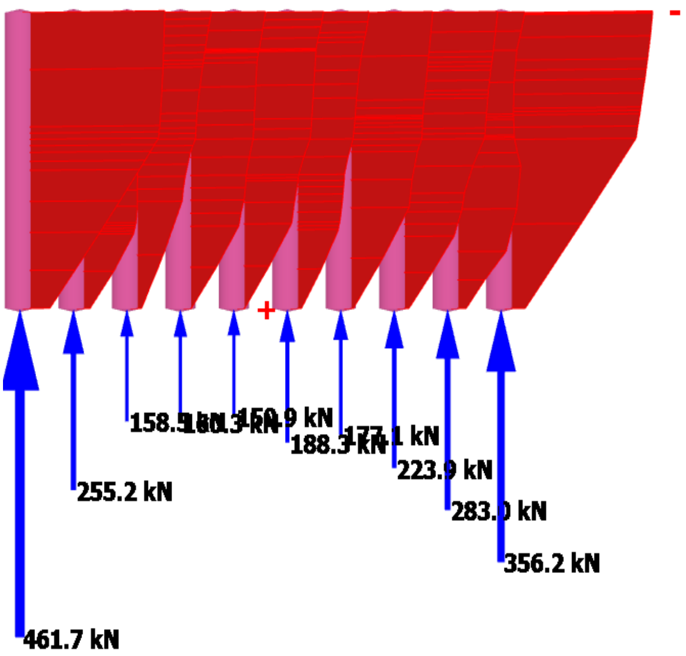


Fig .5AAxial force at piles for rested piled raft

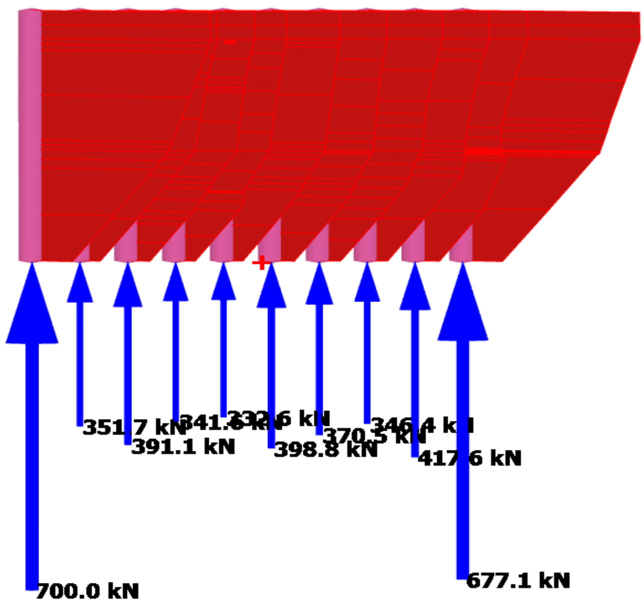


Fig.5BAxial force at piles for un rested piled raft

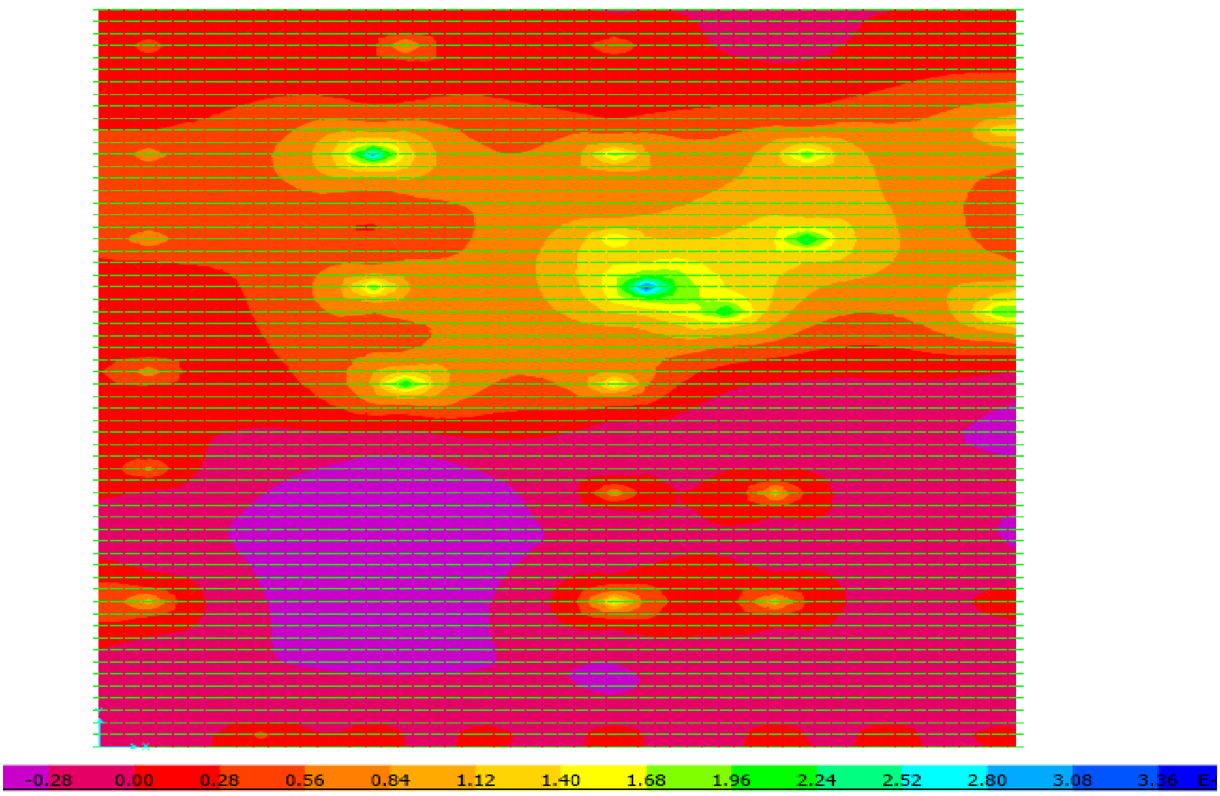


Fig. 6 The bending moment for rested pile raft foundation with pile length 16m

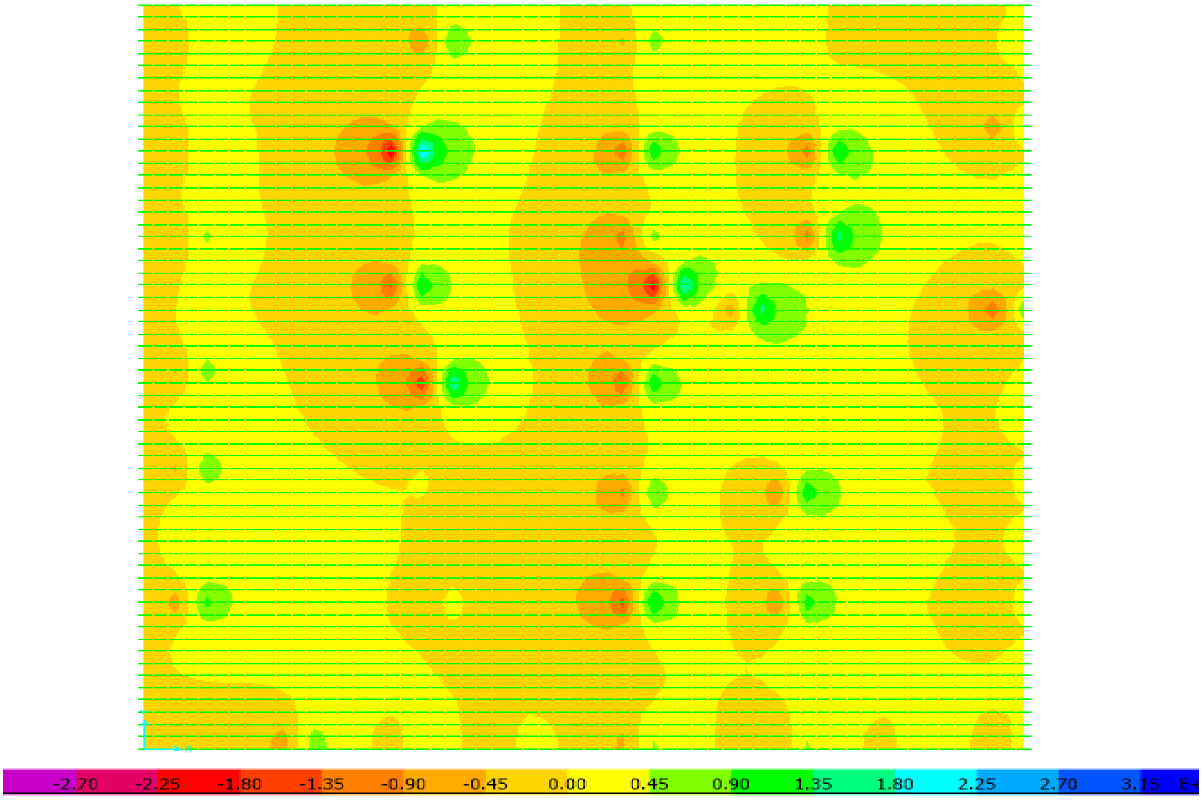


Fig .7 The raft shear force for rested piled raft foundation with pile length 16m

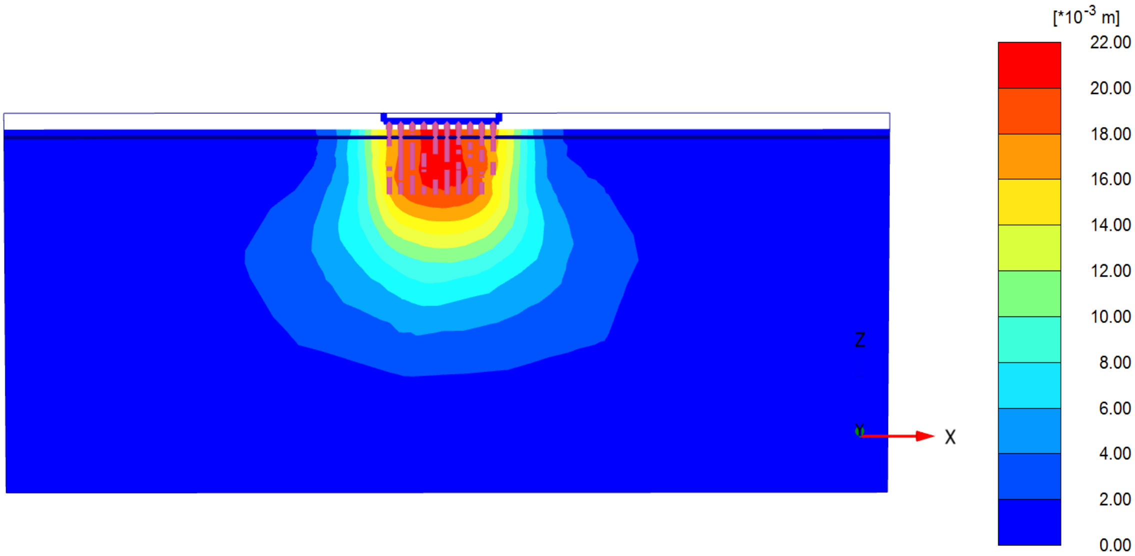


Fig. 8 The vertical displacement for un-rested piled raft foundation with pile length 16m

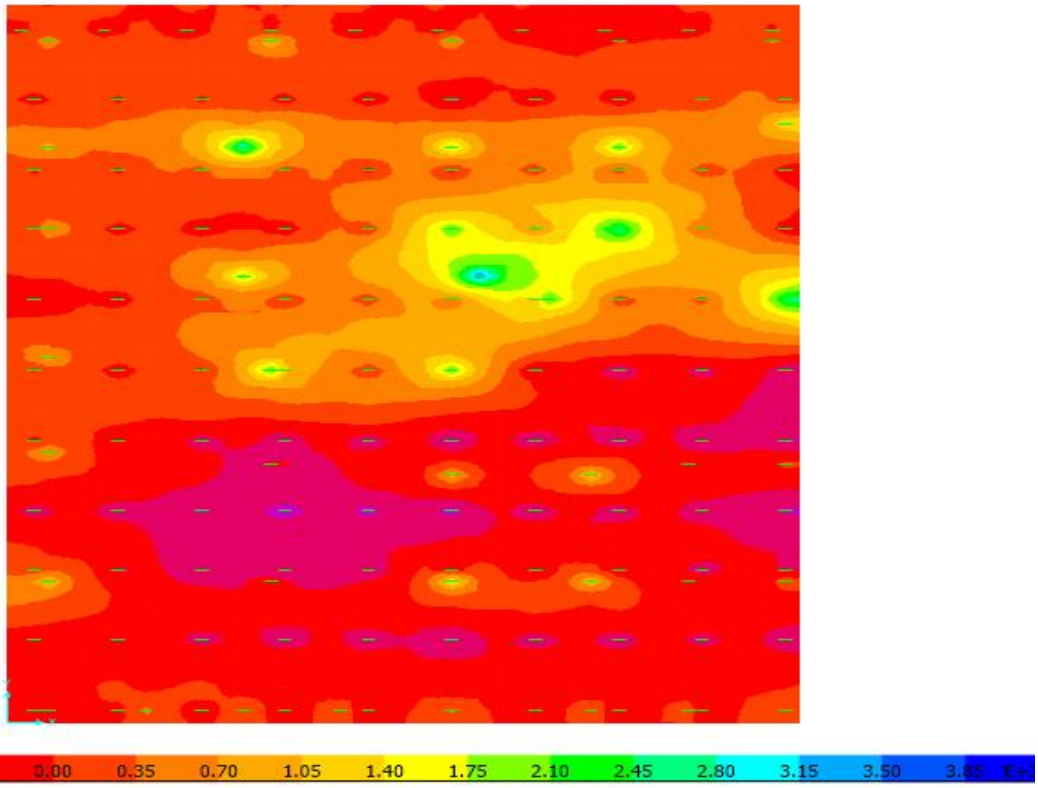


Fig .9The bending moment in the raft for un-rested piled raft foundation with pile length 16

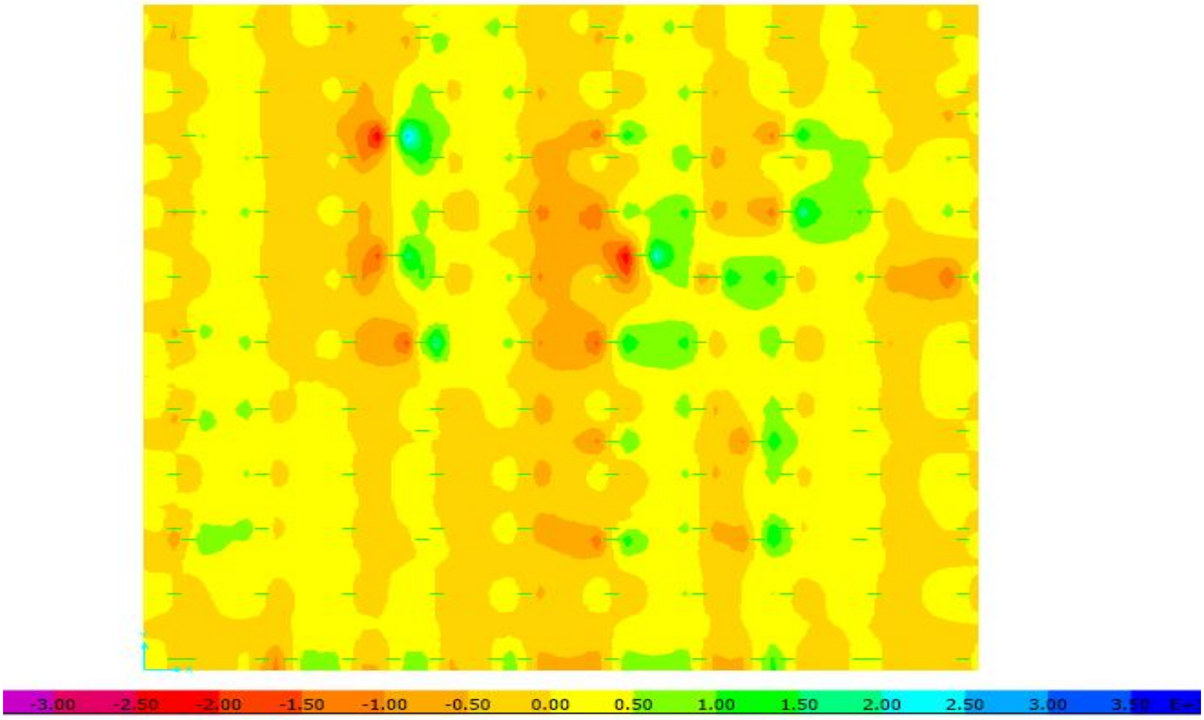


Fig .10The raft shearforce for un – rested piled raft with pile lengt

5. RESULTS AND DISCUSSION

5.1 Settlement Behavior

It can be seen in Figure 9 and clarified in Table 4, a longer pile length diminishes the settlement of the piled raft foundation considerably. The increase in pile length from 8 m to 12 m resulted in only 42% reduction, while additional increases to piles of length 14 m and 16 m caused a 12.7% reduction and a 9.97% reduction, respectively.. This reflects the law of diminishing returns, particularly beyond 12 m, where deeper soil layers have already been effectively mobilized. The impact of raft-soil contact is clearly evident: in the unrested configuration, where the raft is isolated from the soil, settlement is approximately 48% greater than in the rested configuration. This is visible in the displacement patterns shown in Figures 4 and 8.

5.2 Bending Moment on the Raft

Figure 10 and Table 5 both show that, as the length of the pile increased, the bending moment on the raft becomes less. A reduction of 4.7% was observed from piles 8 m to 12 m, followed by a 2.5% reduction from piles 12 m to 14 m, and from piles 14 m to 16 m.This behavior corresponds to the pile tips reaching the stiffer clayey silt layer, which provides greater lateral restraint and better load distribution. The bending moment distribution across the raft for both contact types is visualized in Figures 6 and 9, reinforcing the positive effect of soil-raft interaction.

5.3 Shear Force Distribution

The variation of shear force is presented in Figure 11 and Table 6. Increasing pile length from 8 m to 12 m leads to a 5.26% reduction in shear force, with further decreases of 2.68% (12–14 m) and 2.7%

(14–16 m). These values support the trend of improved shear performance with longer piles, though the marginal gain diminishes at greater depths. Additionally, Figure 7 (rested case) and Figure 10 (unrested case) highlight the difference in shear behavior. The unrested raft system experiences 17% higher shear force, emphasizing the stabilizing

role of raft-soil contact. further decreases of 2.68% (12–14 m) and 2.7% (14–16 m). These values support the trend of improved shear performance with longer piles, though the marginal gain diminishes at greater depths. Additionally, Figure 7 (rested case) and Figure 10 (unrested case) highlight the difference in shear behavior. The unrested raft system experiences 17% higher shear force, emphasizing the stabilizing role of raft-soil contact.

5.4 Load Sharing Between Piles and Raft

As shown in Table 7 and visualized in Figure 12, load sharing varies significantly with pile length:

At 8 m, the raft carries 38% of the load.At 12 m and

14 m, this share drops to 22%.At 16 m, it further declines to 19%.Longer pilesengage deeper, stiffer soil layers, attracting more load and reducing the demand on the raft. However, overly reducing the raft's contribution may result in overdesign and inefficiency. These shifts in load sharing are also evident in the axial force distributions shown in Figures 5A (rested) and 5B (unrested).

5.5 Key Findings

Settlement decreased by 42% when increasing pile length from 8 m to 12 m, with diminishing returns there after.Unrested rafts showed 48% more settlement and 17% more shear force than rested rafts .Bending moments reduced progressively with increased pile length, particularly up to 12 m.Shear force also declined with increasing pile length, reflecting more efficient load redistribution.

Load sharing shifted from raft to piles, with raft contribution decreasing from 38% to 19%

Table 4.Piled raft settlement with different pile length with pile m and 16 m..

Pile length(m)	Settlement (mm) For rested piled raft	Settlement (mm) For unrested piled raft	Settlement (mm) For raft without piles	0.02D+0.5QL/EA allowable settlement(mm)
8	-23.72	-42.07	-47.29	12.1327
12	-13.53	-24.16	-47.29	12.17398
14	-11.8	-22.7	-47.29	12.19167
16	-10.73	-20.77	-47.29	12.20642

Table5. The influence of pile length on the bending moment on the raft with pile diameter 60cm.

Pile length(m)	Bending moment(KN.m) rested piled raft	Bending moment (KN.m) un rested piled raft
8	3445	3560
12	3281	3560
14	3199	3560
16	3117.8	3560

Table 6.The influence of length of pile on the raft shear forceon piled raft foundain.

Pile length (m)	Shear force (KN) Rested piled raft foundation	Shear force (KN) Un Rested piled raft foundation
8	-2316	-2435
12	-2197	-2435
14	-2138	-2435
16	-2079	-2435

Table 7. The load distributionbetween pile &raft

pile length(m)	rested piled raft load carried by pile(KN)	un rested piled raft load carried by pile(KN)	% of load carried by raft	% of load carried by pile
8	843.9	1361	38.0	62
12	1761	2250	22	78
14	1920	2450	22	78
16	2360	2900	19	81

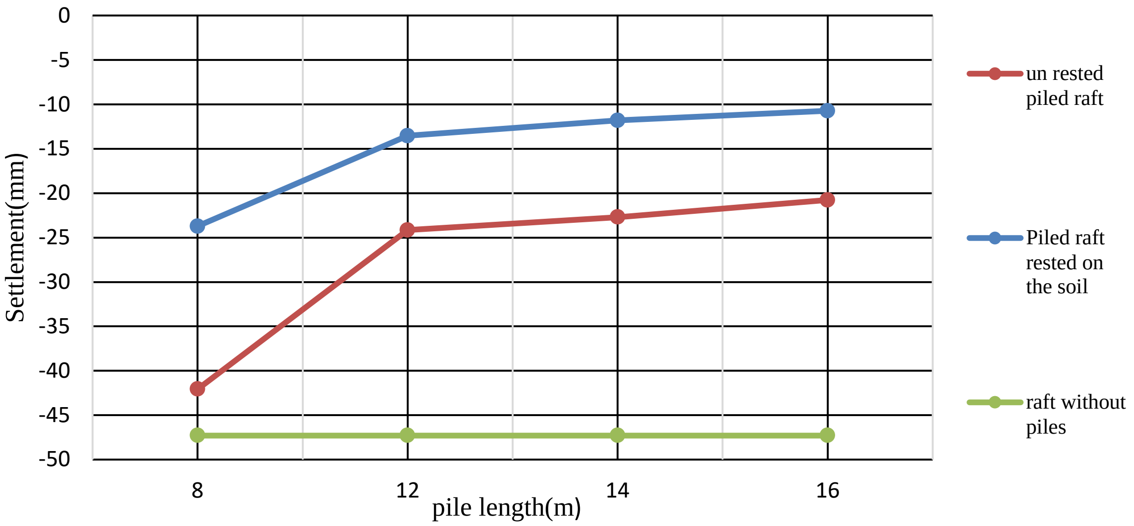


Fig .9. Relationship Between Pile Length and Settlement in Piled Raft Foundations The figure demonstrates that increasing the length of Pile from 8m to 16m leads to a 55% reduction in settlement, highlighting the effectiveness of longer piles in enhancing foundation stability

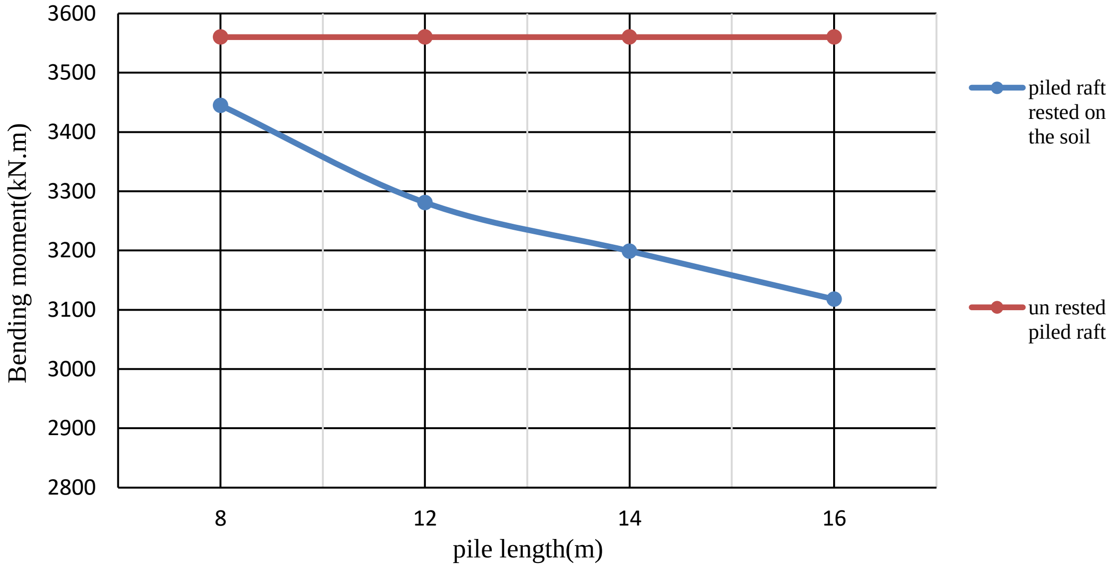
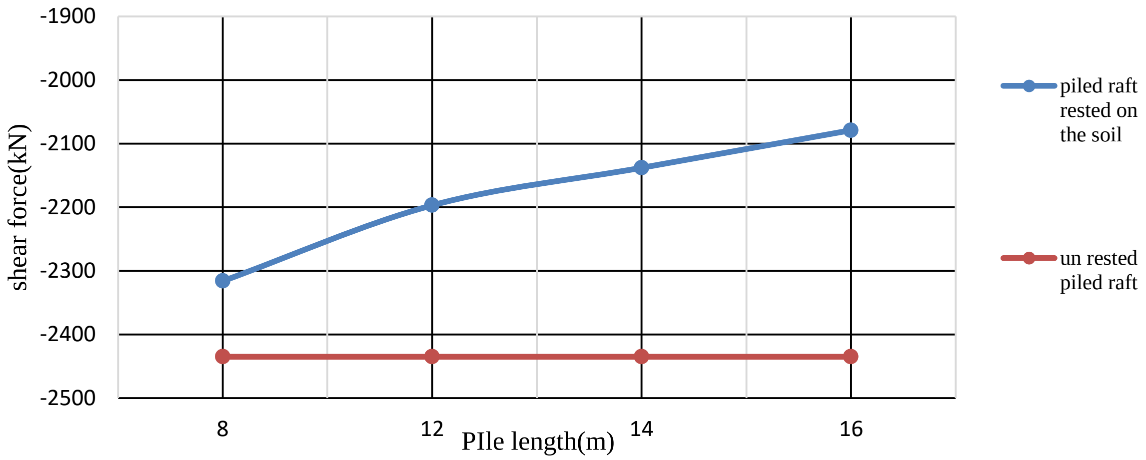


Fig .10 Correlation Between Pile Length and Bending Moment in Piled Raft Foundations The figure illustrates how bending moment on the raft is influenced by pile length. It is evident that as pile length increases from 8m to 16m, the bending moment on the raft experiences a reduction of 10



.Fig .11 Variation of Shear Force on the Raft with Pile Length The figure shows that extending the pile length from 8m to 16m results in an 11% reduction in shear force on the raft, demonstrating the impact of pile length on shear distribution.

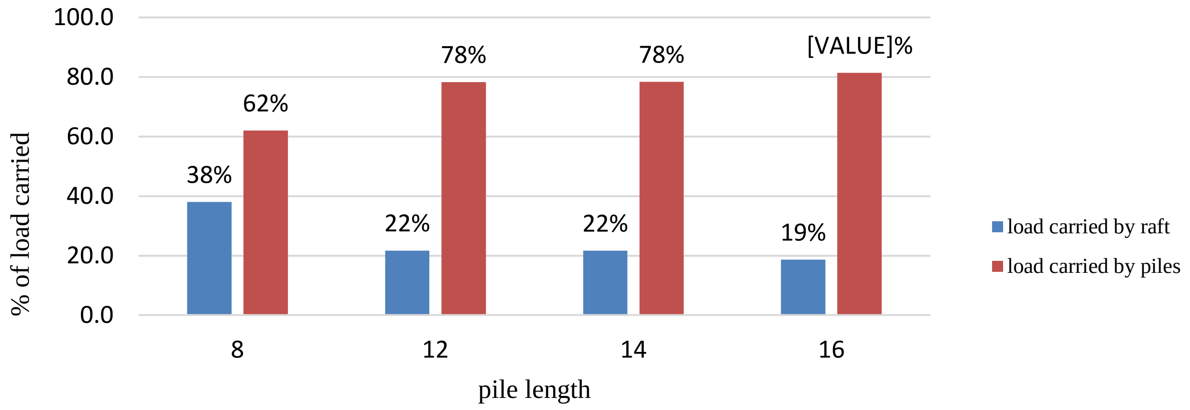


Fig .12 The relation between load sharing between piles &raft

6. Future Research Directions& limitations

Although this study provides valuable insights into the behavior of piled raft foundations, several

6.1 limitations Should be Acknowledged:

Simplified Soil Modeling Using Mohr-Coulomb: The soil was modeled using the Mohr-Coulomb constitutive model, which is widely adopted in geotechnical engineering due to its simplicity. However, it does not capture complex behaviors such as non-linearity, strain-softening, or time-dependent effects (e.g., creep and consolidation), which may influence real-life performance.

No Advanced Interface Modeling: The interaction between the raft, piles, and soil was modeled without using advanced interface elements to simulate slip and friction. This simplification may affect the accuracy of the load transfer mechanism in the simulation. Static Loading Conditions Only: The analysis was limited to static loading scenarios. Dynamic loads such as seismic effects, traffic-induced vibrations, or cyclic loading were not considered, although they are critical in certain design contexts Fixed Structural Parameters: The study kept pile diameter, spacing, and raft thickness constant across. All cases. Varying these parameters could affect the results and broaden the understanding of system behavior under different design configurations. Single Soil Profile: The numerical analysis was conducted using a specific soil profile representative of a site in Egypt. Therefore, the findings may not be universally applicable without adjustments for different soil conditions.

6.2 future Research Could Explore

Different Soil Profiles: Examining how varying soil types (e.g., sands, soft clays) affect pile-raft interaction and settlement trends. Based on the study findings, the piled raft foundation system with varying pile lengths performs most effectively in medium-stiff to soft clay soils, as these soils benefit significantly from deeper pile penetration to stiffer layers. In contrast, dense sandy soils may not necessitate such pile lengths, as adequate bearing capacity can be achieved at shallower depths .Raft Thickness Variations: Assessing how changes in raft thickness influence bending moments and load-sharing .Pile Diameter and Spacing: Investigating the effects of different pile geometries system performance Seismic and Dynamic Loading: Evaluating the behavior of piled raft foundations under earthquake or vibration-induced loads .and Spacing: Investigating the effects of different pile geometries on system performance.

The findings Suggest that partial contact stiffness between the raft and soil should be incorporated into future models to better capture the transitional behavior between full contact and no contact conditions. Such advanced modeling would allow a more realistic simulation of soil-structure interaction, particularly for cases involving non-uniform settlement

7 CONCLUSION.

This study investigated the impact of pile length on the structural behavior of piled raft foundations using finite element analysis through PLAXIS 3D and SAP2000. The analysis demonstrated that increasing pile length significantly improves foundation performance by reducing settlement, bending moments, and shear forces. However, the results also reveal diminishing returns with longer piles beyond 12 meters. Key conclusions include: Increasing pile length from 8 m to 12 m results in a 42% reduction in total settlement. However, the settlement reduction between 12 m to 14 m and 14 m to 16 m was only 12.7% and 9.97%, respectively.

The raft bending moment decreased by 4.7% when increasing pile length from 8 m to 12 m, with smaller reductions of 2.5% in subsequent intervals. Raft shear force was reduced by 5.26% for the 8 m to 12 m range, again showing reduced benefits beyond this length Load distribution shifted significantly: at 8 m, the raft carried 38% of the total load, while at 16 m, it carried only 19%, emphasizing the increasing role of piles in load resistance The comparison between rested and unrested raft conditions shows that direct raft-soil contact significantly enhances performance, reducing settlement by up to 48% and decreasing internal stresses. These findings highlight the importance of optimizing pile length, rather than merely increasing it, for cost-effective and structurally sound foundation designs. The results can assist engineers in designing more efficient piled raft foundations, especially in soft or layered soil conditions

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