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Three-Dimensional Numerical Modelling of Performance of Piled Raft Foundation

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Abstract. Because of its intricate three-dimensional soil-structure interaction scheme, which consists of the pile-soil interaction, pile-pile interaction, raft-soil interaction, and finally the piles-raft interactions, the pile raft foundation system presents a feasible option for high-rise building foundations. Using the pile raft foundation system concept, many megaprojects have been built in recent years. Consequently, a considerable amount of research has been done to examine and comprehend the behavior of pile raft foundation systems under vertical loading. Pile raft foundations have been shown to be more cost-effective for high-rise structures built on clay (lacustrine), and they can meet serviceability and safe bearing capacity requirements. Strategically placed piles increase the raft's load capacity and lessen differential settlement. We are looking for 3D numerical models to look into these intricate relationships. The piled rafts in the study were set up in lacustrine clay, which has stiffness that changes linearly with depth. Many foundation parameters, including pile diameter and pile spacing, were examined in detail using a parametric analysis. It is determined how much weight the piled raft can support as well as how the load shearing mechanism works between the raft and the piles. As a result, the numerical analysis's findings are; as the diameter of the piles increased from 0.8 m to 1.5 m, a greater settlement was observed. This settlement increased gradually. The point where the column is provided in the raft component of the piled raft foundation is where the bending moment magnitude reaches its maximum. Sixty-seven percent of the load is carried by the pile, and the remaining thirty-three percent is carried by the raft foundation.

Keywords: Impermeability, Paper Sludge Ash, Saw Dust Ash, Sugarcane Bagasse Ash, Concrete Water Absorption.

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1. Introduction

The literature that is currently available makes clear that piled-raft foundation was built roughly 50 years ago, and that efforts to understand its behavior began in early 1980s and have gotten stronger in recent years. Despite this, no suitable design strategy has yet been developed. This is due to the intricate relationships between raft, pile, and soil, which are 3D in nature and are beyond the scope of any analytical technique that has been created to date. Researchers are currently attempting to simulate the intricate behavior of pile raft foundations thanks to advancements in computer technology and numerical code. Researchers have developed several analysis methods for pile-raft foundations and are working on developing a suitable model to simulate the discussed interaction. Butterfield and Banerjee's (1971) attempt were cited by Randolph (1983) as the "first" analysis of this intricate interaction [1,4]. This analysis, though, was done for a small pile group. Analysis method for pile raft foundations was created by Davis & Poulos in 1972, but Randolph's analysis method from 1994 is still the most widely used [2,5]. Hooper (1973) made a noteworthy addition to simplified analysis of pile raft foundation [6] in addition to these important studies. According to

Davids (2008), the raft and the piles share the superstructure loads, with the piles bearing between 50 and 80 percent of the total load [3, 7].

Modeling the piled raft foundation as a plate-loaded spring allows for the investigation of alternative design and analysis techniques for this kind [2, 3, 4]. Significant contributions to the study of the intricate behavior of pile raft foundations have come [6, 7, 8]. With development of computer technology and its fast processor, geotechnical engineers now have more computing power for numerical methods. This computational breakthrough makes it easier for researchers to understand the intricate behavior of the foundation. One may argue that Brown deserves recognition for his 1969 popularization of the numerical approach in geotechnical engineering [9]. Nonetheless, in [7] presented the numerical analysis for the pile cap foundation.

The Finite Element Method (FEM) was initially applied by Hooper in 1973 to analyze the intricate behavior of piled raft foundations. [6, 7, 8] made a noteworthy contribution to the behavior analysis. They claimed that the traditional approach to designing piled raft foundations makes the assumption that the pile will support the entire weight without any help from the raft. Since the raft bears a large portion of the load due to its direct contact with the soil, this approach is overly cautious [10]. Keeping above limitation, this study focuses on 3D modelling of performance of piled-raft foundation.

2. Methodology

2.1 Three-Dimensional Modelling Analysis

This paper discusses the FEM approach to modeling piled-raft foundation system. Here is a detailed description of the general process for creating geometry, creating a mesh, carrying out the finite element calculation, and tracking the development of the output results. The software PLAXIS V20 Version was used to carry out the analysis.

2.2 Procedure of Numerical Modelling

In outlining the numerical analysis process for a typical case, the following steps were followed. Step 1 involved the creation of a three-dimensional numerical model of a Rigid Foundation. This involved launching a new project, creating initial stresses through the use of the K0 procedure, defining a Plastic calculation, assigning material properties, defining material data sets, implementing local mesh refinement, and generating mesh. Next, we'll move on to Step 2, where we modified the current data set, specified a soil stiffness profile that increases with depth, modeled plates and defined material data sets for them, modeled beams and defined material data sets for them, assigned point and line loads, activated these loads, and examined structural outputs. All of this was done in order to 3D model the Raft Foundation. Finally, Step 3 centered on the creation of a Piled Raft Foundation. This involved input of the geometry of embedded beams, generating mesh, performing calculations, and subsequently viewing and analyzing the results.

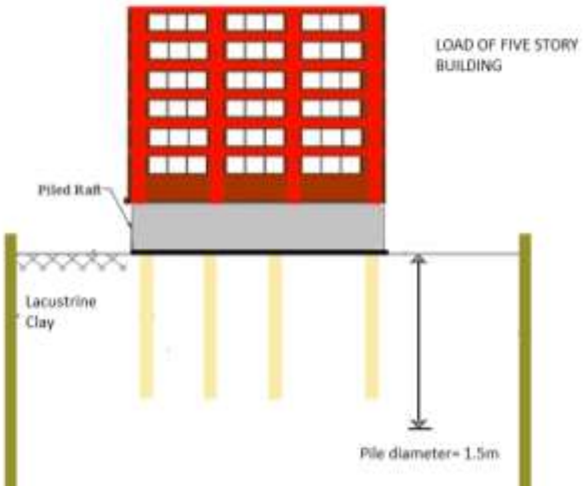


Figure 1: Geometry of the problem adopted in this study

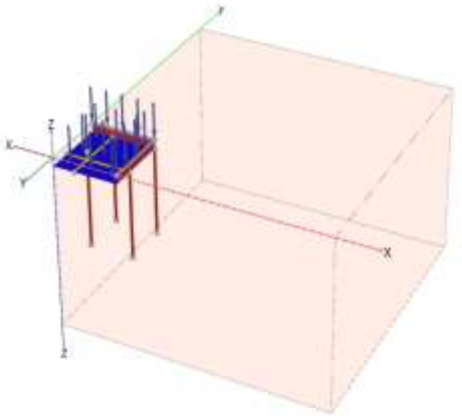


Figure 2: Three-Dimensional Description of Geometry

Table 1 Material parameters of beam

Parameter	**Name**	**Pile foundation**	**Unit**
Young's modulus Unit weight	*E* *γ*	$3 \cdot 10^7$ 6.0	kN/m^2 kN/m^3 – m – kN/m kN/m kN/m kN
Beam type	-	*Predefined*	
Diameter	*Diameter*	1.5	
Predefined beam type	-	Massive circular beam	
Axial skin resistance	*Type*	*Linear*	
Maximum traction allowed at the top of the embedded beam	*Tskin,start ,max*	200	
Maximum traction allowed at the bottom of the embedded beam	*Tskin,end ,max*	500	
Base resistance	*Fmax*	1 x 10^4	

3. Results And Discussion

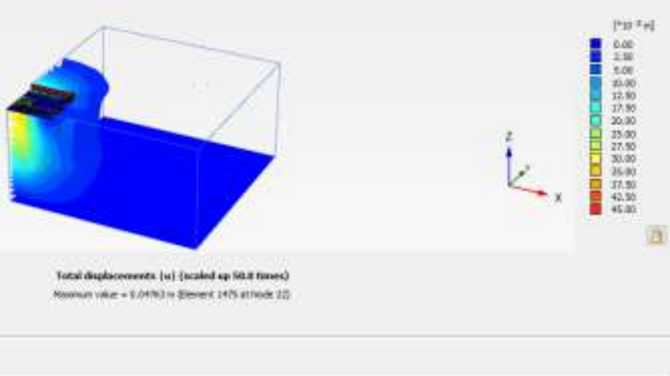
3.1 Influence of Pile diameter on bending moment and total displacement

When transferring the load to the soil, the pile's size is crucial. Through the analysis of the three models created for the various pile diameters of 0.8 m, 1.2 m, and 1.5 m of circular cross-section, the load settlement behavior of piled rafts has been observed. The properties, boundary conditions, and modeling methods discussed in the previous chapter were applied to the soil continuum. The concrete properties for piles and rafts in the preceding section are the same, and the foundation system was exposed to the same surface loads of 5.3 kN/m2, line loads of 385 kN/m, and point load of 11650 kN. The output of PLAXIS 3D's numerical simulation, which includes total displacements and bending moments, is shown.

3.1.1 Case 1 for 0.8 m of pile diameter

Figure 3 shows that for 0.8 m diameter piles, the maximum value of total displacement (settlement) at Element 1475, Node22, occurs when a five-story building load is applied to a piled raft foundation. The previous section's concrete properties for rafts and piles are the same, and the foundation system was subjected to the same point load of 11650 kN, line loads of 385 kN/m, and surface loads of 5.3 kN/m^2.

Figure 4 shows that at Element 33, Node 15, the maximum value of the bending moment is 572.1 kN m. At Element 113, Node 14, the minimum value of the bending moment is -440.1 kN m. The previous section's concrete properties for rafts and piles are the same, and the foundation system was subjected to the same point load of 11650 kN, line loads of 385 kN/m, and surface loads of 5.3 kN/m^2.



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Total displacements |u| (scaled up 50.0 times)
Maximum value = 0.04763 m (Element 1475 at Node 22)
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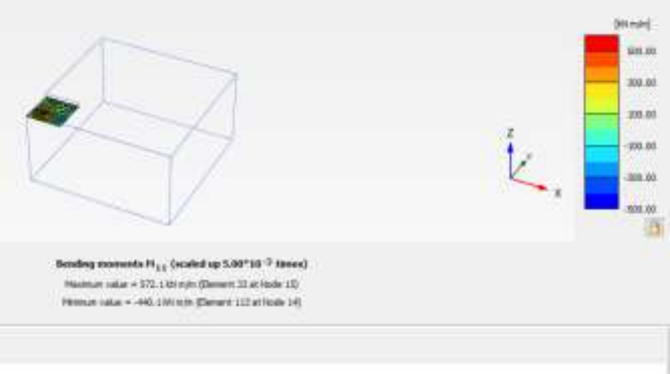
Figure 3: Shading of Total Displacement for 0.8 m diameter of piles



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Bending moments M11 (scaled up 5.00*10^-3 times)
Maximum value = 572.1 kN m/m (Element 33 at Node 15)
Minimum value = -440.1 kN m/m (Element 112 at Node 14)
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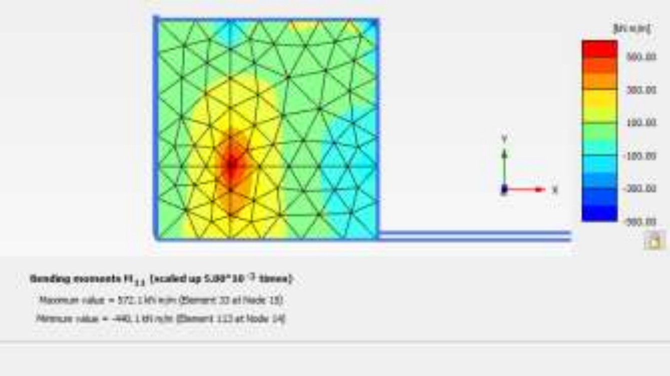
Figure 4: Bending moment in the basement floor for 0.8 m diameter of piles



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Bending moments M11 (scaled up 5.00*10^-3 times)
Maximum value = 572.1 kN m/m (Element 33 at Node 15)
Minimum value = -440.1 kN m/m (Element 113 at Node 14)
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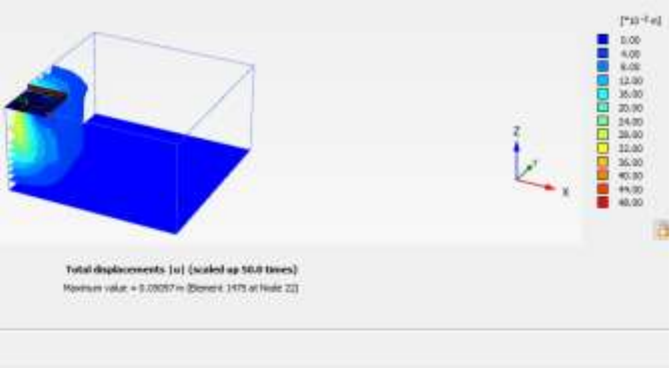
Figure 5: Bending moment (Top View)

3.1.2 Case 2 for 1.2 m of pile diameter

Figure 6 illustrates that under a load from a five-storey building, the piled raft foundation experiences a maximum total displacement (settlement) of 0.05097 m for piles with a diameter of 1.2 m at Element 1475, Node 22. The concrete properties for both the raft and piles are consistent with those outlined in the preceding section, and the same applied loads of 11650 kN as a point load, 385 kN/m as line loads, and 5.3 kN/m2 as surface loads were utilized on the foundation system.

Additionally, Figures 7 and 8 demonstrate that under the same five-storey building load, the maximum bending moment reaches 535.7 kN m, while the minimum bending moment is recorded at -694.4 kN m for piles with a diameter of 1.2 m at Element 113, Node 14. Similar to the previous section, the concrete properties and applied loads remain consistent.



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Total displacements |u| (scaled up 50.0 times)
Maximum value = 0.05097 m (Element 1475 at Node 22)
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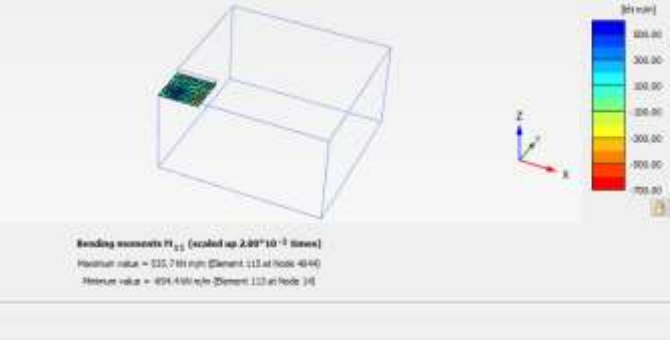
Figure 6: Shading of Total Displacement for 1.2 m diameter of piles6



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Bending moments M11 (scaled up 2.00*10^-3 times)
Maximum value = 535.7 kN m/m (Element 113 at Node 4844)
Minimum value = -694.4 kN m/m (Element 113 at Node 14)
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Figure 7: Bending moment in the basement floor for 1.2 m diameter of piles

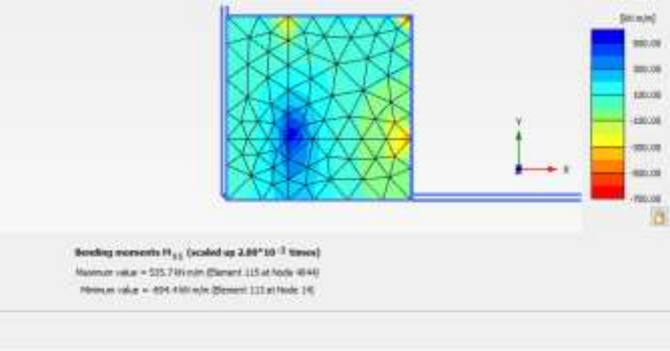


Figure 8: Bending moment (Top View)

3.1.3 Case 3 for 1.5 m of pile diameter

In Figure 9, it is evident that under the load of a five-storey building, the maximum total displacement (settlement) of the piled raft foundation is 0.05265 m at Element 1475, Node 22, for piles with a diameter of 1.5 m. The concrete properties for both the raft and piles remain consistent with those described in the prior section, and the same applied loads of 11650 kN as a point load, 385 kN/m as line loads, and 5.3 kN/m2 as surface loads were employed on the foundation system.

Furthermore, Figure 10 highlights that the maximum bending moment is 581.5 kN m at Element 115, Node 4044, while the minimum bending moment is -797.1 kN m at Element 113, Node 14. Once again, the concrete properties and applied loads remain constant based on the previous section.

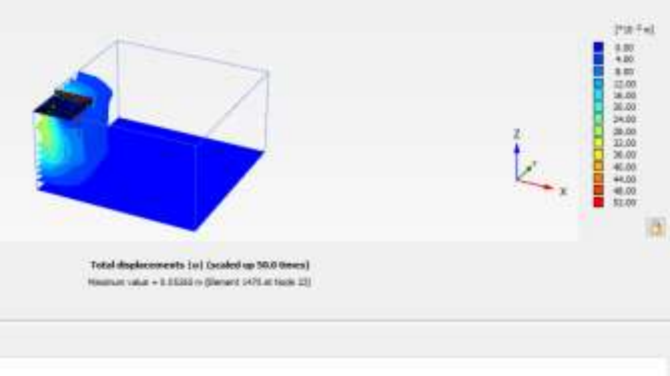


Figure 9: Shading of Total Displacement for 1.5 m diameter of piles

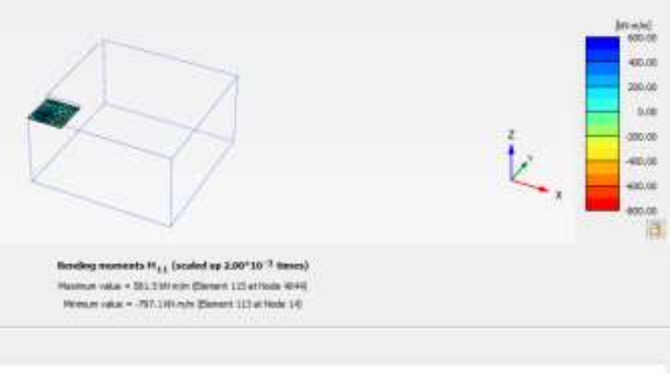


Figure 10: Bending moment in the basement floor for 1.5 m diameter of piles

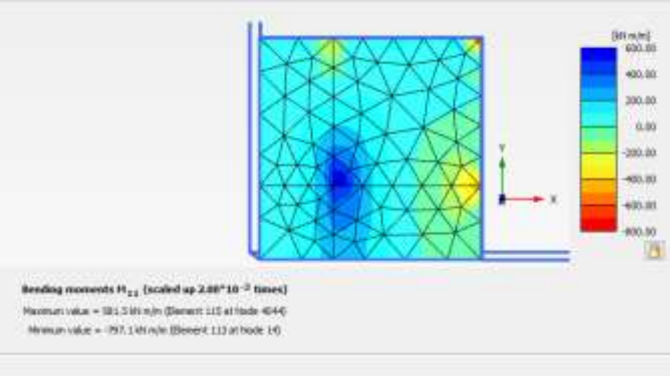


Figure 11: Bending moment (Top View)

3.2 Load Sharing Between Pile Group and Raft

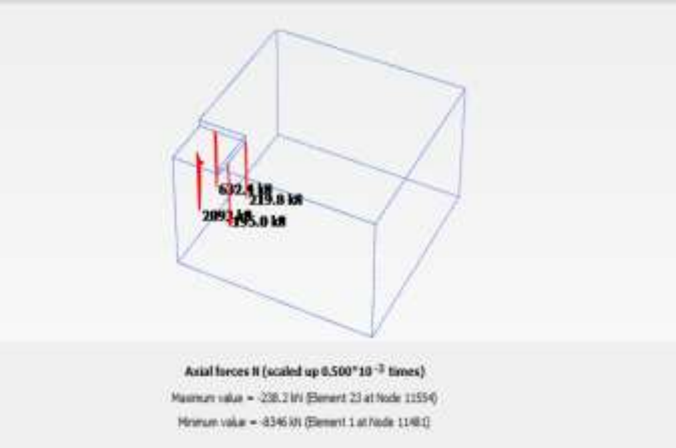
The analysis in the previous section concentrated on the requirement to determine the load resistance of the structural elements of this kind of foundation. The precise estimation of load sharing is the only factor that influences the pile raft foundation's design. Once more, the soil property, raft geometry, pile geometry (diameter, length), and spacing all affect this load sharing.

Keeping all other factors constant, an investigation was conducted for a soil continuum with the feature listed in Table 1 for a pile diameter of 1.5 meters. The load sharing ratio is presented succinctly in Figures 13 and 14 (tables), where the values are tabulated. In a piled raft foundation, the raft component carries about 33 percent of the load, while the piles can carry up to 67 percent of the load.

3.3 Effect of pile spacing on total displacement (settlement)

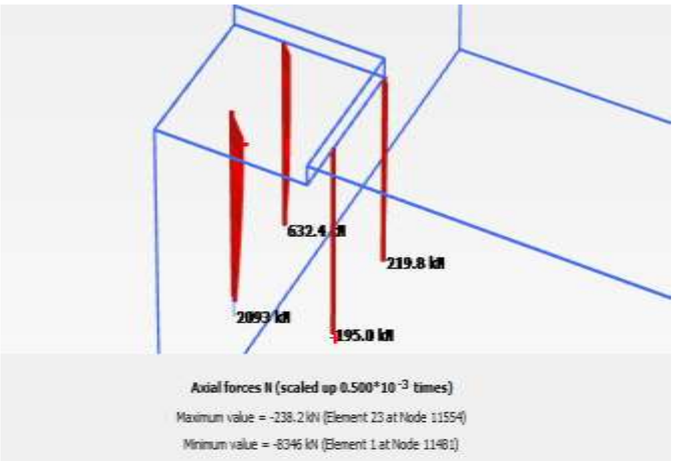
The group pile's main concern is how far apart the piles should be spaced. In addition to dictating the quantity of piles needed and, consequently, the cost of construction, it also ensures structural safety by making the structure stiff. Investigation was therefore made to monitor the influence of pile spacing by fixing the load applied on the raft and fixing all other parameters pile and raft foundation. Figures 13, 14 & 15 and figure 15 represents the total displacement obtained from the developed models at pile spacing of 2D of 0.8 m, 1.2 m, 1.5 m.

It can be seen that maximum value of total displacement (settlement) is 0.05311 m for 1.6 m diameter of piles at Element 1475, Node22. The maximum value of total displacement (settlement) is 0.05675 m for 2.4 m diameter of piles at Element 1475, Node22. The maximum value of total displacement (settlement) is 0.05995 m for 3.0 m diameter of piles. at Element 1475, Node22 for 3.0 m diameter of piles as shown in figures below. Consequently, increase of pile spacing will lead to increase of settlement and vice versa.



Axial forces N (scaled up 0.500*10^{-3} times)
Maximum value = -238.2 kN (Element 23 at Node 11554)
Minimum value = -8346 kN (Element 1 at Node 11481)

Figure 12: Resulting axial forces (N) on 1.5 m diameter of piles



Axial forces N (scaled up 0.500*10^{-3} times)
Maximum value = -238.2 kN (Element 23 at Node 11554)
Minimum value = -8346 kN (Element 1 at Node 11481)

Figure 13: Resulting axial forces (N) on 1.5 m diameter of piles (Zoomed).

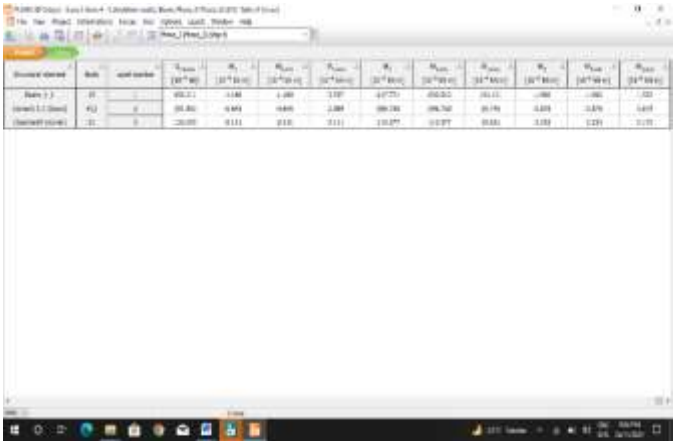
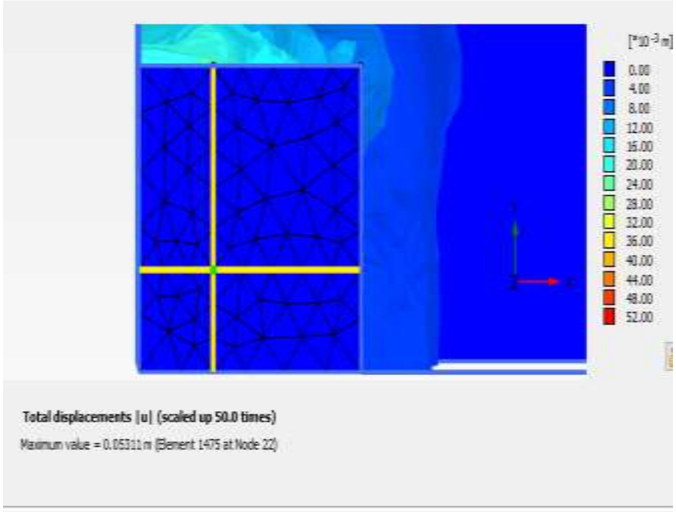
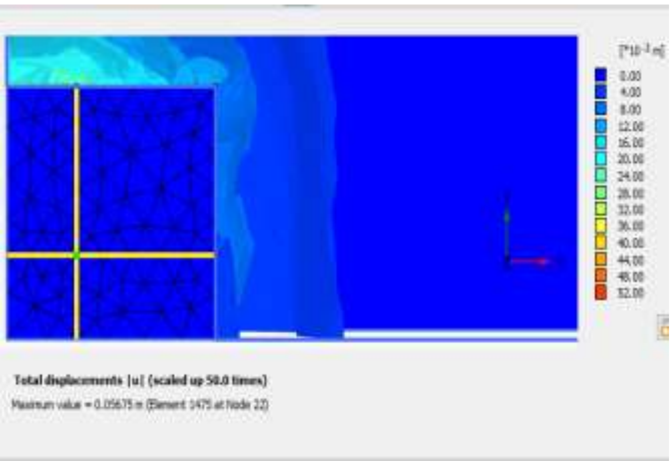


Figure 14: Table shows loads on beam and column



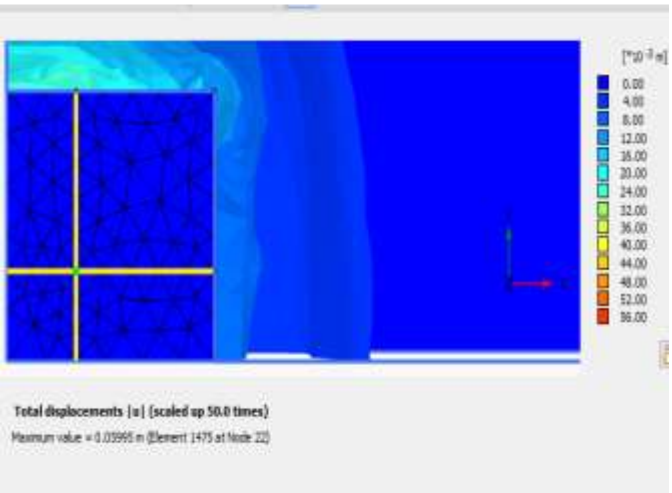
Total displacements |u| (scaled up 50.0 times)
Maximum value = 0.05311 m (Element 1475 at Node 22)

Figure 15: Shading of Total Displacement for 1.6 m diameter of piles



Total displacements |u| (scaled up 50.0 times)
Maximum value = 0.05675 m (Element 1475 at Node 22)

Figure 16: Shading of Total Displacement for 2.4 m diameter of piles



Total displacements |u| (scaled up 50.0 times)
Maximum value = 0.05995 m (Element 1475 at Node 22)

Figure 17: Shading of Total Displacement for 3.0 m diameter of piles

4. Conclusions

- The maximum value of total displacement (settlement) is 0.05265 m at Element 1475, Node22 for 1.5 m diameter of piles. The settlement is observed greatest for 1.5 m diameter of the pile and increased gradually as the pile diameter increased from 0.8 m to 1.5 m.
- The Maximum value of Bending moment is 581.5 kN m at Element 115, Node 4044 (the point where the column is provided in the raft component of piled raft foundation) for 1.5 m diameter of piles
- The Minimum Value of Bending moment is -797.1 kN m at Element 113, Node 14, for 1.5 m diameter of piles.
- The Value of bending moment is also observed greater around the column zone and decreased gradually to the farther point from the column.
- The relation of bending moment is not linear with pile diameter or pile spacing, it increases and decreases depending upon soil, raft and pile parameters.
- The percentage of load shared between pile and raft is as 67% by pile and remaining 33% is carried by raft foundation.
- The settlement behavior of pile raft foundation is also affected by pile spacing, an increase of pile spacing will lead to an increase of settlement and vice versa. For 3.0 m of piles diameter settlement value is 0.05995 m, for 1.6m of piles diameter settlement value is 0.05675 m, and for 1.6 m of piles diameter settlement value is 0.05311 m.

5. Recommendation

The axial and static loads on the piles and rafts in piled raft foundations are the main subject of this study. Thus, in future research, lateral and dynamic/cyclic loads can be taken into account, potentially revealing a proper/realistic behavior of piled rafts under dynamic conditions. It is crucial to take into account the weight of the excavated material as well as additional structural weights, such as the raft, during the FE analyses of the model using PLAXIS. In addition, if the pile capacity is derived from field tests, the PLAXIS embedded pile feature could be utilized in computations with greater accuracy. A real-world example is used to validate both the suggested approach and the embedded piles.

Furthermore, distinct validations can be carried out using various PLAXIS 3D components, such as volume piles, beams, etc. A more thorough comparison and realistic behavior of piled raft foundations can be achieved by using the Hardening Soil Model in conjunction with detailed soil data. In this study, the model has been subjected to uniform distributed loads and identical piles arranged equally apart. In actuality, though, this is not the case in day-to-day structural design. It is generally advised to adjust the pile diameters and/or lengths while taking the superstructure load pattern into account. As a result, load considerations must be made on a project-by-project basis, with piles being strategically placed through trial and error or parametric study. When designing and building, local design codes and regulations should be considered.

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