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Numerical Analysis of Combined Piled Raft Foundation (CPRF) in Cohesive Soil under Inclined Loading Condition

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ABSTRACT

The Combined pile raft foundations provide an economical foundation option for circumstances where the raft foundation can satisfy the bearing capacity requirement but fails to keep differential as well as maximum settlement below the maximum allowable limit. It had been established that augmenting features like thickness of raft, length of piles etc has decreased the settlement of raft and on other hand decreasing 'spacing/depth' of piles has increased settlement of raft. In this paper uniform arrangement of piles. In this paper CPRF is analysed using Finite Element Software Plaxis 3D with Uniform arrangement of piles.The study encompassed a model foundation test that examined different combinations of eccentricity e/B (0, 0.05, 0.10, 0.15) for load inclination angles (0°) and an eccentricity e/B of 0 specifically for a load inclination angle of (0°,15°,30°,45°,60°,75°,90°), all relative to the vertical direction. Software to determine the loads to be transferred, after fixing dimensions of raft and settlement analysis of raft Plaxis 3D work programme was composed. The research findings provide valuable insights and serve as a reference, demonstrating that as the inclination angle increased relative to the vertical direction, the bearing capacity of the CPRF decreased and as eccentric load applied on CPRF, the carrying capacity of piled raft decreases and differential settlement increases.

Keywords: Combine Piled-Raft Foundation, Plaxis 3D, Eccentric Loading, Inclined Loading, e/BRatio

INTRODUCTION

Piled raft foundations provide an economical foundation option for circumstances where the performance of the raft alone does not satisfy the design requirements. All the previous studies to evaluate the settlement reduction potential were done considering uniform arrangements of piles. A three-dimensional analysis of CPRF with Inclined Loading of was never done. From this study we could arrive at certain conclusions which will suggest some criterions that would help to improve the performance of CPRF for reduction of settlement.

CPRF has intricate soil-structure interactions, hence to obtain authentic results 3-dimensional Numerical analysis had to be adopted. Finite Element Method is one of the numerical methods which is a powerful tool to model this complex geometry of piled-raft foundation. Plaxis 3D is one of the sophisticated finite element software which is well suited for foundation analysis. It has high flexibility in 3-D modelling, in meshing, in incorporate field conditions and in analysing.

Effectiveness of CPRF in reducing settlement was experimentally proven and the result was published by Mr. Van Impe, in the technical paper titled "Technical Report on Methods of Analysis for Piled Raft Foundations", (As a report prepared on behalf of technical committee TC-18 on piled foundations for international society for soil mechanics and geotechnical engineering in 2011).

De Sanctis et al (2001) and Viggiani (2001) have distinguished between two classes of piled raft foundations: "Small" piled rafts, where the primary reason for adding the piles is to increase the factor of safety and "Large" piled rafts, where piles installed reduce settlement or differential settlement. In such cases, the width of the raft is large in comparison with the length of the piles.

P.C. Varghese in his book Foundation Engineering (2009) has classified CPRF into two classes according to their use "Piled Rafts for Settlement Reduction" and "Piled Raft for Load Transfer"

In this study, to Analysis of Combined Piled Raft Foundation in Inclined Loading Condition, the Mohr-Coulomb model was adopted and Finite Element Method (FEM) was performed using PLAXIS 3D program. The Load vs Settlement Curve for different model is presented in the form of design charts.

Numerical Model

The model comprises a soil continuum, a rectangular raft (20*20*2 cm),a group of pile of (3*3, Length 20cm and diameter 2 cm), an interface component, and a Point Load; a drained analysis was utilized.

Constitutive Modelling

The Mohr–Coulomb model, commonly employed in geotechnical works, requires a few input parameters such as cohesion, internal friction angle, young's modulus, and Poisson's ratio which can be obtained from standard soil tests. The soil and Raftwere represented using 10-nodeVolume elements and the piles were modeled as embedded beam elements.

The load-bearing behaviour of a piled raft is characterized by a complex soil-structure interaction between the piles, raft, and the subsoil. The raft and piles remain elastic due to their higher modulus of elasticity compared to soil, making them linearly elastic. They are rigidly connected, and their interface is represented by the interface reduction factor (Rinter), which shows the interface strength as a percentage of adjacent soil's shear strength. The raft-soil interface, considered a smooth contact with a Rinter of 0.7, follows the Plaxis 3D manual's recommendations (0.8–1 for sand-concrete and 0.7–1 for clay-concrete interactions). The soil-pile interaction is modeled using embedded interface elements of 3-node line elements with node pairs. Interface elements have zero thickness (h=0), follow the Mohr–Coulomb failure criterion, and enable simulating displacement discontinuity between structural elements (raft and piles) and the soil mass.

INPUT PARAMETER FOR NUMERICAL ANALYSIS

Soil

The analysis studied Cohesive soil characteristics using a Mohr–Coulomb Elastoplastic medium 0.6 m from the surface. Geotechnical parameters were sourced from collected data, and missing information was estimated using empirical equations derived from Standard Penetration Test (SPT) values. Young's modulus, cohesion, angle of friction, and Poisson's ratio were determined using methodologies from references.

Raft

The raft, a fat slab of consistent thickness on the ground had a smaller occupied volume than the soil mass. A square raft foundation with a 1.0 length-to-width ratio (Lr/Br = 1.0), a width of 0.2m (Br), and a length of 0.2m (Lr) was modelled .The initial raft thicknesses of 0.02 m were assumed using SAFE 20 software, which imported loads from the ETABS output, to resist punching forces.

Pile

This study models piles usingdiameters of 0.01 mand spacing of 6D on the 3*3 pile group, Pile lengths of 0.2 m, where piles primarily reduce settlement. Pile numbers 9were tested in 3 × 3 configurations(See Figure 3).

Load

The Point load is acting on the top of raft. It is act at different location as the angle of inclination will change and as the eccentricity of system will change.

Table 1: Properties used for Numerical Study

Parameter	**Soil**	**Raft**	**Pile**
Material model	Mohr Coulomb	Linear Elastic	Embedded Beam
Unsaturated unit weight(Yunsat) in KN/m3	17	25	25
Unsaturated unit weight (Ysat) in KN/m3	18	-	-
Modulus of Elasticity(E) in KN/m2	5000	2.5 x 106	2.5 x 106
Poison's Ration(μ)	0.3	0.2	-
Cohesion(C) in KN/m2	100	-	-
Angle of Internal friction(ϕ) in Degree	2	-	-

Model Validation

Andre Ryltenius et al. 2011, Validates The geometry of the piled raft is illustrated in Figure 4.12. The piled raft is situated on a single layer of soft clay and supports a uniform load of 30 kN/m3 . The piles are chosen to SP3 piles (Swedish standard), which are square pre-cast concrete piles with the width of 275 mm [5]. The raft and the piles where assumed to have a Young's modulus of 35 GPa. The firm rock is situated 40 m below the ground surface and the ground water table is situated three meters below the ground surface.

The model is160x160x40 m3, thus the same width as the plane strain model. A borehole was defined, which is 40 meter deep and with the water level situated 3 meters below the ground surface. The bore hole was assigned the material properties (clay). Thethickness of Raft is 0.5m(See Figure 1).

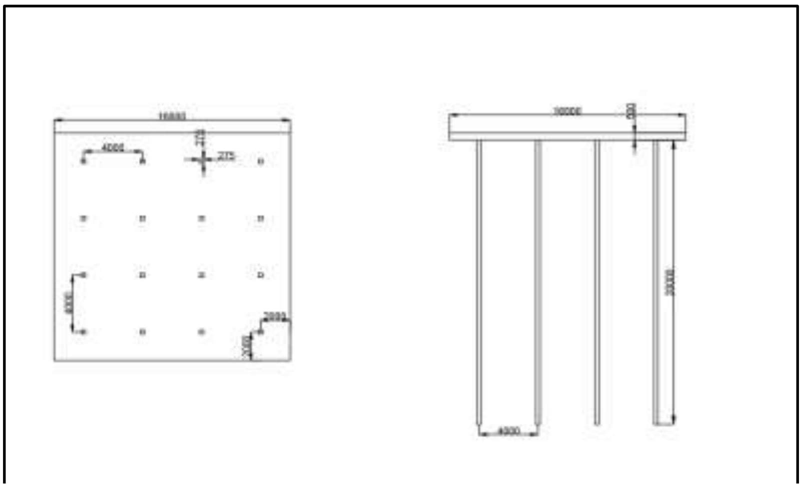


Figure 1: Pile raft Description

Table 2: Properties used for Numerical Study

Parameter	**Soil**	**Raft**	**Pile**
Material model	Mohr Coulomb	Linear Elastic	Embedded Beam
Unsaturated unit weight(Yunsat) in KN/m3	18	25	25
Unsaturated unit weight (Ysat) in KN/m3	18	-	-
Modulus of Elasticity(E) in KN/m2	5000	35 x 106	35 x 106
Poison's Ration(μ)	0.35	0.2	-
Cohesion(C) in KN/m2	4	-	-
Angle of Internal friction(ϕ) in Degree	30	-	-

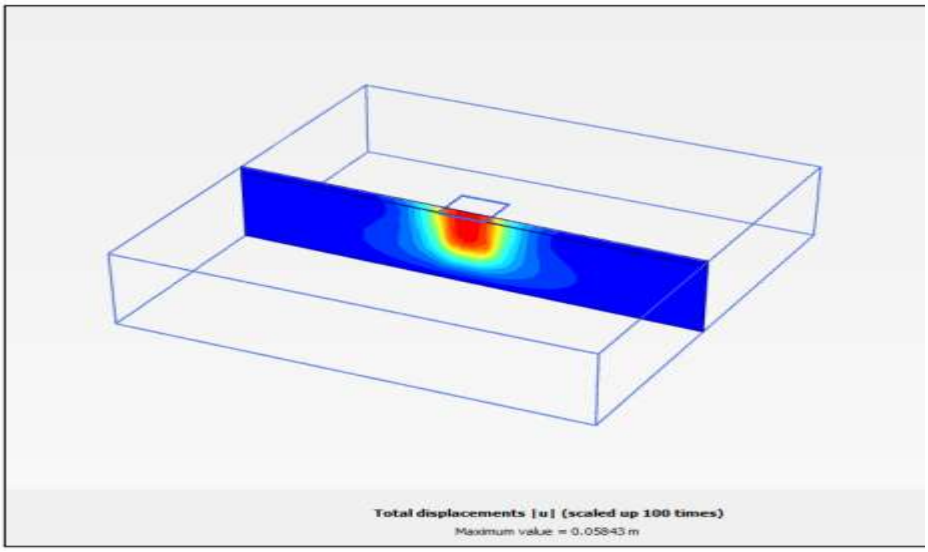


Figure 2: Total displacement for the study

The displacement obtained was 56mm. For the present work it was found to be 58mm.

Numerical Study

In this parametrical Study we have taken a Piled Raft Foundation as shown in figure 1, then we have to change the angle from (0', 15', 30', 45', 60', 75',90') and changing the eccentricity from(e/B=0.0B,0.05B, 0.1B, 0.15B)
(See Figure 3,4 and 5).

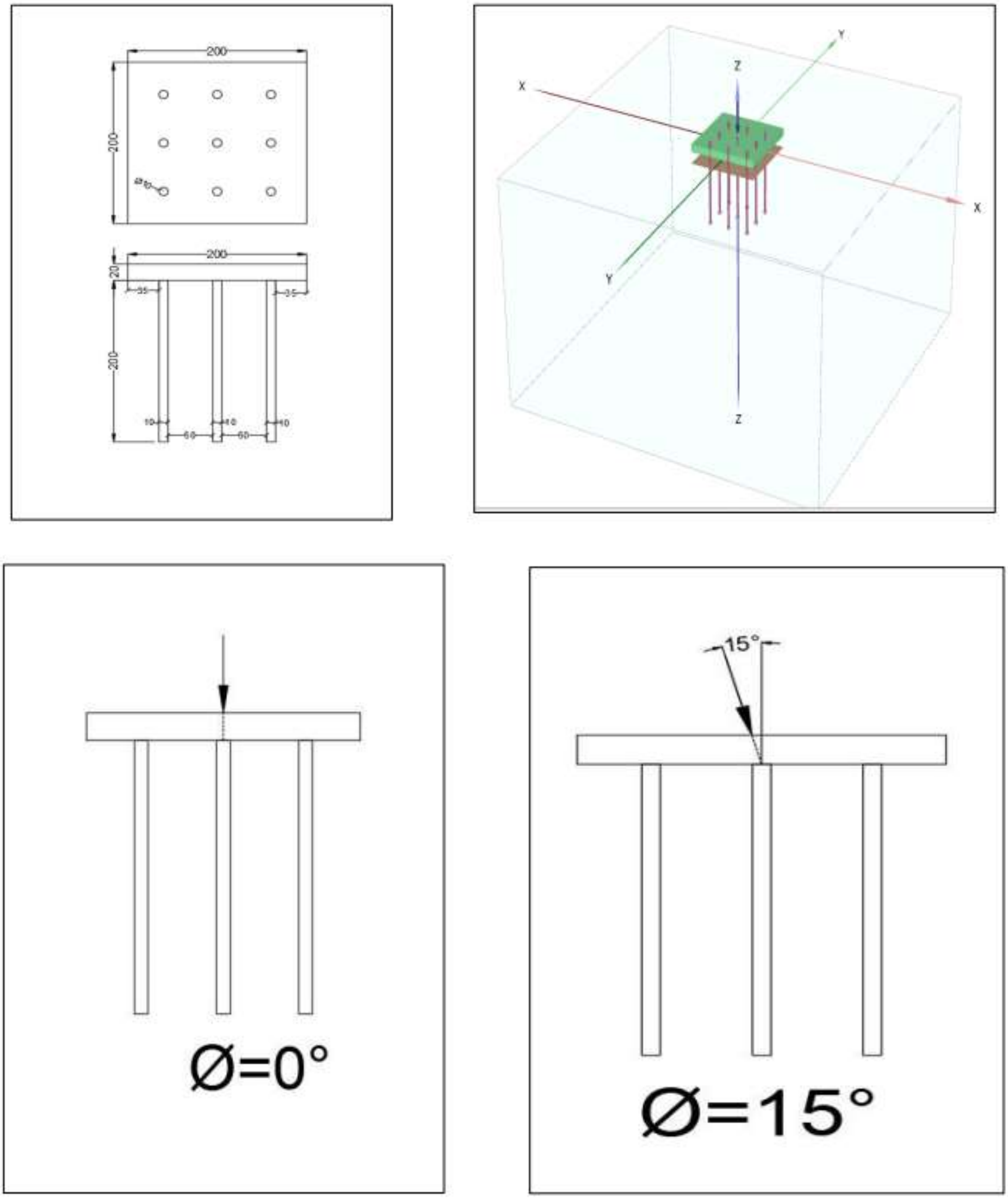


Figure 3: Piled Raft Arrangement, (0,15 Degree)

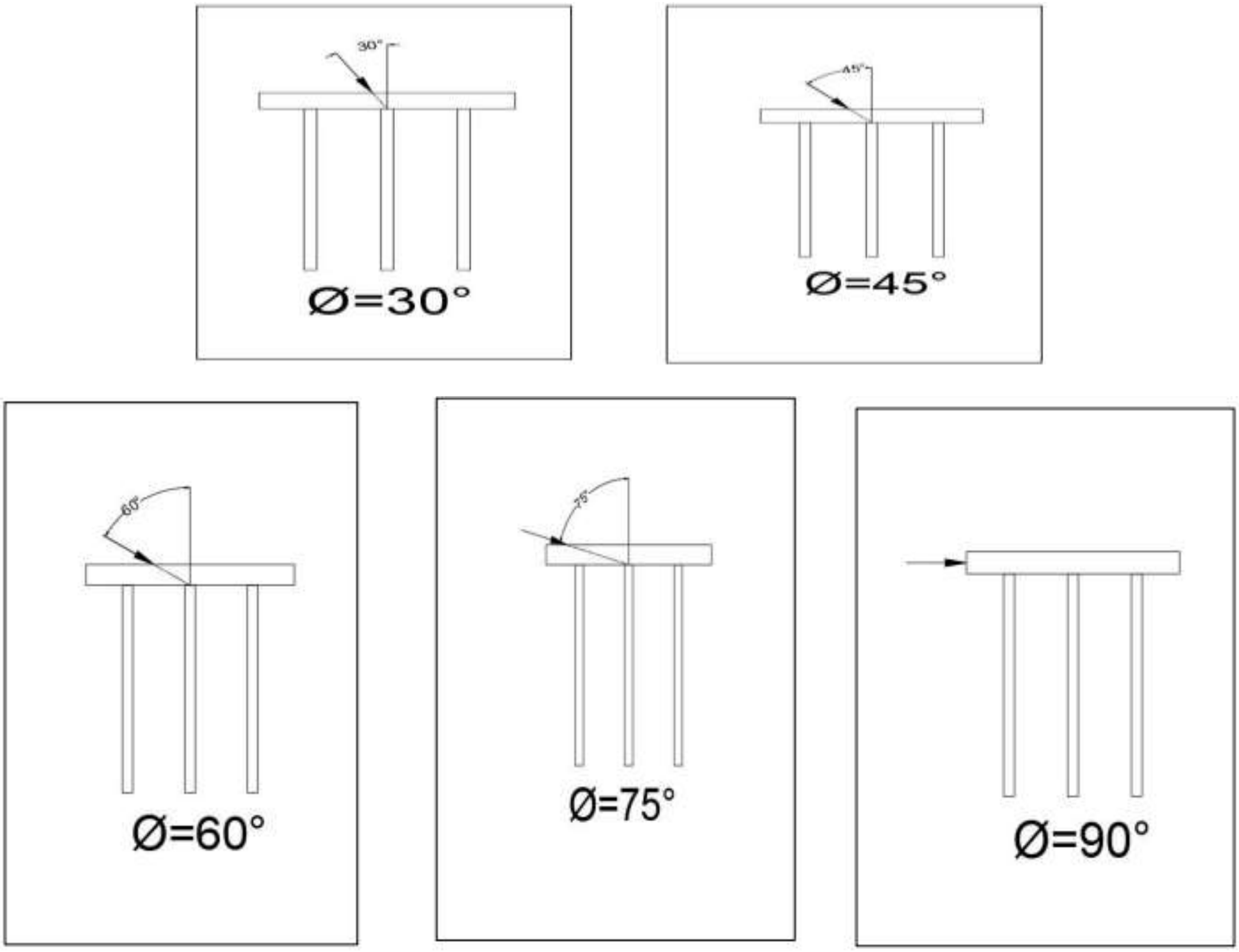
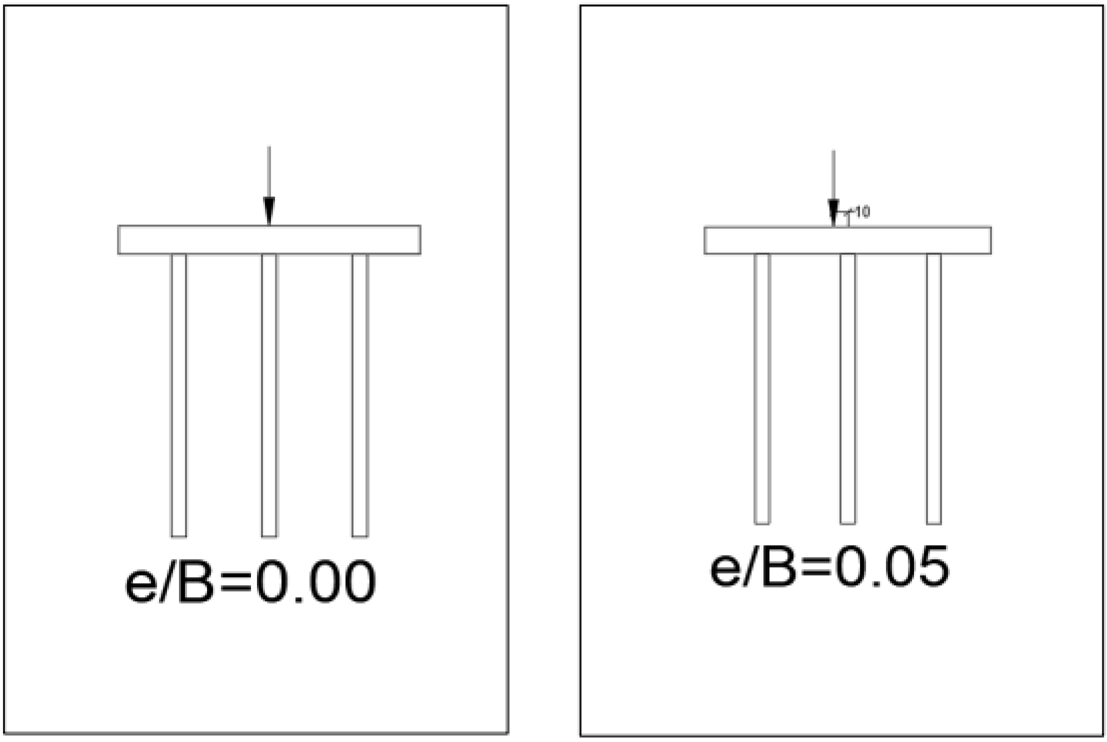


Figure 4: Piled Raft Arrangement, (30,45,60,75,90 Degree)



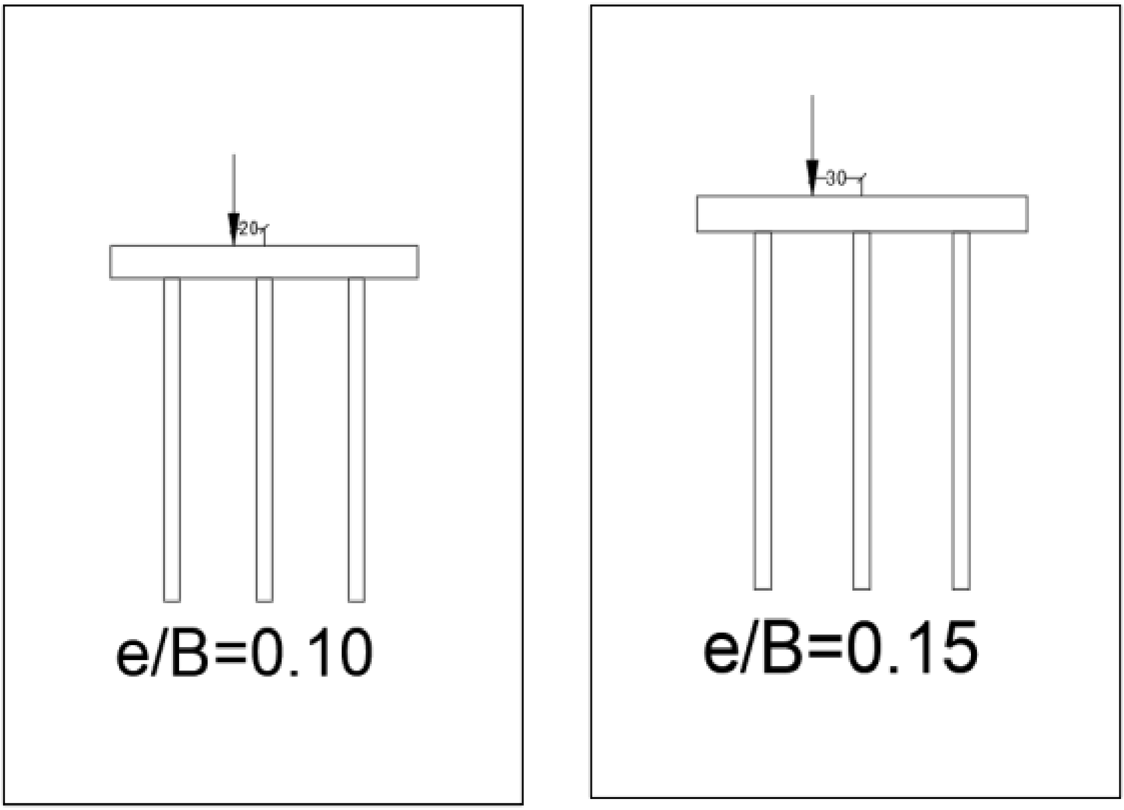
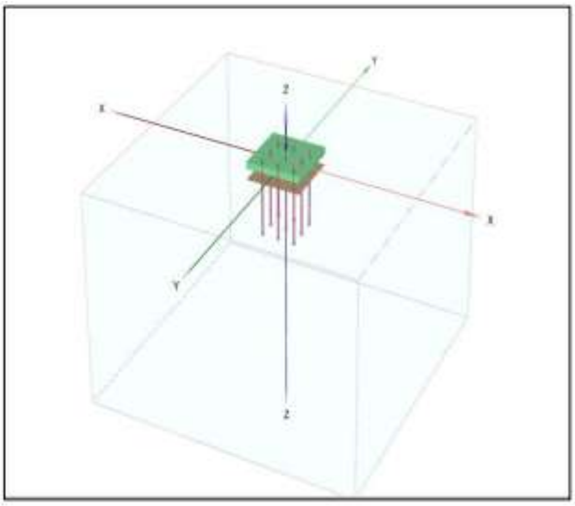


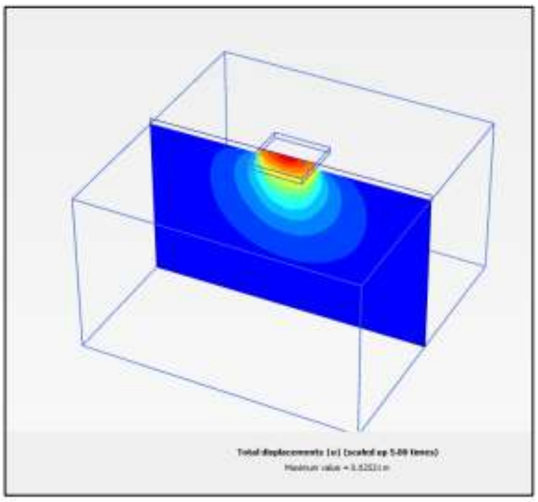
Figure 5: Different Eccentricity on Piled Raft (e/B=0.00, 0.05, 0.10, 0.15)

Numerical Study Results

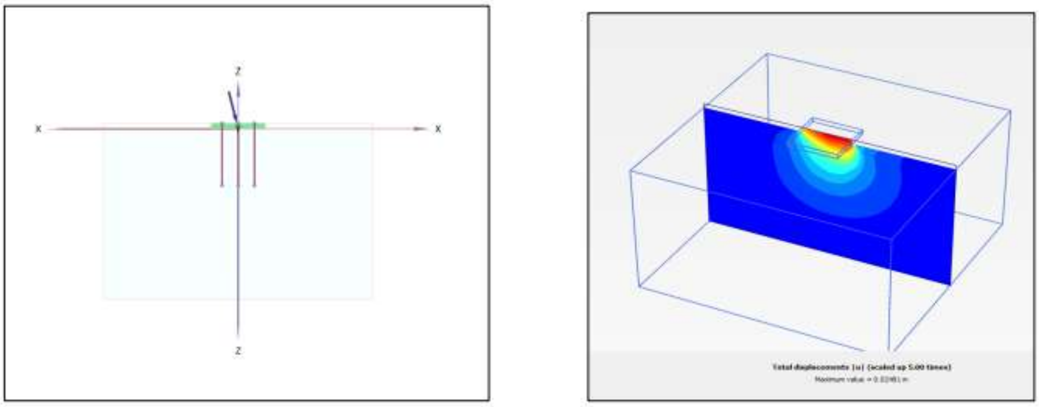
Plaxis 3D is a three-dimensional Plaxis program, developed for the analysis of foundation constructions including raft foundations and offshore structures. It is part of the Plaxis 3D product range, a suite of finite element programs that are used worldwide for geotechnical engineering and design. Plaxis 3D is one of the geo-technical software which can model, analyse and present complex geo-tech problems easily. Pile was modelled as Embedded Pile (Massive circular) and Volume as plate element. 11 different arrangements were modelled and analysed. Properties of pile and properties of raft are given in Table 1.Now how the Load carrying capacity is decreasing with inclination of angle and increase the eccentricity is shown in Figure 7 and Figure 8.



Ø=0 Degree



Ø=0 Degree



Ø=30 Degree Ø=30 Degree

Figure 6: Numerical Analysis Results on Piled Raft (0,30 Degree)

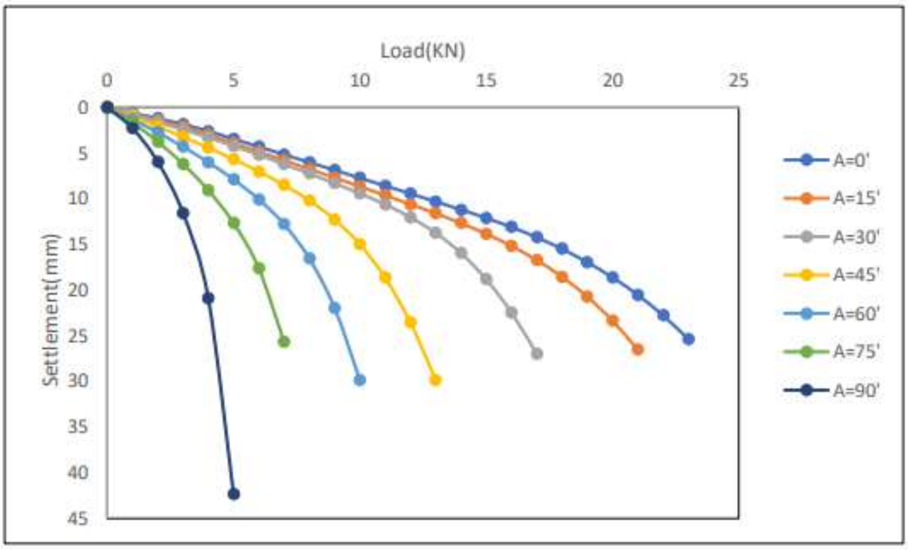


Figure 7: Load-settlement curve for piled rafts in Different Angle

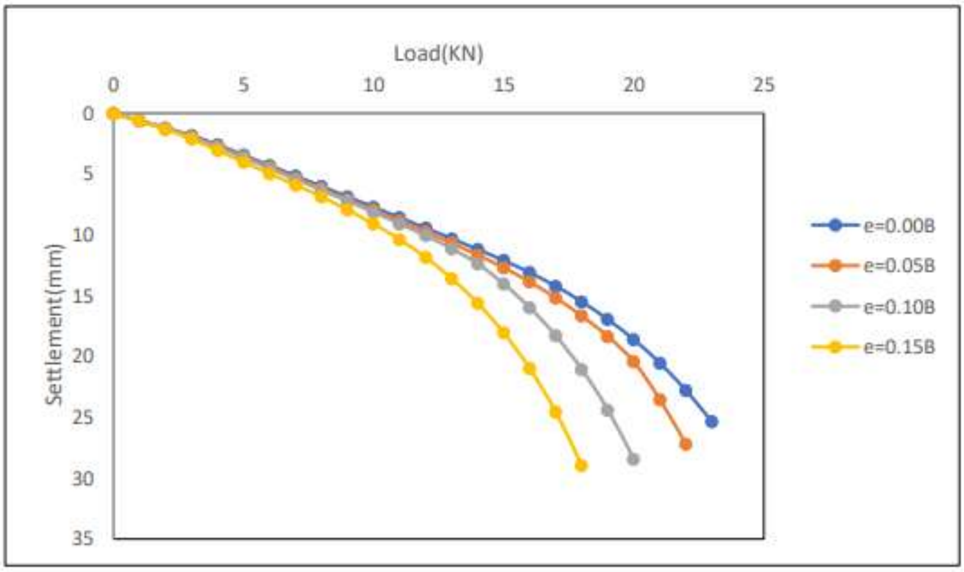


Figure 8: Load-settlement curve for piled rafts in Different Eccentricity

CONCLUSION

The Combined Piled-Raft Foundation (CPRF) is a foundation type that combines the advantages of shallow and deep foundations. It uses piles to enhance the load-bearing capacity and minimize settlements when the raft alone is insufficient. An experimental study focused on the behaviour of CPRF in Cohesive soil. Different combinations of eccentricity and load inclination angles are tested.

The study found that as the inclination angle increased, the CPRF's bearing capacity decreased. These findings offer valuable insights for designing piled raft foundations subjected to inclineand eccentric loading.

- The settlement increases at a slow rate, this behaviour is described as curvilinear with a concave downward shape, indicating a gradual increase in displacementas the load increases. As the loading progresses further, the load-settlement relationship transitions into a straight line with a higher rate of progressive displacement. This indicates if the load on the foundation continues to increase, the settlement also increases at a faster rate.
- When the inclination of the load increases from 0º to 90º with respect to the vertical axis, the carrying capacity of a piled-raft decreases. This means that the piled raft is less effective in carrying the load when it is inclined because, during inclined loading whole raft doesn't carry its full bearing compared to when the load is applied vertically. Additionally, the load-settlement curve of a piled-raft exhibits stiffer behaviour initially when the load is applied in the vertical direction.
- However, when the load is applied in an inclined direction with respect to the vertical axis, the load-settlement curves show a reduction in stiffness. This means that the settlement is greater for the same increase in load compared to the vertical load case. The curves tend to lean towards the displacement axis, indicating a softer or less stiff response.
- The observation aligns with the understanding that inclined loading introduces additional eccentricity to the system. The introduction of a horizontal component of force further affects the stress distribution within the soil, resulting in uneven stress distribution and subsequently larger differential settlement. As the load inclination angle with respect to the vertical increases, the differential settlement also increases.

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