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Original Article

Analysis of Pile-Raft Foundation in Cohesionless Soil Strata

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***Abstract* -** *Soil that alters with the variation in environmental situations when used for constructional activities is usually present. For ages, construction on such ground has been a pronounced challenge in the arena of geotechnical engineering, as it results in the slow progress of work due to instability of the ground and cost overruns in the accomplishment of the project. The major geotechnical issues associated with such types of soils include slope instability, excessive settlement, bearing capacity failure, etc. Such soil shows common challenges for the sustainable and serviceable design and further construction of structural foundations. Thus, the study of pile-raft foundations is of utmost importance to use such soils. Hence, the current paper contains a study made on pile-raft foundation on cohesionless soil with the help of PLAXIS 3D, which is a 3D Finite Element Method (FEM) / programme which is used for distortion as well as stability analysis of numerous geotechnical applications. The analysis involves the effect of internal friction angle (ϕ) in the settlement study of cohesionless soil. The current study also noted that the dilatancy angle can impact the load settlement of cohesionless soil. It was observed from the current effort that with an increase in the angle of internal friction angle, the settlement was noted to decrease gradually. Thus, the study of cohesionless soil should be conducted in depth to comprehend the effects of other vital parameters.*

***Keywords* -** *Cohesionless soil , PLAXIS 3D , Settlement , Modelling.*

1. Introduction

Problematic soils can alter with the variation in environmental situations when used for constructional activities. For ages, construction on such ground has been a pronounced challenge in the area/field of geotechnical engineering, as it results in slow progress of work due to instability of the ground and cost over-run in the accomplishment of the project. Different technicalities related to such types of soils include slope instability, excessive settlement, bearing capacity failure, etc., either during or after the building construction phase, owing to its high values of compressibility and low shear strength.

One type of such problematic soil is defined as any cohesionless soil that can withstand relatively high apparent shear stresses but undergoes radical rearrangement of particles within its matrix when wetted, leading to a large and sudden reduction in its volume. The existence of such soil in embankments of pavement and construction areas leads to conspicuous changes in load-bearing capacity with changes in climatic surroundings, creating distress resulting in its structural deformation. These soils can prove to be problematic for structures due to their large settlement potential.

North Eastern Region (NER) of India is known for the existence of a wide variety of unstable soils with high compressibility and low strength. If these issues are not taken into account during the design phase, it might cause major engineering issues. To carry the excessive loads from superstructures, viz. multi-storey buildings, bridges, power plants, or any other civil structures and to avoid excessive settlements and to counter such soils, piled foundations have been developed, which is widely used in recent times. However, it has been observed that the design of foundations considering either pile or raft is comfortably not a feasible/practicable solution because of the load-sharing mechanism. Thus, a combination of the systems, namely “Pile-Raft Foundation systems” (illustrated in Figure 1), has been developed (Clancy and Randolph 1993). The pile-raft foundation system has been proven to be an economic foundation that mitigates differential and total settlement. The study by Wadhwa et al. (2017) also mentioned that the pile raft system is a proven system for problematic subsoil scenarios or cohesionless soil, which can carry a high axial load. A similar vision was made by Tom and Sindhu (2016), who mentioned that the superimposed transmission of load mechanisms occurs through the combined action of piled-raft arrangements. The combined system, i.e. piled raft, consists of three (3) bearing essentials viz. pile, raft and the sub-soil, as stated by Shukla and Desai 2014 unlike the traditional system, i.e. the load can be transferred either to the pile or to the raft; hence the present work is on the piled-raft system.

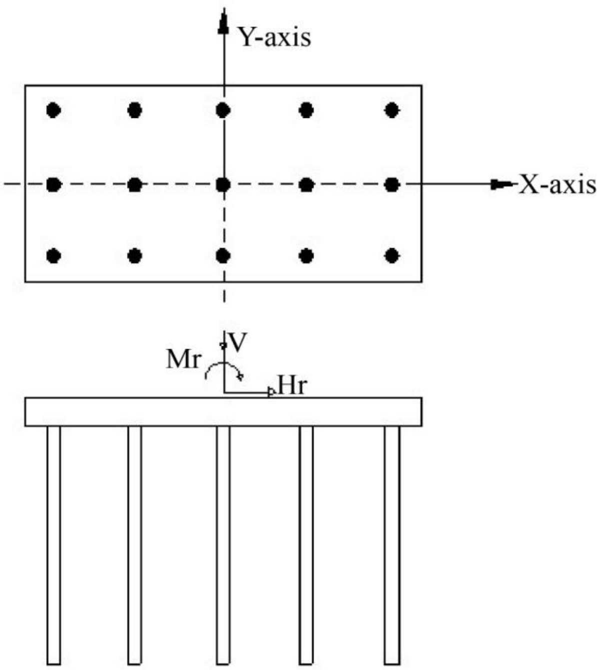

Fig. 1 Pile-raft foundation (Clancy and Randolph 1993)

2. Sensitivity Analysis

Sensitivity analysis of foundations, including pile foundations, raft foundations, and piled-raft foundations, is basically dependent on the input parameters used to generate the mesh and the method used to understand the mechanism. Further, loading conditions in an unavoidable scenario. The study made by Chow and Small 2006 mentioned that pile–pile interaction, pile-soil interaction, soil-pile interaction and soil -soil interaction are the factors which are needed to be computed or considered in the analysis. Thus, in pile foundation, pile diameter, pile length, pile group action, and soil properties give an outline of the foundation settlement and load resistance. Similarly, only for raft foundations, the raft's thickness and soil's bearing capacity determine the settlement and load bearing. Further, as per the current study on piled–raft, piled-raft load distribution, pile spacing and arrangements of the pile, skin friction, and end bearing determine the total settlement, lateral load resistance and axial load distribution. (Hanna and Sinha 2016).

3. Numerical Model

Three three-dimensional models were considered to study the specific case of the pile-raft foundation system. These models comprise the soil continuum, foundation elements, geometry, and functional loads. FEM serves as a challenging tool to model various geotechnical challenges, for example, from excavation, consolidation, seismic analysis, settlement, foundation and many others (Johari and Kalantari 2021, (Mansur et al. 2022). The finite element model demands the model boundaries, which need to be selected in accordance with the analysis made and the pattern of the soil model. Also, defining the element type, its size, and the type of interface is essential to get accurate results. The study by Brinkgreve and Swolfs (2008) states that directly feeding shear strength is sufficient to measure the bearing capacity, but advanced modelling is necessary to calculate the deformations accurately. The FEM modelling is limited to the input made. Thus, the current numerical model employs instances to address the issue related to excavation in cohesionless soil deposits. Hence, the study was made in PLAXIS 3D as it allows geotechnical engineers to conduct various three-dimensional finite element analyses for projects that involve soil and rock in the civil engineering sector. The programme includes interactions, static, elastoplastic deformation, and advanced soil mechanics with updated mesh analysis. The model utilised in the study consisted of the raft as a plate element and an embedded group of piles. The model was considered as isotropic matter, Homogenous media in this current work. Globally, medium coarse mesh was selected for the complete soil strata. Figure 2 explains a 3D view of a pile-raft foundation with applied pressure.

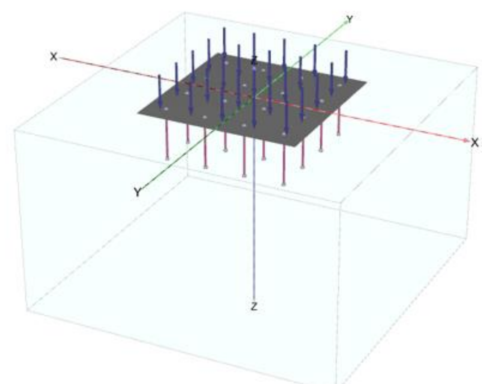

Fig. 2 Numerical modelling of piled raft foundation

4. Model Validation

The 3D numerical model was associated with the study of piled raft foundations. The current FEM analysis in the above-mentioned software, i.e. PLAXIS 3D, is being authenticated with the findings/results shown by Sinha and Hanna 2017. 16 number of piles with 1m diameter and 15 m length in 24 m X 24 m raft size with 2m thickness were considered for the current study. Pile spacing was maintained at six times the pile diameter, and a UDL of 0.5 MPa, i.e., 500 kPa, was placed on the foundation. Table 1 below displays the material characteristics of the raft, the piles, and the soil. Figure 3 displays the comparison between the current results and the published findings. It is evident that the current findings matched well with previously published findings for pile raft foundations. The Raft size of 24m x 24m and a thickness of 2m was considered. The water table was considered at the ground level. A pile with a length of 15m and 1m diameter was placed with a spacing of 6D, considering a total of 16 piles. Two-stage analysis was involved for the piled raft, i.e., the initial stage(1st stage) and the loading stage(2nd stage). The study was conducted by activating piled-raft geometry along with an applied load, and the model was run. In the current study, drained soil media was modelled.

Table 1. Parameter used for validation (Sinha and Hanna 2017)

Parameters	Unit	Pile	Raft	Soil
Young's Modulus(E)	MPa	25000	34000	54
Unit weight(γ)	kNm^3	25	25	19
Poisson's Ratio(μ)		0.2	0.2	0.15
Submerged Unit weight(γ')	kNm^3	-	-	9
Cohesion(C')	kPa	-	-	20
Angle of internal friction (ϕ)	°	-	-	20

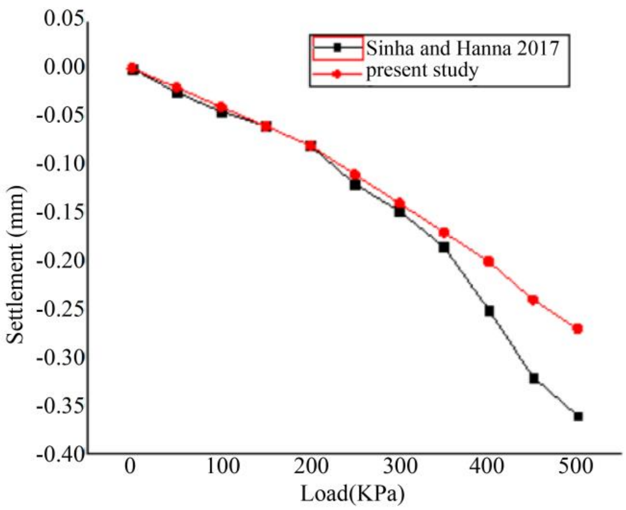

Fig. 3 Validation of the current study

5. Parametric Study

The subsequent section observes the parameters leading to the load-settlement mechanism of pile-raft foundations. The study of pile-raft has a two-fold aim, enhancing the total bearing capacity and reducing the average/ differential settlement (Ferchat et. al. 2021). The current parametric study is made to keep the size and numbers of piles constant with constant loading and utilize the material property as per Table 2. The variation is made in the dilatancy angle, and the angle of internal friction is studied. The pile- raft was fixed in a sandy soil deposit, which was subjected to axial pressure. An embedded beam element was used to model the pile, and a plate element was used to model the raft. The parametric study contains the behaviour considering group piles of 4x4, i.e. a total of 16 number of piles as per Figure 4 with a 1 m diameter and length of 15m. The spacing between the piles was maintained as 6d, i.e. 6m. A uniformly distributed vertical pressure of 0.5 MPa, i.e. 500 kPa acting at the upper surface of the raft, was considered in this work. A raft with a size of 24 m X 24 m and 0.5 m thickness was kept constant for the current findings.

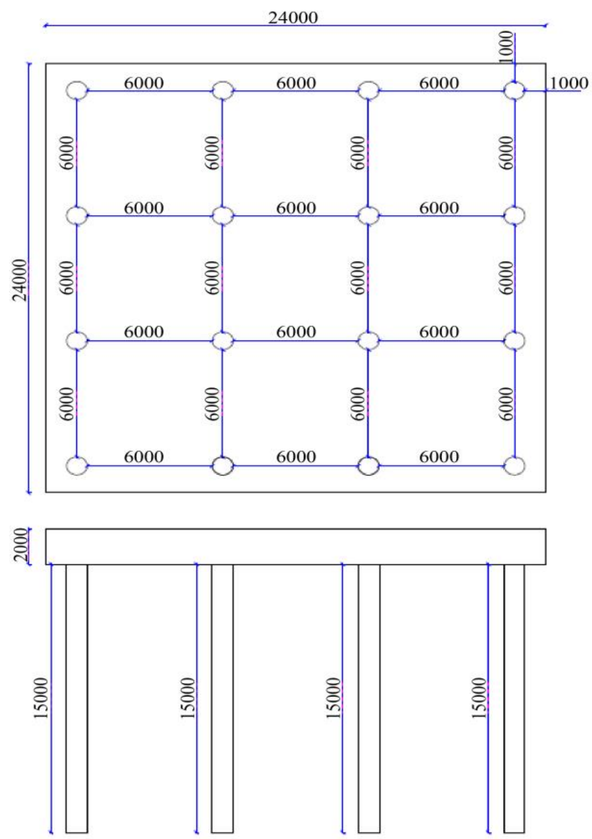

Fig. 4 Layout of 4x 4 pile-raft

Table 2. Material properties for current parametric studies

Parameters	Unit	Soil	Pile	Raft
Young's Modulus (E)	MPa	54	25000	25000
Poisson's Ratio (μ)		0.15	0.2	0.2
Unit weight (γ)	kNm^3	16	25	25
Saturated Unit weight (γ')	kNm^3	18	-	-
Angle of internal friction(ϕ)	°	28,30,32,34,36	-	
Cohesion (C')	kPa	20	-	-
Ψ		0,7	-	-

5.1. Effect of Friction Angle on the Load-Carrying Capacity

In the current series, piles that had a length of 10m and were placed in a space of 6D were studied. Other conditions/parameters remain as per Table 2. The effect of the phi angle was studied on the piled-raft foundation carrying the vertical/axial pressure. The internal angles considered are 28°, 30°, 32°, 34° and 36° as the soil domain is considered cohesionless. The current work considers sandy deposit. The study conducted by Chen and Gong 2020 stated that the ϕ value influences the settlement, which increased from 13.4 mm to 126 mm, i.e. approximately eight(8) times, which is far beyond the allowable range of specification when ϕ was varied. When ϕ = 20° increased to ϕ = 43°, the settlement progressively reduced as per the observation made by Chen and Gong 2020. Similarly, in the current effort, when the phi angle increased from 28° to 36°, settlement gradually decreased eventually.

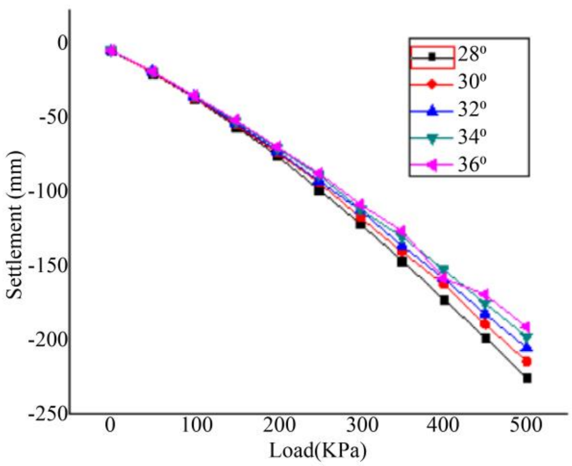

Fig. 5 Variation in load settlement curve with varying phi angle

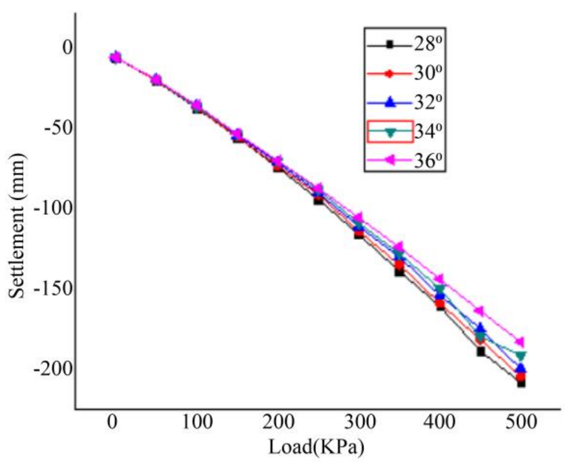

Fig. 6 Load settlement variation curve with varying ϕ with dilatancy angle

5.2. Effect of Dilatancy Angle on Load-Carrying Capacity

At present, tests were conducted on the piles, which had a length of 15m, and placed at a space of 6D. Other conditions/parameters remain as per Table 2. The study reveals that settlement gradually decreased when the ϕ angle was increased from 28° to 36°,. The effect of phi angle with a dilatancy angle of 7° was studied in the piled raft foundation carrying UDL. A positive dilatancy is considered in the drained soil strata, indicating the occurrence of shear deformation. The internal angles considered are 28°, 30°, 32°, 34° and 36°.

5.3. Effect of Dilatancy Angle with Constant Internal Friction Angle Value

A study of the effect of dilatancy angle is important as it influences many aspects of coarse material, which ranges from shear strength to stress-strain behaviour. Further research made by Taylor 1948 and Bolton 1986 mentioned that the dilatancy of coarse-grained soils influences the strength of granular material and, at the same time, affects the geometry of shear planes (Cinicioglu and Abadkon 2015). Thus, a study has been made to co-relate the load settlement graph when the dilatancy angle was added to the soil strata. Figure 7 shows the plot when the angle of internal friction was kept at 36°. The observation made indicated that at the initial phase of loading, the settlements are at par with each other, but as the loading condition increases, the settlement of soil upsurges with the addition of a dilatancy angle.

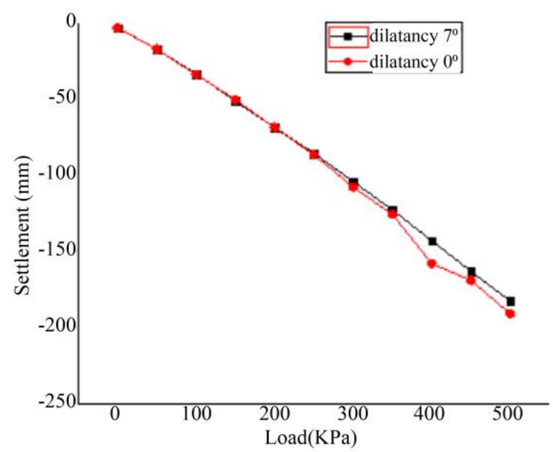

Fig. 7 Load Settlement graph varying dilatancy angle

6. Conclusion

Considering ϕ and dilatancy angles, which are quantified as prime concerns in the cohesionless soil strata with due application of axial vertical pressure on the raft. This study indicates that the change in the phi angle of soil varied the soil settlement while loading. The increase of ϕ in soil from 28° to 36° brings down soil settlement by 18%. In line with it, calculating load settlement with a minimum dilatancy in sandy soil and varying the ϕ by 28° to 36° brings down soil settlement by 14%. Further, the comparative analysis was made keeping ϕ constant, and it was noticed that the incorporation of dilatancy in sandy soil increases the settlement in the soil domain by 4 %, i.e. by 8mm at the final loading stage. Thus, to gain thorough knowledge about cohesionless soil and its complex behaviour, a study of other factors affecting cohesionless soil should be conducted.

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