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Numerical Study on Lateral Capacity of Piles with Casing in Cohesive Soil

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Abstract. The interaction of soil and structure is important in the behaviour of structures under dynamic or static loading condition. It has an impact on the behaviour of the soil and also how the pile behaves when load is applied. The analysis is critical for predicting more precise behaviour of the structure and improving structural safety under extreme loading conditions. When subjected to lateral loads, a pile behaves like a transversely loaded beam. In response to applied load, the pile shifts horizontally, resulting in pile bending, rotation, or translation. Resistance to lateral loads is typically provided by the shear which is on the base of the cap, soil passive resistance on the face of the cap, and the passive resistance provided by the soil against the shaft of pile. If the lateral load towards the pile increases beyond the limit due to earthquake, wind action, naturals calamities etc., casings can be provided to improve the lateral capacity. This paper presents the numerical study on lateral capacity of piles with different casing material with different thickness in cohesive soil. Steel, BFRC and Polypropylene fibre were used as casing materials. Pile with steel casing of 18 mm thickness shows minimum lateral deflection. Steel casings effectively improves the ultimate capacity of piles when lateral load is applied. Analysis is performed through the usage of PLAXIS 3-D software. The evaluation has become less difficult with the advent of excellent computers and software tools such as finite element analysis software.

Keywords: Soil - Pile Interaction, casing, lateral capacity, soil resistance.

1 Introduction

Soil Structure Interaction (SSI) is critical in the behaviour of structures under dynamic or static loading conditions. SSI influences both the behaviour of soil and the behaviour of the pile under loading. Analysis is critical to get better and accurate structural behaviour prediction and increased structural safety under extreme loading conditions. When subjected to lateral loads, a pile behaves like a transversely loaded beam. In response to applied load, the pile shifts horizontally, resulting in pile bending, rotation, or translation. If the lateral load towards the pile increases beyond the limit due to earthquake, wind action, naturals calamities etc., casings can be provided to improve the lateral capacity. The paper presents numerical study on lateral capacity of piles with different casing using Plaxis 3D software. Kuttanad Clay is considered for this study.

2 Methodology

Soil sample for this study was taken from Kunnamkary near Kuttanad in Alappuzha District. The laboratory tests were conducted based on IS 2720-1965and determined the geotechnical properties of untreated soil samples. Preliminary tests like specific gravity, natural moisture content, sieve analysis, liquid limit and plastic limit were conducted. Triaxial test was done to find the value of cohesion and angle of internal friction. In this work, analysis is done using Plaxis 3D software. The geotechnical properties obtained from the laboratory test results of collected sample are shown in table 1.

Table 1. Geotechnical properties of soil sample

Property	**Results**
Natural Moisture Content (%)	110.43
Specific Gravity	2.53
Liquid Limit (%)	103
Plastic Limit (%)	35
Plasticity Index (%)	68
Maximum Dry Density (g/cc)	1.409
Optimum Moisture Content (%)	23.9
Type of soil	CH
E_{50} (kN/m^2)	1.8 x10^3
Angle of Internal Friction	9.8^0
Cohesion (kN/m^2)	7.8

For the pile design, structural design was carried out. Structure with 8 stories and 3 bays were designed in ETABS software. According the obtained critical load values, suitable pile diameter and pile length is selected. A total of thirty-eight models are to be developed in order to accomplish the objectives of the study. Initially 19 models were developed for analyzing the behaviour of pile for the design load obtained from ETABS. A model of pile without casing and 18 models of pile with three different casing materials (Steel, Basalt fibre reinforced concrete (BFRC), Polypropylene fibre) with 6 sets of various casing thickness. Later parametric study was conducted for load- deflection behaviour for the same. 19 models were modelled with different lateral load increment as 2 kN, 4 kN, 6 kN, 8 kN and 10 kN.

2.1 Finite Element Modelling

The model used in this study consists of cohesive soil (Kuttanad clay), dense sand layer, pile as volume element, pile casing as plate element, and interface element. The first step in modelling is the simulation of ground conditions. The ground is taken to be made of a layer of clay of about 70 m depth and a dense sand layer of 30 m depth. The properties of clayey soil and dense sand are given below in table 2. Soil model of size 100 m x 50 m x 50 m was taken for the purpose of the study. Analyses were carried out using the finite element model. Initially pile without casing was modelled. Then piles with different casing materials with varying casing thickness were modelled. Interface elements are provided to consider the pile - soil interaction. To evaluate the concept, numerical tests were carried with various element counts in the mesh surrounding the pile, considering mesh refinement through a mesh convergence study. A mesh made from finite elements was used to conduct the parametric studies.

Table 2. Properties of soil

Properties	Values	Values
Type of soil	Clay	Dense Sand
Material Model	Mohr-Coulomb	Mohr-Coulomb
Drainage Type	Undrained	Undrained
γ_{unsat} (kN/m^3)	12.94	22
γ_{sat} (kN/m^3)	15.1	25
E (kN/m^2)	1800	1600
ν	0.3	0.4
c (kN/m^2)	7.8	0
φ	9.8^0	45^0
ψ	0^0	0^0

The next step in modelling includes the modelling of pile and pile casing. Pile and pile casing are modelled as volume element and plate element respectively in soil. Three different casing materials are used with varying thickness. ie., the effect of different casing materials was studied using various thicknesses of 8 mm, 10 mm, 12 mm, 14 mm, 16 mm and 18 mm. For all the cases, the lateral load taken is the design load which is obtained from the structural design in ETABS. The grade of concrete assumed for pile is M_{25}. The properties of pile are given below in table 3.

Table 3. Properties of pile

Properties	Values
Material	Concrete
Shape	Circular
γ (kN/m^3)	25
E (kN/m^2)	25 x 10^6
Diameter	0.7 m
Length	75 m

After modelling pile, casing is provided. Properties of casing materials are shown in table 4. All the properties are assigned to the casing materials. After simulating the casing material, interface element is provided. Then lateral load is simulated for various casing materials with different thickness. For the analysis, fine mesh is taken.

Table 4. Properties of casing materials

Materials	Properties	Value
Steel	E (kN/m^2) μ γ (kN/m^3)	210 x 10^6 0.28 76.982
BFRC	E (kN/m^2) μ γ (kN/m^3)	90 x 10^6 0.189 25.29
Polypropylene	E (kN/m^2) μ γ (kN/m^3)	1.325 x 10^6 0.49 8.87

3 Result and Discussions

The results were in the form of lateral deflection for the design load for piles with and without casings with various thickness. Also, the result of parametric study is discussed to find the effective casing material and effective casing. Analysis results shows that lateral capacity of a pile can be increased by providing casings to pile. The results obtained for the design load condition for pile with various casing materials is shown in fig 1. Curve is plotted between lateral deflection and casing thickness and the response of pile is examined. This obtained result is compared with that obtained in pile without casing.

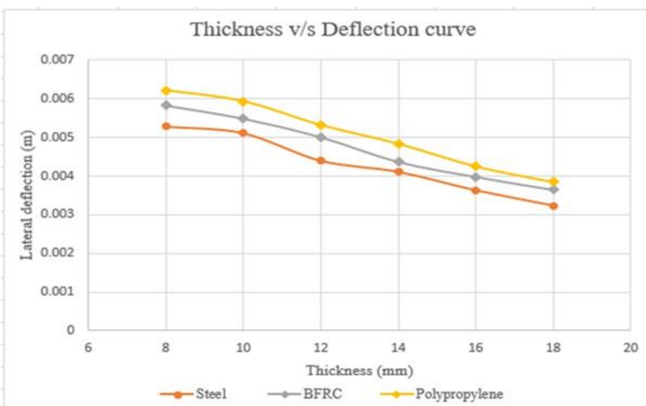


Fig 1. Thickness v/s lateral load curve for the design load

From the parametric study, load-deflection curve for pile without casing and with different casing materials with varying thickness are obtained and are shown in fig 2, fig 3, fig 4 and fig 5 respectively.

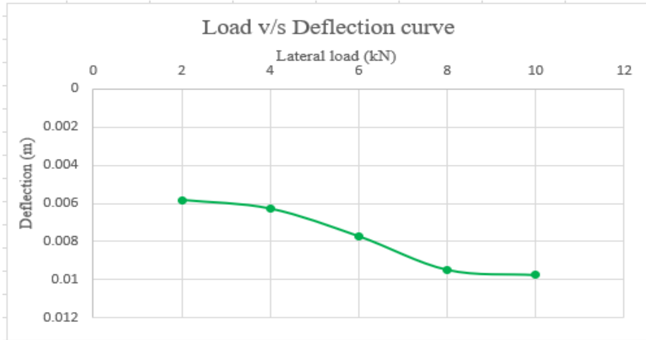


Fig 2. Load v/s deflection curve for pile without casing

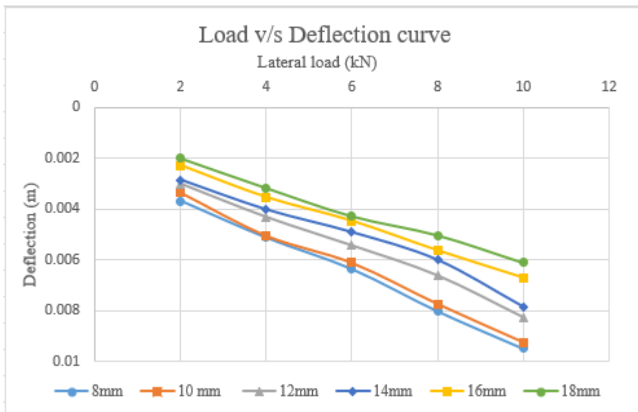


Fig 3. Load v/s deflection curve for pile with steel casing

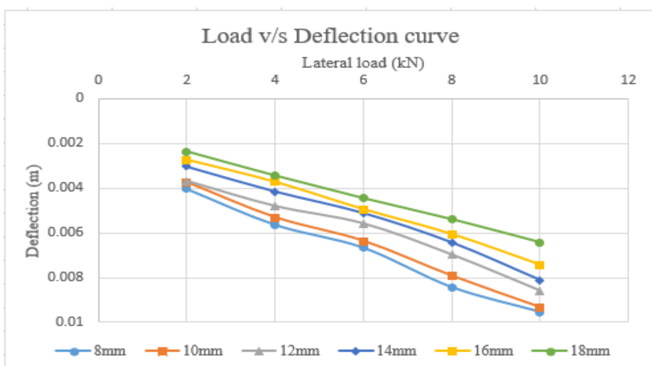


Fig 4. Load v/s deflection curve for pile with BFRC casing

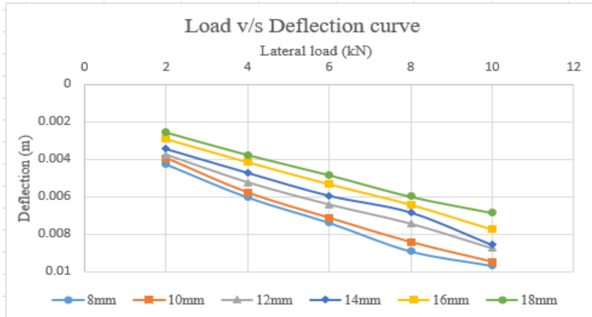
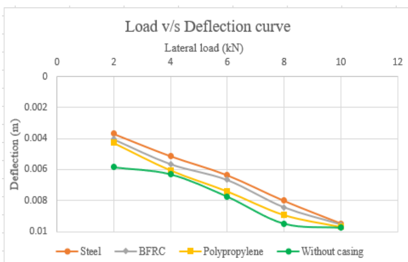
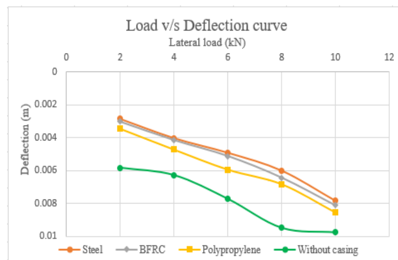


Fig 5. Load v/s deflection curve for pile with polypropylene casing

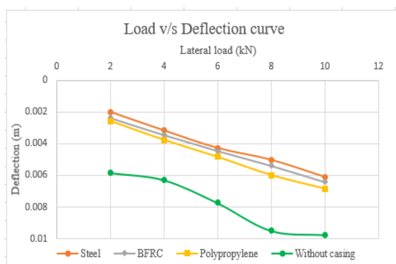
To find the optimum thickness of casing, the analysis result of 8 mm, 14 mm, and 18 mm thickness were compared with that obtained



(a)



(b)



(c)

Fig 6. Load v/s deflection curve for pile with (a) 8mm (b) 14mm (c) 18mm casing

From the graph obtained, it can infer that the most suitable casing material is steel which shows less amount of lateral deflection compared with other casing materials. Also, among various casing thickness 18mm is found to be most suitable one. From the analysis, for the design load, the obtained value of lateral deflection of pile without casing is 0.00637 m. This deflection value is compared with the rest of the deflection obtained for different casing material with various casing thickness. Lateral deflection for pile with steel casing of 8 mm thickness is 0.00529 m and for casing thicknesses of 10 mm, 12 mm, 14 mm 16 mm and 18 mm were 0.00512 m, 0.00440 m, 0.00414 m, 0.00363 m and 0.003231 m respectively. Lateral deflection of pile with BFRC casing of 8 mm thickness is 0.00583 m and that of for casing thicknesses of 10 mm, 12 mm, 14 mm 16 mm and 18 mm were found to be 0.00549 m, 0.00501 m, 0.00437 m, 0.00398 m, and 0.003646 m respectively. The lateral deflection of pile with polypropylene casing of 8 mm is 0.00621 m and for the casing thicknesses of 10 mm, 12 mm, 14 mm 16 mm and 18 mm were 0.00593 m, 0.00532 m, 0.00484 m, 0.00426 m, and 0.003855 m respectively.

For the parametric study, lateral load is incremented by 2 kN, 4 kN, 6 kN, 8 kN, and 10 kN and study is conducted for both pile with casing and without casing. For pile without casing, the obtained value of lateral deflection are 0.00584 m, 0.00629 m, 0.00773 m, 0.00948 m, and 0.00975 m for 2 kN, 4 kN, 6 kN, 8 kN, and 10 kN respectively. For pile with steel casing with 8 mm thickness, the lateral deflection corresponding to 2 kN, 4 kN, 6 kN, 8 kN, and 10 kN are 0.00369 m, 0.00513 m, 0.00636 m ,0.00801 m and 0.00947 m respectively. Similarly, this parametric study was conducted for pile with steel casings of above-mentioned various thicknesses. The for BFRC casing and polypropylene casing also lateral load is incremented and analysis were carried out for various thicknesses. From all the analysis results, it can infer that the casing material which provide effective lateral resistance to the pile is steel. The optimum value of thickness that should be adopted for the casing material to improve the lateral capacity is found to be 18 mm.

4 Conclusions

This study investigates the effect of casings on the performance of lateral capacity of pile foundation in cohesive soil. A parametric study is conducted on pile with different casing materials with various thickness. Casing materials includes steel, BFRC, polypropylene with 8mm, 10mm, 12mm, 14mm, 16mm and 18mm thickness. Analysis results shows that lateral capacity of a pile can be effectively increased by providing casings to pile. From the study, the following conclusions were obtained.

- Casing increases the stiffness and thus improves the lateral capacity of pile
- The provided casings are seen to provide good estimates of lateral capacity for piles.
- On compared with other casings, steel casing provides more lateral resistance to the pile.
- For 8 mm thickness, steel casing shows 16.9 % reduction in deflection, BFRC shows 8.4 % and polypropylene shows 2.5% reduction.
- As the thickness of casing increases, the lateral deflection decreases
- 18 mm thick steel casing shows 49% reduction in lateral deflection compared with pile without casing.
- Steel casings with 18 mm thickness shows good result
- Casings can be provided to improve lateral capacity of piles in high rise buildings, transmission towers, bridge abutments, off shore structures etc.

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