Proceedings of 14th IOE Graduate Conference
Peer Reviewed
Year: 2023 Month: December Volume: 14
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Numerical Analysis of Micropile in Soft Clay

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Abstract
Micropiles are drilled and grouted concrete piles with a typical diameter smaller than 300 mm. Micropiles have been widely used to underpin existing foundations for additional loads. The load-bearing capacity of micropile is an essential parameter while designing existing foundations underpinned by micropile. Thus far, only limited studies have been done on the ultimate bearing capacity of a single micropile and variation in ultimate bearing capacity with variation in diameter and length of micropile. This paper analyzes the load-deformation characteristics of a single pile of varying length(6,8,10m) and varying diameter (0.15,0.2,0.25m) using PLAXIS 3D. Initially, a 3D numerical model was developed and verified by comparing the result with the result obtained from the field test. The model was used to simulate the single pile in the soft clay of Chyasal, Lalitpur. The variations in the ultimate bearing capacity of micropile of different diameters and lengths were compared. The parametric study concluded that the ultimate bearing capacity of micropile increases significantly with an increase in the length of the micropile. The study also concluded that increasing the diameter of a micropile initially boosts bearing capacity, but further increases may not significantly enhance capacity after reaching a specific size.

Keywords
Micropile, Underpinning, Load bearing capacity, PLAXIS 3D

1. Introduction

Building supports are usually made of shallow foundations. Most of them are well thought out and built. However, due to incorrect design or construction or unpredicted changes in the loading conditions of the foundation, some foundations may need help with bearing capacity, settlement, or stabilization [1]. In light of these conditions, it is necessary to implement corrective measures to restore or maintain the current foundation's performance. To this end, several technologies are available. The underpinning of foundations is often referred to as the mitigation or improvement of the performance of existing foundations. Various underpinning technologies were described by [2] and [3] in which micropiles are considered to be one of the most common. Micropiles are also commonly known as minipiles derived from roots and piles. [4], [5], and [6, 7] defined micropiles as drilled and grouted concrete piles with a typical diameter smaller than 300 mm. Micropiles are commonly used to increase bearing capacities and control settlements of existing foundations. They can be used to solve problems associated with foundations. Micropiles can resist most loads and reduce loads transferred to the soil. Micropiles can be installed vertically or at an inclined angle under a low-headroom condition; therefore, they are suitable for underpinning. [8], reports that the American Museum of Arts and Sciences in the U.S. has improved its foundations by installing micropiles after they were devastated by a hurricane. In China, the first micropiles were used in 1980 to support existing shallow walls that resisted additional loads, which were exacerbated by two additional stories being inserted into a fifty-year-old three-story building. Although micropiles were not used to underpin the Hu-Qiu Tower, a series of field tests and applications followed this initiative, including a comprehensive experimental study by [9].

A feasible way to increase the working space of an organization is to add stories to existing buildings. However, the load-bearing capacity and its fluctuation with variation in length and diameter of micropile has yet to be studied well. Personal experiences or judgment have been used to design micropiles that reinforce stories inserted into an existing building. A simple method for the design of support piles was introduced by [10]. Nevertheless, verification of this design has been made possible by a minimal amount of field data. The results of field tests in micropiles and the existing foundation supported by micropiles were reported by [11, 12] and proposed to simplify the design. [13] argues that micropiles are the perfect choice to build foundations on sites with poor soil conditions for controlling ground movement. In order to move applied loads into the solid underlying layers, [14] used micropiles on a railway embankment in order to prevent the cracking of loose foundation soils. PLAXIS 3D software based on the finite-element method was used to develop three numerical models, in which the embankment was modeled as an elastoplastic material with the Mohr-Coulomb failure criterion, and micropiles were modeled as linearly elastic elements. [15] evaluated the performance of micropiles that included a state-dependent constitutive model for sand formulated within the critical-state framework using another numerical analysis program, FLAC3D 3.0 (the Fast Lagrangian Analysis Continua).

Kathmandu Valley comprises non-uniform soil layers of low bearing capacity and high compressibility. These conditions cause foundation problems during construction or carry additional loads from adding stories to existing buildings Figure 1. Through numerical analysis utilizing the advanced finite element analysis software PLAXIS 3D, this study endeavors to investigate the influence of micropile diameter and length on their load-bearing capacity. For the study, the soil properties were considered from the geotechnical report of the Chyasal, Lalitpur, Nepal.

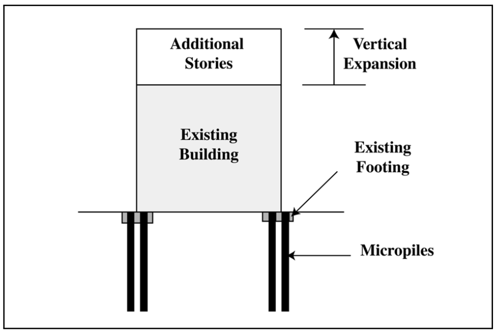

Figure 1: Micropiles used to support additional loads [16]

2. Validation of Numerical Model

2.1 Numerical Modeling

A 3D finite element method software, PLAXIS 3D, was used for the parametric study. A numerical model was developed to simulate the single pile compression test on the field. The soil volume was modeled as the Mohr-Coulomb constitutive model to match the results of a field test. In the unified soil classification system context, the field comprised several distinct soil layers. These layers consisted of a surface layer of topsoil, followed by a crust of lean clay (classified as CL), beneath which lay a layer of soft lean clay (SLC), and finally, a substantial layer of thick fat clay (CH). The 1m topsoil was removed, and the remaining soil profile and parameters were assigned as per Table 1. The water table was at around 1m depth. The model was modeled in the undrained condition. The pile was modeled as a cylindrical volume element. The properties of micropile were assigned to the cylindrical volume element as per data from Table 2. The positive interface was assigned on the surface and tip to develop pile-soil interaction. The pile was loaded incrementally in 30, 60, 90, and 120kN orders. The load was applied as surface load over the cross-section of the pile.

Table 1: Soil profile and parameters for validation

Parameters	CL	SLC	CH
Thickness of soil layer, H (m)	1.6	8	> 3
Young's Modulus of soil, E (Mpa)	5.2	3.1	2.39
Saturated unit weight, γsat (KN/m3)	19.1	17.6	17.1
Cohesion, C (kPa)	8	9	10
Friction angle, ϕ (°)	12	8	9
Void ratio, e	0.86	1.22	1.42
Poisson's ratio, μ	0.4	0.4	0.4

Table 2: Micropile parameters for validation

Parameters	Values
Material	Concrete
Young's Modulus, E (Mpa)	3×10^4
Unit weight, γ' (KN/m^3)	25
Poisson's ratio, μ	0.15
Shape	Cylindrical
Length, L (m)	8
Diameter, d (m)	0.15

2.1.1 Validation

Numerical models were verified using field data by [11]. The numerical results of the simulation of the field study by [16] were also compared. Figure 2 shows a comparison of the load-displacement response of the micropile under compression in the field, numerical analysis of [16] and our study. The numerical result of our study matched both the results very well. Hence, the same approach can be followed for parametric study.

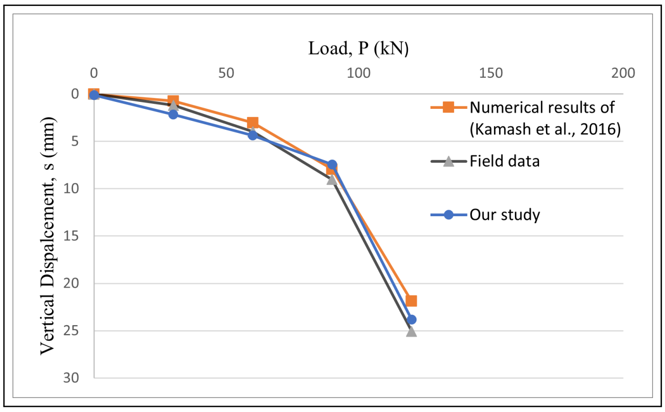

Figure 2: Load-Displacement responses of a micropile under compression in the field and from the numerical analysis

3. Parametric Study

This study aims to find the bearing capacity on a single micropile of varying length (6,8,10m) and varying diameter (0.15,0.2,0.25m) in cohesive soil at Chyasal using PLAXIS 3D. A numerical model was developed to study the behavior of a single micropile, as shown in figure 3. The soil volume was modeled as Mohr- Colomb constitutive model in undrained condition. The soil volume dimensions were defined so that no boundary effects could be found. Moreover, the pile was modeled as a cylindrical volume element with a triangular node of ten. The soil is mesh as coarse with a coarseness factor for the pile as 0.05. The material parameters for soil and pile used are shown in Table 3 and 4, respectively.

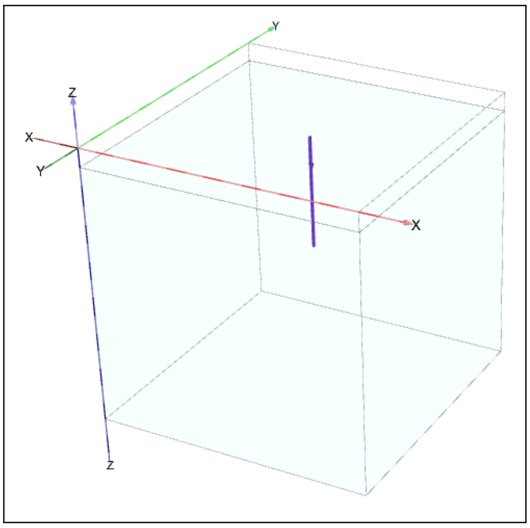

Figure 3: Model of micropile in soil in PLAXIS 3D

Table 3: Soil parameters for parametric study

Parameters	Values
Young's Modulus of soil, E (Mpa)	6.75
Saturated unit weight, γsat (KN/m3)	15.7
Cohesion, C (kPa)	20
Friction angle, ϕ (°)	23
Void ratio, e	1.781
Poisson's ratio, μ	0.4

Table 4: Micropile parameters for parametric study

Parameters	Values
Material	Concrete
Young's Modulus, E (Mpa)	3×10^4
Unit weight, γ' (KN/m^3)	25
Poisson's ratio, μ	0.15
Shape	Cylindrical
Length, L (m)	6,8,10
Diameter, d (m)	0.15,0.2,0.25

4. Results and Discussions

Parametric analysis of the micropile was conducted using FEM. Load displacement curves for various cases are plotted, and bearing capacity was evaluated using the tangent method, as shown in figure 3

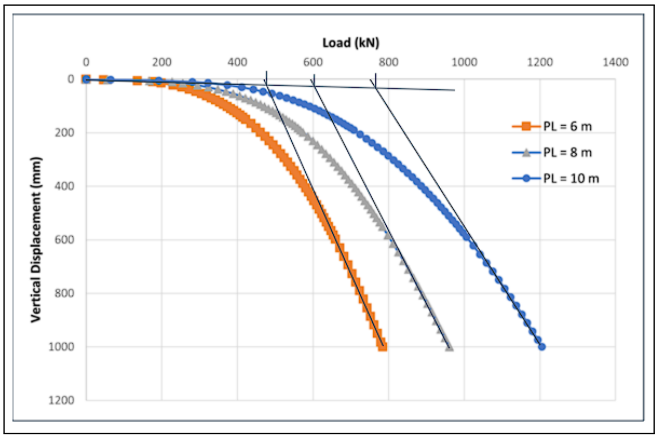

Figure 4: Typical example of the tangent method to obtain the ultimate bearing capacity of a pile from a load-displacement curve

4.1 Variation in the load-displacement graph for different lengths of micropile

Figure 5, 6, and 7 displays the variation in the load-displacement graph for different pile length of micropile having diameter 0.15, 0.2, and 0.25 m, respectively.

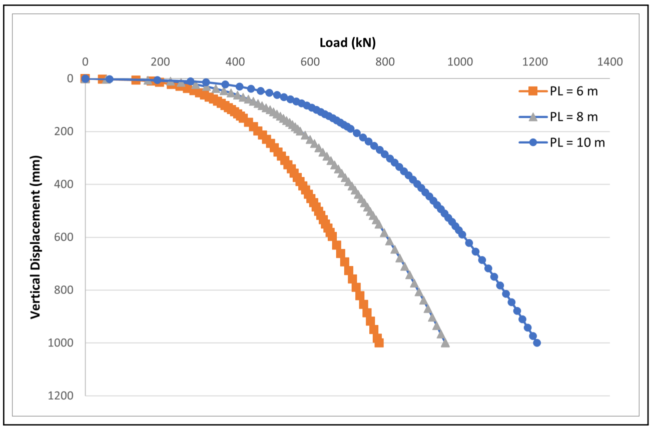

Figure 5: Load Displacement Graph for different lengths of micropile having diameter 0.15 m

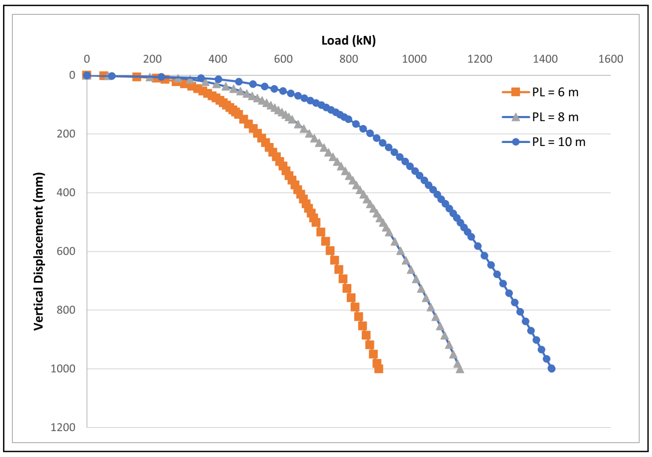

Figure 6: Load Displacement Graph for different lengths of micropile having diameter 0.2 m

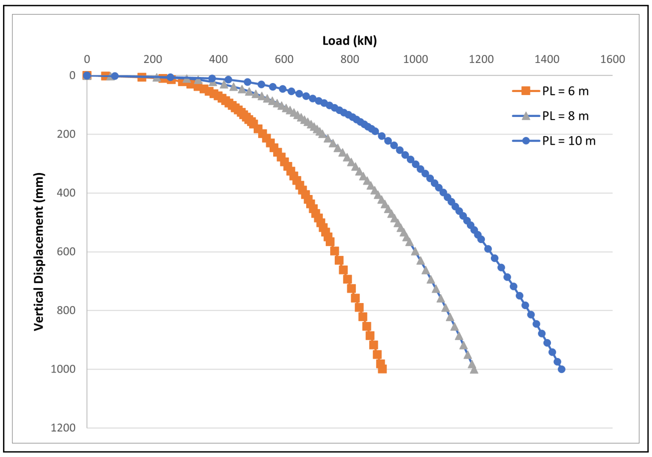

Figure 7: Load Displacement Graph for different lengths of micropile having diameter 0.25 m

The load-bearing capacity of a micropile, for a given displacement criterion, is notably augmented when the micropile possesses a greater length while maintaining a consistent diameter. This enhancement in load capacity is primarily attributed to the substantial influence of micropile length on its frictional resistance characteristics.

4.2 Variation in the load-displacement graph for different diameters of micropile

Figures 8, 9, and 10 display the variation in the load-displacement curve for different micropile diameters with lengths 6, 8, and 10 m, respectively.

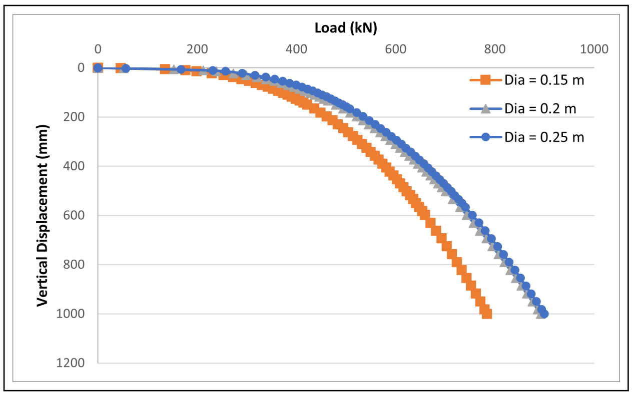

Figure 8: Load Displacement Graph for different diameters of micropile having length 6 m

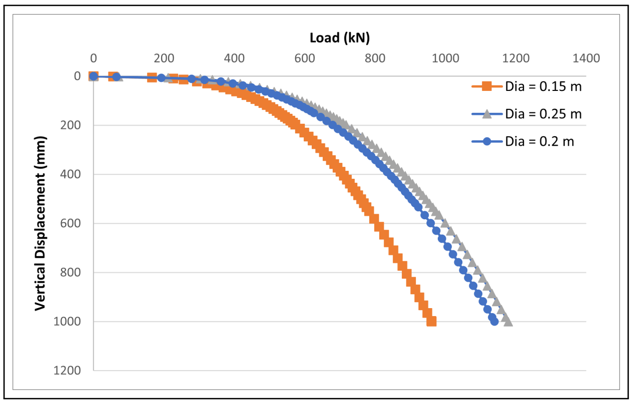

Figure 9: Load Displacement Graph for different diameters of micropile having length 8 m

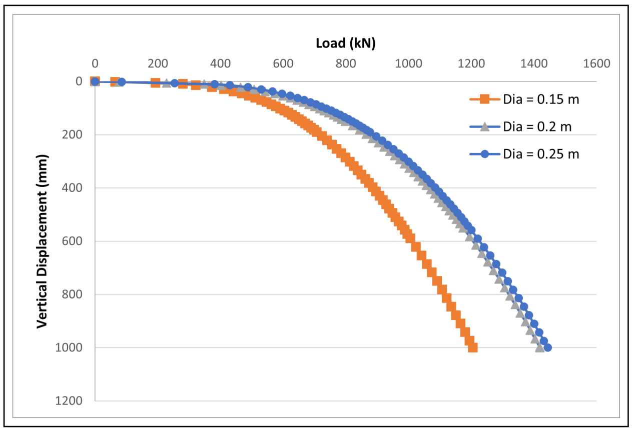

Figure 10: Load Displacement Graph for different diameters of micropile having length 10 m

Initially, an increase in micropile diameter led to a notable enhancement in load capacity, primarily due to heightened frictional resistance and shear strength. However, this effect plateaued as the zone of influence, with a diameter of 0.2 meters, became saturated, resulting in diminishing returns and no significant variations in load capacity upon further diameter increments.

4.3 Variation of Ultimate Bearing capacity

Figure 11 displays the variation of the ultimate bearing capacity of micropile with length for different diameters.

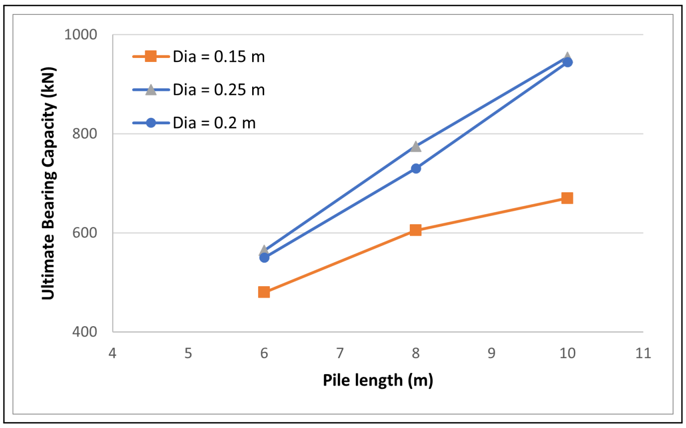

Figure 11: Variation of Ultimate bearing capacity with length for different diameters

The augmentation in micropile length exerts a pronounced impact on its bearing capacity, a phenomenon influenced by the inherent soil parameters and surface area. Initially, elevating the micropile diameter yields a noteworthy surge in bearing capacity, but beyond a certain point, further diameter increments do not result in substantial variations in bearing capacity.

5. Conclusions

A comprehensive 3D numerical analysis was conducted to explore the fluctuations in the ultimate bearing capacity of micropiles in response to variations in micropile length and diameter. The following conclusions can be made from this numerical study.

- The length of a micropile is a critical factor in determining its bearing capacity and load transfer capabilities. Longer micropiles provide increased skin resistance, deeper penetration, and improved load-carrying capacity. Hence, it is widely used for underpinning purposes.
- The relationship between the diameter of a micropile and its bearing capacity is complex. The increase in diameter of a micropile leads to an initial increase in bearing capacity, but once the micropile reaches a specific size, there may be no significant increment in bearing capacity. In this study, a zone size of 0.2 meters was optimal. Pursuing additional increments in diameter may prove economically impractical.

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