Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Lateral Load Carrying Capacity of Vertical Micropiles

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Abstract. Micropiles are a small-sized deep foundation with diameter usually in 150 mm to 300 mm range. Micropile has been widely adopted for various engineering application such as increase bearing capacities, reduce settlements, underpinning, in situ soil reinforcement, seismic retrofitting and rehabilitation for the existing foundation. It can also be utilized for controlling the differential settlement and strengthen the weak historical monuments. It may be economical in such situations as well as stabilizing the distressed foundation. In this study, small scale laboratory tests have been conducted to investigate the behaviour of a vertical group of micropile under lateral load. Group of 4 Steel micropiles have been used and installed both in bottom ash and sand. The angle of internal friction was obtained 43º and 32º for bottom ash and sand respectively corresponding to 50% relative density. Results indicate that the length to diameter ratio is a major variable, which influences the lateral load-carrying capacity of micropile. Besides, the failure mechanism of the piles was also found to be influenced by the L/D ratio. Further, numerical analysis has been carried using PLAXIS 3D. The comparison of experimental and numerical results shows good agreement.

Keywords*:* Micropile, L/D ratio, relative density, Bottom ash, sand, PLAXIS^{3D}.

1 Introduction

Micropile is a type of pile which is used to support the existing structure to transfer the load from the building to ground. It is a small diameter pile having diameter ranges from 150 mm to 300 mm, and length, 20 m to 30 m. Micropile can be used to carry out the compressive or tensile service load nearly about 300 kN to 1000 kN [1]. Micropile is a foundation system generally resist the vertical loads, lateral loads, as well as the oblique pull. In a situation at which horizontal load exceeds the permissible bearing capacity of vertical piles, require to use either batter or inclined pile with a combination of vertical piles. If the lateral load applied on the pile in the direction of batter, it is called a negative or in-batter pile [2,3]. When the lateral load acts in the opposite direction to that of the batter, it is called a displaced or positive batter pile (Sharma et. al., 2014). The construction of micropile involve of following stages: drilling, placing reinforcement, and placing or pressurizing the grout (grouting pressure about 0.8 to 1.0MPa [2,3]). Micropile has been widely adopted for various engineering applications (i.e. structural support and in situ reinforcement). As structural support, it can be used in (i.e. Seismic retrofitting and rehabilitation, increase bearing capacities, reduce settlements, underpinning) for existing foundations and distressing historical monuments. In situ soil reinforcement can be used as slope stabilization, excavation support in a congested area, and retaining structure, controlling different settlements. Micropile may be used as economically to save our historical monuments as well as serving the main foundation in such a situation [2-10].

Sometimes slope failures lead to catastrophic. Micropile can be installed in an area with limited apparatus, access, like hilly, mountainous areas and is considered to be an environment friendly [7,9,11]. In steepest slopes which are safe and stable should be provided with a micropile group or an individual [12, 13]. It has been seen that the various researcher has investigated the behaviour of micropile in sandy or clayey soil. However, in the coming decade due to the several industrial development bottom ash is a by-product of coal combustion, provided by steel Industry has been dump nearby the city in low line area. Due to the expansion of the city, the structure and foundation for transmission tower, some multistory building need to be built over it. Hence it is essential to study the behaviour of pile in such soil. Because of this, the present study aims to investigate the actual behaviour of micropile in bottom ash as well in the sand for a better understanding. Subsequently, the numerical models have been developed to estimate the load-carrying capacity of the micropile as well.

2 Properties of Backfill Materials used in the Study

The soil used for small scale model testing consisted of bottom ash, which is a by-product of coal combustion and provided by Usha Martin Limited. The bottom ash has been chosen because it is an industrial waste product having both fine and coarse particles size. Another backfill material, Sand has been collected from the bed of Kharkayi River, which is situated in Jamshedpur. The absence of fines allowed for air Pulverization placement. Hence, rainfall method was adopted for both backfill material (i.e. bottom ash & sand) through diffuser sieves at a constant height of 1000 mm. The grain size distribution of the soils is shown in Fig. 1. The properties of sand and bottom ash obtained are presented in Table 1.

Table1. Physical properties of backfill materials

Property of materials	Bottom ash	Sand
Specific gravity (G_S)	2.65	2.65
The angle of internal friction (φ)	43^0	32^0
Coefficient of uniformity (C_u)	3.45	2.24
Coefficient of curvature (C_c)	0.82	1
Effective grain size (D_{10}) in mm	0.561	0.414
Maximum dry density ($\gamma_{d, max}$) in kN/m^3	14.91	16.67
Minimum dry density ($\gamma_{d, min}$) in kN/m^3	12.06	14.42
Maximum void ratio (e_{max})	1.15	0.80
Minimum void ratio (e_{min})	0.74	0.55
Relative Density (I_D)	50%	50%
Classification of soil (USCS)	SP	SP

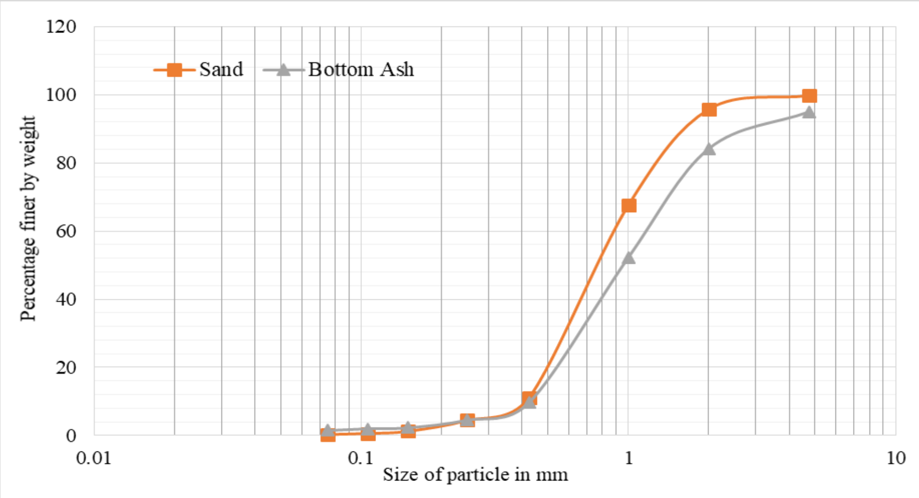


Fig. 1. Particles size distribution curve used in the study

3 Experimental Procedure

The schematic and actual experimental setup used in this study is shown in Fig.2. The test setup consists of pulley arrangement for applying a lateral load, loading frame, displacement measuring unit and model tank with inside dimension 750mm × 750 mm× 750 mm. The model tank was made of G.I. sheet with 4mm thickness, which was enough to avoid the boundary effect [5, 11]. The bottom ash and sand was spread uniformly in the tank and was levelled it properly. The desired dry density of bottom ash (γ_d =14.91kN/m^3) and sand (γ_d =16.67kN/m^3) for the respective test soil were achieved through height fall method. In this study, steel micropile was taken as 25 mm diameter (D) and thickness of 1.4 mm. Micropile was installed as a square group of four Micropile with different L/D ratio (i.e. 5, 8,11,13,15, and 18) with a spacing ratio of 3.5D where D is the diameter of Micropile. The testing of micropile was completed in two separate phases. In the first phase consists of a lateral load to the group of Micropile in bottom ash and other in the sand. The group of micropile placed at the required depth, following which raining of soil was done. After completion of raining, the free end of the wire was attached gently to the hook of the pile cap (Fig. 2). The other end was attached to the hanger and the wire passed over the pulley was attached at the outer part of the testing tank. A dial gauge was attached to the side of pile cap to note down the horizontal deflection of the pile group. Before the application of load, the initial reading on the dial gauge was noted.

The lateral load was gradually placed on the platform until the load is reached to failure points. A steel plate of known weight is then slowly placed (1.67 kg each time) on the load support hanger and the load is transferred to a group of micropiles by cable tension. The test was tested up to lateral failure [15,16]. Damage of micropiles has been described as excessive bending of the micropiles group assembly so that no additional weight could be added to the loading hanger. The method of applying the lateral load achieves a truly independent head state (which allows the head of the pile to rotate). In all tests, deflection at the head of the group of micropiles was recorded continuously throughout the test [15-17].

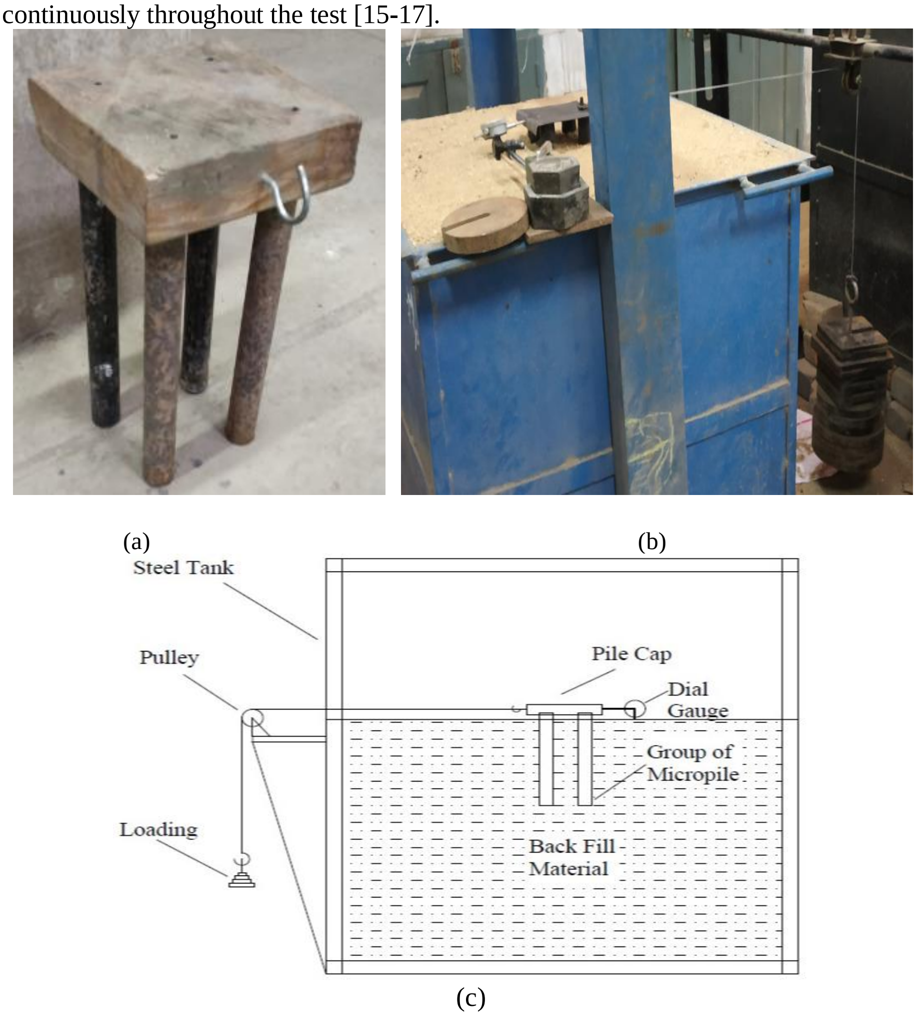
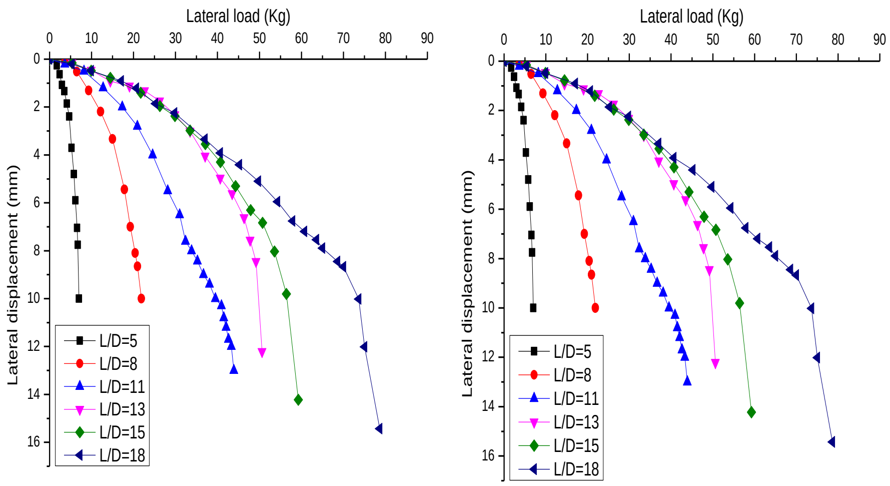


Fig. 3. Diagram of (a) Group of micropile; (b) experimental setup for lateral loading arrangement; (c) Schematic diagram for Lateral loading arrangement.

4 Results and Discussion

Four groups of micropiles have been installed with different length/diameter ratio (i.e. 5, 8, 11, 13, 15 & 18) in two different geomaterials (viz. - bottom ash and sand). The different micropiles have been tested in the laboratory under lateral loading with constant spacing (3.5D). During the experimental program, the relative density of both materials was maintained to 50%. Group micropiles were tested with constant spacing

(3.5D) and varying length to diameter ratio in bottom ash as shown in Fig. 4 (a) Similarly, a group of micropile was also tested for sand which is shown in Fig. 4 (b)



(a) **(b)**

Fig. 4. Lateral load-displacement curve at spacing (3.5D) (a) bottom ash (b) Sand

For a group of micropiles, it was opined that the length to diameter ratio significantly affected the lateral load-carrying behaviour. It was observed that the lateral load-carrying capacity of group micropile at constant spacing (3.5D) gradually increased with an increase in L/D ratio. When the L/D ratio increased, the length of the pile was also increased. Hence, skin friction resistance also increased which led to an increase in load-carrying capacity for a greater L/D ratio. Micropile failure occurred due to soil failure without showing the peak point in both backfill materials (i.e. bottom ash & sand). The maximum displacement of the micropile occurs at the pile head and decrease with depth. This may occur due to weakening the soil structure near the pile cap due to the development of passive resistance near the top surface. The interesting part of the experiment was that the value of the lateral load for sand and bottom ash was almost similar (Table 2). Hence, bottom ash is an industrial waste and available easily, so it may replace sand for backfill material.

Table 2. Influence of L/D ratio on the lateral load at spacing (3.5D)

L/D Ratio	Lateral load (kg)	
	Bottom ash	Sand
5	7	7
8	24	16
11	38	35
13	50	48
15	65	57
18	76	73

5 Numerical Analysis

Numerical analysis has been carried out through finite element software package PLAXIS^{3D}. PLAXIS^{3D} has been developed specifically to carry out three-dimensional analysis of complete geotechnical engineering problems. The analysis was performed on a group of vertical Micropiles, spacing at 3.5D centre to centre, at L/D ratio 15 where D is the diameter of micropile. Mohr-Coulomb model was used to create a soil model in PLAXIS^{3D}. The model was built by using 10-node tetrahedral elements with approximately 7539 elements at 12455 nodes. In numerical model five input parameters such as modulus of elasticity (E=27000 kPa), poison's ratio (υ=0.27), angle of internal friction (φ) and effective cohesion (C =1 kPa) and dilatancy angle (ψ) have been considered. A typical geometry with mess generation for a group of vertical micropiles is shown in Fig. 5. The comparison between experimental and numerical analysis is presented in Fig. 6. It can be seen that the load-displacement response is obtained from the numerical analysis shows good agreement with the experimental one. The displacement contours for piles in sand and bottom ash has also been shown in Fig. 7. From this, it is clear that behaviour micropiles in both the material is identical and similar. Hence, both experimental and numerical results indicate that the bottom ash which is an industrial waste can be used in place of sand as the bottom ash is easily available, economical and eco-friendly nature.

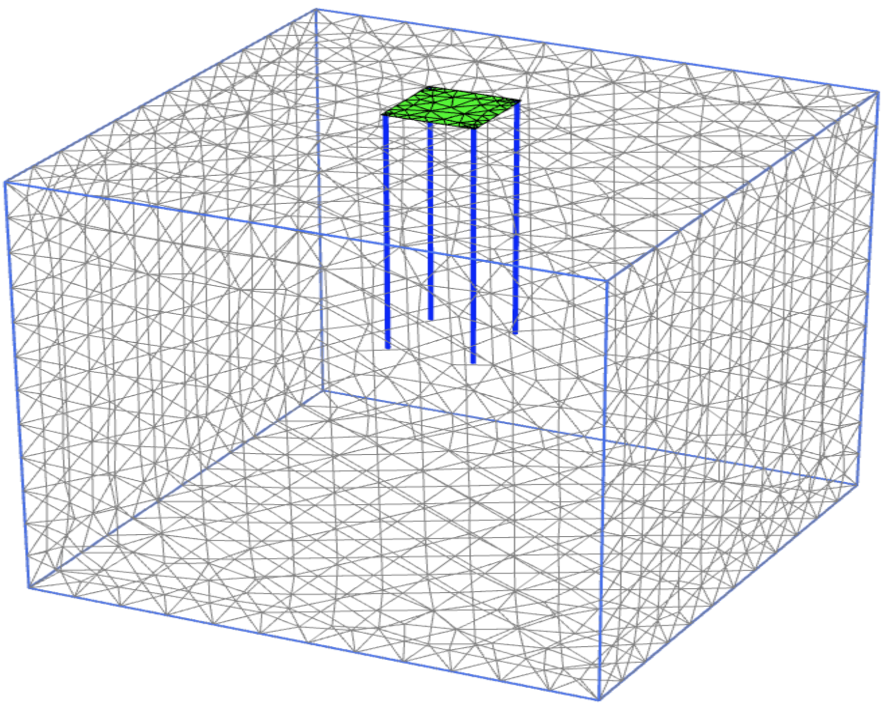


Fig. 5. Mesh generation for a group of vertical Micropiles.

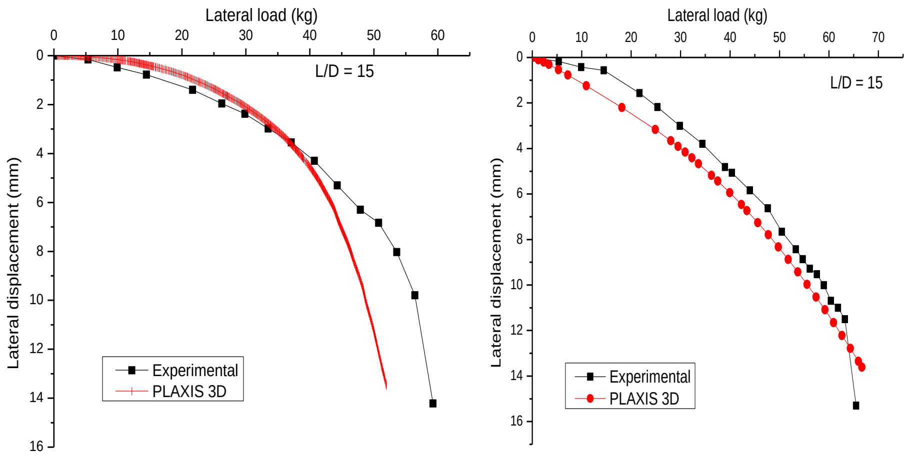


Fig. 6. Comparison of experimental and numerical lateral load-displacement curve (a) Sand (b) Bottom ash

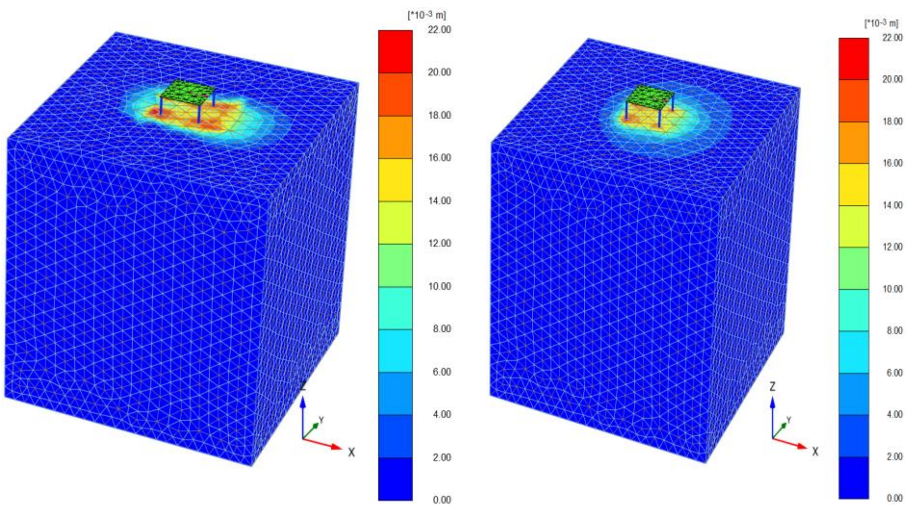


Fig. 7. Displacement contours for sand and bottom ash

6 Conclusions

In the group of vertical micropiles, Lateral load-carrying capacity is found to be increased with increase in L/D ratio. It has been also seen that the settlement before reaching the ultimate load capacity decreased with an increase in length to diameter ratio. Besides, the lateral load resistance capacity of bottom ash was observed slightly larger than the sand. Hence, bottom ash, which is an industrial waste may be used instead of sand as backfill material. The comparison of experimental results with numerical results obtained using the finite element technique shows encourages agreement. Therefore, it can be said that the present numerical model is sufficient to simulate the lateral behaviour of a group of vertical micropiles.

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