

A Model Study of Micropile Group Efficiency under Axial Loading Condition

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Abstract

The application of micropiles in retrofitting or as structural support is a technically viable and economically feasible solution in many situations. Micropiles are especially useful in places where heavy machinery cannot gain access in order to lay down conventional piles. As suggested by their name, micropiles have a smaller diameter than conventional pile. These piles comprise of a central steel reinforcement surrounded by grout that fastens the pile with the soil. Owing to its wide application, it is logical to study the interaction between the soil and micropiles under various loading conditions. This paper deals with the investigation of a model experimental study of group micropiles of different length to diameter ratio as well as different spacing between the piles in the group. The piles were installed in sand bed of 50% relative density and subjected to axial loading condition. Ratio of length to diameter has been found to be a major factor that influences ultimate axial resistance of the group. Group efficiencies of micropiles groups were determined at length to diameter ratio varying from 30 to 70 and at 2D, 4D and 6D spacing between the piles.

Keywords: Micropiles, pile group efficiency.

1. Introduction

Micropiles are piles with a smaller diameter (generally ranging from piles of about 100mm to 250 mm) than conventional piles. These piles comprise of a central steel reinforcement surrounded by grout that fastens the pile with the soil. The grout is interjected under a pressure ranging from 0.8Mpa to 1Mpa. The high pressure grouting causes the fluid part of the cement mix to penetrate into the interstices of the

surrounding soil; thereby creating a transition zone comprising of grout mixed soil between the body of the micropile and the soil, resulting in a strong grout-ground bond. The introduction of micropiles occurred in Italy in the year 1950 as a means for underpin old historic buildings and monuments. Micropiles have been gradually gaining popularity around the world since the late 1980's when the method gained acceptance as a mean to underpin the existing structures.

Micropiles exhibit high skin friction, as a result of which the load carrying capacity of micropiles is higher than that anticipated by the conventional bearing capacity theory. Its '*quick response*' to the slightest movement of the structure is one of its most notable features. Even when the load reaches crushing strength of concrete they display settlement of only a few mm. Micropile systems are also known to demonstrate flexibility under dynamic loading. Another distinguished feature of micropile is that retrofitting methods that employ micropiles can be applied to liquefied ground. Furthermore, its small boring diameter allows its construction almost at any ground condition and with equipment smaller than that required for a conventional pile.

In this investigation a model experimental study has been undertaken on micropiles. Single piles having different length to diameter ratio, and grouped piles having different length to diameter as well as different centre-to-centre spacing were installed in a sand bed having a 50% relative density. The piles and pile groups were subjected to downward vertical axial load. Subsequently their ultimate bearing capacities were determined and the load-settlement curves were plotted in order to determine their group efficiency.

2. Experimental Setup

2.1. Properties of sand

The micropiles of different L/D ratio were installed in sand placed inside a model tank of size (1.7m x 1.5m x 0.93m). The coefficient of curvature and uniformity coefficient of the sand were found out to be 0.98 and 2.08 respectively. The effective grain size of the sand was determined as 0.22mm. The minimum void ratio and maximum void ratio were ascertained as 0.68 and 0.88 respectively. The specific gravity of the sand was found out to be 2.67. Since the tank used for the experiment was to be filled with uniform density, rainfall technique was adopted. Sand was poured uniformly through a strainer from a constant height of 60cm from the surface of the sand bed. The corresponding relative density obtained in the sand was 50%. For sand with relative density of 50%, density and angle of internal friction (ϕ) was found to be 1.5 gm/cc and 38° respectively.

2.2. Installation of the micropiles

Micropiles were installed as single piles of L/D ratios of 30, 50 and 70, and as square groups of 4 piles per group with spacing of 2D, 4D and 6D with L/D ratios of 30, 50 and 70 for each of the spacing conditions. Steel pipes of external diameter 1.2cm and internal diameter 1.0cm were used for casting the piles. At the lower end of the pile a conical wooden shoe was attached. A 2mm diameter mild steel rod was fixed to the

wooden shoe and inserted into the pipe as reinforcement. Keeping the steel pipe perfectly vertical, it was driven into the sand manually along with the steel reinforcement and the wooden shoe. The piles were then grouted with cement slurry of water cement ratio 0.6 under a constant gravity head of 100cm. Pile caps were constructed using wooden framework and were reinforced with steel wire mesh.

2.3. Measurement of load and deflection

Application of load was carried out using a mechanical jack system where the jack was fixed such that it could slide when required. The proving ring with a constant of 0.99 kg per division (Figure 2) was fixed to the top of the pile cap by ball and socket arrangement. Load tests were carried out four days after grouting. Load-deflection test was done according to the norms of IS 2911 (Pt-4) 1985 code of practice for load test on group piles. Load was measured by means of the proving ring and displacement was measured by a dial gauge fixed to the pile cap.

3. Test Results

3.1. Single micropiles

Individual micropiles were cast with L/D ratios of 30, 50 and 70. On the load versus displacement curve (Figure 3), the point at which the curves reach their peak values from which the pile load reduces with further displacement is taken as the ultimate load capacity of the micropile. Figure 4 shows the plot of ultimate axial load resistance versus L/D ratio. It is observed from the plot that the ultimate axial resistance gradually increase from L/D 30 to L/D 70.

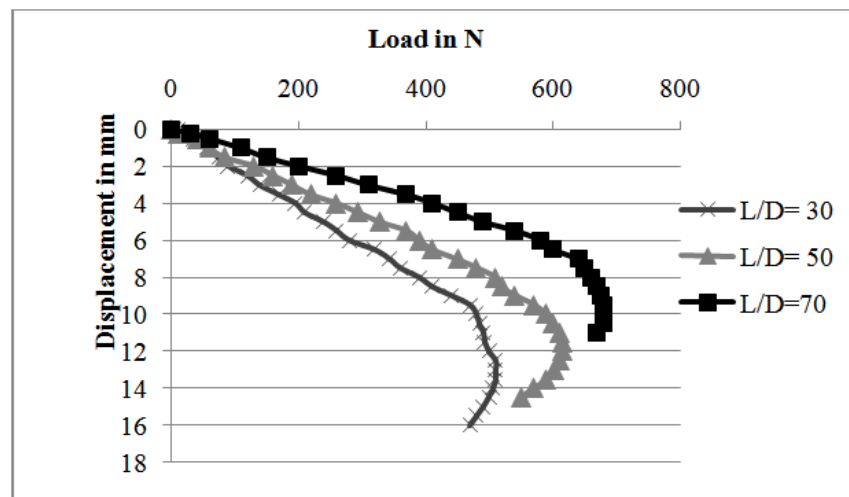


Fig. 1: Load versus settlement plot for single pile at L/D= 30, 50, 70.

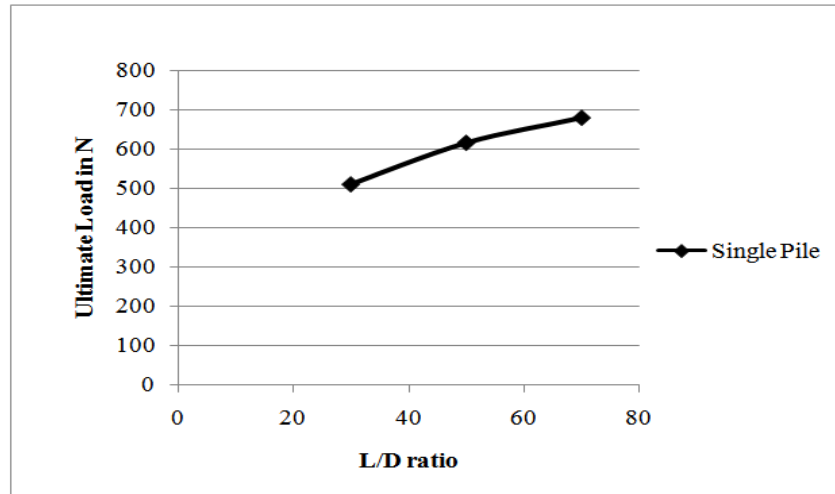


Fig. 2: Ultimate load versus L/D ratio for single pile.

3.2. Micropile Groups

Micropiles groups of the same L/D ratio as that of the single piles were cast. The pile groups consisted of 4 piles at spacing of 2D, 4D and 6D. Because of space limitations, only the variations in axial pile capacity with the pile head displacement for pile group 4D are shown in Figure 5. Figure 5 clearly shows that the load gradually increases with increase in displacement until the load displacement curves reach their peak values from which the pile load reduces with further continuous displacement. Thus, the ultimate load capacities of the pile groups were determined.

It can be seen in Figure 5 that the ultimate load capacity increases with the increase in L/D ratio. Further, with increase in L/D ratio of the pile groups exhibit a decrease in the settlement before failure.

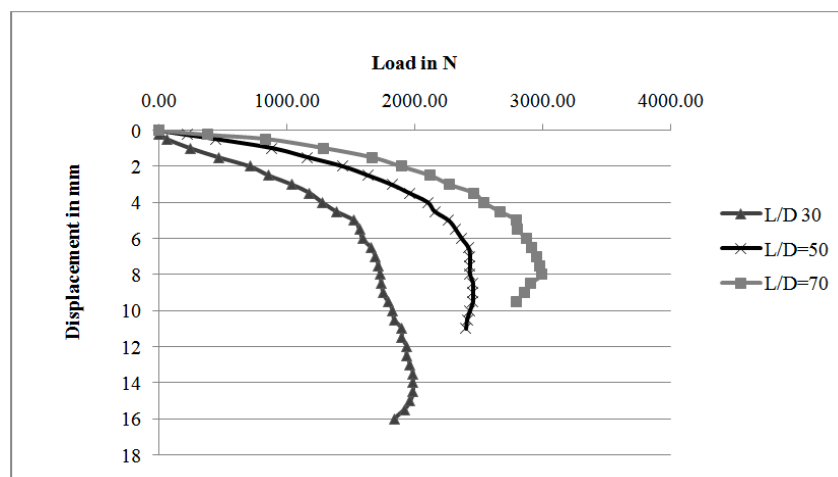


Fig. 3: Load versus settlement plot for pile groups at 4D spacing.

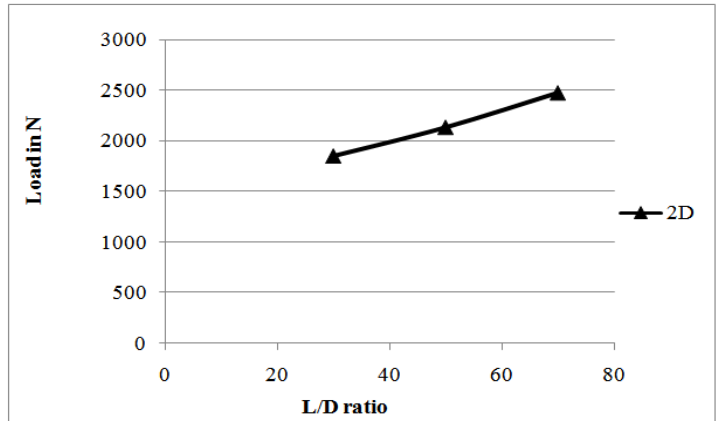


Fig. 4: Load Vs L/D ratio for 2D spacing.

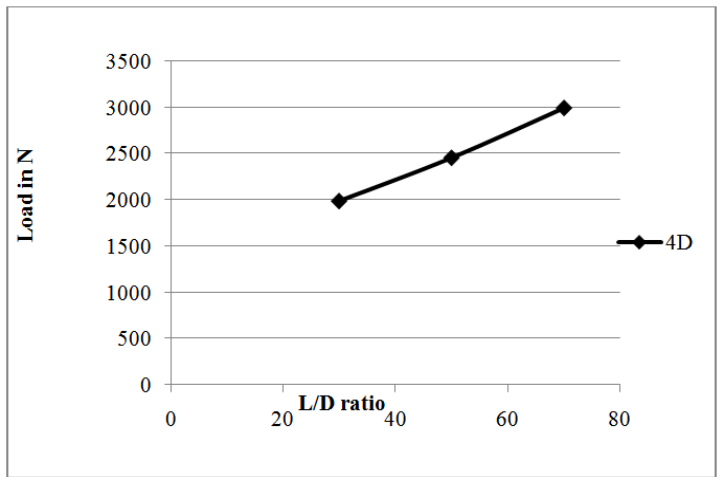


Fig. 5: Load Vs L/D ratio for 4D spacing.

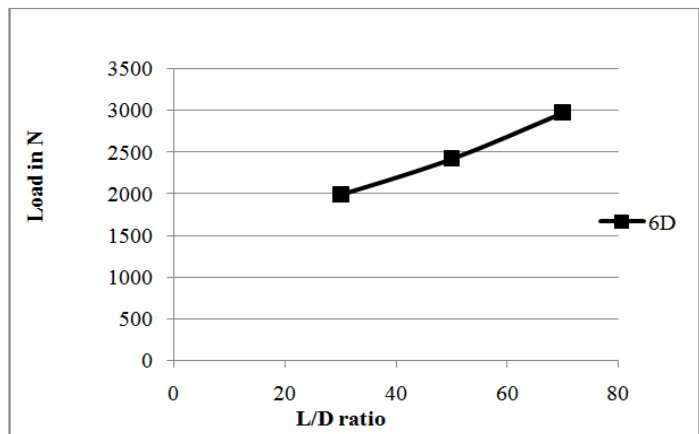


Fig. 6: Load Vs L/D ratio for 6D spacing.

Figure 6, 7 and 8 show the variation of ultimate axial load with length to diameter ratio of the micropile groups at the three different spacing. It is seen that all the three plots show an almost identical trend. L/D ratio of the micropile groups could not be increased due to the limited tank depth of 0.93 m.

4. Group Efficiency

There has been quite a lot of research regarding the group efficiency of micropiles. However, the results have not been in agreement and a reasonable explanation has not yet been arrived at. In the study of piles under vertical loading, a parameter termed as efficiency is often used to evaluate the group effect:

$$\eta = \frac{Q_g}{nQ_s} \dots \dots (1)$$

where η = efficiency of the pile group; Q_g = axial capacity of pile group; Q_s = axial capacity of single pile; and n = number of pile group.

The group efficiencies of the pile groups at 2D, 4D, and 6D spacing had been determined. Table 1 shows the group efficiency of the various pile groups that we studies in our experiment.

Table 1: Group efficiency table for different L/D ratio and spacing.

Length(cm)	L/D ratio	Q _u (N)	Ultimate Load (N)			Group Efficiency		
			2D	4D	6D	2D	4D	6D
30.00	30.00	510.03	1855.24	1984.53	1989.24	0.91	0.97	0.98
50.00	50.00	615.47	2137.82	2451.66	2417.82	0.87	1.00	0.98
70.00	70.00	679.23	2478.32	2991.03	2967.32	0.91	1.10	1.09

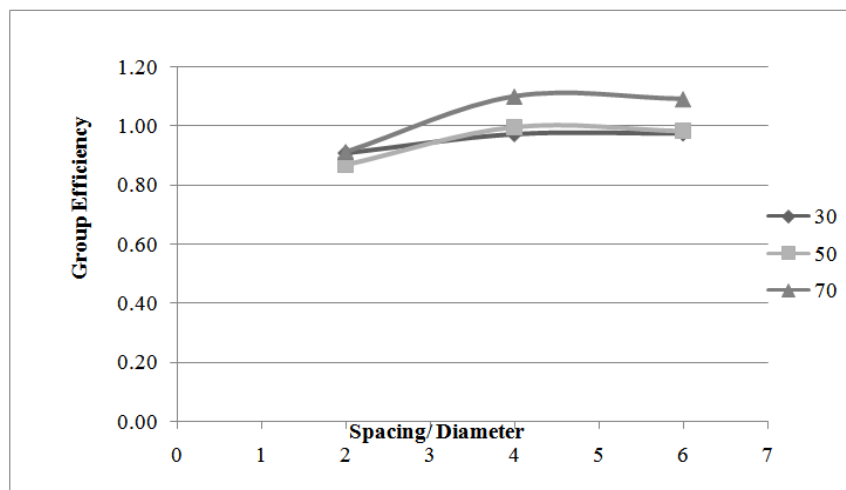


Fig. 7: Group efficiency (η) versus Spacing/Diameter ratio

Group efficiency versus spacing/diameter ratio is shown in Figure 11. The observation shows that the group efficiency increases when the spacing increases from 2D to 4D. However, when the spacing is further increased to 6D, the group efficiency shows a very insignificant change. Thus, maximum group efficiency is observed when the spacing in 4D and the maximum value increases with increase in L/D ratio. The results also show that positive group effect is only observed in the piles groups with L/D ratio 50 and 70 at 4D and 6D spacing.

5. Comparison with Previous Literature

Lizzi (1985) reported model test results of group efficiency of micropiles on coarse sand. The experimental consisted of four series of tests, with piles length of 50, 100, 150, and 200 pile diameters, respectively. Each series consisted of 6 groups of 3 piles each, spaced at 2 to 7 diameters, plus additional single piles. The results of the tests are as summarized in the Figure 13. The result showed positive group effect at spacing ranging from 2 to 6 times the pile diameter.

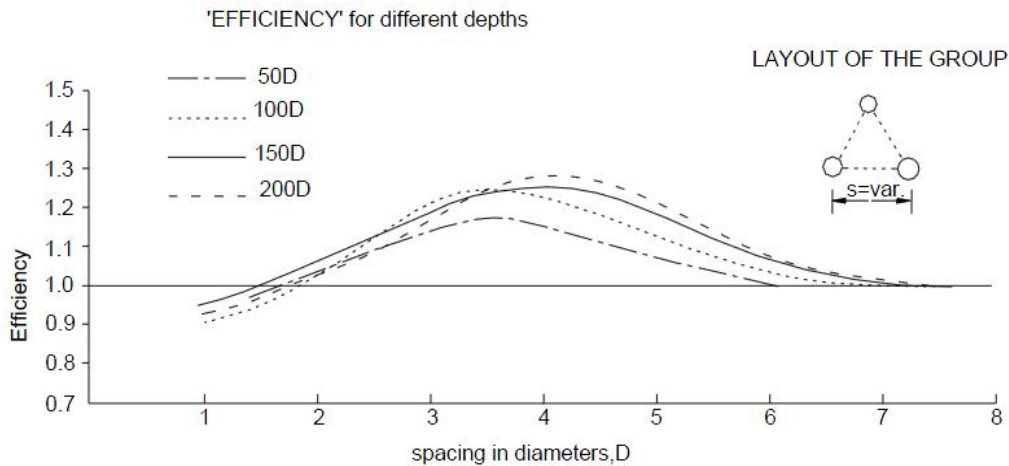


Fig. 8: Efficiency Vs Spacing (Lizzi 1985).

Comparing the result of the present experiment with that of Lizzi, it was observed that both results show a similar trend for pile groups with L/D ratio of 50 and 70. A positive group effect was observed in all of the piles groups of lengths 50D to 200D studies by Lizzi, while the present experiment show positive group effect in pile groups with length 50D and 70D, and not for 30D. Nonetheless, an increase in the group efficiency from 2D to 4D spacing, similar to the Lizzi’s results, has been invariably observed in all the piles groups. Again, it is seen that Lizzi’s result shows an increase in the maximum efficiency with increase in depth, similar to the findings of the current experiment.

Furthermore, O'Neill's (1983) study on group of 4 piles conducted on medium dense to dense sand (relative density 50% to 90%) also shows that there is an increase in group efficiency from 2D to 4D spacing and very little decrease thereafter. It can be seen in Figure 14 that the curve is quite similar to the one deduced by the current experiment.

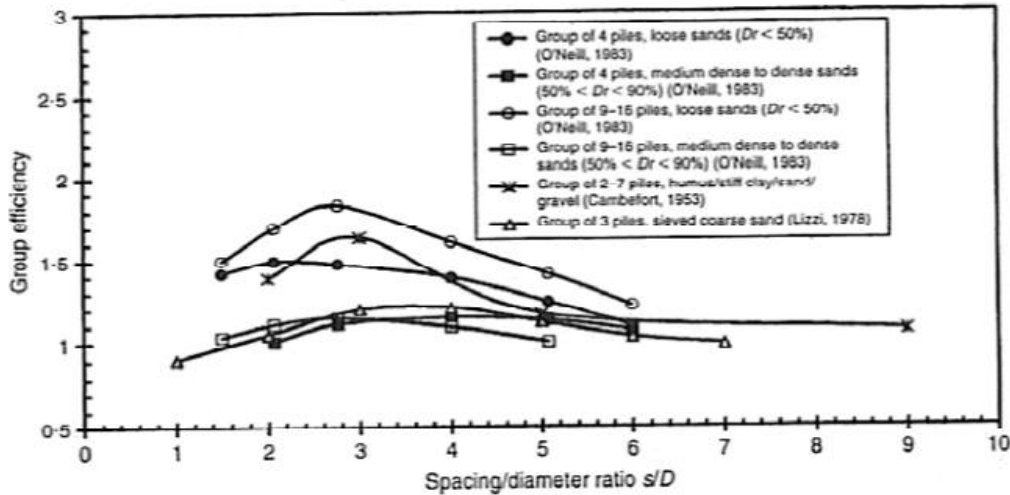


Fig. 9: Group efficiencies from test model pile groups in cohesionless soil subjected to vertical loads reported by O'Neill (1983), Lizzie (1978) and Cambefort (1953)

Based on the comparisons, it is seen that there is inconsistency of results of the various researcher workers. However, it is observed that for micropile groups of four, maximum group efficiency is observed when the spacing between the piles is 4D. Most of the curves (group efficiency versus spacing) have shown a similar trend of increase followed by a gradual decrease.

6. Conclusions

Based on the results of the present experimental investigation, some conclusions are drawn with respect to ultimate load capacity of micropiles and micropile groups. Ultimate load capacity increased with the increase in length to diameter ratio but the increase was not linear. Furthermore, the settlement before reaching the ultimate load capacity decreased with the increase in length to diameter ratio.

A few conclusions were also drawn regarding group efficiency of micropiles. The efficiency increased with increase in spacing between piles in a group up to 4D then slightly decreases with the increase in spacing. It was seen that the maximum efficiency occurs when the spacing between piles is 4D. The maximum efficiency is dependent on L/D ratio and increases with the increase with L/D ratio.

Further comprehensive experimental work, covering a broad range of pile characteristics and soil properties, is needed to get definitive conclusions about the effects of spacing on efficiency of pile groups.

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