

Research Article

Ahmed S. A. Al-Gharbawi*, Mohammed Y. Fattah and Sajad Abdullah Abduhussain

Behavior of soil reinforced with micropiles

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Abstract: Soil investigation is very important to check the bearing capacity before constructing any structure. There are different types of soils that cause many problems for the structure in short and long term, which are known as problematic soils. A lot of researchers dealt with improvement and reinforcement of the problematic soils by physical and chemical treatments. The objective of this study is reinforcing the problematic soil with micropiles with different depths and different configurations. In this study, two types of soils, soft clay and loose sand, were used to study the effect of adding micropiles of different depths and different configurations to investigate the best improvement of bearing capacity for shallow foundations on these soils. The results showed that reinforcing the natural soil with micropiles could improve the pressure carrying capacity of the problematic soils. When the design width is changed from under foundation alone to under foundation and $2B$ width, the soil reinforced with $2B$ depth of micropiles can raise the soil's load carrying capacity by 45 to 65% when compared to untreated soil. Just 7% more bearing capacity may be achieved by increasing the depth of the micropiles from $2B$ to $3B$ (where B is the footing width); as a result, going deeper than $2B$ is not advantageous. Additionally, the bearing capacity of the micropiles increases by only 3% when the breadth of the configuration is increased from $1B$ to $2B$; so, wider configurations than $1B$ are invalid.

Keywords: problematic soil, micropiles, reinforcement, soil treatment

1 Introduction

Problematic soils are soils that have low bearing capacity, undergo excessive settlement, or even fail under relatively low stress conditions [1].

Numerous techniques have been documented in the literature to enhance the behaviors of soft clay and loose sand soils; however, selecting the best technique can be difficult due to a number of issues, including building and economic considerations.

In the research, a large number of mathematical equations connecting bearing capacity to traditional soil properties have been constructed. The vast majority of these mathematical equations can be adapted to the particular soil for which they were intended. Put differently, despite soils having comparable physical qualities, they differ in their microstructures and, consequently, in their mechanical behavior. For this reason, recommended empirical equations do not translate to standard geotechnical engineering practice.

Through experimentation and creativity, contractors have created a variety of soil improvement technologies in recent years. During this time, researchers in engineering have looked into the fundamental mechanisms underpinning these technologies to confirm their applicability and efficacy. In general, mechanical or chemical methods are used in soil improvement operations; however, in some circumstances, a combination of methods is employed. There are several widely used mechanical procedures, including ground reinforcement [2–5], compaction [6,7], and drainage and dewatering [8–11]. Chemical additives and biological processes are frequently used in chemical techniques and biological approaches to improve problematic soils [12–18]. Chemical additions that stabilize soil can be classified as either conventional or unconventional [19]. According to Kampala et al. [20], examples of conventional additives include lime, cement, bituminous materials, and manufacturing by products such as fly ash, carbide calcium residue, and granules blast furnace slag.

The effects of fly ash treating on the shear strength and pressure capacity of the soil were investigated by Baqir et al. [21] using clay columns stabilized with 5% fly ash

* **Corresponding author: Ahmed S. A. Al-Gharbawi**, Civil Engineering Department, University of Technology, Baghdad, Iraq, e-mail: ahmed.s.algharbawi@uotechnology.edu.iq

Mohammed Y. Fattah: Civil Engineering Department, University of Technology, Baghdad, Iraq, e-mail: 40011@uotechnology.edu.iq

Sajad Abdullah Abduhussain: Building and Construction Engineering Technology Department, Al-Israa University, Baghdad, Iraq, e-mail: eng.sajad@esraa.edu.iq

supplied to soil with various L/D values of 4 and 6 and with different curing periods of days. The results of the treatment time of days in 14 days and 28 days were close to one another. Between 14 and 28 days, the two (L/D) 4 and 6 have an incensement ratio of about 5%. (L/D) 6 has demonstrated a notable improvement over L/D 4; there has been a 30% reduction in bearing ratio breakdown.

A linear shrinkage test is used by Sulaiman *et al.* [22] to examine the linear shrinkage of a problematic soil and its response to eco-processed pozzolan EPP at 20 and 30% concentrations as a soil stabilizing ingredient. The following deductions have been made in light of the research: The soil index criteria included both pH and moisture content, both of which were determined to be suitable. For peat soil, eco-processed pozzolan, the soil with 20% EPP, the average water content of the soil's sample was 580.5%, and the pH values were 3.1, 13.02, and 9.00, respectively. It is possible that EPP will contribute to a nearly 66.66% reduction in shrinkage. Furthermore, the findings show that the shrinkage behavior of both untreated and treatment soils with EPP is greatly reduced by adding EPP as a filler material, with 4.29% decreased to 1.43% significantly.

Sand's engineering qualities (compaction, unconfined compressive strength), as well as the effects of cement and nanosilica, were researched by Choobbasti *et al.* [23]. Three percent of cement quantities (5, 9, and 14% by weight of the sand at dry condition) were mixed with four different nanosilica ratios (0, 5, 10, and 15% by weight of cement). The mixture was then compressed into a cylindrical specimen. The study's findings indicated that sands' engineering qualities are enhanced by the addition of cement and nanosilica. With the rise in cement concentration, an increase in the maximum dry unit weight of sand was observed. The mechanical qualities of cement sand can be greatly enhanced when nanosilica is present in the right amounts.

In comparison to far more expensive driven piles, micropiles are simply small-diameter piles (which is frequently steel bars or pipes) coated into predrilled holes to construct shorter frictional piles with great capacity and a generally smaller amount of settlement. They can be put in practically any kind of soil, including rock. The most typical applications for micropiles are slope stabilization, wall support, underpinning, and structural foundation support. Micropiles have several important benefits, one of which is that they do not require overhanging or lateral site constraints, which would make installation demanding much larger equipment impossible. Micropiles have the ability to give both tensile and considerable compressional strength, in contrast to the variety of structural reinforcement techniques previously discussed. According to industry data, micropiles can function at in excess of

2,200 kN (250 tons). Conventional micropiles are inserted into predrilled holes filled with concrete. In place of pricey deep foundations, they are frequently used in groups to transmit bearing pressures to subsurface soils. Micropiles are coated in a high pressure in place to boost capacity. Side resistance is greatly increased by this process, which also densifies the surrounding earth and increases lateral pressures. Micropiles are non-displacement piles with small diameters that are drilled, grouted, and often strengthened in the center with high strength steel bars. A borehole is drilled, steel reinforcement is added, and the hole is grouted to create a micropile. In various applications of ground improvement, including the reinforcement of existing foundations, micropiles have been used successfully to increase bearing capacity and decrease settlement. The design process and application of this strategy are outlined in federal highway administration (FHWA) [24].

The modification of the load conditions for operation on the subgrade employing reinforcing components in the form of micro and helical piles is one of the most popular and efficient strategies for improving the ground used in useful uses. The lateral micropiles are one of the strategies that have been developed in this regard [25]. Large-scale projects such as roads and embankments can use soil reinforcement extensively, and in these kinds of projects, it can be used to lengthy piles with weak underlayers that are buried deeply.

Using the finite element method, Fattah *et al.* [26] investigated the effect of micropiles under static as well as dynamic loading scenarios. The analysis is done using the open-source tool OpenSees, which also gives availability of its source data and details on the software architecture and construction procedure. A model was developed to investigate the effect of defects on the lateral effectiveness of groups of horizontally compressed pipe piles in sand. A total of 2, 4, and 6 evenly spaced piles were arranged in group series in the geometric layout. The pile and the surrounding dirt are modelled using eight node brick parts. After placing steel micropiles in two distinct orientations adjacent to the damaged pile, it was determined that the deformation of horizontally pressured piles is reduced. When the defective pile is modelled in the front row, the rise in the group displacement is larger.

A calculating approach taking into account the stiffness of soil-reinforcing devices mounted vertically was proposed by Popov [27]. It is significant to remember that standard building materials such as concrete, geosynthetic-encased columns, steel, and crushed stone are all listed as vertical reinforcement in the codes. However, the standards do not go into depth on fiberglass or other comparable composite materials [28].

Table 1: Soil properties

Property	Sand	Clay
Natural water content; (w. c%)	1.7	5.0
Liquid limit %	—	44
Plastic limit %	—	19
Plasticity index %	—	25
Specific gravity (Gs)	2.64	2.69
Gravel, (>4.75 mm)%	0	0
Sand, (0.075–4.75 mm)%	96	16
Silt, (0.005–0.075 mm)%	4	34
Clay, (less than 0.005 mm)%	—	50
D_{60}	0.38	—
D_{30}	0.23	—
D_{10}	0.16	—
Uniformity coefficient	2.38	—
Curvature coefficient	0.87	—
Max. dry unit weight (kN/m ³)	18.82	—
Min. dry unit weight (kN/m ³)	15.32	—
Soil classification (USCS)*	SP	CL

*Unified Soil Classification System.

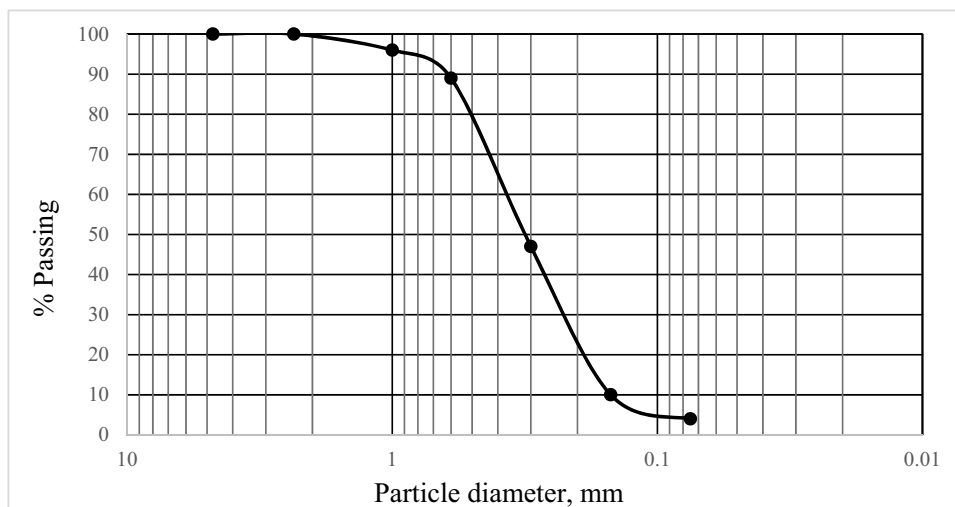
With the aid of an expanding polyurethane resin that was pumped into the soil body during hydrofracturing, Sabri and Shashkin [29] examined the behavior of soil reinforcement. As part of their follow-up research, Sabri and Shashkin [30] created a novel approach for calculating the reinforcing displacement and stress characteristics of expanding soils made of polyurethane resin following the grouting procedure, taking into account the resin as rigid reinforcement elements in the vertical orientations.

Russo et al. [31] reported a new installation process for the footing pile of a new mall that is being designed in a former industry area. Pushing and auguring methods are

used in tandem to install hybrid piles. This installation technique makes it possible auguring methods to avoid having to remove and then dispose of shallowly polluted soil. Three loading tests are used to examine the mechanical characteristics of the three hybrid piles that have strain gauges installed along the shaft. The possibility of providing a completely sustainability foundation solution by outfitting the piles with heat transfer pipes is also being looked into within the context of designing a new mall in a former industrial area. A comparison between two different heat exchanger pipe configurations and further advantages of the novel hybrid installation method is provided by mathematical models of the behavior of energy hybrid piles.

A field investigation was carried out by Han and Ye [32] to look into the mechanisms of load transfer at the micropile link to the plate of concrete both underneath the initial pressure and under the load adding. Throughout the loading and hookup processes, they kept an eye on changes in stresses. In order to analyze the outcomes from the field, they used theoretical answers. In a field study using soft clay, Han and Ye [33] looked at the behavior of a single micropile under compression and tension. Based on the findings of field tests, they selected a theoretical approach for calculating the proportion of tip resistant to the overall load, the pressure capacity of piles, and the bearing capacity of soil.

The findings of a case study on employing 350 micropiles to enhance loose sandy soil layers were provided by Moayed and Naeini [34]. They looked at how soil stress–displacement behavior improved and how micropile injection affected liquefaction remediation. Prior to and during the installation of micropiles, they assessed the outcomes of Standard Penetration Tests and Plate Load Tests on a

**Figure 1:** Grain size distribution of the loose sand.

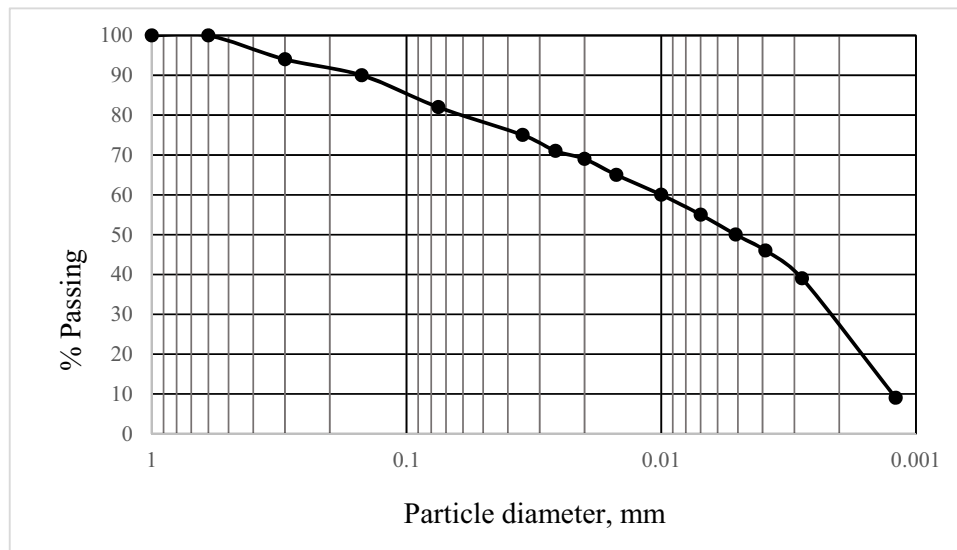


Figure 2: Grain size distribution of the soft soil.

genuine site. They demonstrated that employing micropiles can dramatically improve the pressure carrying capacity of loose sandy soil as well as the subgrade reaction of the soil, k_s , as well as the reactivity of loose silty sand soils to load the surface. After improving the soil, they reported that installing micropiles raised the SPT value.

Moghaddam et al. [35] conducted multiple static processes with strain control tests with a rate of breakdown of 10 mm/min and a laboratory setup using a large-scale physical modeling apparatus in order to evaluate different variables, which includes the depth, radius, interact radius, and interact skin friction of micropiles in sandy soils with varying relative densities. Additionally, the pressure

carrying capacity of drilled and driven micropiles was checked, and the outcomes showed the behavior of every parameter as well as installing techniques on the micropiles' pressure carrying capacities. The findings demonstrated the relative density parameter's significant contribution to the micropile's load-bearing capacity values when compared to other factors. In contrast to the drilling approach, the experiment's results also showed that the forced insertion technique may raise its load carrying capacity to a maximum level of 84%, and indicating that, on average, the radius variable influences the pressure carrying capacity quantities at various soil densities by 12% greater than the measurement parameter.

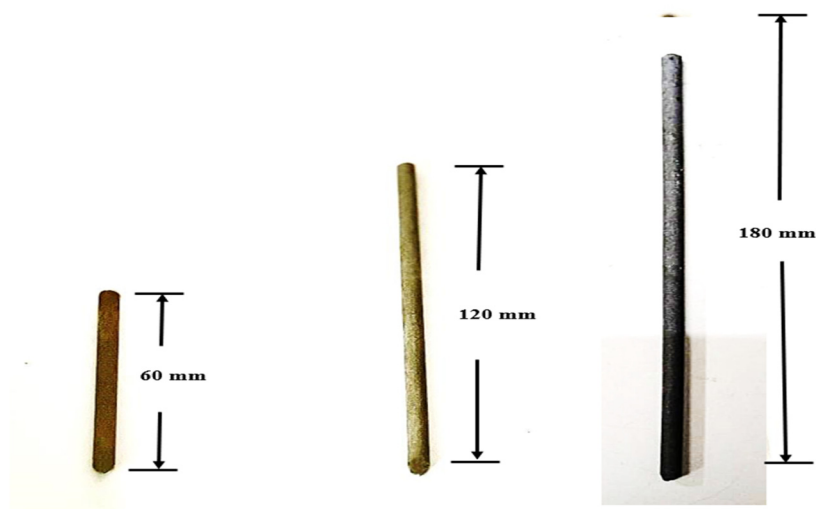


Figure 3: Micropiles used.

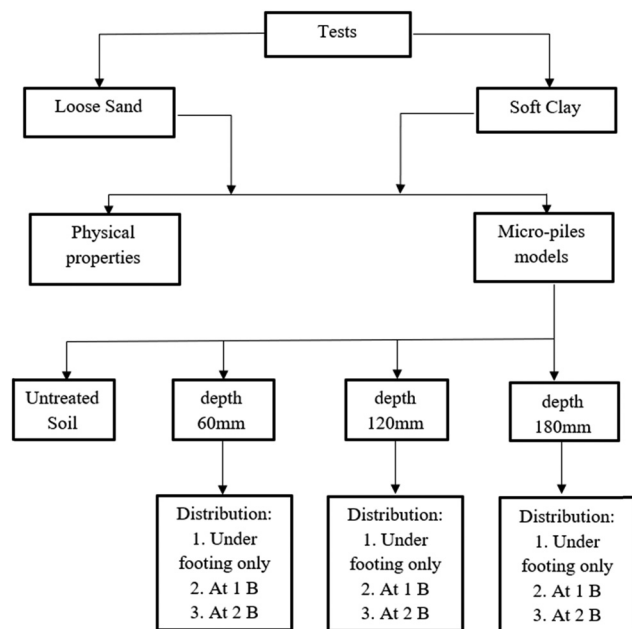


Figure 4: Testing program.

Even while chemical stabilization materials have been very successful in changing the behavior of unstable soil, they cannot be regarded as environmentally benign materials because they are poisonous, change the pH of the soil, and contaminate soils and groundwater.

The objective of this study is reinforcing the problematic soil with micropiles with different depths (1B, 2B,

and 3B) and different configuration widths (under footing only, 1B and 2B). Two soils are used in this study: loose sand and soft clay.

2 Materials

2.1 Soil characterization

Two types of problematic soils were used in this study. The first one is loose sand brought from Kerbala city, south west of Baghdad and the second one is soft clay brought from a site south of Baghdad. The properties of loose sand and soft clay are illustrated in Table 1, and the grain size distribution is illustrated in Figures 1 and 2.

2.2 Micropiles

The micropiles are employed as structural supports and soil reinforcement in structures with a diameter of little more than 300 mm FHWA [22]. Steel micropiles of 2 mm in diameter and three depths of 60, 120, and 180 mm were employed in this investigation. These depths correspond to 1B, 2B, and 3B, respectively (i.e., B breadth of the foundation). The micro-piles utilized are shown in Figure 3.

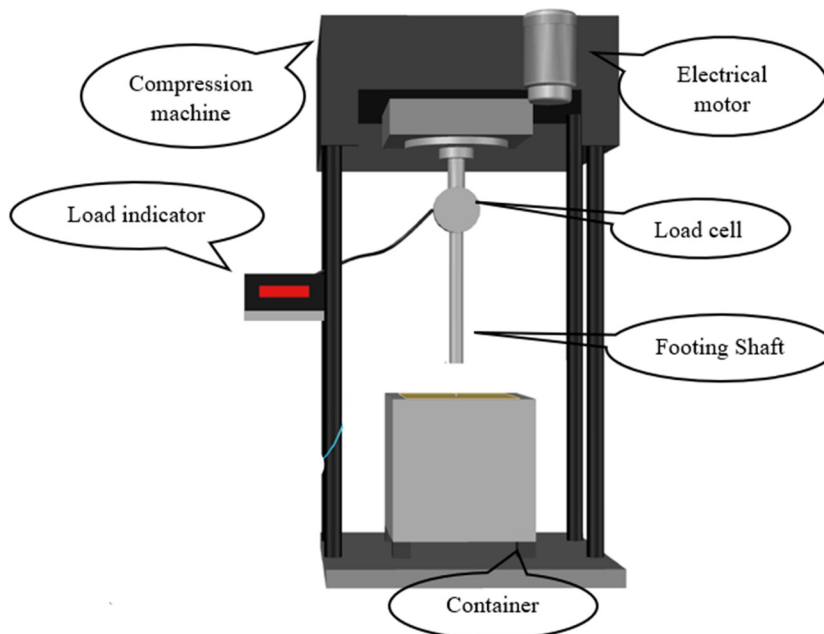


Figure 5: Experimental setup.

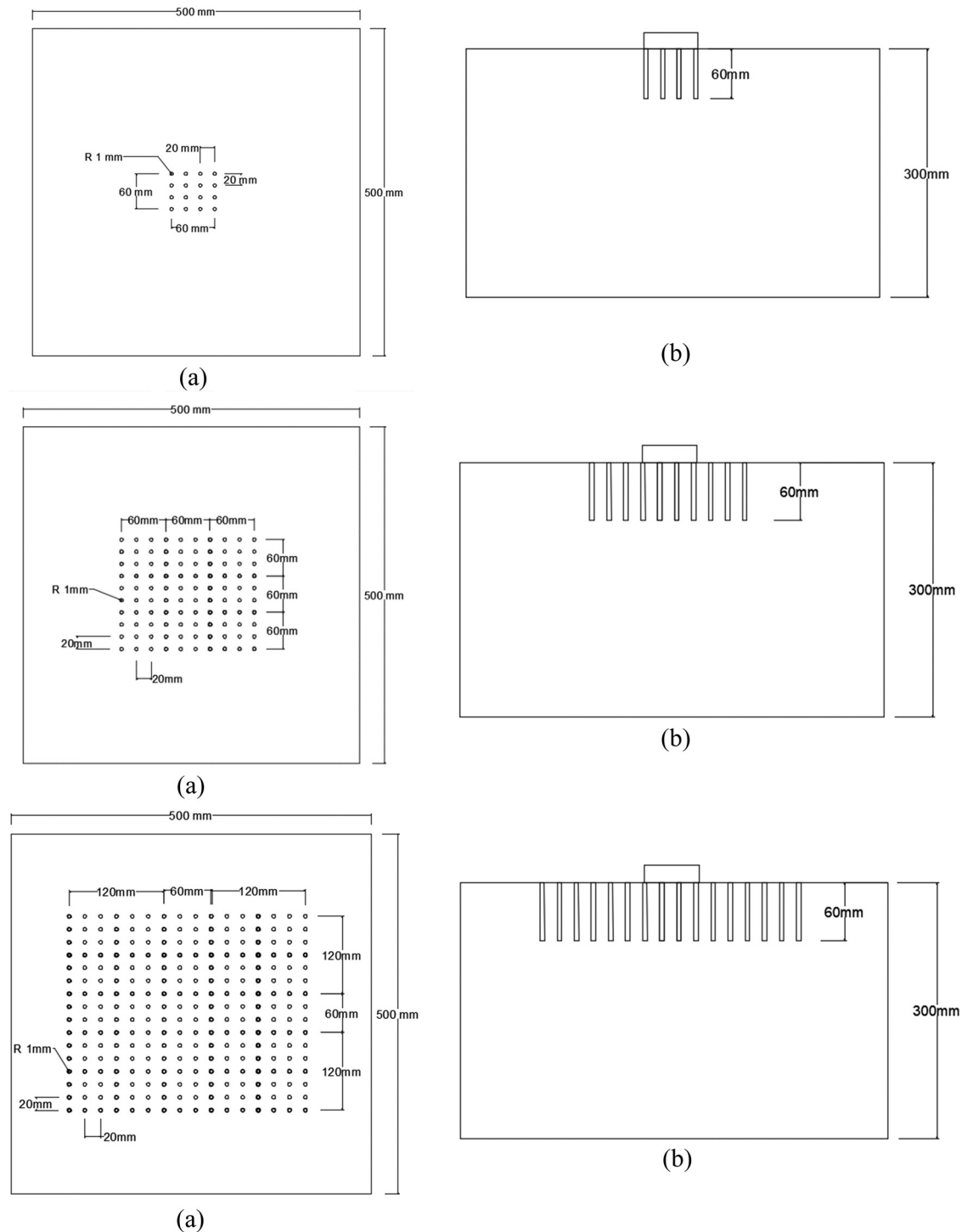


Figure 6: Design for the 60 mm depth models in which micropiles are positioned beneath the foundation to heights 1B and 2B.

3 Testing program

The present study uses a method to improve the load carrying capacity of the problematic soils by inserting micropiles within the soil. The testing program is divided into two sections: the first one looks at the impact of the

reinforcement micropiles in loose sand, and the second one looks at the impact in soft clay. Although the model is set up according to the first section, the soil is loaded to the point of failure. A relative density of 30% was selected for loose sand and the undrained shear strength used 16 kPa for soft clay. Figure 4 illustrates the testing program.

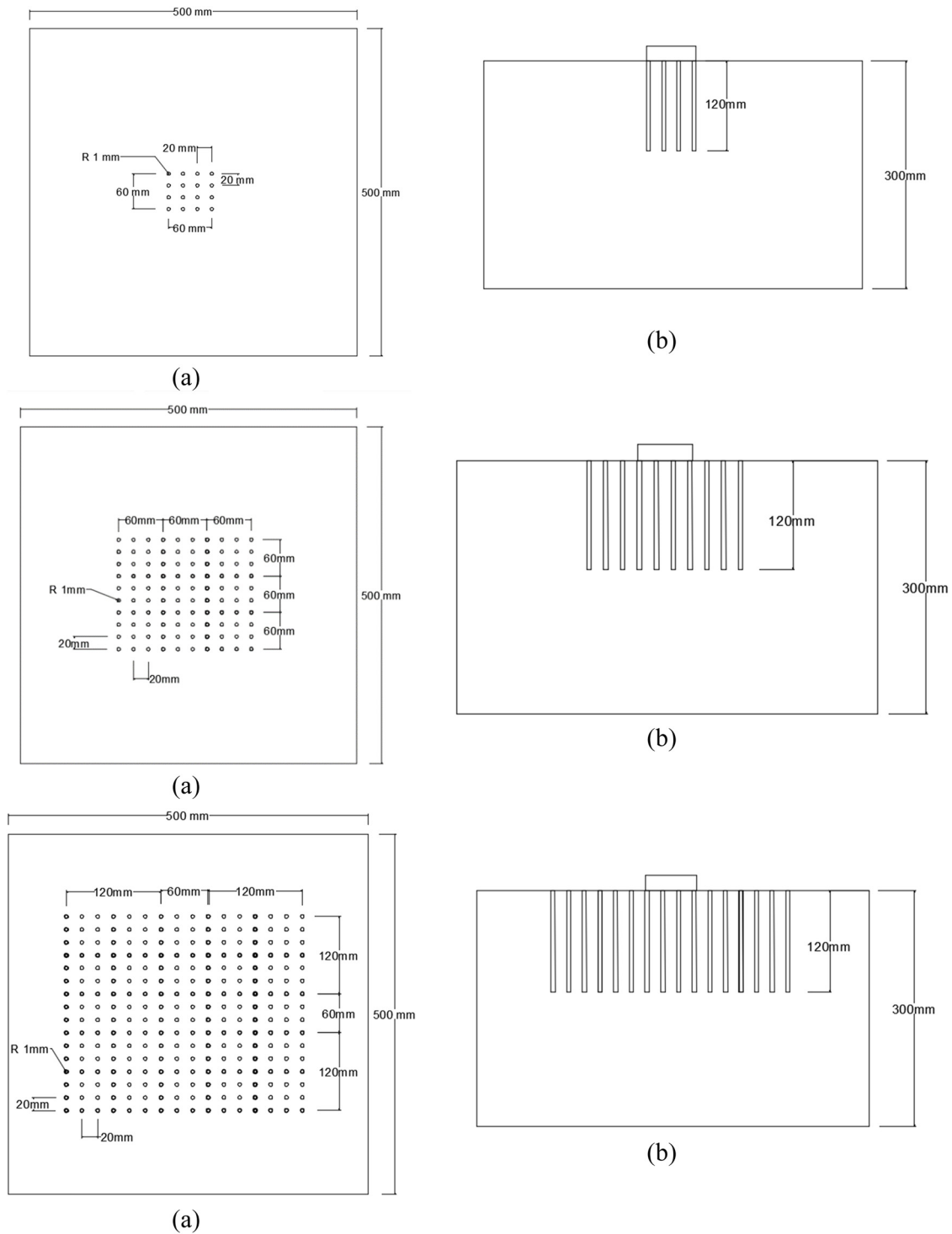


Figure 7: Design for the 120 mm depth models in which micropiles are positioned beneath the foundation to heights 1B and 2B.

The loading machine is shown in Figure 5. Figures 6 and 8 display the testing program's model sketch, which shows the model sketch for depths of 60, 120, and 180 mm, respectively. The dimensions of the container utilized in

the investigation are 500 mm × 500 mm × 300 mm. A foundation measuring 60 mm by 60 mm by 10 mm was used to press down on the soil underneath in order to assess the soil's capacity to support loads.

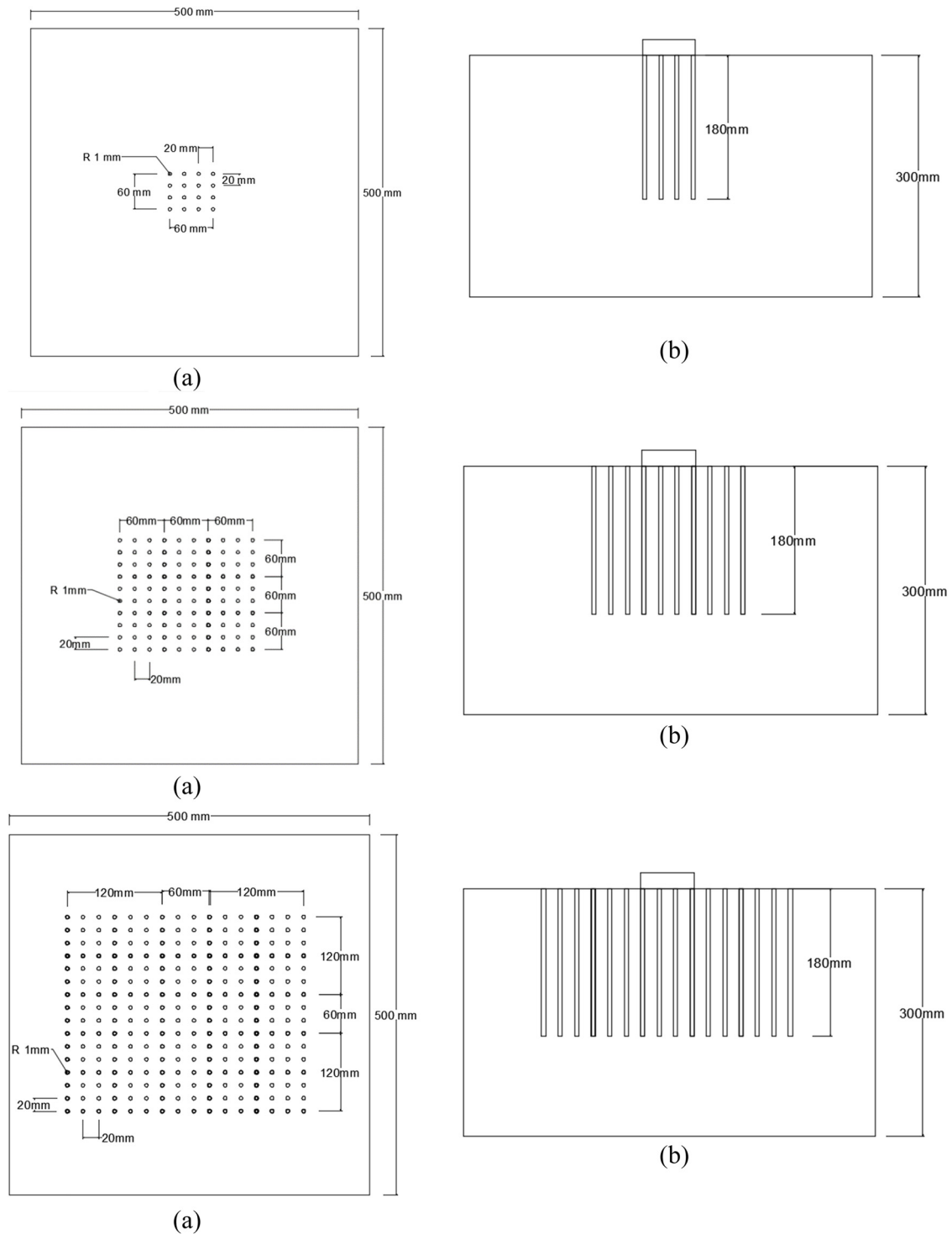


Figure 8: Design for the 180 mm depth models in which micropiles are positioned beneath the foundation to heights 1B and 2B.

Each model is prepared by adding the soil gradually to the container. The container is divided into three equal depths to give the adequate density to the soil. After that, the face of the soil is smoothing very well and then divided

into grids as the width configuration of micropiles. The point of micropile is drilled and then inserted into the micropile gently to the hole. The insertion of micropile started from middle to edge.

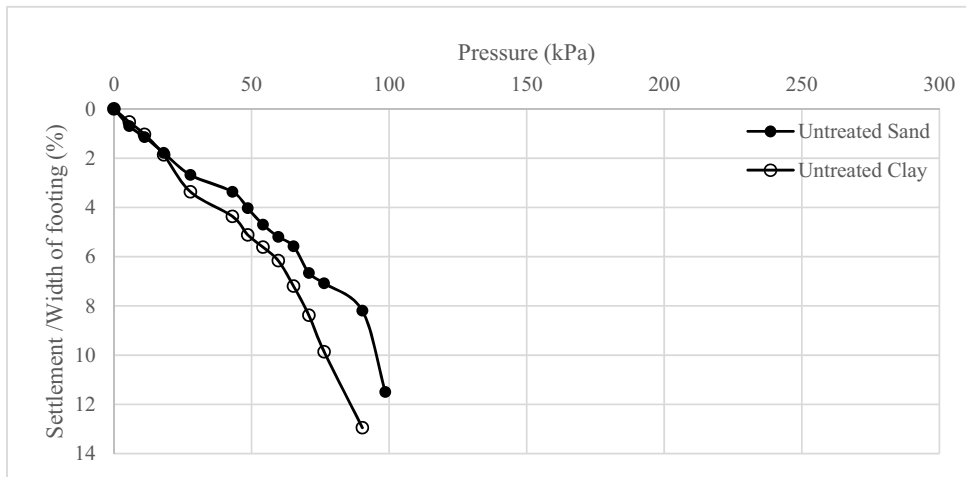


Figure 9: Pressure settlement relationship for a footing on untreated soils.

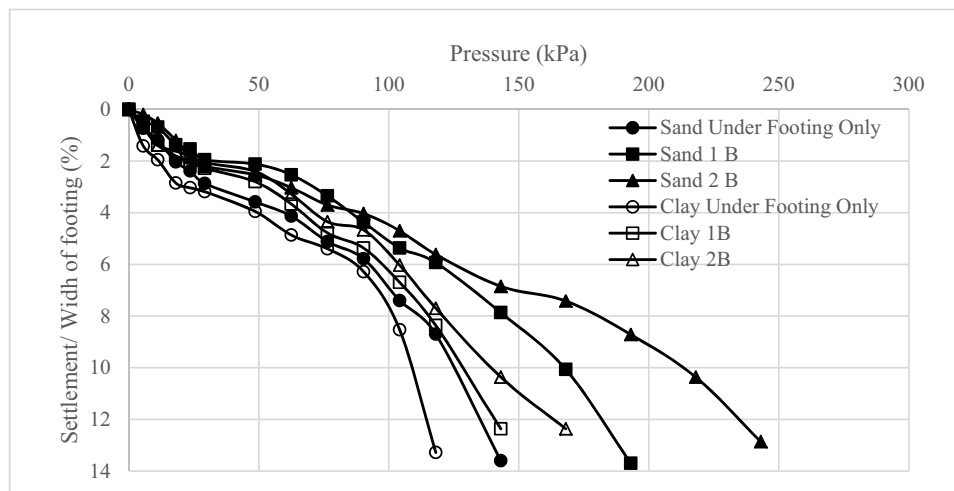


Figure 10: Pressure settlement relationship for a footing on soils reinforced with 1B deep micropiles.

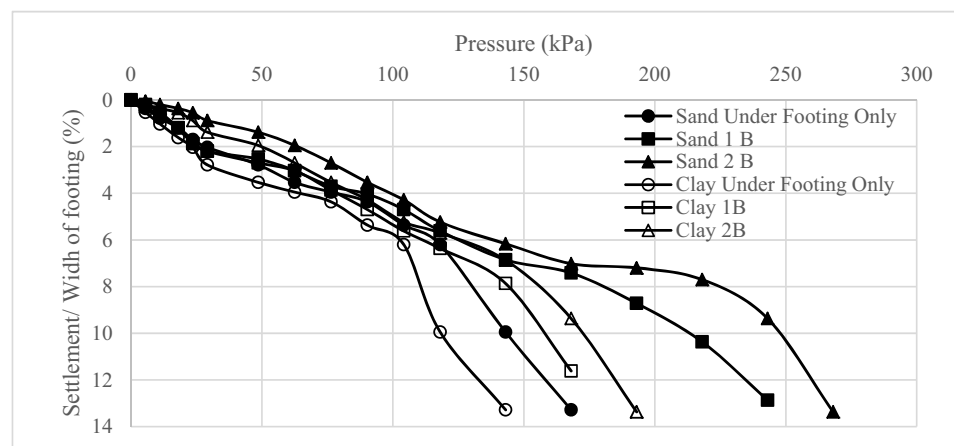


Figure 11: Pressure settlement relationship for a footing on soils reinforced with 2B deep micropiles.

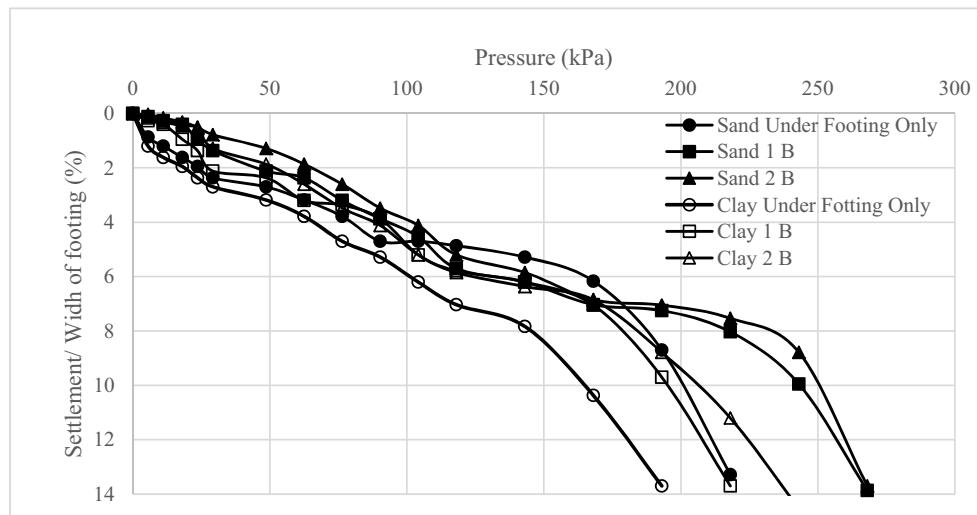


Figure 12: Pressure settlement relationship for a footing on soils reinforced with 3B deep micropiles.

4 Presentation and discussion of test results

Tests are conducted on a number of models to examine the spread foundation's ability to withstand pressure on soil reinforcement at varying depths and micropile configurations. The relationship between footing pressure and settlement on untreated soils is shown in Figure 9. Figure 10 shows the connection between pressure and settlement for the foundation on soil supported by 1B deep micropiles, or 60 mm of depth. Figures 11 and 12 show the relationship between pressure settlement and footing pressure on soil supported with 2B and 3B depth of micropiles, which correspond to 120 and 180 mm depths, respectively. The failure load is said to be defined as one that results in a 10% settling of the foundation width. A summary of the pressure at breakdown, or at a 10% S/B ratio, is presented in Table 2.

Table 2: Applied pressure at failure

Depth of micropile	Width of micropile	Pressure at failure (kPa)	
		Loose sand	Soft clay
Untreated soil		91	72
1B	Under footing only	125	108
1B	1B	168	128
1B	2B	211	141
2B	Under footing only	143	118
2B	1B	212	157
2B	2B	247	175
3B	Under footing only	200	165
3B	1B	243	190
3B	2B	250	210

Equation (1) can be used to define the load carrying capacity ratio, and Table 3 provides an illustration of the bearing capacity city ratio summary.

$$BCR = \frac{\text{Bearing capacity of footing on treated soil}}{\text{Bearing capacity of footing on untreated soil}} \quad (1)$$

As compared to untreated soil, the results clearly show an improvement in the footing's carrying capacity and soil shear strength. There is a slight improvement in bearing capacity for 3B deep micropiles when compared to micropiles with a dimension of 2B, and the effect of the micropile arrangement becomes steady when utilizing 2B deep micropiles.

Mollaali et al. [36] studied the effect of micropiles on improvement of pressure carrying capacity and modulus of the subgrade of the raft footing placed on soft soil layer. Two grids of micropile spacing of $1.5 \times 1.5 \text{ m}^2$ and $1.75 \times 1.75 \text{ m}^2$ are perceived. The findings showed that while the

Table 3: Bearing capacity ratio

Depth of micropile	Width of micropile	BCR	
		Loose sand	Soft clay
1B	Under footing only	1.4	1.5
1B	1B	1.9	1.8
1B	2B	2.3	2
2B	Under footing only	1.6	1.6
2B	1B	2.3	2.2
2B	2B	2.7	2.4
3B	Under footing only	2.2	2.3
3B	1B	2.7	2.6
3B	2B	2.8	2.9

micropile technique can be used to improve the parameters for design of foundations positioned on particularly soft soil layers, it is a poor choice for foundations positioned on moderately dense soil layers.

Borthakur and Dey [37] looked at how cast-in-situ grouted micropiles behaved as a group in very high plastic clayey soil. The micropiles were built in a test pit measuring 2.0 m × 4.0 m × 3.0 m on clayey soil with a very soft consistency, the pressure versus settlement patterns are studied of two separate setups of the micropile groups. Micropile caps were made in two different sets: one where they rested on the ground, and the other where they were suitably elevated above it. The radius, depth, number, and space of group of micropiles are the factors in this investigation. Experimental observations were used to calculate the ultimate pressure bearing capability of the group of the micropile and the group settling under the adequate pressure. The effect of using micropiles inserted in clayey soil and sandy soil was studied by [38]. The studied concluded that the using micropiles in the small scale model increase the pressure bearing capacity of both soils by about 55 to 65% for the clayey soil and sandy soil, respectively.

From the current investigation and as compared with other previous studies, it was also possible to evaluate the group effectiveness and the resisting provided by the micropile cap lonely. It has been found that the increase in diameter, depth, quantity, and space of micropiles results in an increase in the pressure bearing capability of the micropile group. The experimental results are used to create a nonlinear equation that quantifies the maximum load a micropile group can carry.

5 Conclusions

The test results on soft clay soil and loose sand soil treated with inserting micropiles lead to the following conclusions:

1. The soil structure was stabilized and its pressure bearing capacity was increased by the addition of micropiles to soft clay and loose sand soil.
2. The pressure bearing capacity of a rigid steel footing on soil between 40 and 60% can be increased by treating the soils with 1B deep micropiles whenever the arrangement of width changes from under foundation only to under foundation and 2B width in comparison to unreinforced soil.
3. The application of 2B deep micropiles to the soil can enhance a footing's bearing carrying capacity by 45 to 65% whenever the arrangement of width is changed from under foundation only to under foundation and 2B width in comparison to unreinforced soil.

4. When the arrangement of width is changed from under footing alone to under foundation and 2B width, the soil treated with 3B depth micropiles may increase the soil's bearing carrying capacity by 55 to 65% when compared to untreated soil.
5. Only 7% more bearing capacity can be obtained by deepening the micropiles from 2B to 3B; for this reason, the increase in micropile depth is invalid. Additionally, the bearing capacity of the micropiles can only be increased by 3% when the width of the arrangement is increased from 1B to 2B; for this reason, an increase in width beyond 1B is invalid.

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Data availability statement: Most datasets generated and analyzed in this study are composed in this submitted manuscript. The other datasets are available on reasonable request from the corresponding author with the attached information.

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