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Studying the Behavior of Expansive Soil Reinforced by Micropiles

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Abstract

Expansive soil is a form of soil that can expand and contract, changing its volume. Montmorillonite, a mineral with the ability to dissolve in water, makes up the majority of these kinds of soils, and by increasing the volume of the soil, it causes the soil to heave. Expansive soils could be a substantial concern for engineered buildings due to their capacity to adjust to seasonal variations by contracting or expanding moisture content. Many researchers focused on soils that were swollen and looked at how they behaved as well as how they could be improved. In this study, the work depends on inserting micro-piles with different depths and configuration widths to investigate which depth and configuration can be obtained to improve the bearing capacity of foundations on expansive soil. The main purpose of this study is to reinforce the expansive soil with micro-piles with different depths (1B, 2B, and 3B) and different configuration widths (under footing only, 1B and 2B). It was concluded that the soil reinforced with micro-piles improved the load-bearing capacity of the expensive soil and decreased the swell pressure. The increasing depth of the micropiles 2B to 3B (B is the width/diameter of the foundation) can increase the bearing capacity by just 6%; therefore, increasing the depth beyond 2B is not beneficial. Also, the increase in width of the configuration of the micro piles from 1B to 2B increases the bearing capacity by just 4%; therefore, the increase in width greater than 1B is not valid.

Keywords: Expansive Soil; Micro-Piles; Reinforcement; Stabilization.

1. Introduction

There are numerous ways to construct the clay particles that resemble plates. Some clay particles have a remarkable capacity to draw water molecules to their surfaces, keep those molecules there, and absorb them. The process known as polarization is well known to occur in water molecules because each molecular has unique charges on each of its opposite sides, one positive and the other negative [1]. Every one of the plate-shaped particles is adhered to by these polar water molecules, which creates a charged fluid film on them. The swell or heave that is seen in swelling soil whenever the moisture content of this soil is enhanced is brought on by the "two layer phenomenon," which happens when discrete adjacent particles are considered. This phenomenon is created by clay particles resisting one another. Clay soils are more equipped to absorb water into their geometries because of their larger charge densities and more specialized surfaces for clay particles.

Clay soils are more equipped to absorb water into their structure due to higher charge densities and greater clay particle-specific surfaces. The ability of a fine soil to maintain water components within its structure is assessed using the liquid limit and plastic limit indices. Compared to other clay minerals, montmorillonite clays have the highest tendency to expand, whereas kaolinite has a comparatively modest swelling potential [2, 3]. The shape of the shrinkage path was most accurately defined by the ratio of soil volume change to water volume change. According to the curve,

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drainage occurred from the majority of the large holes with little to no change in volume, the remaining huge pores and the majority of the tiny pores with approximately equal change in volume, a few tiny pores with little to no change in volume, and the remaining small particles with no change in volume [4].

A range of techniques have been used to estimate the possible amount of swelling in clay in order to assess the characteristics and uses of this type of soil in environments akin to those found in the field. The "oedometer test" was introduced by Das [5] and is a straightforward lab. test that is used to gauge the severity of swell pressure in soils. According to ASTM D 4546 [6], the specimen is inserted in the oedometer cell with a minor load of approximately 6.9 kN/m^2, after which water is added to increase the volume of the soil sample to enlarge and be measured until equilibrium is reached.

An affordable, efficient, and environmentally beneficial method for treating expansive soils is stabilizing the soil through the use of admixtures. It is possible to overcome the superior swelling, shrinkage, and swelling potential of expansive soils with a variety of chemical and physical stabilization techniques. There are five different widely used admixtures, including marble dust, eggshell, fly ash, stone dust, and lime, that are used to stabilize expansive soils, and they are demonstrated to be capable of stabilizing expansive soils and being environment-friendly [7].

Research was conducted by Kumar et al. [8] on the behavior of expansive soil reinforced with geocell and chevron patterns. The geocell mattress placement depth beneath the footing base, the geocell pocket size, the height of the geocell mattress, and the geocell pocket aspect ratio were among the several characteristics taken into consideration in this experimental work. The incorporation of geocells as reinforcing has the potential to significantly enhance load-carrying capacity and mitigate soil settling in expansive foundation beds. The load settlement behavior of the geocell-reinforcing soil layer is approximately steady for its settlements up to 10–12% of the foundation diameter. Comparing this to the static load of the unreinforced soil at failure, an improvement in load-carrying capacity of over 201% and an 82% decrease in settlement can be obtained. A performance boost of 1.25 at geocell height (H/D) is noteworthy, but when geocell height (H/D) gets closer to 2, or twice the footing diameter, it becomes insignificant.

Al-Gharbawi et al. [9] investigated the experimental and theoretical methods to evaluate the swell pressure and free swell by using the previous studies on the swelling soil, tested new swelling soil with traditional tests, and made new relations between free swell and swelling pressure with the traditional tests. Various macro- and microstructural laboratory studies were used to quantify the increases in stiffness and strength of clay treated with xanthan gum [10]. The first 28 days of curing caused the largest changes in the mechanical properties of the stabilized specimens, while the next 90 days of curing caused just a slight rise in those same qualities. Even after only 7 days of curing in treated clays at lower additive amounts, the engineering characteristics often demonstrated notable increases. According to these readings, xanthan gum may be able to stabilize expansive soils in an efficient and environmentally responsible manner. The findings also show that new cementation products were formed as a consequence of the chemical reactions between xanthan gum and stabilized soil particles. By decreasing the outer surface area of the soil particles, these newly produced cementation products fused the soil particles together and, through particle agglomerations, blocked the empty spaces between the soil particles.

In China, grouted steel pipe micropiles are frequently utilized for in situ development and structural support. In this study, the measurement of excess pore water pressure and radial soil stress during the construction of a jetted steel pipe micropile implanted in marine soft clay (with an enlarged driven shoe) is presented. A common foundation issue, such as erecting low- to medium-rise structures beyond the soft to extremely soft fine soils at vast depths, can be resolved with the use of large-capacity micropiles, which is why their employment is highly sought after nowadays. For this kind of soil, the standard procedure for building lengthy cast-in-field piles of concrete is expensive and time-consuming.

Significant upward movement over expansive soils may be experienced by lightweight reinforced concrete structures, which could result in unfavorable fissures in the structure. Annual repair efforts are necessary for these fissures, and in certain situations, the expense can be substantial. Some of the design options include replacing the soil, using micropiles and stabilizing chemicals, using stiff raft footing, drilled pier footing, separated footings positioned at depths deeper than seasonal variations in moisture content, and more. The selection and application of any of these procedures are dictated by the kind of soil and the structure, environmental factors, estimating surface swell, produced distresses, and cost effectiveness.

The superstructure rises when excavation for underground space is necessary for locations under the water table because of buoyancy issues with the foundation system. An urban area may receive civil complaints due to excessive driving forces and associated noises when a deep footing system is utilized in the presence of a hard layer. Since micropiles operate well even at shallow installation depths, they can be a useful substitute. Higher interfacial characteristics between the micropile and soil are achieved by using pressurized grouting in conjunction with a packer.

Tension and creep tests were used to compare the field effectiveness of micropiles placed via gravitation grouting or pressure grouting utilizing a rubber packer or geotextile packer. In weak and cracked zones, pressure grouting was used to install micropiles. As a result, compared to micropiles implanted using gravitational grouting, those grouted under pressure exhibited stronger and more stable behaviors. Furthermore, compared to the pressure-grouted micropile placed using the geotextile packer, the one installed with the rubber packer performed better.

When it comes to supporting foundations on expanding soils, micropiles are clearly superior to other underpinning techniques. These benefits include being simple to build, having the foundation operate as a reaction block for drilling equipment to be secured, being able to be installed in small locations, and being able to be progressed to a specific effective depth in stiff, expansive soil [11].

The load transfer system can be greatly improved by the presence of this kind of pressure grouting within the micropiles. It enabled the axial load capacity to be increased by fully mobilizing the strength of the nearby soil [12, 13]. The building method utilized to embed the micropile on the soil and the jetting pressure has a significant impact on how well any drilled micro-pile performs. According to the starting point of the jetting process and pressure, drilled micropiles are classified into categories *A* through *D* [14]. The behavior of micro-piles as modeled and tested in small-scale techniques has been researched by numerous researchers. The tested of micro piles for reinforcing model rafts are investigated in the lab for a variety of conditions, such as soil type, pile depth, and inclination angle. The outcomes of the experiment revealed that the micro piles will resist deflection of the soil and expand the zone at failure if the micropile depth is long enough relative to the thickness of the footing's failure surface. However, a field study examining the application of micro piles for methods of ground improvement has been done [15–17].

Micropiles were suggested by Lizzi [17] as a means of controlling landslides. Since that time, a large number of academics have investigated the reinforcing mechanism and design methodology of micropiles [19-21]. In the southern Shaanxi Province, landslide management frequently involves the usage of micropiles. Additionally, the increasing the shear strengths of the landslide, they provide a function comparable to that of retaining walls when strengthening landslides. Because of the structural characteristics of the tiny diameter of the pile and the high density of pile placements, the soil arch structure is created between piles, and many rows of piles cooperate to create a core anti-slip body [22].

The mechanism by which compacted sand-enclosed micropiles regulate the upward motion of lightweight structures over expansive soils was outlined in a simplified mathematical formulation by Nusier & Alawneh [23]. With this formulation, the important factors affecting the effectiveness of micropile reinforcement are identified. Using the obtained formulation, a design technique for micropile reinforcement was presented and shown using a fictitious case.

In a laboratory experiment, Nusier et al. [24] investigated the efficacy of inserting small scale micro-piles surrounded by a high relative density of sand into pre-drilled apertures of greater diameter produced in high swelling soft soil to regulate the ascending process of lightweight constructions. The large soft soil was finally compressed to a height of 20 cm within a steel box measuring 50 cm × 50 cm ×35 cm. To model footings, steel plate of 25 cm × 25 cm ×1 cm was utilized. The steel plate was attached to by the model micropiles' heads. Footings with one, two, four, or no micropiles were built. After that, water was poured over the dense clay that had been used to construct the laboratory box, and it was noted that the compacted clay caused the model footings to rise over time. According to the findings, roughened micropiles had a greater impact on the percentage decrease in swell caused by micropile reinforcement, and both the quantity and diameter of micropiles rose. The largest percentage decrease in swell that could be measured was 87.2% and was attained when four 18 mm diameter roughed micropiles were utilized.

Fattah et al. [25] examined the behavior of micropiles under both monotonic and cyclic stress situations using the OpenSees finite element method. The impact of flaws on the lateral performance of groups of horizontally pressured pipe piles in sand was investigated using this model. There were group series of two, four, and six similarly spaced piles in the geometric layout. The deformation of lateral loads is found to be lessened when steel micropiles are inserted next to the pile of defects in two different instructions. Modeling the defective pile in the first-row results in a larger rise in the group deflection.

In highly flexible clayey soil, Borthakur & Dey [26] looked at the group reactions of cast in-situ jetted micropiles. on a test pit of 2.0 m × 4.0 m × 3.0 m, the micro piles were built on clayey soil with a very soft consistency. Two distinct setups of many groups of micropiles were examined in terms of their load-settlement tendencies. A set of micropile caps had them built enough above the ground, while another set had them resting on the ground. The diameter, length, quantity, and distribution of micropiles within a group were the characteristics examined in this study. We used experimental observations to calculate the group settlements under the safe pressure and the final pressure bearing capability of a micro-pile group. The current study also determined the opposition provided by the micro-pile cap alone, as well as the group efficiency. It is found that as the diameter, length, quantity, and distance of micropiles rise, so does the group's capacity to support a load for the experimental data is used to build a nonlinear equation that calculates a micropile group's maximal pressure bearing capacity.

Kong et al. [27] carried out a comparative study between the maximum stress values measured in situ and the predictions made using the cavity expansion method (CEM). The findings demonstrated that the stress shift in the soil around it during penetration is impacted by the presence of the bigger driving shoe. During micropile penetration, the highest radial stress at its total stress and excess pore water pressure produced are roughly 4-6 σ_{v0}' and 1.5-2.5 σ_{v0}', respectively. Approximately 5-7cu and 4-6cu, respectively, are the highest extra pore water pressure and radial total stress that were observed close to the pile wall during the post-grouting phase. The data from the field tests and the CEM predictions for the pore water pressure during micropile penetrating and post grouting were reasonably in agreement.

Baqir et al.'s [28] study used clay columns treated with 5% fly ash applied to the soil with different relations of L/D of 4 and 6 and with changing curing periods of days to examine the effects of fly ash treatment on the shear strength and bearing capacity of the soil. Treatment times of 14 days and 28 days produced results that were reasonably comparable to each other. Over the course of 14 to 28 days, the incensement ratios for the two (L/D) 4 and 6 is about 5%. Less than 30% less bearing ratio breakdown occurs when comparing L/D 6 to L/D 4. This is a substantial improvement over L/D 4.

Because polymeric materials are readily available and devoid of hazardous, non-toxic, or environmentally harmful ingredients, they are currently being employed in soil stabilization. In order to improve the properties of soft soils, such as strength and compressibility, a white, powdery substance was used as a soil binder. This product has lack of taste, non-toxic and odorless, and has a high capacity to absorb water characteristics as it functions by drawing soil particles together and altering the structure of the soil [29]. It was found that the quality of the soil had significantly improved with the addition, increasing the soil's durability and strength.

Tessema et al. [30] examined the possible application of coffee husk ash for the improvement of physical qualities such as the Atterberg limit, swelling parameters, compaction characteristics, CBR, and UCS of expansive soft soil. Based on the study findings, the soil's flexibility is decreased when coffee husk ash A is added. The addition of 20% coffee husk ash resulted in reductions of the LL and plastic index of 24.5% and 57.4%, respectively. Comparable patterns were noted in the specimen stabilized with 9% gypsum; a 16% decrease in LL and a 64.8% decrease in the plastic index were recorded. With the additive quantity of 15% coffee husk ash and 9% gypsum, it was observed that the LL was reduced by 41.5% for the gypsum-coffee husk ash mixture treatment and a comparable decrease in the plastic index of 81.5%. The lowered PI assisted in lowering the treated soil's potential for swelling because PI is a useful predictor of the actions of soils that swell.

In order to assess different parameters, including the length, diameter, connect radius, and connection skin friction of micropiles in sandy soils with varying relative densities, Moghaddam et al. [31] performed several static strain control loading tests with an acceleration of deflection of 10 mm/min and a lab schedule using a large-scale physical simulation device. Furthermore, a comparison was made between the pressure-bearing capacities of driven and bored micropiles, and the findings showed how each parameter and installation technique affected the micropiles' ability to support loads. The findings demonstrated that, in relation to other factors, the relative density index had a significant influence in determining the micropile's load-bearing capability. The experiments also showed that the driven insertion technique may improve the pressure-bearing capacity up to a maximum of 84% when compared to the bored method and that the diameter parameter has an average contribution to pressure-bearing capacity measurements at different soil densities of about 12% more than duration.

The impact of Enset ash on the physical characteristics of expansive soil, which is employed as a subgrade material in road building projects, was investigated by Neguse et al. [32]. The micro-structural characteristics of both natural and treated soil were chosen based on their strength attributes, and the results of using a scanning electron microscope (SEM) imaging technology make it evident how the natural soil's fabric and shape have changed. The XRD method is used to determine the mineralogical composition of expansive soil. The results indicate that quartz and montmorillonite make up the majority of the expansive soil in the research area, accounting for 50% and 38.5% of the total dried in the air sample, respectively, while kaolinite makes up 11.5%.

Cheng et al. [33] looked at the mini pile design calculation method as well as the micropile length optimization approach. Because rapid modeling allows for the automation of the optimizing process, automated generation of optimizing commands, output, and examination of the optimizing outcomes, and the application of numerical modeling to pile length optimizing, the compact pile length optimizer using the numerical modeling finite difference method improves upon the previous method. It does this by improving the effectiveness of the optimizing of the pile length under the assumption of ensuring precision and achieving the collaboration of precision and effectiveness. Examples from engineering support the viability of this optimization technique.

It was suggested by Ghrairi et al. [34] to enable simulation of the installation of granular columns and their effect on the mechanical characteristics of the soil near the column. The findings of the current analysis demonstrated that the methodology and procedure used in this study were capable of precisely predicting the change in soil brought on by the placement of the coarse soil column. The experimental findings indicate that there is a large increase in the earth's lateral pressure coefficients, or K_0, once the column is inserted. Under various swelling degrees, the average values for the sand and clay layers, respectively, range from 1.30 to 2.05. The pressure from the lateral coefficient for the clay and sand layers was positively impacted by the improvement zone that surrounds the installed granular columns. This zone extends to a maximum distance of around 6 to 10 times the column diameter (Dc).

The main purpose of this study is to reinforce the expansive soil with micro-piles with different depths (1B, 2B, and 3B) and different configuration widths (under footing only, 1B and 2B).

The importance of this study is to reduce the free swelling and swelling pressure of the expansive soil as well as increase the load bearing capacity for these soils using micropiles.

2. Material and Methods

A field south of Baghdad city is where the soil is transported from. Table 1. displays the soil's characteristics, and Figure 1. shows how the distribution of grain sizes is represented. For the purpose of determining the soil qualities, the ASTM specifications were adhered to. The soil is classified as highly expansive soil according to AbdulJawad & Al-Sulaimani [35].

Table 1. Soil properties

Property	Value
Natural water content (w.c%)	5.5
Liquid limit (L.L%)	122
Plastic limit (P.L%)	25
Plasticity index (P.I%)	97
Specific gravity (Gs)	2.68
Gravel (> 4.75 mm) %	0
Sand (0.075 to 4.75 mm) %	15
Silt (0.005 to 0.075 mm) %	33
Clay (less than 0.005 mm) %	52
Max. dry unit weight (kN/m^3)	17.6
Optimum moisture content (%)	16.4
Soil symbols (USCS)*	CL

*Unified Soil Classification System.

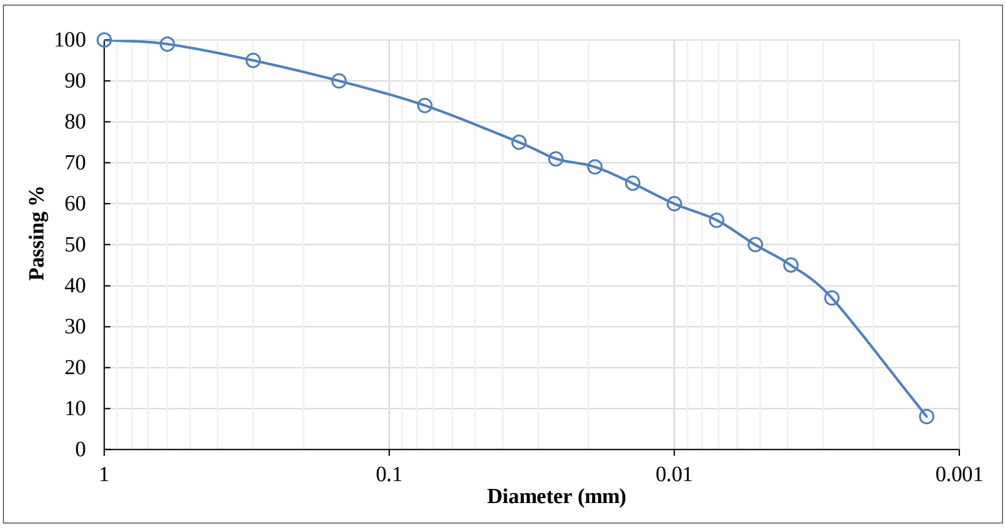


Figure 1. Grain size distribution

The micro-piles used as soil reinforcement, and structural supports are generally less than 300 mm in diameter [14]. In this study, steel micro piles 2 mm in diameter were used with three depths of 60 mm, 120 mm, and 180 mm which represents 1B, 2B, and 3B, respectively (i.e.: B width of the foundation), Figure 2. represents the micro-piler used.

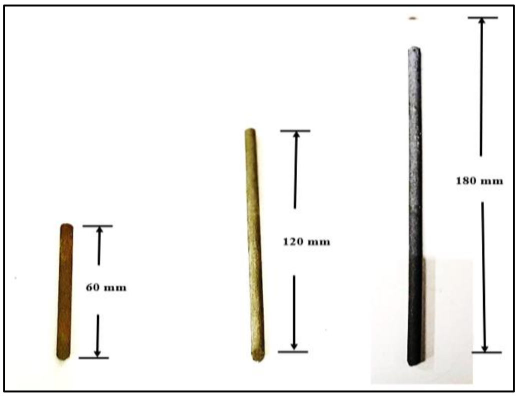


Figure 2. Micropiles used

There are two sections the first is to study the effect of the inserting micropiles on the free swelling. The model is prepared for soil with or without micropiles and just saturated with water for 24 hours without any load to record the heave of the soil and the pressure needed to return to the beginning point. The second section studies the pressure bearing capacity of the soil reinforced with micropiles. The model is prepared typical to the first section but the soil is loaded till failure. Figure 3. illustrates the testing program. The micropiles model contains several parts as shown in Figure 4. The sketch of the models of the testing program is shown in Figures 5 to 7. which illustrate the sketch of models for depths 60, 120, and 180 mm, respectively. The container used in the study has dimensions of 500×500×300 mm. To test the soil's ability to support loads, a foundation with dimensions 60×60×10 mm was utilized to force the underlying soil.

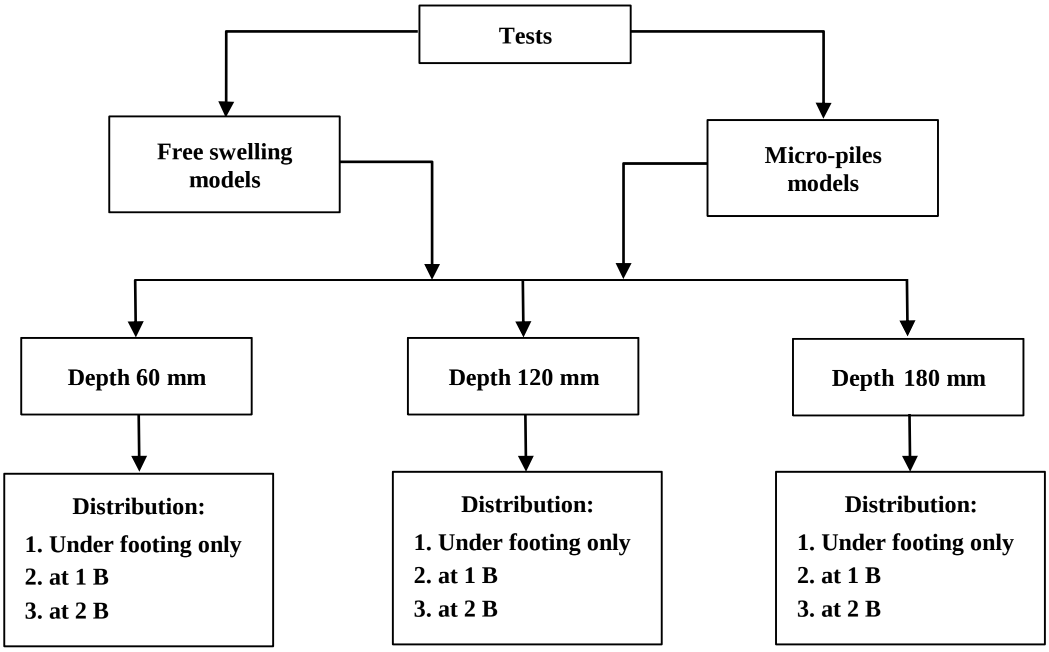


Figure 3. Testing program

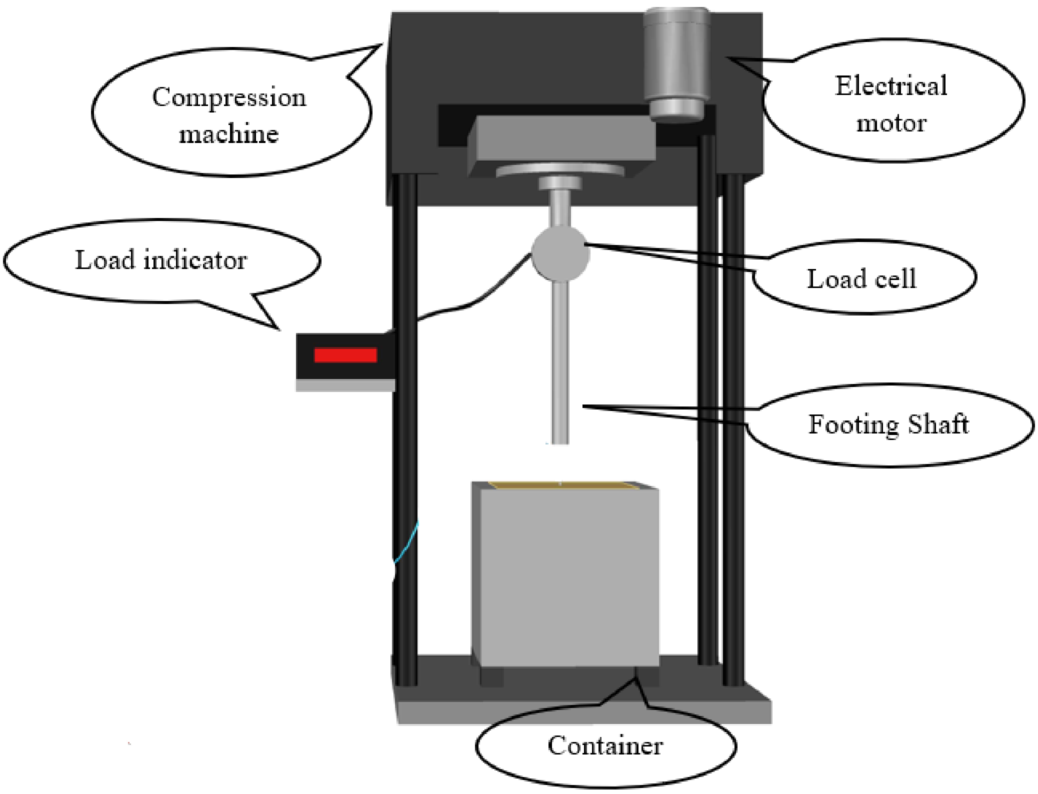
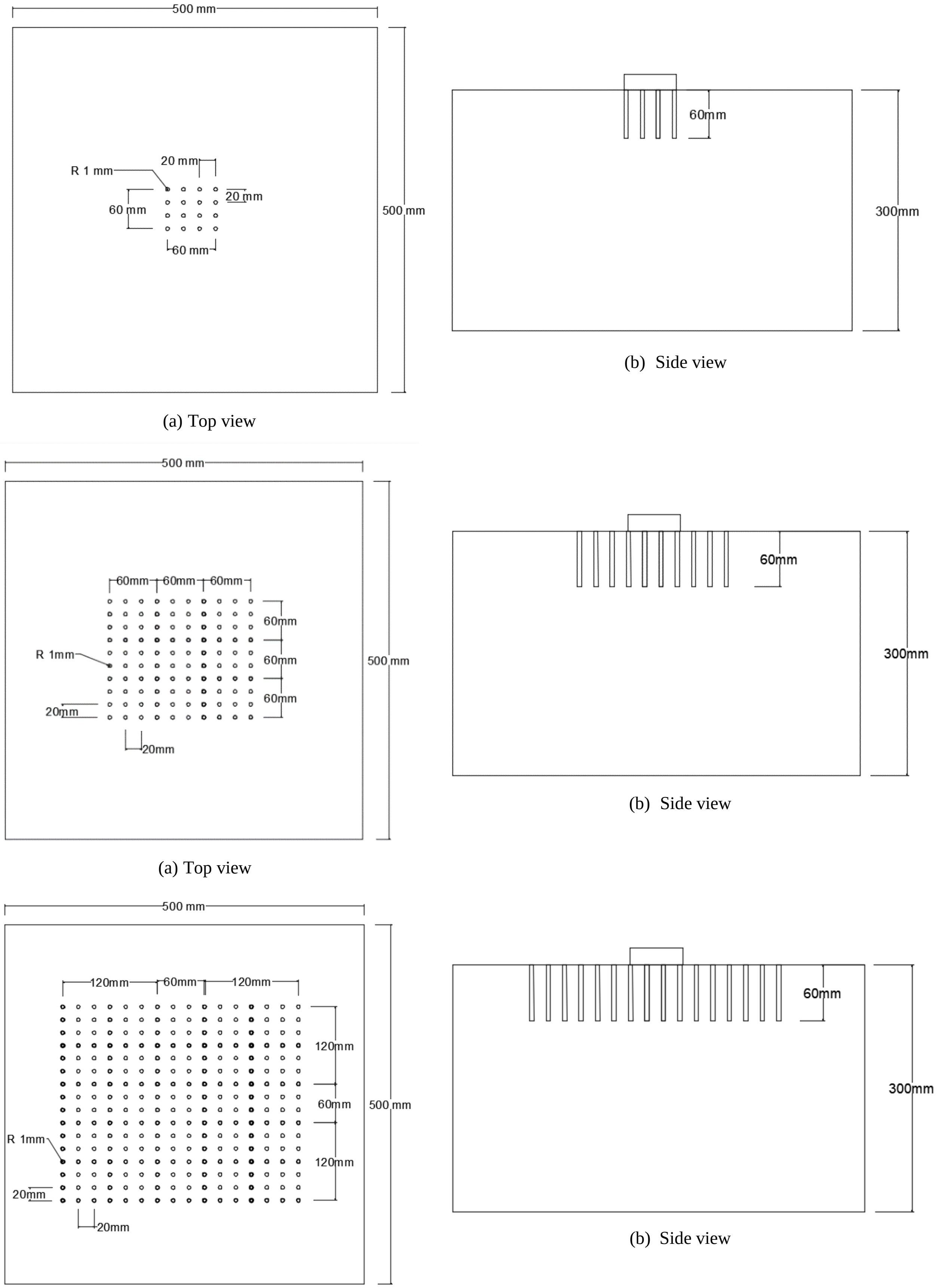


Figure 4. Experimental setup



(a) Top view (b) Side view

(a) Top view (b) Side view

(a) Top view (b) Side view

Figure 5. Sketch for the models of depth 60 mm for configuration where micropiles are installed under the footing to depths 1B and 2B

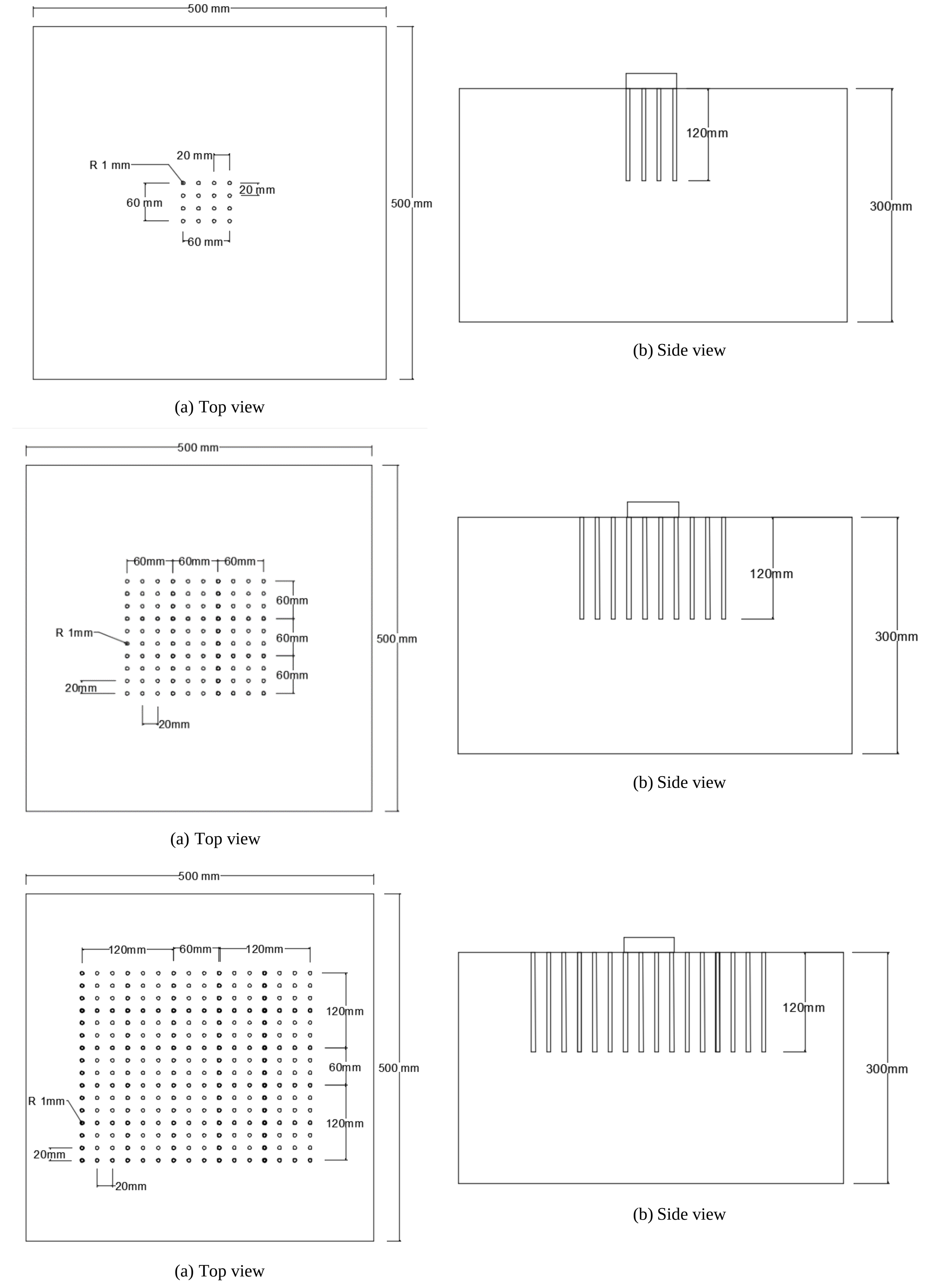
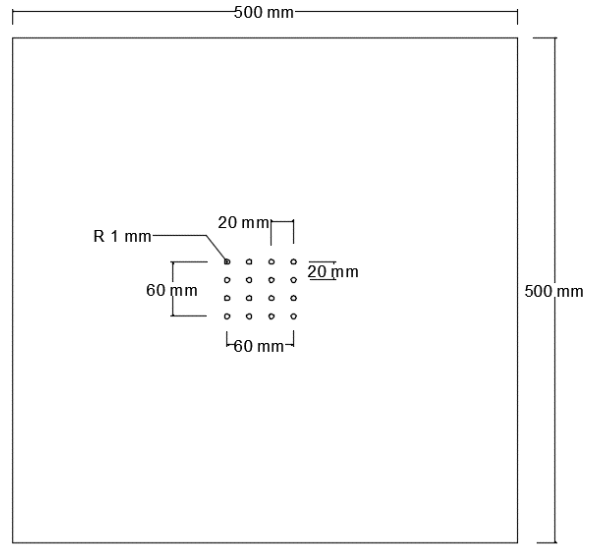
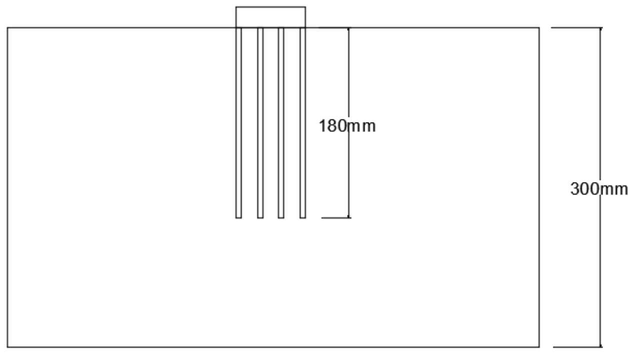


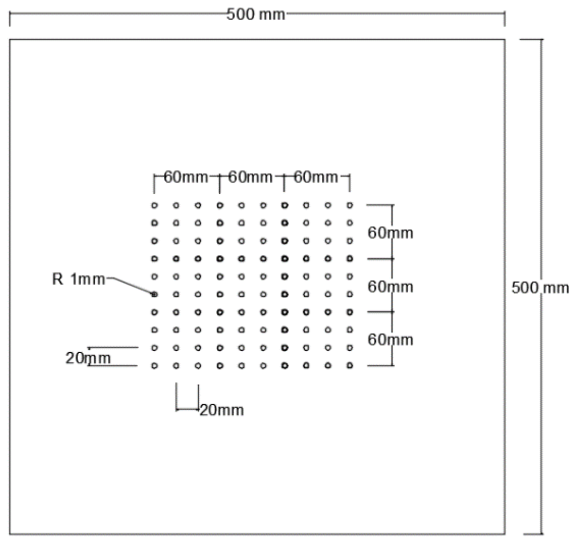
Figure 6. Sketch for the models of depth 120 mm for configuration where micropiles are installed under the footing to depths 1B and 2B



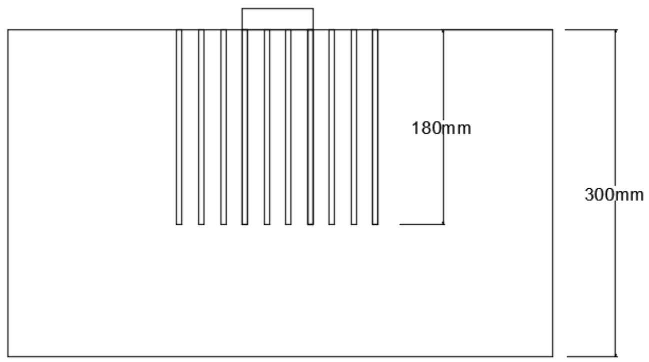
(a) Top view



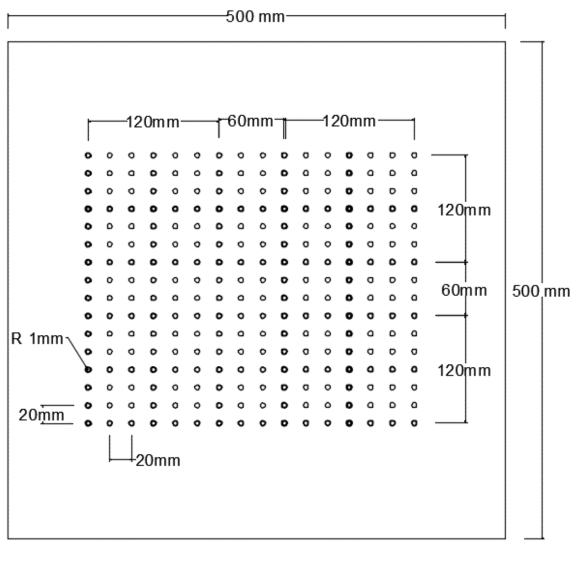
(b) Side view



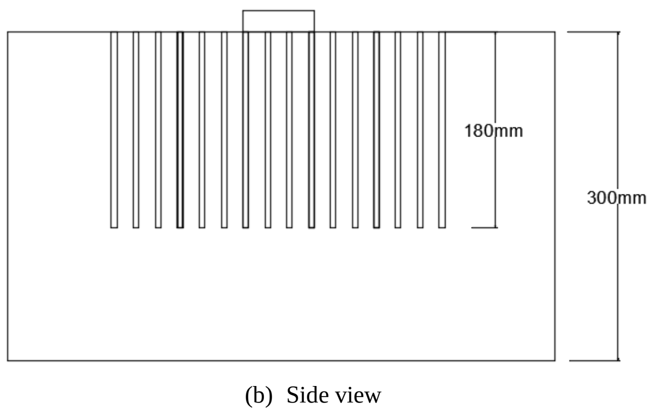
(a) Top view



(b) Side view



(a) Top view

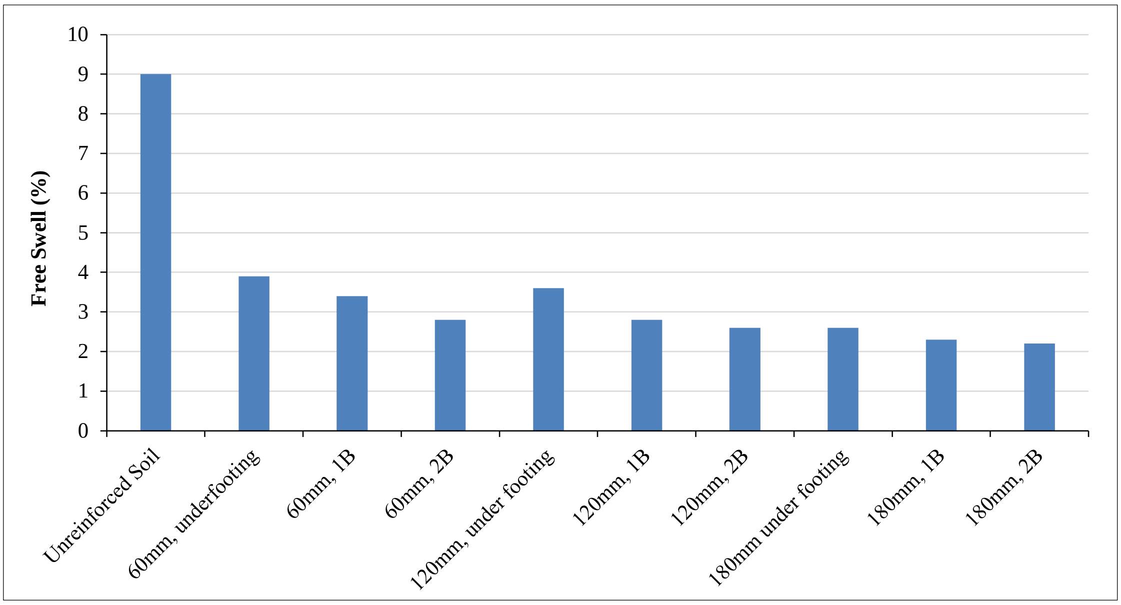


(b) Side view

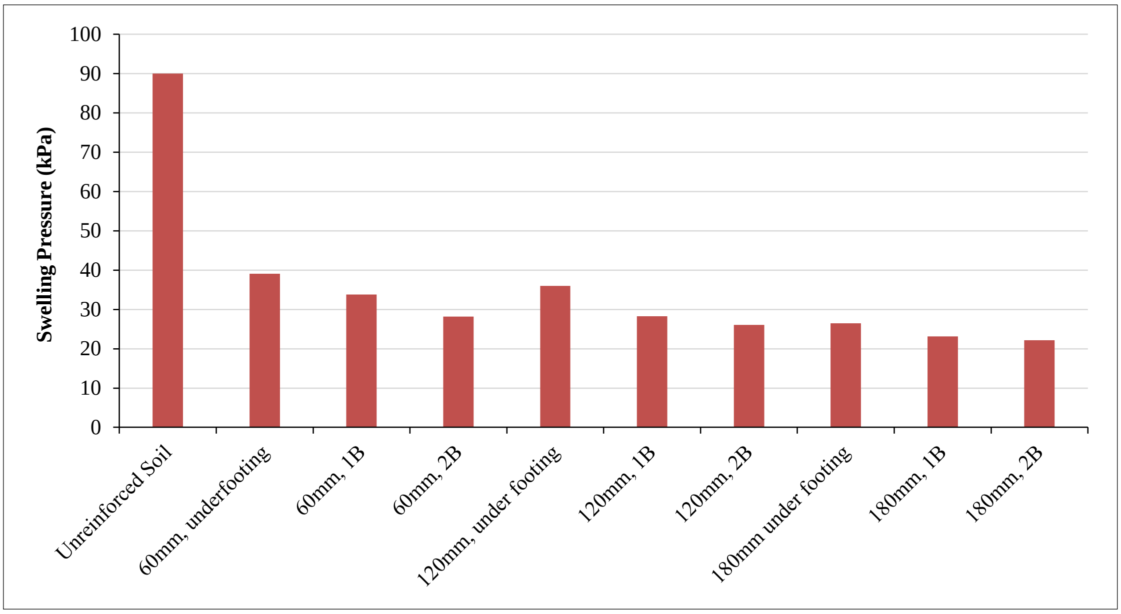
Figure 7. Sketch for the models of depth 180 mm for configuration where micropiles are installed under the footing to depths 1B and 2B

3. Results and Discussion

The first part of the models is tested by preparing the model with unreinforced soil or soil reinforced with micropiles prepared at the natural water content and then saturated with water. The models were kept for 24 hours to trace the heaving in the soil. The free swelling and swell pressure were recorded at the end of 24 hours. Figure (8a) presents the histogram for the free swell of unreinforced and reinforced soil models whole Figure (8b) presents the histogram for the swelling pressure of unreinforced and reinforced soil models.



a). Free swell histogram



b). Swelling pressure

Figure 8. Free swelling and swelling pressure histograms.

Several models are tested to look into the pressure carrying capacity of the spread footing on expansive soil reinforced with different depths and configurations of micro-piles. In Figure 9, the pressure-settlement relationship for footing on untreated soil is depicted. The pressure-settlement relationship for the footing on soil reinforced with 1B deep micro-piles which represents 60 mm depth is illustrated in Figure 10. The pressure-settlement relationship for the footing on soil reinforced with 2B and 3B deep micro-piles which represent 120- and 180-mm depths is illustrated in Figures 11 and 12. It is believed that the failure pressure that causes a settlement of 10% of the foundation width is considered the failure load. Table 2 shows an outline of the stress at failure (i.e., at a 10% settlement ratio).

The pressure carrying capacity ratio (BCR) is defined as shown in Equation 1 and the summary of the bearing capacity ratio is illustrated in Table 3.

$$BCR = \frac{Bearing\ capacity\ of\ footing\ on\ treated\ soil}{bearing\ capacity\ of\ footing\ on\ untreated\ soil} \tag{1}$$

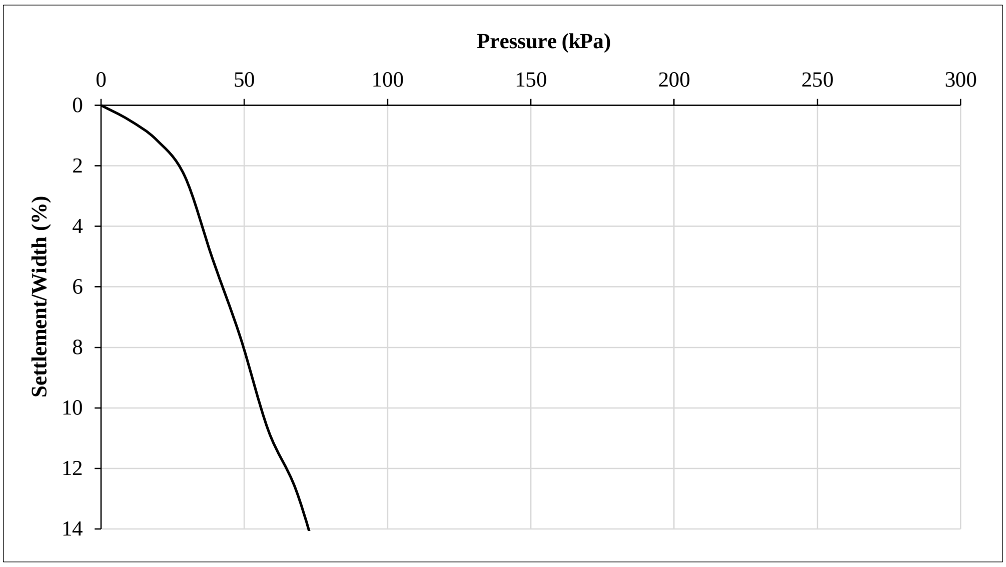


Figure 9. Load-settlement relationship for untreated soil

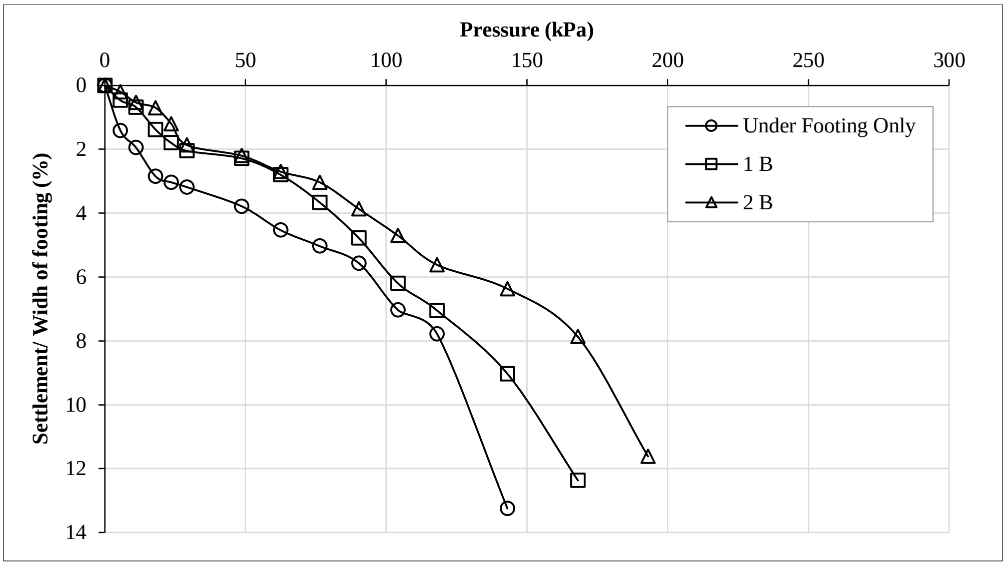


Figure 10. Load-settlement relationship for a footing on soil reinforced with 1B deep micro-piles

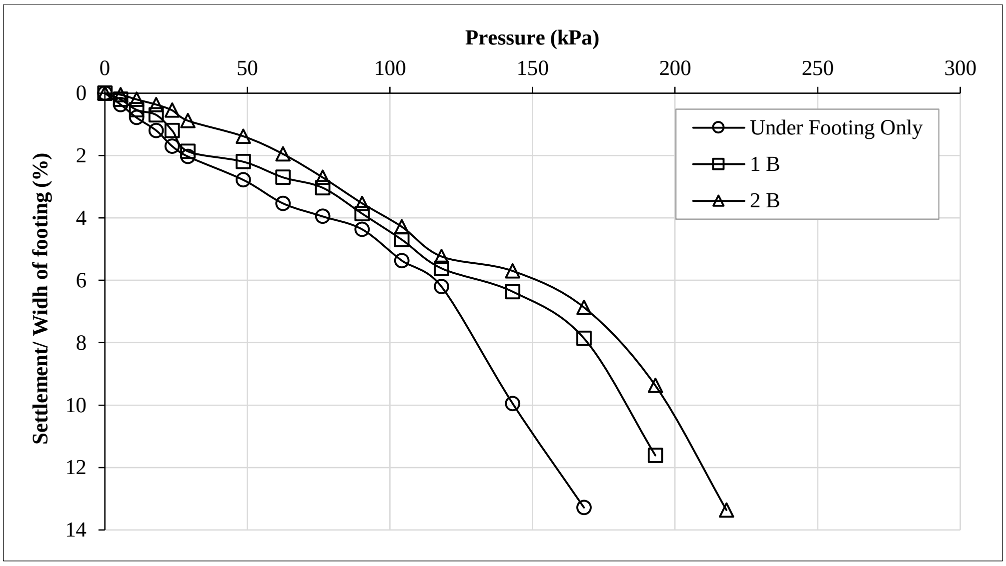


Figure 11. Load-settlement relationship for a footing on soil reinforced with 2B deep micro-piles

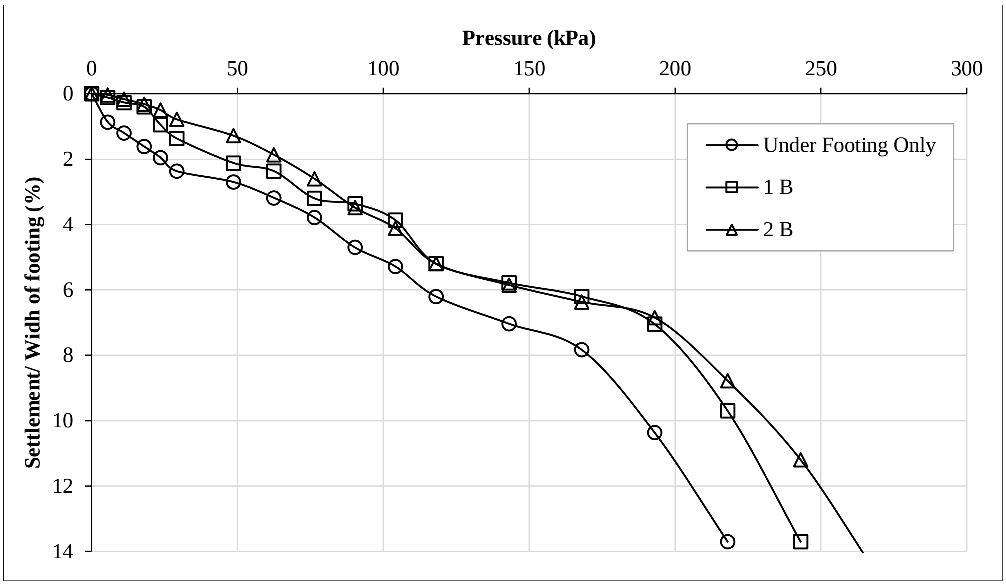


Figure 12. Load-settlement relationship for a footing on soil reinforced with 3B deep micro-piles

Table 2. Applied pressure at failure

Depth of micropile	Width of micropile	Pressure at failure (kPa)
Untreated Soil		56.5
1B	Under footing only	130.6
1B	1B	150
1B	2B	181.2
2B	Under footing only	143.1
2B	1B	179.8
2B	2B	195.4
3B	Under footing only	192.2
3B	1B	219.7
3B	2B	228.5

Table 3. Bearing capacity ratio

Depth of micropile	Width of micropile	BCR
1B	Under footing only	2.31
1B	1B	2.66
1B	2B	3.2
2B	Under footing only	2.53
2B	1B	3.18
2B	2B	3.45
3B	Under footing only	3.4
3B	1B	3.89
3B	2B	4.04

From the results, there is a clear increasing in the soil shear strength and bearing capacity of the footing as compared with untreated soil. The effect of the configuration of micropiles becomes steady when using 2B deep micropiles and there is a small increase in bearing capacity for 3B deep micropiles as compared with micropiles with a depth of 2B.

To assess the performance of the geotextile and micropile in preventing the in upward direction of structures placed on swelling soil [36]. For the purpose of this investigation, the swelling clay was compressed to a depth of 20 cm in a steel box measuring 50 cm × 50 cm × 50 cm, and two different techniques to prevent soil heaving were used to examine the results. Four 16 and 20 mm diameter micropiles were first placed in the ground with as well as without obstructions to friction. The micro piles were secured with a nut and bolt method to the corners of a foundation that measured 15 cm ×15 cm ×0.5 cm. Additionally, single and double layers of geotextile were used to support the footing at vertical intervals of 0.1 and 0.3 B. Following the saturation of the soil with water, the rising motion of the model footings, or swelling was watched over a period of time. According to test results, micropiles with frictional resistance had a maximum heave reduction of 79% for a 20 mm diameter.

In order to regulate the upward movement of lightweight buildings sitting atop expansive soils, Ali & Ahmed [37] attempted to investigate the efficacy of employing micropiles as a strategy. To do this, swelling clay was compacted to a height of 20 cm in a steel box measuring 50 cm × 50 cm × 50 cm. Small-scale steel model micropiles with diameters of 12, 16, and 20 mm were then placed in holes that had been predrilled with a 25 mm diameter, both with and without sand surrounding them. The steel plate, which serves as a model footing, was 25 cm × 25 cm × 1 cm. The heads of the micro-piles were connected to the plate with a system of nuts and bolts. After that, water was added to the boxes, and the model footings' upward movement—known as swelling—was watched over time. The findings demonstrated that for micropiles encircled simply filling a predrilled hole with sand with a 25 mm diameter, the percentage decrease in swell caused by micropile reinforcement was higher. Using four micro piles with a diameter of 20 mm and encircled by sand resulted in the greatest recorded reduction in the heave of 94%. The reduction in heave for a single micropile varies between 10% (for 12 mm diameter) and 20% (for 20 mm diameter), according to research on the impact on heave reduction of micropile diameter.

The behavior of expansive soil reduces the swelling as a percentage (0.5, 1, and 2%) of the weight of dry soil. made by Hussein & Ali [38]. The findings demonstrated that a rise in the percentage of (PPF) resulted in a reduction in edema and an increase in unconfined compression strength. The findings of the PPF's soaking and drying phases demonstrated that, with repeated cycles, the influence of PPF continues to reduce swelling, and that PPF's 2% generates a lower ratio of swell to shrink, achieving an improvement factor of swell and shrink that is higher than 57%. The impact of polypropylene reinforcing fibers on the potential for swelling and shear resistance of soft soil is examined in the study by Yacine et al. [39]. The first step in the experimental protocol used in this study is to evaluate the soil samples' mechanical, mineralogical, and physical properties without the use of reinforcement. After that, the swell potential of these samples is evaluated using the swell pressure, swell rate, and swelling index. There is a noticeable decrease in free swelling following the reinforcement with different concentrations of polypropylene fiber (2 to 6% of the dry soil's weight). In this instance, 4% is the ideal reinforcing rate, which resulted in a 90.7% reduction in heaving.

Al-Gharbawi et al. [40] investigated the behavior of expansive soil stabilized with lime, cement, and silica fume by mixing and grouting. The results showed that the quick lime gave more improvement than other additives. The swell pressure and free swelling were reduced with increasing the percentage of grouting materials and also the free swelling was reduced with an increase in the percentage of grouting additives. The bearing capacity increases rapidly with grouting the expansive soil.

4. Conclusion

The aim of using micropiles is to increase the bearing capacity of the soil and reduce the swelling in these soils. From the all-test results can be concluded that the soil reinforced with micropiles reduced the free swelling and swell pressure to more than 70% as contrasted with unreinforced soil. The treated soil with 1B deep micro piles can increase the bearing carrying capacity of soil between 35 – 55% when the configuration of the with varied from under footing only to under footing and 2B width compared to unreinforced expansive soil. The treated soil with 2B deep micro piles can increase the bearing carrying capacity of soil between 44 – 61% when the configuration of the with varied from under footing only to under footing and 2B width compared to unreinforced expansive soil. The treated soil with 3B deep micro piles can increase the bearing carrying capacity of soil between 50 – 61% when the configuration of the with varied from under footing only to under footing and 2B width as compared with untreated soil. The increasing depth of the micropiles from 2B to 3B can increase the bearing capacity by just 6% therefore the increasing depth of micropiles is not valid. Also, the increase in width of the configuration of the micropiles from 1B to 2B can increase the bearing capacity by just 4% therefore the increase in width more than 1B is not valid.

5. Declarations

5.1. Author Contributions

Conceptualization, M.Y.F.; methodology, A.S.A.-G. and M.Y.F.; validation, A.S.A.-G. and M.Y.F.; formal analysis, M.Y.F.; investigation, A.M.N.; resources, A.M.N.; data curation, A.M.N.; writing—original draft preparation, A.M.N.; writing—review and editing, A.S.A.-G. and M.Y.F.; visualization, A.S.A.-G.; supervision, M.Y.F.; project administration, A.S.A.-G.; funding acquisition, A.M.N. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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