

Swell Mitigation in Expansive Soils Using Micro Piles, Geotextiles, and Bio-Enzymes: A Performance Study

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ABSTRACT

Expansive soils pose persistent challenges to geotechnical infrastructure due to their significant volume changes under varying moisture contents. Conventional stabilization methods often address only specific aspects of the heave mechanism, resulting in limited long-term performance. This study evaluates the effectiveness of three distinct ground improvement techniques—micro piles, geotextiles, and bio-enzymes—in mitigating heave in expansive soils. Laboratory swell index tests were performed on expansive clay under multiple conditions: varying micro pile diameters with and without frictional resistance, different numbers of geotextile layers placed at selected depths, and multiple dosages of bio-enzyme additives. The corresponding changes in swell characteristics were monitored and systematically recorded. The results provide a comparative understanding of the influence of each method on swelling reduction and offer insights into selecting appropriate heave-control strategies for civil engineering applications on expansive soils.

KEYWORDS: Expansive soils, Swell mitigation, Soil stabilization, Micropiles, Geotextiles, Bio-enzymes, Load-bearing capacity, Differential settlement

1. INTRODUCTION

Expansive soils present a persistent challenge in geotechnical engineering due to their pronounced volume changes under varying moisture conditions. These soils, typically containing high percentages of active clay minerals, tend to swell when wet and shrink upon drying, leading to significant ground movement. Such behaviour can cause cracking in pavements, uneven settlement of foundations, and long-term damage to infrastructure. The problem is particularly critical in regions experiencing alternating wet and dry climatic cycles, where repeated expansion and contraction adversely affect the stability and serviceability of engineering structures.

Conventional techniques adopted to address swelling soils include chemical stabilization using lime or cement, soil replacement, and moisture control methods. Although these approaches are widely used, they often involve high material costs, environmental concerns due to carbon emissions, and limitations in long-term effectiveness. In recent years, attention has shifted toward more sustainable and innovative ground improvement methods that not only enhance soil performance but also reduce environmental impact.

Among emerging solutions, the use of Micropiles, geotextiles, and bio-enzymes has gained considerable interest. Micropiles function as deep foundation elements that transfer structural loads to more stable soil layers, thereby minimizing the influence of active expansive zones. Geotextiles, as reinforcement materials, improve the tensile strength of soil and help in distributing stresses more uniformly, reducing deformation and settlement. Bio-enzymes, a relatively newer approach, act at the microstructural level by modifying soil-water interactions, leading to reduced plasticity and swelling potential.

While each of these techniques has demonstrated effectiveness individually, their combined application offers a promising approach for enhanced performance. The integration of structural support, mechanical reinforcement, and biochemical treatment may provide a more comprehensive solution to mitigate swelling-related issues.

This study focuses on evaluating the effectiveness of these three techniques in controlling swell behavior and improving the engineering properties of expansive soils. Laboratory experiments and performance analyses are carried out to assess parameters such as strength, swelling characteristics, and load response. The outcomes of this research aim to support the development of efficient, durable, and environmentally responsible ground improvement strategies.

2. LITERATURE REVIEW

- Jean-Louis Briaud et al. (2001) proposed a method to evaluate vertical ground surface movements caused by shrink–swell behavior in soils due to variations in moisture content. Their study demonstrated that the relationship between water content and volumetric strain can be approximated as linear, and the slope of this relationship represents the shrink–swell modulus.
- Thomas M. Petry and Dallas N. Little (2002) presented a comprehensive review of the stabilization of expansive soils, summarizing developments over approximately five decades. Their work highlights various techniques used to control volume change behavior and emphasizes the effectiveness of calcium-based stabilizers. The study concludes that such stabilizers have a well-established record in enhancing soil strength while significantly reducing swelling potential.
- Prakash Chand et al. (2013) conducted an investigation at CBRI focusing on controlling heave in expansive soils through reinforcement techniques. The study demonstrated that incorporating a pipe-type reinforcing element beneath footings, along with a surrounding sand layer, significantly minimizes heave and settlement under conditions of wetting and drying. This approach was found to be effective in improving the stability of foundations for light structures built on expansive soils. However, introducing perforations in the reinforcing pipe to increase surface roughness did not provide any notable improvement in performance.
- Lekha B. M (2013) investigated the use of non-conventional stabilizing agents for black cotton (BC) soil, focusing on bio-enzyme treatment. The soil samples were treated with a commercially available bio-enzyme and cured over different durations, including 0, 7, and 28 days. Post-treatment, various engineering properties of the soil were evaluated to assess improvement. In addition, mineralogical and chemical analyses were carried out to better understand the underlying stabilization mechanism. The study concluded that bio-enzyme treatment can effectively modify the properties of expansive soils, making them more suitable for applications such as pavement construction.

OBJECTIVES

This study focuses on mitigating heave in expansive soils using Micropiles, geotextiles, and bio-enzymes treatment. The specific objectives are outlined as follows:

- To evaluate the performance and effectiveness of Micropiles with varying diameters installed beneath footings in resisting uplift forces generated by soil swelling.
- To investigate the influence of geotextile reinforcement with multiple layers and optimized vertical spacing on reducing the swelling behaviour of expansive soils.
- To assess the effectiveness of bio-enzyme treatment in modifying the swelling characteristics of expansive soils.
- To compare the extent of heave reduction achieved using Micropiles, geotextiles, and bio-enzyme stabilization techniques.

3. MATERIALS AND METHODOLOGY

In this various laboratory tests are performed to obtain the basic properties of soil. And this section deals with the same. frictional material (sand) and different experimental methods of controlling heave for expansive soil. The specifications of various materials used for the experimental methods are described in this section.

3.1 Materials:

A. Black Cotton Soil

The soil considered in this study is black cotton soil, known for its highly expansive nature and tendency to undergo significant swelling upon water ingress. Such soils are commonly found in semi-arid regions and pose challenges for foundation stability. In the present investigation, the soil sample was procured from Kundwada Village in Davangere, Karnataka.

The sample was obtained using a disturbed sampling technique, collected at a depth of approximately 1.5 m below the ground level. Care was taken during collection and transportation to ensure that the sample remained free from contaminants such as organic waste, plastics, or other foreign materials. After collection, the soil was transported to the laboratory for further analysis.

B. Sand

In our case of study or test sand was as used as a frictional resistance material to provide the frictional resistance. And it was collected from the Davangere District, Karnataka State.

C. Micro Piles

The mild steel bars are used as micro-piles with and without frictional resistance, which acts as reinforcing material into the soil for reducing swelling of expansive soil with following specifications

Table 1.1 Specifications of micro-piles

Micro-pile diameter	Number of micro-piles	Length of piles
16 mm	04	150 mm
20 mm	04	150mm

D. Model footing, steel box and dial gauge

A footing (square) of dimensions 150mm*150mm*5mm and box dimensions being 500mm*500mm*500mm were used for conducting the experiment. And are made up of mild steel. In addition, dial gauge of accuracy 0.01mm was used to record the amount of heave.

E. Geo-textiles

Geo-textile layers are used as reinforcing material into the soil, which is made from polypropylene fiber of woven multifilament geo-textile with following properties.

Table 1.2 Properties of Geo-textiles

Property	GWF (26-136)	UNIT
Unit area mass	136	GSM
Mechanical Properties		
Bending Strength(tensile)	26	KN/m
Elongation % age at		%
Specific Tensile Strength	25	
Tearing Strength	300	N
Puncture Strength	250	N
Hydraulic Properties		
Opening Size (apparent)	75	microns
Flow rate	10	L/m ² /s
Packaging		
Width of roll	3.5-5	M
Length of roll	100	M

F. Bio-enzyme

In the present experimental study Bio-enzyme named as terrazyme was used which is available commercially. And it is used in diluted form with water. Basically, it is available in the form of concentrated liquid. It is to be well diluted with water for a specified proportion before mixing with the soil. The Physical or Chemical properties for this product are mentioned in Table below.

Table 1.3 Properties of Bio-enzyme

Physical or Chemical Characteristics	
Boiling Point	211°F
G _s Specific gravity	1.04
Rate of evaporation	Similar to water
Water solubility	Complete
Color / appearance	Brown liquid
Odor	Non-obnoxious

3.2 Geotechnical engineering properties of expansive soil

As per Indian standard codes such as IS 2720 (part 3, 4, 5, 6, 7 & 40) the basic properties of soil sample are investigated by carrying out the suitable laboratory tests and are tabulated as shown below.

Table 1.4 Basic properties of soil

Nos.	Properties	Specification range
1	G _s – Specific gravity	2.52
2	% Distribution based on grain size Clay Silt	68 32
3	Consistency limits (%) W _L - Liquid limit W _p - Plastic limit W _s - Shrinkage limit I _p - Plasticity index	84.50 33 9.71(Critical) 51.49
4	Soil classification as per IS	Highly compressible CH
5	Swelling parameters Free swell index (%) Swell potential	100 Very high
6	Compaction parameters MDD Max. dry density(g/cc) OMC Opt. water content (%)	1.29 28
7	K-Hydraulic conductivity (m/sec)	1 x 10 ⁻⁶

Table 1.5 Basic properties of frictional material (Sand)

SL. No	Property	Specification range
1	G _s –Specific gravity	2.68
2	D ₁₀ -Grain size (mm) D ₃₀ -Grain size (mm) D ₆₀ -Grain size (mm)	0.38 0.59 0.85
3	IS classification	SP (Poorly Graded sand)
4	Coefficient of uniformity (C _u)	2.23

5	Curvature coefficient (C_c)	1.06
6	Internal frictional angle	
	Loosely arranged	37°
	Densely arranged	34°

3.3 Preparation of soil for testing

Firstly 4.75mm IS sieve is taken and the soil which was brought was prepared for sieving by pulverizing once it air dried using hammer.

A. Methods for heave control

For unreinforced soil, the study was carried for heave determination and to mitigate the heave obtained three different methods was utilized they are as follows.

B. Micro Pile Technique

The collected soil was prepared and its optimum moisture content (OMC) was determined. The soil was then mixed with the corresponding water content and placed in a steel box, whose inner surfaces were lubricated to minimize sidewall friction. Compaction was carried out in layers of approximately 50 mm thickness using a standard Proctor hammer, applying 136 blows per layer with a drop height of 100 mm to achieve the desired density. During preparation, steel pipes of 22 mm diameter were inserted vertically into the soil mass to create cavities. After compaction, these pipes were carefully removed, leaving holes for micropile installation. Steel rods of 16 mm and 20 mm diameter were used as micropiles in the study. The micropiles were inserted into the preformed holes, and the annular space was filled with sand to develop frictional resistance. A footing plate was then placed over the compacted soil and connected to the micropiles using nuts and bolts. Similar procedures were followed for both micropile diameters. Additionally, frictionless conditions were simulated by directly inserting micropiles of actual diameter into the soil without providing sand in the surrounding space.



Fig 1.1 Micro-piles of 16 mm and 20 mm diameters with nut and bolt system

The experimental setup was arranged as per the test configuration. After preparing the soil sample and installing the micropiles, a dial gauge was positioned on the footing to measure heave. Water was then introduced into the soil in controlled quantities to induce swelling. Heave readings were recorded at regular intervals: every 5 minutes during the first hour, every 30 minutes for the next three hours, and subsequently at 24-hour intervals until the maximum swell was reached.

C. Geotextile Reinforcement

The optimum placement depth was determined prior to using geotextiles for heave control. The soil sample was prepared, placed, and compacted in the steel box following the same procedure adopted in the micropile tests. Geotextile layers were then introduced at predetermined depths below the footing. For a single layer, the geotextile was placed at a depth of 15 mm (approximately 0.1B, where B is the footing width). For double-layer reinforcement, the layers were positioned at depths of 15 mm and 45 mm (i.e., 0.1B and 0.3B, respectively). The monitoring procedure and recording of heave readings were carried out in the same manner as described for the micropile tests.

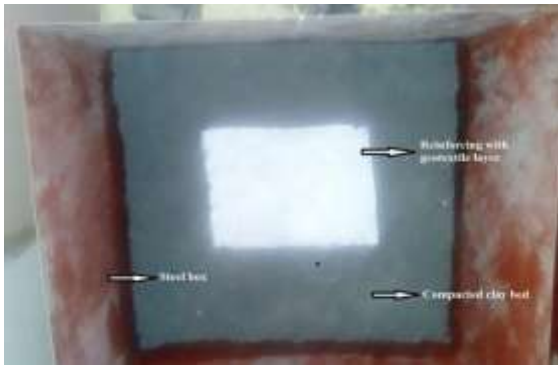


Fig 1.2 Soil sample reinforced with geo-textile at different layers

D. Use of Bio- Enzyme

Bio-Enzyme was blended with calculated amount of water in different dosages such as 100 and 200 ml respectively for 1m³ soil. The compaction and monitoring of results remains same as above two methods. Dosages required are calculated as follows.

Dosage: 200 ml of enzyme for 1.0 m³ of soil Density = 1.29g/cc

Volume of soil for 200ml dosage= 1m³= 1 x 10⁶ cc

Therefore weight of soil required for 200ml of dosage = $1.29 \times 1.0 \times 1000 = 1290$ kg for 1 kg of soil, dosage required = 0.155 ml.

Similarly, dosage required for 100 ml = 0.077 ml.

Time of saturation and quantity of water required

Water is allowed into the compacted thickness of clay bed, the required time and water quantity is determined to saturate the soil mass as follows.

Calculated time required = 9 days 16 hours 18 minutes. Calculated quantity of water required = 8 liters 696 ml.

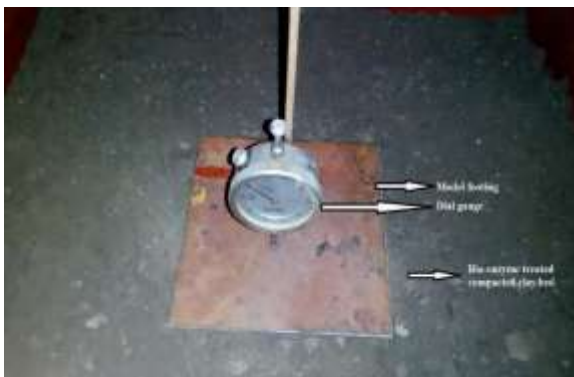


Fig 1.3 Experimental set for Bio-enzyme mixed with soil

4. RESULTS & DISCUSSIONS

The experimental work conducted by using Bio-enzyme, geo-textile reinforcement and micro-pile techniques to control heaving of expansive soil and their results are put forth as follows.

A. Results from micro-pile technique

Results of maximum heave reduction drawn from micro-piles as reinforcement into the soil with different diameter are as follows.

Table 1.6 Results obtained in case of soil reinforced with micro-piles.

Diameter of micro- pile	Micro- piles quantity	Length of piles	Heave value of unreinforced soil	Max. Heave reduction	
				Without frictional resistance	With frictional resistance
16 mm	4	150 mm	31.29 mm	18.88 mm	10.33 mm
20 mm	4	150 mm		15.83 mm	6.73 mm

B. Results from geo-textile reinforcement

Table 1.7 Results obtained from use of geo-textile as reinforcement

Nos. of geo- textile layers	Reinforcement placing depth	Heave value of unreinforced soil	Maximum heave reduction
One	15mm or 0.1B	31.29 mm	25.26 mm
Two	0.1B(15mm) and 0.3B (45mm)		8.43 mm

C. Results from soil treated with Bio-enzyme

Table 1.8 Results obtained by use of Bio-enzyme

Enzyme dosage for 1kg of soil	Heave value without Bio-enzyme	Maximum heave reduction
0.077 ml	31.29 mm	25.03 mm
0.155 ml		18.25 mm

D. Deliberations

The graphs of heave (mm) along Y-axis and time (min) along X-axis are plotted on a semi log graph in log scale. Then the percentage of heave reduction is determined by considering with and without treated values using following percentage expression

$$RH(\%) = ((H_U - H_r) / H_U) * 100$$

H_U = Heave value in case of untreated soil

H_r = Heave value of treated soil

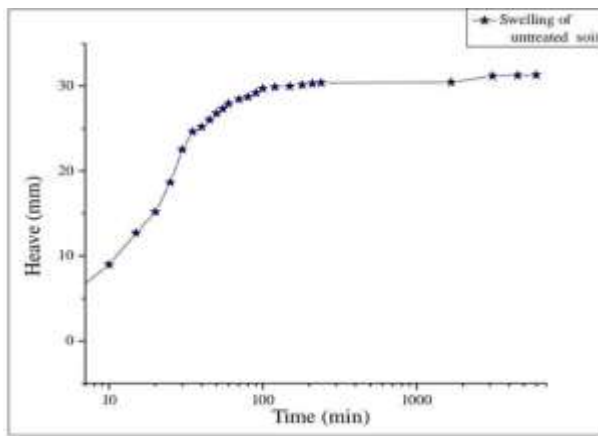
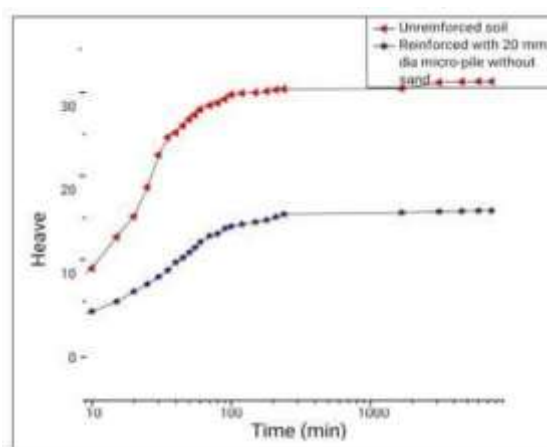
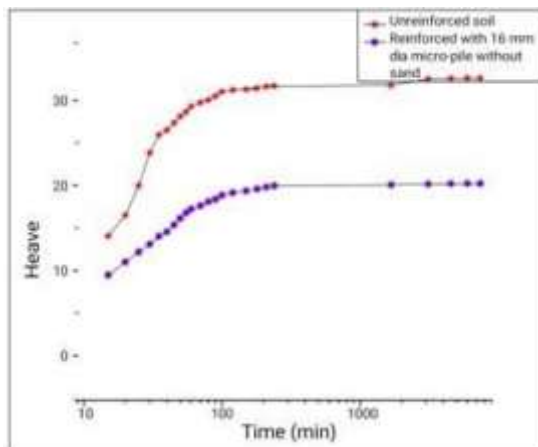
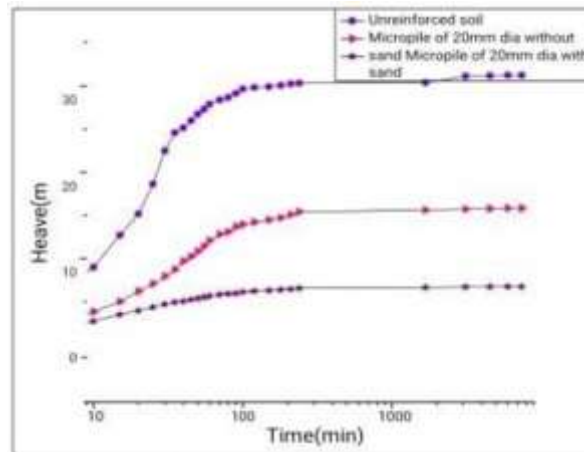
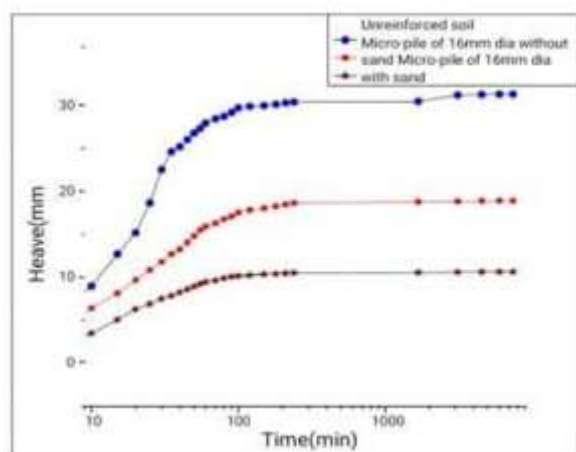


Fig 1.4 Graph representing heave values of untreated soil

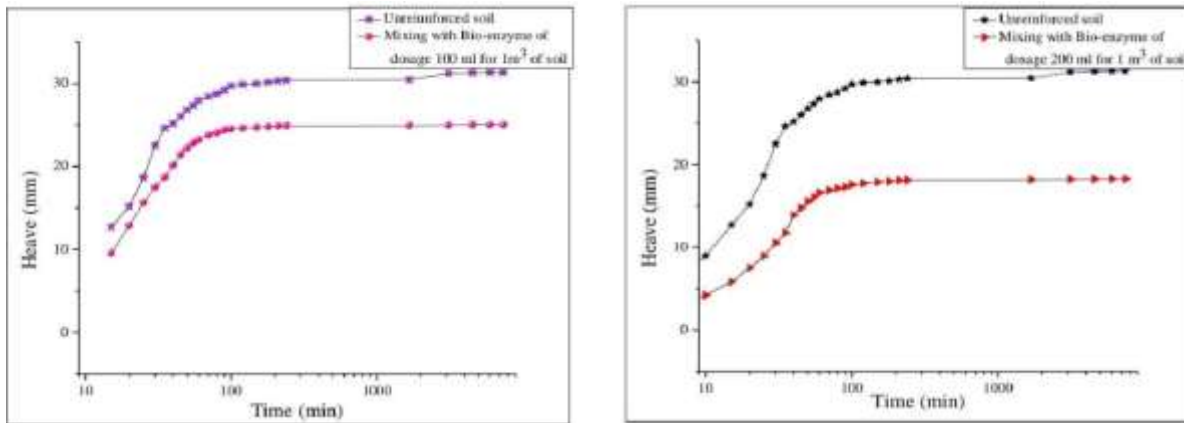
Above plotted graph represents the heave in mm against logarithmic time in min without reinforcement for expansive clay. Gradual increase in heave was observed with time and after attained equilibrium. Max. heave recorded was to be 31.28 mm.



Above plotted graphs represent the results for assessing swelling of expansive clay using 4 micro-piles without frictional resistance. The swell percentage reduction for soil reinforced with 16mm and 20mm micro-piles were 39.66% and 49.41% respectively.



Above graphs represent the results of assessing the swelling of expansive soils reinforced with four micro-piles with frictional resistance. And reduction percentage of swelling for 16mm and 20mm micro-piles were 66.97% and 78.48% respectively.



Above graph gives the comparative results of swelling of expansive clay treated with Bio-enzyme. The percentage decrease in the heave due to provision of 100 ml and 200 ml dosage for one m^3 of soil was 20 % and 41.67% respectively.

5. CONCLUSIONS

The effectiveness of Micropiles, geotextile reinforcement, and bio-enzyme treatment in controlling swelling of expansive soil was evaluated through laboratory investigations. The following key conclusions are drawn:

- Micropiles significantly reduce swelling, with a maximum reduction of approximately 79% observed for 20 mm diameter piles with sand providing frictional resistance. Heave reduction improves with increasing Micropiles diameter.
- Geotextile reinforcement effectively controls swelling, and its performance increases with the number of layers. A maximum reduction of about 73% was achieved using two layers placed at depths of 0.1B and 0.3B below the footing.
- Bio-enzyme treatment reduces swelling potential, with effectiveness increasing with higher dosage. A maximum reduction of approximately 42% was observed at a dosage of 200 ml/m^3 of soil.
- Larger footing dimensions contribute to improved heave control, indicating better load distribution and resistance to swelling.
- Overall, Micropiles and geotextile reinforcement were found to be more effective compared to bio-enzyme treatment, although the latter offers a sustainable alternative for soil stabilization.
- Overall, the controlled incorporation of MP and RHA can lead to the development of eco-friendly, cost-effective bricks with acceptable strength and performance characteristics.

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