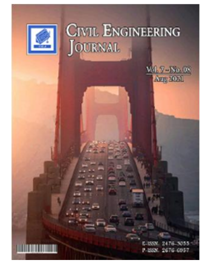
Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 7, No. 08, August, 2021



Study on the Swelling Behavior of Clayey Soil Blended with Geocell and Jute Fibre

Sanjeev Kumar [1*], Anil Kumar Sahu [2], Sanjeev Naval [3]

[1] *Research Scholar, IKGPTU, Kapurthala (Punjab), India.*

[2] *Professor, Department of Civil Engineering, Delhi Technological University, Delhi, India.*

[3] *Associate Professor, Department of Civil Engineering, DAV Institute of Engineering & Technology, Jalandhar, India.*

Received 17 February 2021; Revised 29 June 2021; Accepted 04 July 2021; Published 01 August 2021

Abstract

Expansive soils like clays undergo swelling that can both be detrimental and acceptable in different applications. In the Northern part of India, especially Delhi region, natural soils containing clays & clayey sands support most of the buildings. Mechanically stabilized clays mixed with sand are used for local earthwork construction such as roads and landfills. Exact understanding of the swelling behaviour of such soils is a pre-requisite before the start of any construction projects. In this paper the swelling behaviour of clayey soil reinforced with geocell & Jute fibres has been presented. The laboratory investigations include one dimensional swelling tests using California Bearing Ratio (CBR) mould to study the swelling properties for different mix proportions. The maximum decrease in swelling potential of Geocell reinforced specimens was observed at fibre content of 0.80 percent and 40mm fibre length, beyond which increase in the swelling potential and swelling pressure has been observed. With this optimal reinforcement, a reduction of 71.24 percent in swelling and 41.10 percent in swelling pressure has been observed as compared to unreinforced soils. The study provides a solution towards the treatment of expansive soils before starting any construction activity over such soils and a step towards mitigating disasters related to infrastructure facilities grounded on expansive soils.

Keywords: Expansive Soil; Geocell; Jute Fibre; Swelling; Swell Potential; Swell Pressure.

1. Introduction

Expansive soil is one that undergoes large volumetric changes in response to changes in moisture content. These kinds of soils can be found throughout the world. In India the expansive clayey soil is referred as black cotton soil since these are capable of growing cotton plants and covers approximately 20% of total land area. Such soils swells with the increase in moisture content while shrinks upon evaporation. Subsequently, these soils causes risk and damages to the structures like residential buildings, light loaded structures, highway pavements, railway tracks, airfields, retaining walls, and bridges built over them. The damage caused is sometimes small and require minor maintenance but often it is severe damage causing major structural failure. Problems associated with expansive soils have encouraged the researchers to develop different methods of modifying the engineering properties of soil through the process named soil stabilization. Various soil stabilization methods are in use to control the swelling and to limit its effect. The stabilization methods may be divided in to two categories viz. chemical stabilization and mechanical

* Corresponding author: snjvbansal67@gmail.com

http://dx.doi.org/10.28991/cej-2021-03091728

stabilization. Chemical stabilization includes the addition of certain chemical agents like fly ash, lime, cement, polymers, resins, ionic solutions etc. These chemical agents interact with the soil particles and change the index properties [1-3]. In mechanical stabilization, soil is stabilized by compaction with the inclusion of reinforcement, fibres or other non-biodegradable materials. In past, many studies have shown the inclusion of randomly distributed fibres [4-6] and geosynthetics [7-9] improve the strength & bearing capacity of expansive soils.

Patil [10] described a laboratory method to measure the swelling pressure and an apparatus to carry out the test for remoulded or undisturbed soil samples. Basma [11], explained the methods to measure swelling pressure of expansive soils in the laboratory, the Restrained swell test and the Double odometer swell test. The study concluded that the restrained swell test gives more reasonable results. Shridharan and Prakash [12] formulated a basic user-friendly method to classify expansive soil based on the free swell ratio, taking into account the results compatibility with the odometer free swell test and soil clay mineralogy. Vessely and Wu [13] performed soil geosynthetic swell test and suggested that the geosynthetic inclusion helped to control the swelling of the expansive soils. Al-Rawas et al. [14] concluded that except sarooj(a pozzolana) all stabilizers cause reduction in swelling potential while determining the impact of sarooj, lime, cement, and heat treatment on the soil's swelling capacity. Guney et al. [15] when studying the effect of cyclic wetting and drying on the swelling behavior of lime stabilized clayey soil, it was observed that after the first cycle, the beneficial effect of lime stabilization in the early stages disappeared. Further swelling potential increased at the subsequent cycles. Ikizler et al. [16] used sand and EPS Geofoam as stabilizers and showed that these can be used to reduce the swelling pressure in bentonite.

Viswanadham et al. [17] examined the influence of polypropylene tape fibre on swelling behavior and revealed that discrete and randomly distributed fibres are effective in reducing swelling. Mirzababaei et al. [18] studied the effectiveness of polymers to reduce swelling by treating the expansive soils and concluded a significant reduction in free swelling potential and an increase in furan (a polymer) content. Nagaraj et al. [19] studied the effect of vertical drains in the compacted soil on the swell potential and swelling pressure and found to have a sizeable influence. Yazdandoust and Yasrobi [20] studied the effect of cyclic wetting and drying on the swelling behavior of polymer stabilized expansive clay. In cyclic swelling and shrinkage, the swelling potential & swelling pressure begin to decrease after the first cycle and achieved equilibrium after fourth cycle. Tiwari and Ajmera [21] studied the action of major clay minerals and their mixtures in terms of consolidation and swelling. The void ratio, liquid limit, and plasticity index all had a close association with compression and swelling index in the early stages. Using the liquid limit, equations were proposed to estimate compression and swelling index. Trouzine et al. [22] performed a study on rubber fibres (extracted from scrap tyres) in composite clayey soils to investigate the swelling behavior and reported that there is significant reduction in the liquid limit, swelling potential, swelling pressure and time taken to attain maximum swelling for the soils having higher swelling potential.

Malekzadeh and Bilsel (2012) [23] reported swelling and compressibility of expansive soils reinforced with polypropylene fibre evaluated and concluded that using polypropylene fibres with expansive soils may be an effective method to restrain swelling potential and the compressibility EIsharief et al. [24] presented results of an experimental study to understand the swelling behavior of two expansive soils and to develop few models to predict swelling pressure and concluded that the swelling pressure increases with the decrease in moisture and increase in soil suction. It also decreased with the increase in liquidity index. Phanikumar and Singla [25] concluded, nylon fibre reinforcement of expansive soils is an efficient way to minimise volumetric changes during primary and secondary consolidation. Jayasree et al. [26] through consolidation, swelling pressure, and three-dimensional shrinkage experiments, it was found that combining coir waste with expansive soil helps in improving volume change behaviour. Elbadry [27] introduced a new method to predict the volume change behavior of expansive soils based upon the results of few standard physical tests. Patil et al. [28] established a relation between the swelling pressure and the free swell index through the physical and swelling properties of soils.

Soltani et al. [29] through free swell tests and unconfined compression tests demonstrated that the chemical and mechanical stabilization methods can guarantee a significant reduction in swelling problem of the expansive soil. Soltani et al. [30] presented the results of an experimental study to conclude that the fibre inclusion brings a substantial reduction in the swelling behavior of expansive soils. Moghal et al. [31] performed a thorough study of the influence of fibre treatment on the swelling and compressibility characteristics of lime stabilized expansive soil, and proposed mixing polypropylene fibres in lime stabilization as an alternative to address the shrinkage and swelling issue. Muthukumar et al. [32] studied the swelling and shrinkage behavior of expansive soil using lime and fibres in varying proportions and concluded that with the increase in fibre content swelling decreased slightly while there was significant reduction in shrinkage. Both, swelling and shrinkage, decreased significantly with the increase in lime content. Onyelowe et al. [33] through a laboratory study showed that crushed waste ceramic based geopolymer cement and other geopolymer cement can replace Portland cement in civil engineering works. Tiwari and Satyam [34], studied the swelling pressure and expansion properties of the silica fume stabilized clayey soil and found a significant affect using the polypropylene fibre. The fibre content in the matrix affects the swelling pressure and expansion. Onyelowe et al. [35] concluded that quarry dust is a good additive to treat the expensive soils in the moist environment and its addition consistently improved the swelling potential and shrinkage limit of soils. Bekhiti et al. [36] used waste tire rubber fibre with cement stabilized bentonite clayey soil and concluded that the swelling potential and swelling pressure gradually decreased with the increase in fibre and cement content. Kalkan et al. [37] used quartzite to stabilize the expansive soil and found that the swelling potential, swelling pressure and vertical swelling percentage values of expansive soils decrease due to this. Shukla et al. [38] presents the effect of waste tire fibre on the expansive soil and concluded that the swelling potential and swelling pressure of soil reduces significantly.

In the present experimental study, one-dimensional swelling tests were performed in CBR mould on expansive soil, belonging to New Delhi area. Geocell, fabricated from woven polypropylene geotextile , and jute fibres has been used as reinforcements to analyze the swell potential and swelling pressure for controlling swelling of expansive soil. Jute being an agricultural waste, this experimental study offers a low-cost and eco-friendly alternative to the expansive soils. Besides other natural fibres, jute has high tensile strength, elastic modulus and low extensibility. It can resist rotting and heat as well [39]

2. Materials and Methods

Flow chat illustrating the methodology followed in the present experimental study is given in Figure 1:

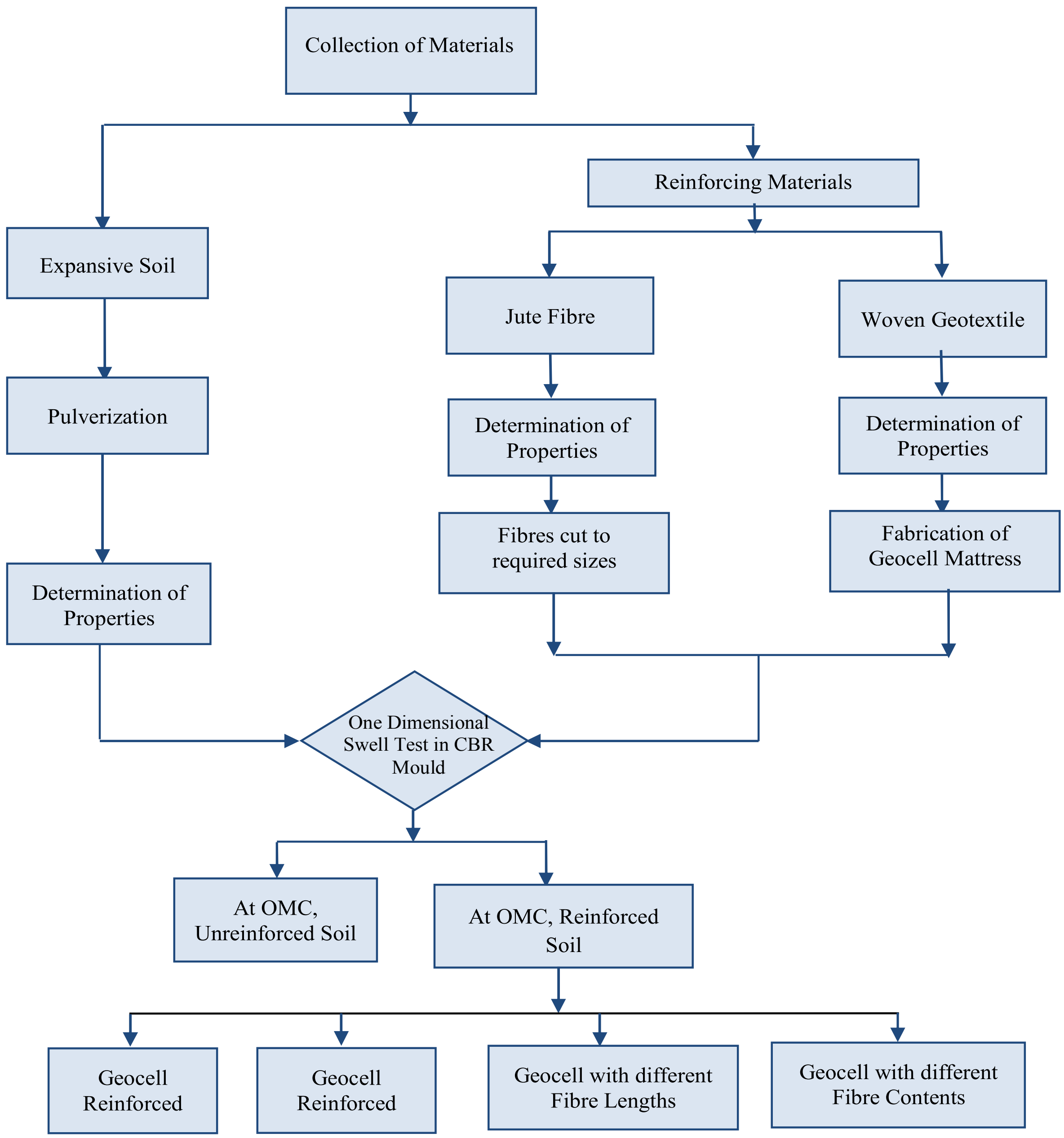


Figure 1. Flowchart showing Methodology Adopted

2.1. Materials

2.1.1. Soil

The expansive soil used in this research programme was a naturally occurring black cotton soil from New Delhi (Northern Part of India). It was excavated from a depth of 1.0 m below the natural ground surface. The collected soil has 96% fraction passing through 75 µm and 64.5% fractions passing through 2 µm IS sieve. Figure 2 shows a particle distribution curve based on the effects of sieve analysis and hydrometer analysis. To evaluate index properties, tests were carried out in accordance with Indian Standard IS: 2720. According to Bureau of Indian Standard classification the soil was classified as high plasticity clay (CH). The soil has a high plasticity index (49.68%) and free swell index 72.5% alongwith an activity of 0.76. Generally a soil having high plasticity, free swell index and clay activity will have higher swelling tendency. The index properties of the soil are listed in Table 1. Figure 3 shows the result of X-ray diffraction analysis. It indicates that the soil is dominated by quartz, with muscovite and talc as major constituents.

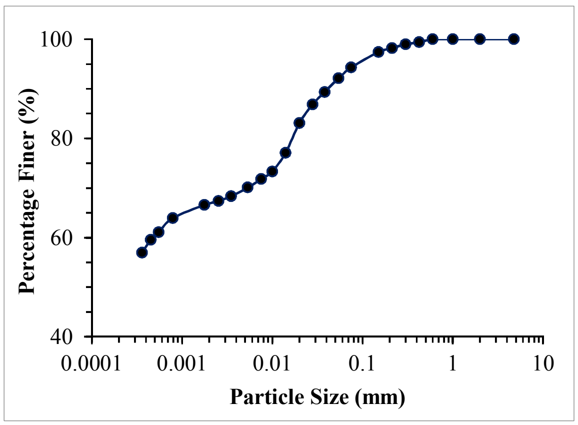


Figure 2. Particle Size Distribution Curve [9]

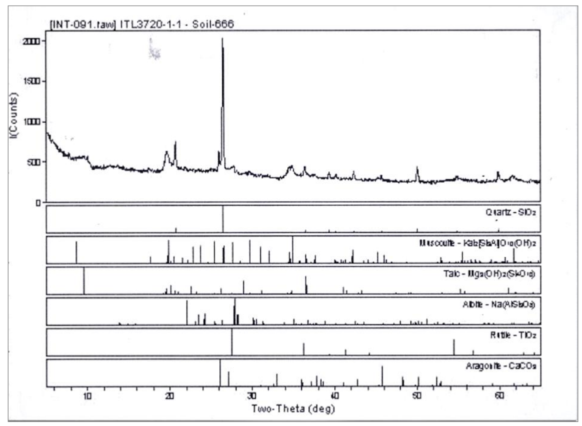


Figure 3. X-Ray Diffraction Analysis of Expansive Soil

Table 1. Properties of soil [9]

S. No.	Parameter		Value
1	Specific Gravity		2.63
2	% Finer than 4.75mm, %		100.00
3	% Finer than 75µ, %		94
4	% Finer than 2µ, %		64.5
5	Liquid Limit, %		87.24
6	Plastic Limit, %		37.56
7	Plasticity Index, %		49.68
8	Free Swelling Index, %		72.5
9	Activity		0.76
10	Maximum Dry Density, kN/m^3		14.85
11	Optimum Moisture Content, %		22.5
12	CBR, %	Unsoake	6.28
		Soaked	1.82
13	Unconfined Compressive Strength, kN/m^2		66.54
14	Cohession, kN/m^2 (uu Test)		33.27

2.1.2. Reinforcing Materials

Two types of reinforcing materials viz. fibre and geocell are used in this study to control the swelling behavior of the expansive soil.

2.1.2.1. Fibre

In this study jute fibre has been used as one of the reinforcing material. It is a commercial and multifunctional natural fibre. It has the highest tensile strength among the available natural fibres. Commercially available jute fibre was procured from GoGreen Products, Chennai, Tamilnadu (India). It was brown in colour, with a diameter of 0.3mm and a density of 14.00 kN/m^3. Table 2 lists the results of various experiments conducted at Shree Ram Laboratories in Noida, Uttar Pradesh (India), to determine its properties. The fibre length was varied as 10, 20, 30, 40, 50 and 60 mm while the fibre content was varied as 0.10, 0.20, 0.40, 0.80, 1.60 and 2.40% by the dry weight of the soil. The image of jute fibres cut to required size is shown in Figure 4.

Table 2. Properties of Jute Fibre [6]

S. No.	Parameter	Value
1	Diameter, µm	300
2	Colour	Brown
3	Specific Area, mm^2	70.65
4	Density, kN/m^3	14.00
5	Tensile Strength, MPa	518.0
6	Young Modulus, GPa	26.40
7	Elongation, %	1.60
8	Water Absorption, %	32.00

Table 3. Properties of Geotextile [9]

S. No.	Parameter		Value
1	Thickness, mm		0.8
2	Weight per unit area, N/m^2		3.4
3	Wide Width Tensile Strength, kN/m	WARP	80
		WEFT	70
4	Elongation at break, %	WARP	25
		WEFT	25
5	Joint Strength, kN/m		13.4

2.1.2.2. Geotextile

Commercially available woven geotextile, PPMF-300, made up of polypropylene was procured from Filter Fabs, New Delhi (INDIA) to fabricate geocell, a cellular confining system, of chevron pattern. Figure 5 shows the image of woven geotextile. IS: 13162 Part 3 was used to measure its thickness, and IS: 14716 was used to calculate its mass per unit area. The wide width test described in IS 13162 was used to determine tensile strength and elongation at break point, while IS 15060 was used to determine joint strength. Different geotextile properties are listed in Table 3.

Figure 4. Jute Fibres Cut to Size [6]

Figure 5. Woven Geotextile [9]

2.2. Test Setup

There exists no defined test method to determine swelling potential of the soil reinforced with geocell. Therefore, in the present study, CBR mould has been used to determine the swelling potential of the expansive soil reinforced with fibre and geocell. CBR mould is a rigid cylindrical metallic mould of 152mm inside diameter and 178mm in height. Rammer of weight 26N and drop 310mm was used to compact the matured soil in the mould. A bucket of 20 litre capacity was used for submerging the soil sample. Dial gauge of 50mm capacity was installed at the top of the test specimen to measure swelling. Figure 6 shows the image of the proposed set up.

Figure 6. Setup for Swelling Test

2.3. Sample Preparation

The excavated expansive soil was pulverized using hand tools and sieved through 75 micron IS sieve. All the test specimen were prepared at their maximum dry unit weight (MDD) and optimum water content (OMC) determined through standard proctor tests in accordance with IS: 2720. Calculated amount of water was added and mixed thoroughly with the required quantity of oven dried soil for achieving maximum dry density. The mixture was kneaded by hand to have a homogeneous mixture. In the case of reinforced soil sample, fibres cut to size and percentages were sprinkled over the soil before adding water. Fibre content (p) is the ratio of the weight of fibres (W_f) to the weight of dry soil (W_s) and expressed mathematically as:

$$p = \frac{W_f}{W_s} \times 100 \tag{1}$$

To avoid floating of fibres, the soil was first moisten by adding a little quantity of calculated water and the remaining water was added gradually afterwards. Moisten reinforced and unreinforced soil was then kept in air tight container for 24 hours for uniform distribution of water.

2.4. Test Procedure

To determine swell potential of the expansive soil, one-dimensional swell test was conducted in the CBR mould on two types of soil specimen viz. unreinforced soil specimen and geocell reinforced soil specimens. Geocell mattress is a three dimensional structure. The chevron pattern geocell mattress was fabricated by cutting strips of required dimensions from the woven geotextile and placing them in transverse and diagonal direction. These strips were joined together with nylon thread by stitching keeping the numbers and the length of stitches same. In unreinforced specimen, the moisten soil was put in the CBR mould in 50 mm layers. Each layer was compacted dynamically to its maximum dry density using the drop hammer. For proper bonding, the top surface of each layer was scratched before putting the next layer over it. To prepare geocell reinforced specimen, the geocell layer was installed over the properly levelled surface upon reaching the desired height in the mould. Geocell pockets were filled with the moist fibre reinforced soil. The prepared test specimen was inundated in water to swell until equilibrium under 3 kN/m^2 applied load. To determine the swelling pressure, the swelled specimen was put under the loading frame and compressive load was applied until the test specimen reached to its original volume.

The authors had also performed an experimental study to determine the optimum parameters for geocell and jute fibre reinforcement to improve the performance of a circular footing resting on expansive soil. A portion of the findings of this study were published in a research article [9]. Experiments with the test series and the parameters specified in Table 4 were therefore carried out to determine the efficacy of these optimal parameters in controlling the swelling of subgrade soil.

Table 4. Details of model test programme

Test Series	Reinforcement Type	Test Parameters
A	Unreinforced Expansive Soil	Compacted at OMC
B	Geocell	Compacted at OMC
C	Fibre	Compacted at OMC
		Constant Parameters: L = 40 mm, p = 0.8%
D	Geocell and Fibre	Variable Parameters: L (mm) = 10, 20, 30, 40, 50, 60
		Constant Parameters: p = 0.8%
E	Geocell and Fibre	Variable Parameters: p = 0.1%, 0.2%, 0.4%, 0.8%, 1.6%, 2.4%
		Constant Parameters: L = 40 mm

3. Result and Discussion

The variation in the amount of swelling with time, plotted on logarithmic scale, is depicted in Figure 7 while Figure 8 shows the variation of swelling pressure with time for the tests conducted under test series A to C. From these plots, it is observed that the unreinforced soil sample swelled larger than the reinforced one and attained a maximum swelling and swelling pressure respectively as 9.04 mm and 137.36 kN/m^2. The equilibrium swelling has been observed in approximately 4320 minutes i.e. 3 days, which is in line with the findings observed by [8, 25]. However, when geocell was used as reinforcement in the expansive soil, swelling was reduced. The maximum swelling observed was 6.44 mm indicating 28.76% reduction in swelling. Swelling pressure reduced to 120.41 kN/m^2. In geocell reinforced soil sample, this reduction is caused mainly through the development of resistive forces as a result of friction between soil particles and the geocell pocket walls during the upward movement of soil while swelling. The magnitude of these resistive forces will be more in case of geocell fabricated with small pocket size compared to larger pocket size. Swelling of expansive soil reduced to 5.41 mm when 0.8%, 40 mm long fibres were mixed randomly causing 40.15% reduction while the swelling pressure reduced to 113.70 kN/m^2. This reduction in swelling in fibre reinforced soil sample is attributed to (i) replacement of expansive soil particles with the non-expansive fibres which causes a substantial reduction in swelling potential of soil [8], (ii) interlocking of soil particles and the fibre [40, 41] and (iii) development of resistive tensile forces in the fibres [25]. These resistive tensile stresses are generated due to the friction between the soil fibre interfaces as a result of strong swelling forces and stretching of fibres. The net effect of these forces can have a major role in reducing the swelling effect of expansive soil.

The rate of swelling, calculated per minute, of the unreinforced and the reinforced expansive soil samples is depicted in Figure 9. This plot indicates that the swelling in the unreinforced expansive soil occurs exponentially until first 120 minutes upon submerging. After that the swelling rate does not show any major changes. Addition of reinforcement lessens the swelling rate. Therefore, the expansive soil does not exhibit the higher rate of change in swelling. In the initial stages, the expansive soil and the reinforcement have air voids which develop pore pressure upon filling with water. Consequently, there is rapid change in the volume of the expansive soil but after reaching the saturation stage the swelling becomes negligible. Therefore, it can be established that the expansive soil absorbs water in the initial stages and on reaching the saturation stage, the change in swelling rate without pressure may be classified as (1) Initial swelling phase, (2) Primary swelling phase, (3) Secondary swelling phase, the phases in which swelling of the expansive soil occur [42-44]. In initial swelling phase micro-structural rearrangement takes place through inter layer swelling and is responsible for a small change in volume, generally, less than 10% of the total swell potential. The inter layer swelling extends in to the primary swelling phase also and continues until approximately 80% of the swell potential. The secondary swelling phase occurs due to the double layer repulsion and resulted into a small time bound volume changes. Both the primary swelling and the secondary swelling phases occur at micro-structural level in which swelling of the active clay mineral take place.

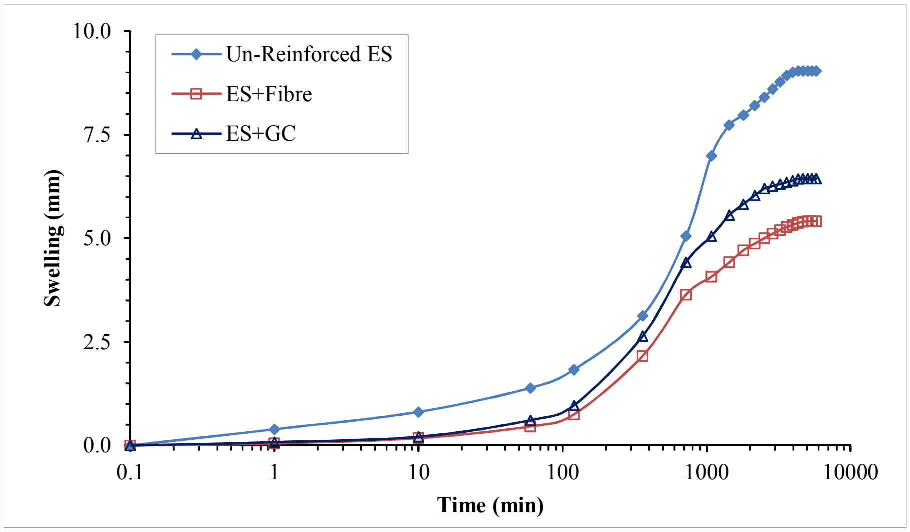


Figure 7. Variation of Swelling with Time for Unreinforced, Geocell Reinforced, Fibre Reinforced Expansive Soil

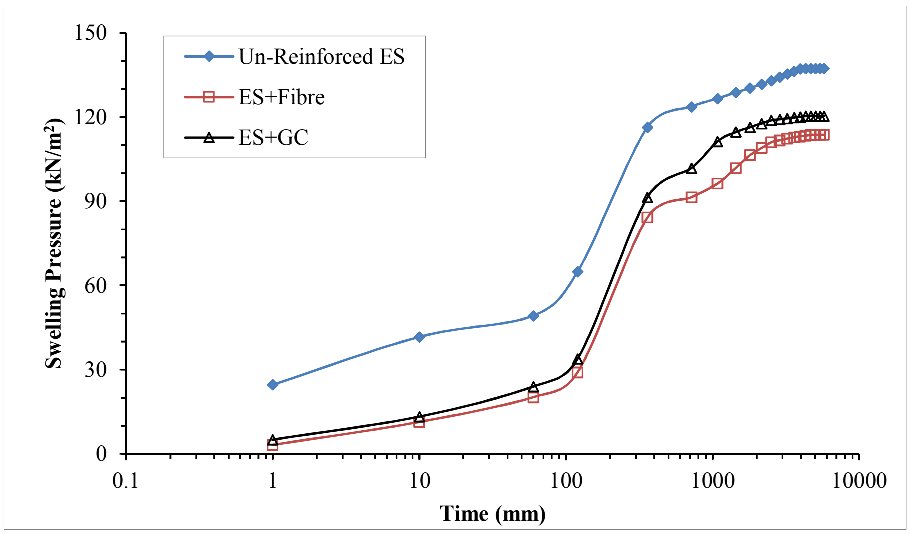


Figure 8. Variation of Swelling Pressure with Time for Unreinforced, Geocell Reinforced, Fibre Reinforced Expansive Soil

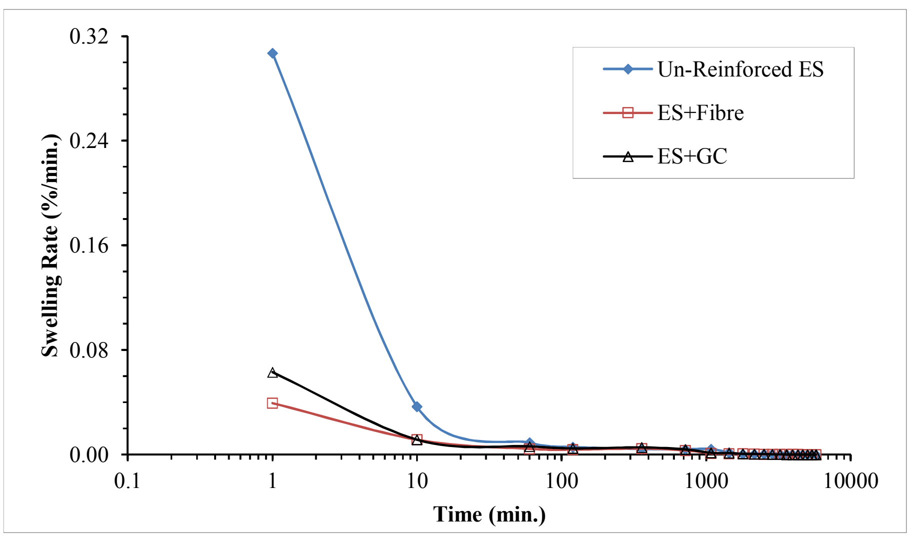


Figure 9. Variation of Swelling Rate with Time for Unreinforced, Geocell Reinforced, Fibre Reinforced Expansive Soil

To analyze the performance of reinforcement viz. geocell and fibre to control swelling of the expansive soil the parameter swell potential (S%) is used. It is calculated as the increase in height at a particular time interval (ΔH) to the initial height (H) of the soil specimen and is expressed in percentage. Mathematically:

$$S\% = \frac{\Delta H}{H} \times 100 \tag{2}$$

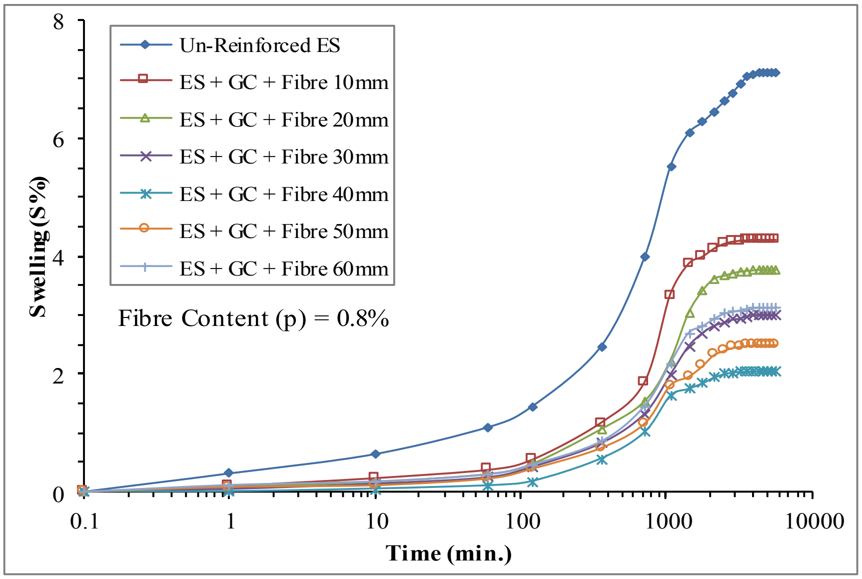


Figure 10. Variation of Swelling with Time for Different Fibre Lengths

3.1. Effect of Fibre Length

The variation of swelling of varying fibre lengths with time, plotted on a logarithmic scale, for the tests conducted under test series D, is illustrated in Figure 10. This plot indicates that the swelling of the expansive soil decreased with the increasing fibre length. However, the reduction in swell potential has been observed until 40 mm fibre length, thereafter, the swelling increased with the addition of 50 mm and 60 mm long fibres. This reduction upto 40 mm long fibres is attributed to the resistance offered by the fibre to swelling which is a function of contact area between the fibre and the soil particles. At smaller lengths, the contact area between the fibre and the soil particles would be more effective and increase in length resulted in increased contact area subsequently an increase in resistance to swelling. Once the fibre become longer than 40 mm, it bends and folds', reducing the effective contact area between the fibre and the expansive soil particles, resulting in reduced resistance to swelling, similar findings have also been reported by [8]. As a result, the use of 50mm and 60mm long fibres experience more swelling. Figure 11 shows the decrease in swelling with the use of different fibre lengths, optimal length is found to be 40 mm, after which it increases for 50mm and 60 mm fibre lengths.

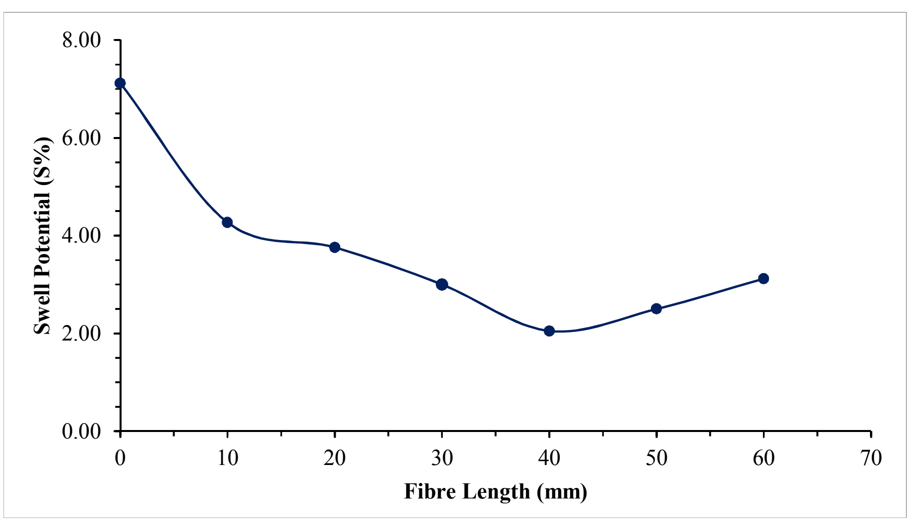


Figure 11. Variation of Swell Potential for Different Fibre Lengths

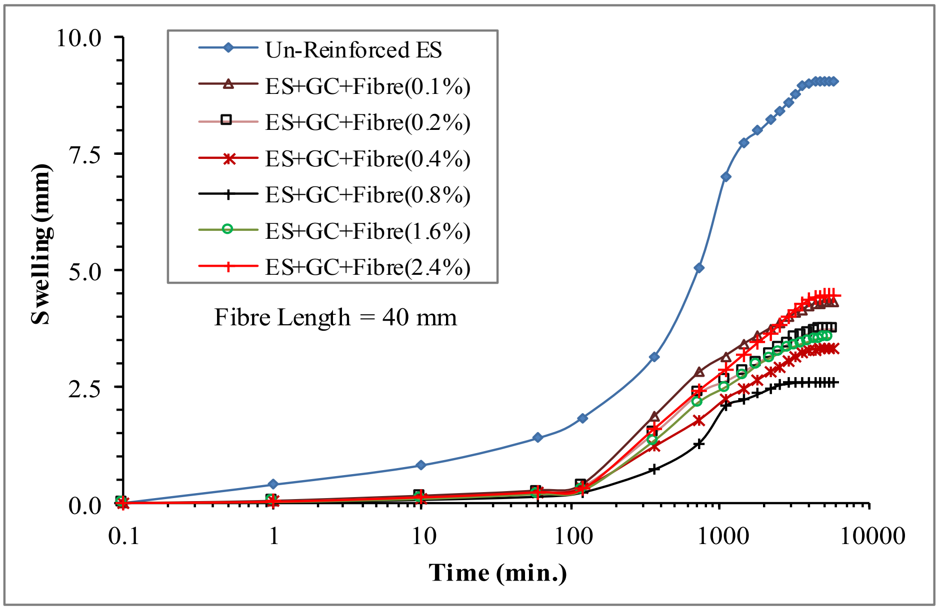


Figure 12. Variation of Swelling with Time for Different Fibre Contents

3.2. Effect of Fibre Content

Figure 12 shows the variation of swelling with time, plotted on logarithmic scale, for the tests conducted under test series E. From this plot, it is observed that the amount of swelling of the expansive soil has decreased with the increasing fibre content. This may be attributed to the replacement larger portion of swelling soil with fibres having no swelling tendency. Therefore, increase in the fibre content results in considerable decrease in swelling. Further, increasing the fibre content denotes that the number of fibres in the soil has increased, thus, a much greater resistance in the fibres has generated due to fibre interlocking and thereby reducing the swelling of the expansive soil. Figure 13 illustrates that the swell potential decreased until 0.8% fibre content, thereafter, with further addition of fibres the swelling potential has increased. It is because at higher fibre contents than the optimum, the fibres are in very high concentration in the soil mass and create voids which resulted in the reduction of the effective contact area between fibre and the expansive soil particles. This leads to increased swelling at higher fibre contents than the optimum. Therefore, 0.8% fibre content can be considered as the optimum fibre content. Table 5 lists the parameters established at the maximum reinforcement.

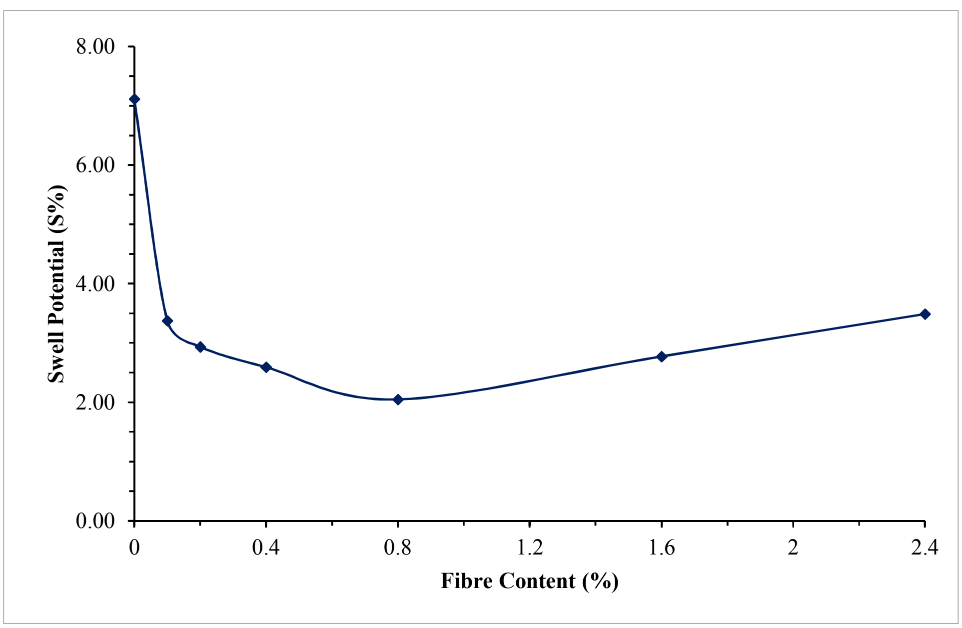


Figure 13. Variation of Swell Potential for Different Fibre Contents

Table 5. Summary of results obtained for geocell reinforced expensive soil with fibres of optimal parameters

S. No.	Parameter	Result
1	Fibre content, %	0.8
2	Fibre Length, mm	40
3	Swelling, mm	2.6
4	Swelling Pressure, kN/m^2	80.5
5	Swell Potential, S%	2.05
6	Reduction in Swelling, %	71.24*
7	Reduction in Swelling potential, %	41.40*

* Similar findings were published in the case of polypropylene fibre by [45].

4. Conclusions

The experimental study performed on the remoulded expansive soil specimens reinforced with geocell and randomly distributed jute fibres proves to be a way ahead for infrastructure development on expansive soils. The effect of reinforcement using geocell and Jute fibre on swell potential and the swelling pressure on expansive soil has been studied. The results show that geocell and jute fibres are effective as reinforcement to control swelling of the expansive soil. Following specific conclusions are drawn from the present research study:

- Geocell reinforcement is effective at reducing swelling in expansive soils. Geocell reinforcement alone resulted in a 28.76 % reduction in swelling and a 12.34 % reduction in swelling pressure;
- For geocell reinforced expansive soil with constant fibre content, swelling potential and swelling pressure both decreased with increasing fibre length. Optimal fibre has been found to be 40 mm beyond which the fibre lengths of 50mm & 60mm don't contribute towards decreasing the swelling of expansive soil;
- Swelling potential and swelling pressure decreased with rising fibre content with geocell reinforced expansive soil at constant fibre length. This decrease was found to be restricted until the fibre content reached 0.8 %, beyond which swelling potential and swelling pressure both begin to increase;
- When the expansive soil is reinforced with geocell and jute fibre of optimal parameters (L = 4 mm and p = 0.80 %), the minimum values for swelling potential and swelling pressure are 2.05 % and 80.50 kN/m^2, respectively, resulting in a reduction of 71.24 % in swelling and 41.40 % in swelling pressure;

5. Declarations

5.1. Author Contributions

S. K., A. K. S. and S.N. contributed to the conception and design of the study; S. K. performed the experimental tests and analyzed the data; S. K. wrote the first draft of the manuscript; A.K.S. and S. N. guided and supervised the research work and commented on the previous version of the manuscript. 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 article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgements

The study for this article was carried out at the Civil Engineering Department of Vaish Technical Institute in Rohtak, Haryana, India. The first author is also grateful to IKG Punjab Technical University, Kapurthala (Punjab), India, for allowing him to conduct research and providing all necessary support.

5.5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Çokça, Erdal. "Use of Class C Fly Ashes for the Stabilizationof an Expansive Soil." Journal of Geotechnical and Geoenvironmental Engineering 127, no. 7 (July 2001): 568–573. doi:10.1061/(asce)1090-0241(2001)127:7(568).

[2] Kalkan, Ekrem, and Suat Akbulut. "The Positive Effects of Silica Fume on the Permeability, Swelling Pressure and Compressive Strength of Natural Clay Liners." Engineering Geology 73, no. 1–2 (May 2004): 145–156. doi:10.1016/j.enggeo.2004.01.001.

[3] Chittoori, Bhaskar C. S., Debakanta Mishra, and Kazi Moinul Islam. "Forensic Investigations into Recurrent Pavement Heave from Underlying Expansive Soil Deposits." Transportation Research Record: Journal of the Transportation Research Board 2672, no. 52 (August 17, 2018): 118–128. doi:10.1177/0361198118758625.

[4] Kumar, Arvind, Baljit Singh Walia, and Jatinder Mohan. "Compressive Strength of Fiber Reinforced Highly Compressible Clay." Construction and Building Materials 20, no. 10 (December 2006): 1063-1068. doi:10.1016/j.conbuildmat.2005.02.027.

[5] Meena, Sunil Kumar, Raghvendra Sahu, and Ramanathan Ayothiraman. "Utilization of Waste Wheat Straw Fibers for Improving the Strength Characteristics of Clay." Journal of Natural Fibers (December 6, 2019): 1–15. doi:10.1080/15440478.2019.1691116.

[6] Kumar, Sanjeev, Anil Kumar Sahu, and Sanjeev Naval. "Influence of Jute Fibre on CBR Value of Expansive Soil." Civil Engineering Journal 6, no. 6 (June 1, 2020): 1180–1194. doi:10.28991/cej-2020-03091539.

[7] Sharma, Radhey S., and Bhyravajjula R. Phanikumar. "Laboratory Study of Heave Behavior of Expansive Clay Reinforced with Geopiles." Journal of Geotechnical and Geoenvironmental Engineering 131, no. 4 (April 2005): 512–520. doi:10.1061/(asce)1090-0241(2005)131:4(512).

[8] Viswanadham, B.V.S., B.R. Phanikumar, and Rahul V. Mukherjee. "Swelling Behaviour of a Geofiber-Reinforced Expansive Soil." Geotextiles and Geomembranes 27, no. 1 (February 2009): 73–76. doi:10.1016/j.geotexmem.2008.06.002.

[9] Kumar, Sanjeev, Anil Kumar Sahu, and Sanjeev Naval. "Performance of Circular Footing on Expansive Soil Bed Reinforced with Geocells of Chevron Pattern." Civil Engineering Journal 5, no. 11 (November 3, 2019): 2333–2348. doi:10.28991/cej-2019-03091415.

[10] Patil, R.M. " Determination of swelling pressure of black cotton soil-A method" In proceedings of 3rd international conference on soil mechanics and foundation engineering, 1, (1953): 170-172.

[11] Basma, Adnan A., Azm S. Al-Homoud, and Abdallah Husein. "Laboratory Assessment of Swelling Pressure of Expansive Soils." Applied Clay Science 9, no. 5 (February 1995): 355–368. doi:10.1016/0169-1317(94)00032-l.

[12] Sridharan, A., and K. Prakash. "Classification Procedures for Expansive Soils." Proceedings of the Institution of Civil Engineers - Geotechnical Engineering 143, no. 4 (October 2000): 235–240. doi:10.1680/geng.2000.143.4.235.

[13] Vessely, Mark J., and Jonathan T. H. Wu. "Feasibility of Geosynthetic Inclusion for Reducing Swelling of Expansive Soils." Transportation Research Record: Journal of the Transportation Research Board 1787, no. 1 (January 2002): 42–52. doi:10.3141/1787-05.

[14] Al-Rawas, Amer Ali, A.W. Hago, and Hilal Al-Sarmi. "Effect of Lime, Cement and Sarooj (artificial Pozzolan) on the Swelling Potential of an Expansive Soil from Oman." Building and Environment 40, no. 5 (May 2005): 681–687. doi:10.1016/j.buildenv.2004.08.028.

[15] Guney, Yucel, Dursun Sari, Murat Cetin, and Mustafa Tuncan. "Impact of Cyclic Wetting–drying on Swelling Behavior of Lime-Stabilized Soil." Building and Environment 42, no. 2 (February 2007): 681–688. doi:10.1016/j.buildenv.2005.10.035.

[16] Ikizler, S. B., M. Aytekin, and M. Vekli. "Reductions in Swelling Pressure of Expansive Soil Stabilized Using EPS Geofoam and Sand." Geosynthetics International 16, no. 3 (June 2009): 216–221. doi:10.1680/gein.2009.16.3.216.

[17] Viswanadham, B.V.S., B.R. Phanikumar, and R.V. Mukherjee. "Effect of Polypropylene Tape Fibre Reinforcement on Swelling Behaviour of an Expansive Soil." Geosynthetics International 16, no. 5 (October 2009): 393–401. doi:10.1680/gein.2009.16.5.393.

[18] Mirzababaei, M., S. Yasrobi, and A. Al-Rawas. "Effect of Polymers on Swelling Potential of Expansive Soils." Proceedings of the Institution of Civil Engineers - Ground Improvement 162, no. 3 (August 2009): 111–119. doi:10.1680/grim.2009.162.3.111.

[19] Nagaraj, H., M. Munnas, and A. Sridharan. "Swelling Behavior of Expansive Soils." International Journal of Geotechnical Engineering 4, no. 1 (January 2010): 99–110. doi:10.3328/ijge.2010.04.01.99-110.

[20] Yazdandoust, Fateme, and S. Shahaboddin Yasrobi. "Effect of Cyclic Wetting and Drying on Swelling Behavior of Polymer-Stabilized Expansive Clays." Applied Clay Science 50, no. 4 (December 2010): 461–468. doi:10.1016/j.clay.2010.09.006.

[21] Tiwari, Binod, and Beena Ajmera. "Consolidation and Swelling Behavior of Major Clay Minerals and Their Mixtures." Applied Clay Science 54, no. 3–4 (December 2011): 264–273. doi:10.1016/j.clay.2011.10.001.

[22] Trouzine, H., M. Bekhiti, and A. Asroun. "Effects of Scrap Tyre Rubber Fibre on Swelling Behaviour of Two Clayey Soils in Algeria." Geosynthetics International 19, no. 2 (April 2012): 124–132. doi:10.1680/gein.2012.19.2.124.

[23] Malekzadeh, Mona, and Huriye Bilsel. "Swell and compressibility of fiber reinforced expansive soils." International journal of advanced Technology in civil engineering 1, no. 2 (2012): 42-45.

[24] Elsharief, A.M., Zumrawi, M.M., Salam, A.M. "Experimental study of some factors affecting swelling pressure" Univ. Khartoum Eng. J, 4, no. 2 (2014): 1-7.

[25] Phanikumar, B.R., and Ravideep Singla. "Swell-Consolidation Characteristics of Fibre-Reinforced Expansive Soils." Soils and Foundations 56, no. 1 (February 2016): 138–143. doi:10.1016/j.sandf.2016.01.011.

[26] Jayasree, P. K., K. Balan, Leema Peter, and K. K. Nisha. "Volume Change Behavior of Expansive Soil Stabilized with Coir Waste." Journal of Materials in Civil Engineering 27, no. 6 (June 2015): 04014195. doi:10.1061/(asce)mt.1943-5533.0001153.

[27] Elbadry, Hossam. "Simplified Reliable Prediction Method for Determining the Volume Change of Expansive Soils Based on Simply Physical Tests." HBRC Journal 13, no. 3 (December 2017): 353–360. doi:10.1016/j.hbrcj.2015.10.001.

[28] Patil, A., Parkhe, D., Shrigriwar, R., Panse, R. "Establishing Relationship Between Swelling Pressure and Free Swell Index of Soils-A Case Study" International Journal of Advances in Science Engineering and Technology, 3, (2016): 4-7.

[29] Soltani, Amin, Abbas Taheri, Mehdi Khatibi, and A. R. Estabragh. "Swelling Potential of a Stabilized Expansive Soil: A Comparative Experimental Study." Geotechnical and Geological Engineering 35, no. 4 (March 13, 2017): 1717–1744. doi:10.1007/s10706-017-0204-1.

[30] Soltani, Amin, An Deng, and Abbas Taheri. "Swell–compression Characteristics of a Fiber–reinforced Expansive Soil." Geotextiles and Geomembranes 46, no. 2 (April 2018): 183–189. doi:10.1016/j.geotexmem.2017.11.009.

[31] Moghal, Arif Ali Baig, Bhaskar C. S. Chittoori, B. Munwar Basha, and Ahmed M. Al-Mahbashi. "Effect of Polypropylene Fibre Reinforcement on the Consolidation, Swell and Shrinkage Behaviour of Lime-Blended Expansive Soil." International Journal of Geotechnical Engineering 12, no. 5 (March 2, 2017): 462–471. doi:10.1080/19386362.2017.1297002.

[32] Muthukumar, M., Sekar, S.K., Shukla, S.K., 2017, July. "Swelling and Shrinkage Behaviour of Expansive Soil Blended with Lime and Fibres" In: Shukla S., Guler E. (eds) Advances in Reinforced Soil Structures. GeoMEast 2017. Sustainable Civil Infrastructures. Springer, Cham (2017): 39-48. doi.org/10.1007/978-3-319-63570-5.

[33] Onyelowe, Kennedy Chibuzor, Duc Bui Van, and Manh Nguyen Van. "Swelling Potential, Shrinkage and Durability of Cemented and Uncemented Lateritic Soils Treated with CWC Base Geopolymer." International Journal of Geotechnical Engineering 15, no. 4 (May 3, 2018): 389–404. doi:10.1080/19386362.2018.1462606.

[34] Tiwari, Nitin, and Neelima Satyam. "Experimental Study on the Influence of Polypropylene Fiber on the Swelling Pressure Expansion Attributes of Silica Fume Stabilized Clayey Soil." Geosciences 9, no. 9 (August 29, 2019): 377. doi:10.3390/geosciences9090377.

[35] Onyelowe, Kennedy, Duc Bui Van, Adrian Eberemu, Man Nguyen Xuan, A. Bunyamin Salahudeen, Charles Ezugwu, Manh Nguyen Van, et al. "Sorptivity, Swelling, Shrinkage, Compression and Durability of Quarry Dust Treated Soft Soils for Moisture Bound Pavement Geotechnics." Journal of Materials Research and Technology 8, no. 4 (July 2019): 3529–3538. doi:10.1016/j.jmrt.2019.06.029.

[36] Bekhiti, Melik, Habib Trouzine, and Mohamed Rabehi. "Influence of Waste Tire Rubber Fibers on Swelling Behavior, Unconfined Compressive Strength and Ductility of Cement Stabilized Bentonite Clay Soil." Construction and Building Materials 208 (May 2019): 304–313. doi:10.1016/j.conbuildmat.2019.03.011.

[37] Kalkan, Ekrem, Necmi YARBAŞI, and Özgür Bilici. "The Effects of Quartzite on the Swelling Behaviors of Compacted Clayey Soils." International Journal of Earth Sciences Knowledge and Applications 2, no. 2 (2020): 92-101.

[38] Shukla, Tejaswani, Mohit Mistry, Chandresh Solanki, Sanjay Kumar Shukla, and Shruti Shukla. "Influence of Randomly Distributed Waste Tire Fibres on Swelling Behaviour of Expansive Soils." Problematic Soils and Geoenvironmental Concerns (September 12, 2020): 319–332. doi:10.1007/978-981-15-6237-2_27.

[39] Wang, Yi-Xian, Pan-Pan Guo, Wei-Xin Ren, Bing-Xiang Yuan, Hai-Ping Yuan, Yan-Lin Zhao, Sheng-Biao Shan, and Ping Cao. "Laboratory Investigation on Strength Characteristics of Expansive Soil Treated with Jute Fiber Reinforcement." International Journal of Geomechanics 17, no. 11 (November 2017): 04017101. doi:10.1061/(asce)gm.1943-5622.0000998.

[40] Tang, Chao-Sheng, Bin Shi, and Li-Zheng Zhao. "Interfacial Shear Strength of Fiber Reinforced Soil." Geotextiles and Geomembranes 28, no. 1 (February 2010): 54–62. doi:10.1016/j.geotexmem.2009.10.001.

[41] Tang, Chaosheng, Bin Shi, Wei Gao, Fengjun Chen, and Yi Cai. "Strength and Mechanical Behavior of Short Polypropylene Fiber Reinforced and Cement Stabilized Clayey Soil." Geotextiles and Geomembranes 25, no. 3 (June 2007): 194–202. doi:10.1016/j.geotexmem.2006.11.002.

[42] Sridharan, A., and Y. Gurtug. "Swelling Behaviour of Compacted Fine-Grained Soils." Engineering Geology 72, no. 1–2 (March 2004): 9–18. doi:10.1016/s0013-7952(03)00161-3.

[43] Rao, S. M., T. Thyagaraj, and H. R. Thomas. "Swelling of Compacted Clay under Osmotic Gradients." Géotechnique 56, no. 10 (December 2006): 707–713. doi:10.1680/geot.2006.56.10.707.

[44] Soltani, Amin, Abbas Taheri, Mehdi Khatibi, and A. R. Estabragh. "Swelling Potential of a Stabilized Expansive Soil: A Comparative Experimental Study." Geotechnical and Geological Engineering 35, no. 4 (March 13, 2017): 1717–1744. doi:10.1007/s10706-017-0204-1.

[45] Tiwari, N., Satyam, N., Patva, J. ”Experimental study on the influence of polypropylene fiber on the swelling pressure expansion attributes of clayey soil” International Conference on Geotechnics for High Speed Corridors, July 2019, Thiruvananthapuram, India.