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Original Research Article

A COMPARATIVE LABORATORY INVESTIGATION INTO THE ROLE OF GEOSYNTHETICS IN THE INITIAL SWELL CONTROL OF AN EXPANSIVE SOIL

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Abstract

Volume change in expansive soils due to the intervention of water causes swell. A laboratory investigation using two different geosynthetic materials was designed to minimise the swell characteristics. The influence of three parameters, being geosynthetic material [Secutex (ST) and Combigrid (CG)], orientation (horizontal and vertical), and number of layers (1, 2, and 3) on the swell of an expansive soil was studied to better understand the potential for geosynthetics in swell control. The study on the immediate swell characteristics (limited to 24 hours) helps in gaining confidence in the use of geosynthetics in the swell control of expansive soils. From the investigation results, it was found that all three parameters, being type of material, orientation, and number of layers influenced the swell control of the soil. When two layers of ST and CG were placed both vertically and crossed, they reduced the swell of the virgin soil by almost 60% and 44%, respectively. It can, therefore, be concluded that geosynthetics can play an effective role in the swell control of expansive soils.

Keywords: geosynthetic material, orientation, layering, swell control, expansive soil

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1. INTRODUCTION

Expansive soils have always posed problems for geotechnical engineers all over the world. Expansive soils are those that swell on absorbing water and shrink on losing it [1], [2]. The montmorillonite group of minerals are responsible for this huge change in the volume of such soils [3]. These soils are characterized by their high cation exchange capacity [4], small size of individual particles [5], and large specific surface area [6]. Such soils have very poor swell-shrink characteristics due to wide fluctuations in volume with changes in water content. Hence, in order to improve the performance of such soils, the swell-shrink characteristics of the soils need to be improved. There are several methods available for improving the swell-shrink characteristics of expansive soils viz. provision of a cohesive non-swelling layer, provision of a moisture barrier, chemical stabilization, and use of geosynthetics. A lot of work has been done on the stabilization of expansive soils by different materials, resulting in improved swell-shrink characteristics [7]-[11] and geosynthetics have found a wide variety of applications in soil engineering in recent times, with a lot of research undertaken on their various applications [12]-[18]. However, the use of geosynthetics in swell control has not been dealt with to the same degree of detail or depth. Stalin et al. [14] studied the effect of multiple layers of geosynthetics in both horizontal and vertical orientations in a model tank. Shelke and Murthy [19] examined the performance of expanded polystyrene geofoam in the swell control of expansive soil. Al-Akhras et al. [20] studied the effect of natural and artificial fibres in controlling the swell of expansive soils. Ikizler et al. [21] explored the role of polypropylene fibres in the swell control of bentonite. Phanikumar et al. [22] considered the effect of freeze-thaw on the heave behaviour of fibre-reinforced expansive soil. Viswanadham et al. [23] investigated the swelling behaviour of geo-fibre reinforced expansive soil. Phanikumar and Singla [24] delved into the swell-consolidation behaviour of fibre reinforced expansive soils. Vessely and Wu [25] researched the feasibility of geosynthetic inclusion for reducing the swell of expansive soil. Loehr et al. [26] attempted to reduce the swell potential of soil with fibre reinforcement. The majority of these studies investigated the effect of random fibre reinforcement and its potential in reducing the swell of expansive soils. However, studies on the effect of the inclusion of geosynthetics as a whole in swell control are relatively rare. Hence, in this study, an attempt has been made to compare the effect of two types of geosynthetics (geotextile and geocomposite) in the swell control of an expansive soil with variations in the number of layers and orientation of the material. The primary objective of the work is to study the effectiveness of geosynthetics in controlling the immediate swell of an expansive soil.

2. MATERIALS USED

The materials used in this study are virgin expansive soil whose swell characteristics were investigated, together with geosynthetics adopted for controlling the swell of the soil. Figure 1 shows images of the materials used in the study. Both geosynthetic material samples were obtained from NAUE GmbH & Co. KG, Germany through a distributor located in Chennai, India.

Fig. 1. (a) Soil (b) ST and (c) CG

2.1. Soil

The soil used in this study was collected from the Tanjore district of Tamil Nadu, India. Visual examination of the soil showed it to be of dark brown colour with the presence of grains, based on its textural appearance and feel when rubbed between the fingers. The soil sample was tested in the laboratory and its properties are shown in Table 1. The degree of expansion was categorized based on the Bureau of Indian Standards (BIS) code.

2.2. Combigrid Geocomposite

Combigrid (CG) is a commercially available geocomposite comprised of a geogrid with needle-punched non-woven geotextile firmly welded between the grid bars and was used as available from the supplier. The properties of CG are tabulated in Table 2.

2.3. Secutex Geotextile

Secutex (ST) is a commercially available needle-punched staple fibre nonwoven geotextile. It was also used as available from the supplier. The properties of ST are tabulated in Table 3.

Table 1. Properties of Soil

Properties	**Values**	**Properties**	**Values**
Liquid limit (%)	59.2	Medium Sand (%)	12.6
Plastic limit (%)	27.9	Fine Sand (%)	11.3
Shrinkage limit (%)	9.9	Silt & Clay (%)	73.1
Free swell index (%)	66.7	Maximum dry density (kN/m^3)	15.5
Gravel (%)	0.6	Optimum moisture content (%)	22.0
Coarse Sand (%)	2.4	Degree of Expansion	Moderate

Table 2. Properties of CG (Grade 40/40 Q1 151 GRK3) [27]

Property	**Value**
Polymer Type	Polypropylene
Structure	Welded Straps
Ultimate Tensile Strength	40 kN/m
Ultimate Elongation	8%
Tensile Modulus at 1%	800 kN/m
Aperture Size	32 mm
Flexural Rigidity	750,000 mg-cm

Table 3. Properties of ST (Grade R601) [28]

Property	**Value**
Tensile Strength (MD)	30 kN/m
Tensile Strength (CMD)	45 kN/m
Elongation (MD)	50 %
Elongation (CMD)	40 %
Static Puncture Behaviour	7 kN
Dynamic Perforation Resistance	5 mm
Aperture Size	0.08 mm

3. METHODS

The soil sample was air-dried, crushed, and pulverized in accordance with the BIS Code [29]. Following this, the soil was sieved through the requisite sieves depending upon the test to be conducted. The soil was subjected to various geotechnical tests to determine its properties, all performed as per BIS, including Liquid and Plastic Limit [30], Shrinkage Limit [31], Free Swell Index [32], Grain Size Distribution [33], and Moisture Density Relationship [34].

Based on the liquid limit and plasticity index, the degree of expansion was also determined in accordance with BIS [35]. After preparation of the sample, a swell test apparatus for the determination of swell of the expansive soil was prepared in a California Bearing Ratio mould of diameter 150mm and height 175mm. The soil sample had a height of 127mm after allowing for the height of the spacer disc. The sample was prepared at maximum dry density and with optimum moisture content of the soil by using static compaction. No additional pressure was placed on top of the soil except for the self-weight of the loading plate. For the soil modified with the placement of geosynthetics, the samples were prepared in a similar way by placing geosynthetics at the required depth. The geosynthetic samples were cut to fit the circular cross-sectional area of the mould for horizontal placement and to the rectangular cross-section of the mould for vertical placement. A filter paper was placed at the top and bottom to prevent the movement of fine particles in the soil. The entire apparatus was immersed in a water reservoir to completely submerge the mould and the swelling of soil was then noted at regular intervals by means of a dial gauge for a period of 24 hours. The study limited itself to understanding the swelling and its control by use of geosynthetics in the early period of swelling, wherein the major portion of the swelling occurs. The parameters that varied were the type, number of layers, and orientation of the geosynthetics. The various combinations of number, orientation, and material are detailed in Table 4. The test set up is shown in Figure 2. The various positions of the geosynthetics are shown in Figure 3. Based on the results of the investigation, a long-term study can be initiated to investigate the full potential of geosynthetic inclusion in swell control. In order to facilitate uniform distribution of water to the soil mass, three layers were chosen (layer one at the top, layer two in the middle, and layer three at the bottom) as criteria while considering the number of layers for horizontal orientation. For vertical orientation, the layers were limited to two due to difficulties in installation and preparation of the specimens with three vertical crossed layers.

Table 4. Nomenclature of Various Combinations of Geosynthetics

Nomenclature	Number of Layers	Orientation	Material
1L-H-ST	1	Horizontal	ST
1L-H-CG	1	Horizontal	CG
3L-H-ST	3	Horizontal	ST
3L-H-CG	3	Horizontal	CG
1L-V-ST	1	Vertical	ST
1L-V-CG	1	Vertical	CG
2L-VC-ST	2	Vertical and Cross	ST
2L-VC-CG	2	Vertical and Cross	CG

Fig. 2. Test set up for swelling of soil

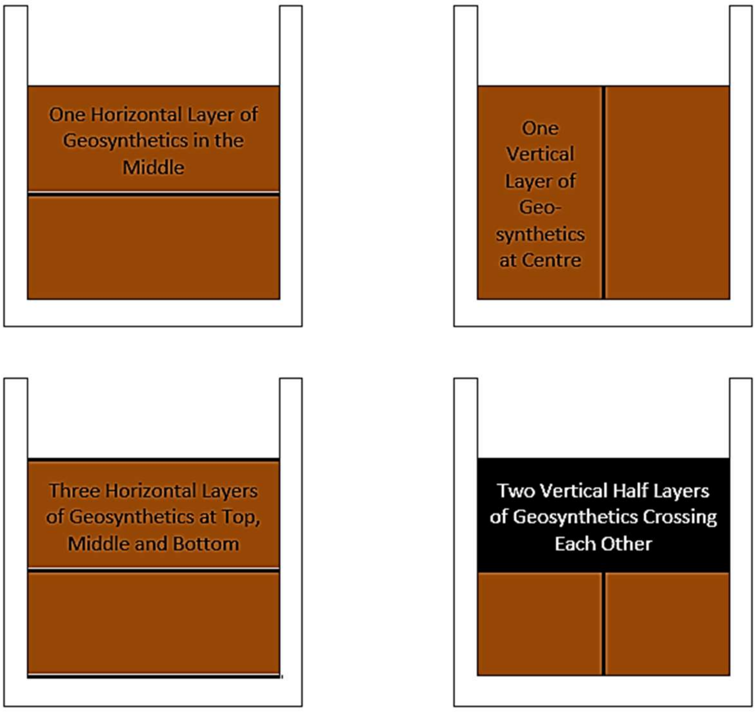

Fig. 3. Arrangements of Geosynthetics in Soil (Cross-Sectional View)

4. RESULTS AND DISCUSSION

The soil samples with and without geosynthetics were immersed into a water reservoir to study the swelling of the soil under various conditions. The plain soil specimen acted as a control specimen to compare the performances of the geosynthetics included in the soil. The swell test result for plain soil is shown in Figure 4. It can be seen from the shape of the curve that the swelling of the soil has clearly not reached equilibrium within the first 24 hours. Thus, the soil under investigation is capable of swelling further with prolonged exposure to moisture and is capable of causing distress over a longer duration of time. It needs to be seen how the inclusion of geosynthetics is going to modify the swell behaviour of this soil and consequently its effect on the swell curve of the soil, which has been discussed in the following sections.

4.1. Effect of Variation of a Single Parameter

At the outset, the effect of varying only one of the three parameters was analysed to study its influence on the swelling of the virgin soil. This was done by comparing the swelling of the virgin soil with that of geosynthetics-included soil, with the comparison allowing variation in only one parameter.

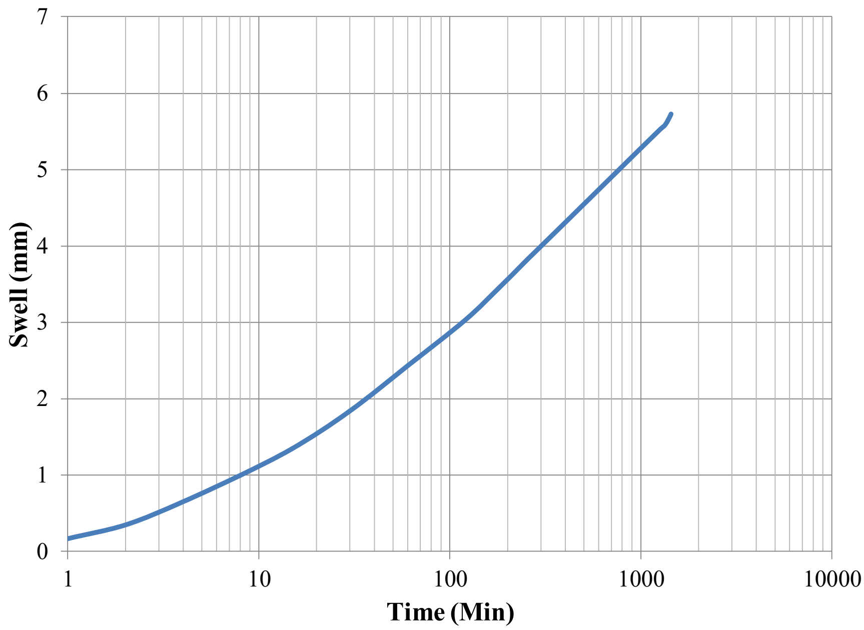

Fig. 4. Immediate Swell of Virgin Soil

4.1.1. Effect of material

Figure 5 shows the effects of the material on the potential to control the swelling of the soil. At the outset, it can be seen that the swell of the virgin soil steadily increases until 24 hours pass, whereas the geosynthetics-embedded soil specimens show a change in the rate of swelling before 24 hours, as seen from the flattening of the curve for both 1LHST as well as 1LHCG. However, it can be seen that when only one layer of material is placed centrally, the effect of the material is clearly in favour of ST when compared to CG. There is a clear reduction in the swelling of the virgin soil when one layer of ST is centrally embedded in the soil, whereas, a similar embedding with one layer of CG resulted in increased swelling of the soil. It can also be seen that the flattening of the curve starts early for ST when compared to CG, thereby indicating an early reduction in the rate of swelling. The geocomposite CG offers greater soil reinforcement when compared to swell control. The inclusion of CG may have resulted in the splitting of the soil mass into two separate entities with each swelling occurring on its own, which indicates the sum of two soil mass swell characteristics instead of a single soil mass. On the other hand, the geotextile ST may have had a better interaction with the soil due to its uniform surface texture.

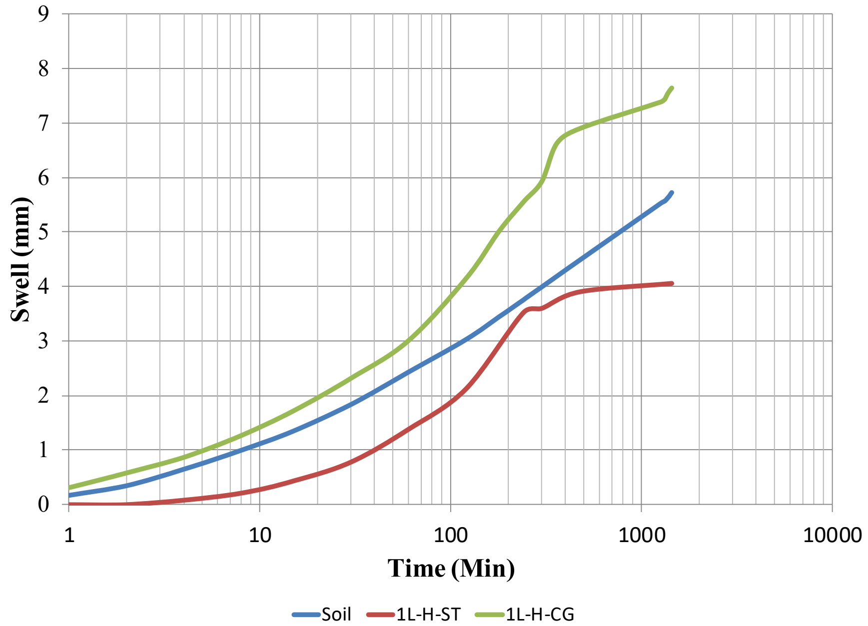

Fig. 5. Swell of Soil Embedded with 1 Layer of Geosynthetics

4.1.2. Effect of number of layers

Figure 6 shows the effect of the number of layers when ST was used for swell control. It can be seen that the provision of three layers of ST was not able to produce better swell control when compared to a centrally placed single layer. Even the change in the rate of swelling is better for 1LHST when compared to 3LHST, as seen from the flattening of the curve. The former shows a clear change in the slope of the curve, whereas, the latter indicates just the initiation of the change in the rate of swelling. When a single layer is placed centrally, the water entering through the top and bottom pores has immediate access only to the soil very close to the pores; it takes more time for the water to spread laterally and reach the entire area of the soil in contact with the top and bottom plates. This may have resulted in reduced swelling due to lesser access to moisture within the available time. However, when geotextile is placed at the top and bottom, it would have distributed the water entering through the pores at the bottom and top more evenly due to the geotextile acting like a drain and conveying the water within the body of the geotextile in the lateral/radial direction. As a result, there is more access to moisture due to the continuous movement of water within the body of the geotextile as it is more permeable when compared to the soil. This may be the reason for enhanced swelling when three layers of geotextile were provided.

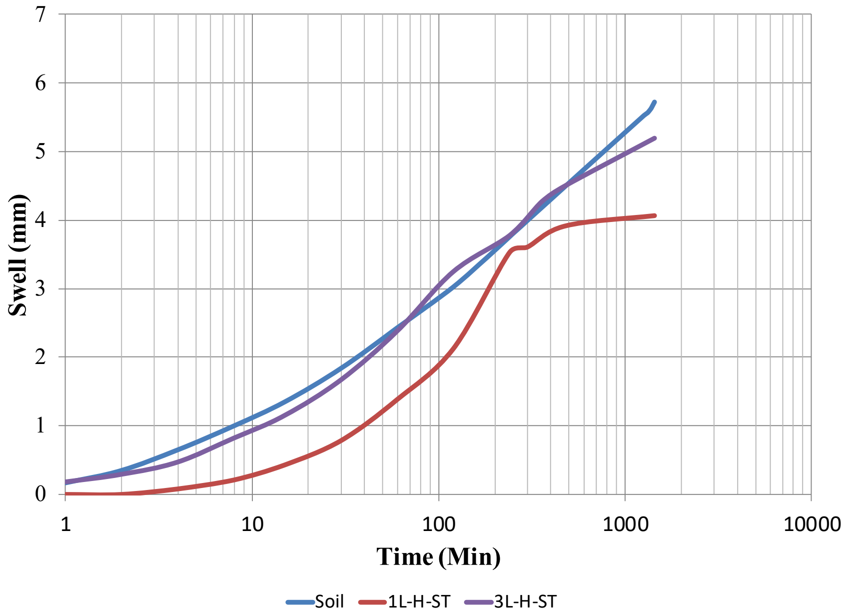

Fig. 6. Swell of Soil Embedded with 1 and 3 Layers of ST

Figure 7 shows the effect of three layers of CG on the swelling of the soil. It can be seen that the result of providing three layers of CG is in contrast with that of ST. Both 1LHCG and 3LHCG show a similar swell pattern but the extent of swell is far less in the latter. When three layers of CG were used, the layers at the top and bottom interacted with moisture first. In contrast to ST, CG is made up of a combination of polymer strips and geotextile as a result of which it cannot smoothly convey moisture across its body like ST. Secondly, the available area that is permeable is less than ST due to the presence of impermeable polymer strips. Thus, access to moisture is also reduced, thereby, controlling the swell of the soil at the top and bottom which contributes to an overall reduction in swelling of the soil.

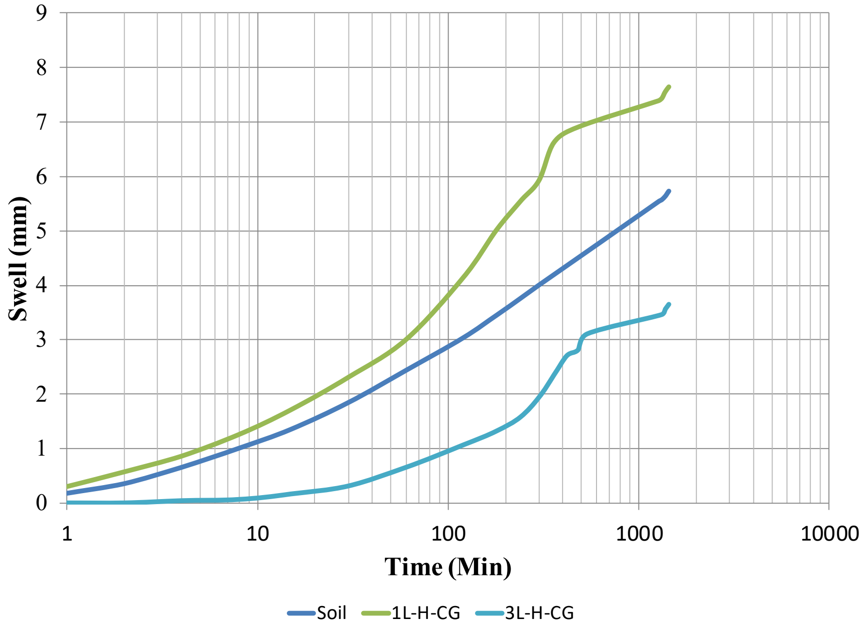

Fig. 7. Swell of Soil Embedded with 1 and 3 Layers of CG

4.1.3. Effect of orientation

Figure 8 shows the effect of orientation of the geosynthetics adopted for swell control. It can be seen that the swelling at the end of 24 hours is more or less the same when the orientation of the geosynthetics layer was altered. However, when the layer was placed in a horizontal orientation, the swelling rate reduced in less time compared to vertical orientation. Thus, there is the possibility of continued swelling when the geosynthetic material is placed in a vertical orientation. When ST was placed in a vertical orientation, it provided a channel for water to travel quickly to the deeper depths of the soil specimen and, hence, increased the access of moisture to the soil sample. However, when the soil sample tries to swell and increase in volume in the vertical direction, the friction developed in the soil mass between the wall (mould) and the geosynthetic layer resisted the swelling. The swelling seen when vertical orientation is adopted is a result of these two possible effects due to ST placed in a vertical orientation. Depending upon the dominance of either the quick access to moisture or the frictional interaction between the soil and the geotextile, the resultant swelling can vary. The likelihood of continued swelling, when exposed to moisture over a longer time, may be due to reduced interaction and possible loss of contact between the soil and geotextile as swelling progresses with continued access to moisture. However, more detailed investigations are necessary to form more reliable conclusions regarding the effects of vertical orientation of geosynthetics. Figure 9 shows the effect of orientation when one layer of CG was placed in different orientations.

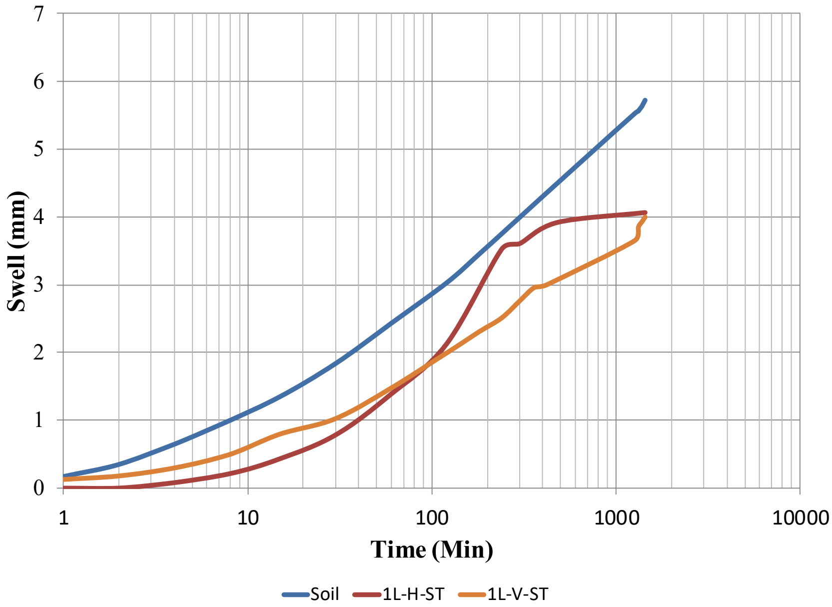

Fig. 8. Swell of Soil Embedded with 1 Layer of ST with Different Orientation

It can be seen that there is not much difference between the swelling when the orientation was changed in the case of CG. There is, however, a small flattening of the swelling in the case of vertical orientation but that does not influence the quantum of swelling at the end of 24 hours. It can be seen that there is no significant influence of orientation on the immediate swell control of the soil when the geosynthetic adopted is CG. This may be due to the fact that CG is interspersed with smooth polymer grids which may not offer much frictional resistance to the swelling of the soil, thereby reducing the effect of swell control offered by a plain geotextile when compared to a geocomposite. Moreover, vertical installation of ST is more difficult when compared to CG due to the difference in stiffness of the two materials. The ST is more likely to buckle into a wavy pattern during compaction when compared to the CG. The effect of this can be seen by comparing figures 8 and 9, wherein the swelling of CG was greater when compared to ST. The wavy undulations of the ST would have offered more resistance to swelling when compared to the CG.

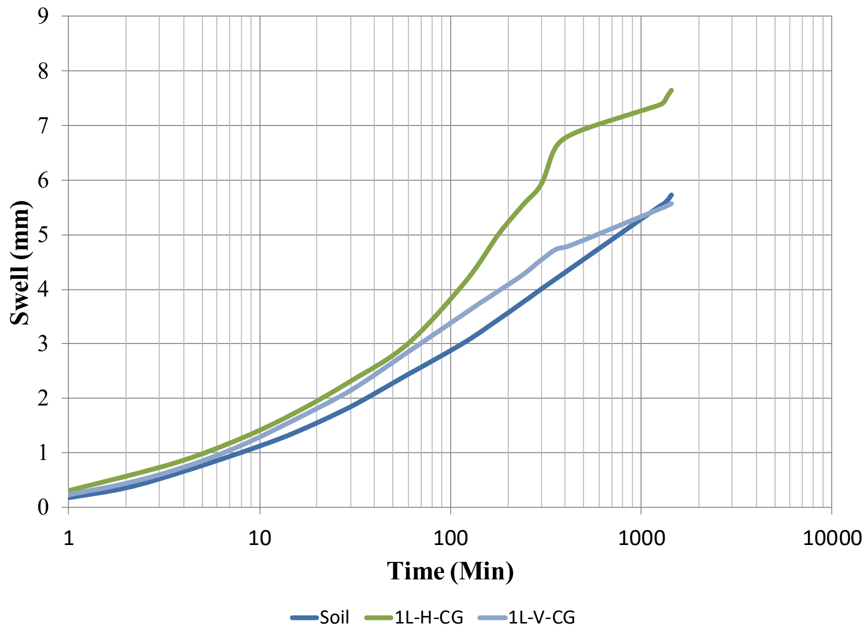

Fig. 9. Swell of Soil Embedded with 1 Layer of CG with Different Orientation

4.2. Effect of Variation of Two Parameters

The next level of comparison was performed by fixing one parameter and varying the other two parameters. With three parameters investigated, a total of three different combinations wherein one parameter was fixed and the other two were varied was possible. These combinations have been discussed one by one in the following sub-sections.

4.2.1. Combined effect of material and layers

In order to study the effects of combining different types of geosynthetics and numbers of layers for swell control, the most conservative combination was selected. In the case of the material, comparing ST and CG, CG was less effective in swell control when a single layer was provided; however, when multiple layers were provided, 3LHST was less effective. Thus, the two worst-case scenarios were selected for comparing the combined effect of material type and number of layers. Figure 10 shows the combined effect of material type and number of layers when 1LHCG is replaced with 3LHST for swell control. It can be seen that there is a drastic reduction in swelling when the effect of material type and number of layers combine for swell control of the soil. However, it should be noted that the reduction in swelling seems significant only because the use of 1LHCG actually resulted in swelling higher than in the virgin soil by 33.51%. Compared to the virgin soil, the reduction in swelling achieved after a period of 24 hours by the combination of change in material type as well as number of layers is marginal, though still a reduction of 9.25%. To have a better understanding of the combined effect of material and number of layers, the corollary of the above combination was also analysed i.e. 1LHST and 3LHCG.

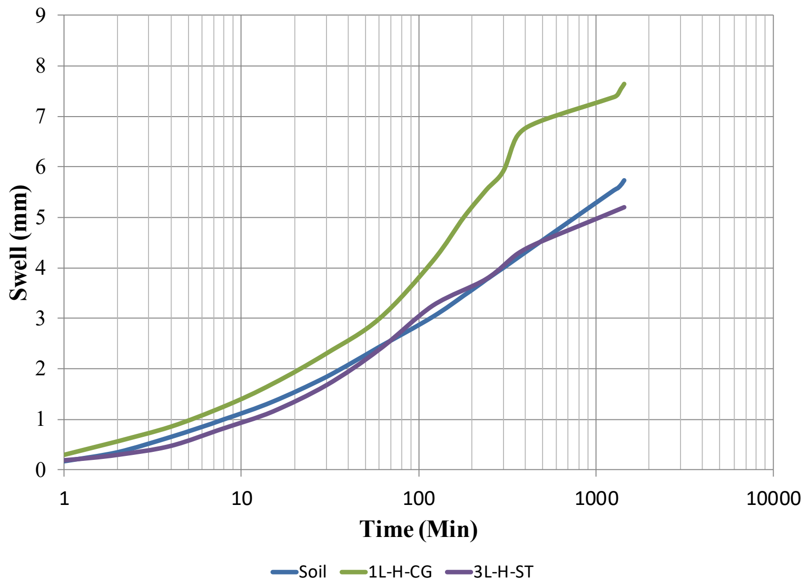

Fig. 10. Swell of Soil Embedded with 1 Layer of CG and 3 Layers of ST

Figure 11 shows the swell control achieved by the corollary combination of 1LHST and 3LHCG. At the outset, it can be seen that both 1LHST and

3LHCG are capable of reducing the swelling of virgin soil. There was a reduction in swelling of 29.14% in the case of the former, whereas, it was 36.13% in the case of the latter. Hence, it is also clear that using 3 layers along with a different material type is capable of further reducing swelling. There was an early reduction in the slope of the swell curve for 1LHST at around 300 minutes as compared to 500 minutes for 3LHST. This is an indication of a slowing in the rate of swell; however, the actual quantum of swelling in the period before this was higher for 1LHST when compared to 3LHCG, the cumulative effect of which can be seen at time periods of 300 minutes and 500 minutes, respectively, resulting in the former swell curve lying above that of the latter. Thus, it can be seen that 3LHCG starts controlling the swelling from its initial stages resulting in better swell control at any particular time position within the zone of investigation. Considering both the combinations of material and layers, it can be stated that the combined effect of material type and number of layers results in a significant improvement in the swell control achieved by geosynthetics inclusion. However, the right combination, depending upon the surface characteristics and stiffness, will help in determining the right choice for a given soil.

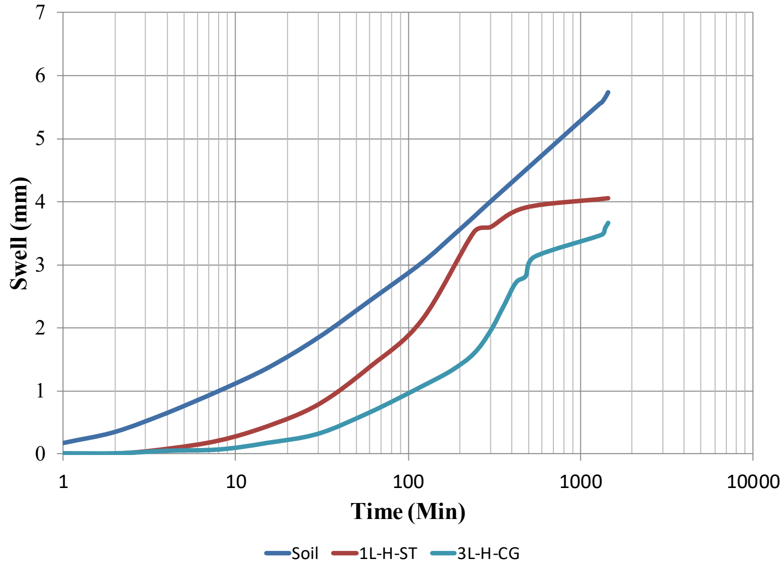

Fig. 11. Swell of Soil Embedded with 1 Layer of ST and 3 Layers of CG

4.2.2. Combined effect of layers and orientation

In order to combine the effect of layers and orientation, the worst case of 1LHCG was selected as one combination. To include the effect of number of layers and orientation, 2LVCCG was selected, in which the layers increased from 1 to 2 and the geosynthetics were placed in a vertical orientation but essentially keeping the material the same. Figure 12 shows the combined effect of number of layers and orientation in the swell control of the virgin soil. It can be seen that there is a significant improvement in the swell control, amounting to 44.15%, when the number of layers is increased together with a change in the orientation from horizontal to vertical. When 1LHCG was used, the swell control was actually ineffective, with the swelling of the soil being greater than the virgin soil. However, the effectiveness of CG drastically improves when the number of layers and orientation of CG is changed. As noted earlier, when 1LVCG was used, it controlled the swelling much better than 1LHCG, but the swelling of the former was only comparable to that of virgin soil without any significant swell control. In the present case, when the number of vertical layers was increased to 2 and crossing each other, the swell control achieved was significantly better than 1LVCG. These two criss-crossed vertical layers may have impeded the free swelling of the soil, especially the lower half of the specimen, encountering additional frictional resistance from two more planes of the top vertical layer. In addition, the soil mass was further divided from a single mass to four small masses with the added intrusion of CG, which is a less permeable material, offering less contact of water to soil, therefore, the tendency for swelling is restricted.

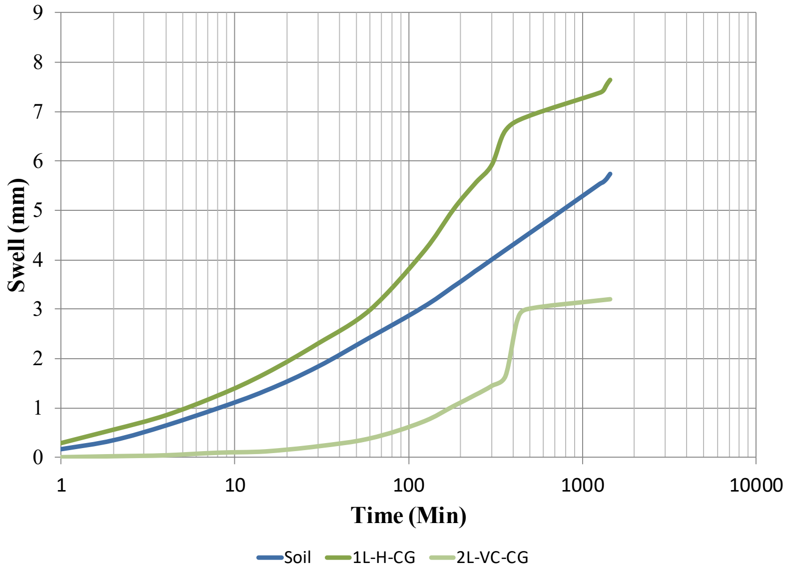

Fig. 12. Swell of Soil Embedded with 1 Horizontal Layer
and 2 Vertical Cross Layers of CG

To better understand the trends of the combined effect of layers and orientation, the effect was also analysed in the other material, ST. Figure 13 shows the combined effect of layers and orientation but for the material ST. It can be seen that the combined effect results in a further reduction in swelling, from 4.06 mm to around 2.31 mm. Comparing the swelling of virgin soil, the combined effect produces a 59.69% reduction in swelling in the soil due to geosynthetic inclusion, whereas the same cannot be said for the use of CG wherein the reduction in swelling looked drastic compared to 1LHCG and 2LVCCG, but less so when the swelling in virgin soil and 2LVCCG were compared. As mentioned earlier, the buckling of ST when preparing samples may have introduced wavy undulations in the geotextile during sample preparation which, in combination with the effect of two criss-cross layers, may have reduced swell even further when compared to CG.

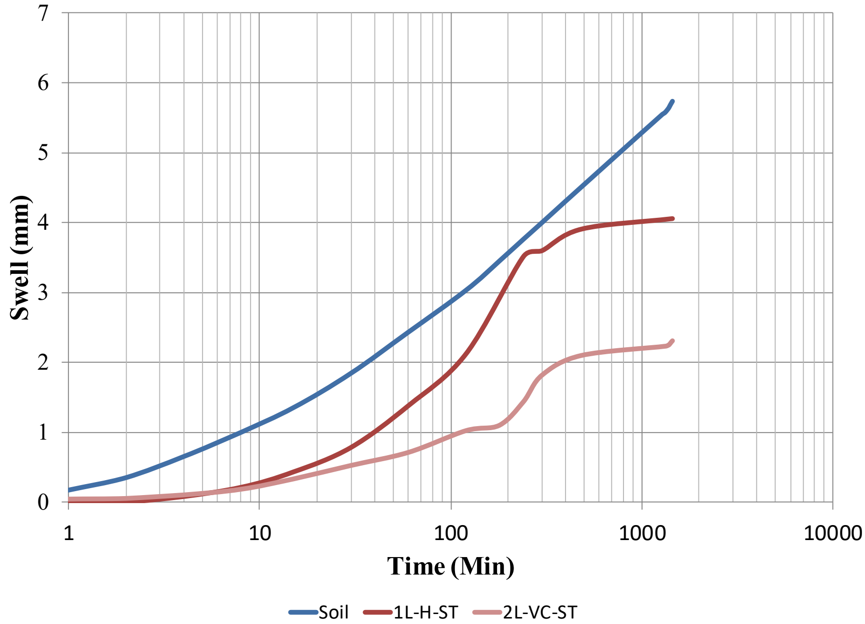

Fig. 13. Swell of Soil Embedded with 1 Horizontal Layer and 2 Vertical Cross Layers of ST

4.2.3. Combined effect of material and orientation

The combined effect of material and orientation was studied by considering the two different geosynthetic materials in different orientation but provided in only one layer in the soil. As in the earlier cases, the worst example of 1LHCG was taken and compared with 1LVST in order to bring in the effect of material and orientation. Figure 14 shows the combined effect of material and orientation on swell control achieved by the inclusion of geosynthetics. The change in material and orientation does give an improvement in the swell control achieved. In comparison with virgin soil, there was a 30.19% reduction in the swelling of the soil. In the case of the complementary combination, wherein 1LHST was compared with 1LVCG, there was a very marginal reduction of 2.97% in swelling of the soil. Thus, the effect of material and orientation was not so significant when the material was changed from ST to CG, and the change in orientation enabled only minor improvement in swell control.

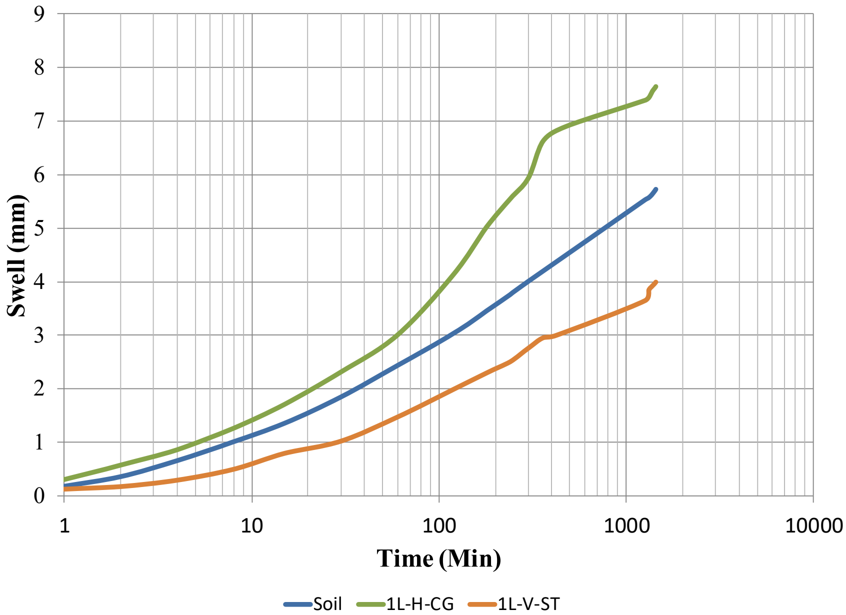

Fig. 14. Swell of Soil Embedded with 1 Horizontal Layer of CG
and 1 Vertical Layer of ST

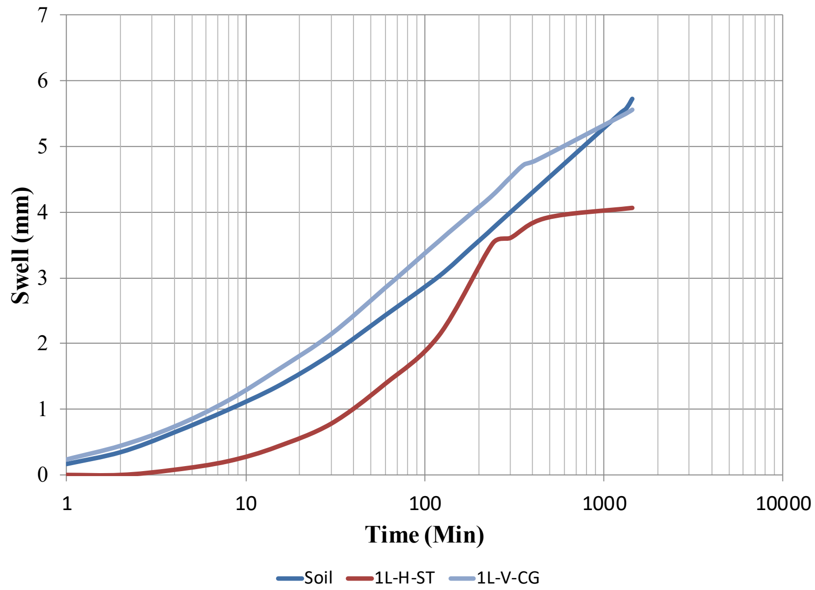

Fig. 15. Swell of Soil Embedded with 1 Horizontal Layer of ST and 1 Vertical Layer of CG

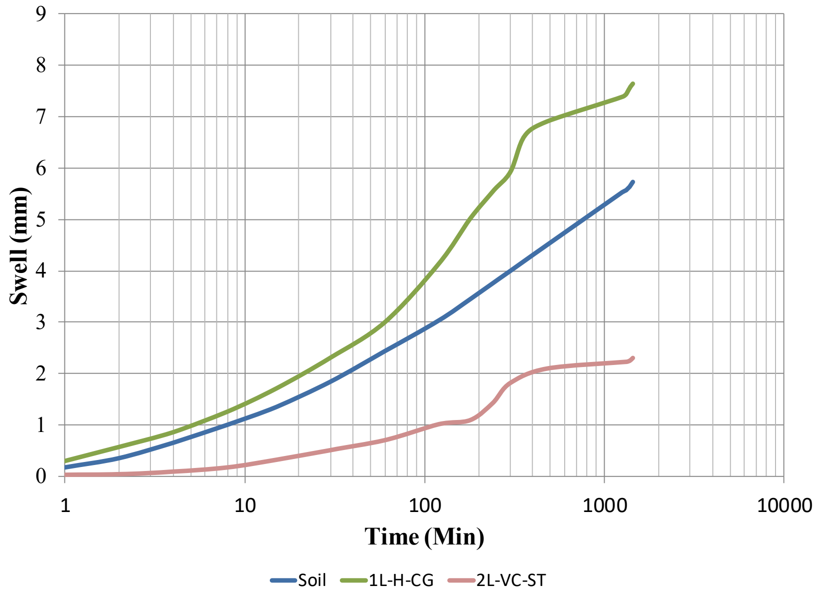

Fig. 16. Swell of Soil Embedded with 1 Horizontal Layer of CG and 2 Vertical Cross Layers of ST

4.3. Variation of All Parameters

The final stage of comparison was to combine the effect of all three parameters of material type, number of layers, and orientation of layers. This was achieved by comparing 1LHCG with 2LVCST, wherein the material type was changed from CG to ST, the number of layers was increased from 1 to 2, and the orientation was changed from horizontal to vertical. Figure 16 shows the combined effect of all three parameters. It can be seen that the combined effect produces a significant reduction in swell control. When the virgin soil was included with 1LHCG, the swelling increased by 33.51%. When the geosynthetic-type layers and orientation were changed, the swelling reduced from 7.65 mm for 1LHCG to 2.25 mm for 2LVCST, which is a 69.80% reduction in swelling. When compared to the virgin soil, the swelling reduction achieved was 59.69%. Thus, combining the various parameters results in a significant reduction in the swelling of the soil. When the reverse combination of 1LHST was compared with 2LVCCG, the reduction in swelling was found to be 44.15% when compared to virgin soil and 21.18% when compared to 1LHST.

4.4. Limitations of the Study

The study attempted to evaluate the controlling ability of geosynthetics on initial swelling of the soil wherein the swells were evaluated for a period of only 24 hours. In reality, the swelling of an expansive soil continues for a much longer duration of time and, hence, the results of the investigation cannot be extrapolated for longer durations of time with absolute certainty. Secondly, the swell test in the laboratory was carried out in a confined chamber limited to one-dimensional swelling whose behaviour may be significantly different from a soil deposit in the field extending infinitely in all directions and swelling three dimensionally. Lastly, installation of geosynthetics in a vertical alignment was extremely difficult and could not be maintained in a perfect vertical alignment in the laboratory. The installation of geosynthetics in vertical alignment in the field may be all the more difficult without a proper technique for installation.

5. CONCLUSIONS

Geosynthetics are used as separators, reinforcement, filters and drains, and containment in general. A laboratory study was attempted to understand the performance of geosynthetics in swell control. The material, it's orientation, and the number of layers were the parameters taken into account. Based on the investigations carried out, the following conclusions can be drawn:

i. Out of all combinations of the three parameters adopted in the investigation, barring one, all combinations resulted in reduced swelling of the soil. Thus, it can be stated that swelling in expansive soil can be controlled by using geosynthetics.

ii. Comparing the two materials, ST and CG, ST was able to control swelling more effectively when compared to CG. Even when considering all the other combinations, barring one case, ST was able to control swelling better when compared to CG. This may have been due to the surface characteristics of ST which may have provided a better interaction of water with soil when compared to CG. Thus, it can be concluded that ST can provide better swell control than CG.

iii. When the number of layers was increased from one to two and then three, there was a general reduction in swelling of the soil. This was true for both the materials as well as orientations barring one odd case. Thus, it can be stated that an increase in the number of layers of geosynthetics can result in better swell control.

iv. Apart from the above two parameters, the placement of the geosynthetics has a major influence. Vertical placement of geosynthetics gave better results in terms of swell control when compared to horizontal orientation, which may have been due to the combined effect of splitting of the soil mass and the direction of swelling allowed. This was also true for variations in the other parameters as well. However, it should be noted that vertical placement in the laboratory conditions itself was achieved with great difficulty and with lesser accuracy when compared to horizontal placement. Thus, it can be stated that vertical placement can control swelling better in expansive soils compared to horizontal placement, but placement difficulties will be encountered which will influence the final efficacy of the alignment. Based on the first three conclusions, it can also be stated that all three parameters; material, orientation, and number of layers will influence the efficacy of swell control achieved.

v. It was found that 2 layers of vertical cross-combination of ST and CG and 3 layers of CG placed horizontally at the top, middle, and bottom were the best combinations, resulting in 60%, 44%, and 36% reduction in swelling, respectively. The swell control achieved by geosynthetics may be due to an increase in soil stiffness and better moisture distribution control in the soil due to the introduction of the geosynthetics. Thus, it can also be stated that the efficacy of swell control will vary with the combinations of parameters adopted, rather than a steady reduction in swell with an increase in parameter combinations.

In overall conclusion, as a bottom line, it can be stated that choosing the right combination of material, orientation, and layering can definitely reduce swelling in expansive soils.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest in the publication of this article.

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