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A new improvement technique for expansive soils

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ABSTRACT

In this study, a Unified Soil Improvement Technique (USIT) that consists of prewetting, calcium lignosulphonate lime piles, fabric, and soil nail was applied to an expansive soil specimen to both accelerate the process and increase the effect of these techniques. 19 boreholes that had 0.45 cm diameter and 1.9 cm height were opened into an expansive soil specimen in an oedometer ring. Then, these boreholes were filled with a calcium lignosulphonate-water mixture prepared in a liquid form during the prewetting process. Thereafter, these boreholes were filled with a mixture including calcium lignosulphonate, water, and lime. Finally, a fabric was laid down over this specimen and seven pieces of soil nails were used for connecting the fabric and the lime piles. To sum up, the swelling potential of expansive soil specimens under 7 kPa decreased from 43.95 % to 1.58 % after 28 day curing period. The CBR swell of the USIT specimens, which waited in the humid room for 90 days, was measured as 1.14% under 7 kPa surcharge pressure and was measured as 0.4% under 25 kPa surcharge pressure. The significant changes in the swell potential values suggest that the Unified Soil Improvement Technique's performance is better than calcium lignosulphonate-added lime piles in the improvement of expansive clays.

Keywords: *Calcium Lignosulphonate; CBR Swell, Expansive Soil; Lime Pile; Prewetting; Soil Improvement; Swell.*

INTRODUCTION

Expansive soils, which are called problematic soils due to their volume change capacity due to the change in water contents of them, is present in many parts of the world. The damages of these soils can be seen on lightweight structures such as roads, pipelines, one-story buildings, etc. Although these damages do not lead to the loss of life, they annually give rise to a significant economic loss in the whole world [1,2].

Many improvement techniques have been developed to minimize the damage caused by the expansive soil for the last decades. These techniques include chemical additives, prewetting, soil replacement with compaction control, moisture control, surcharge loading, and thermal methods [3].

The prewetting technique is that the water content of the soil is increased before the construction to block the volume change of the soil. Under field conditions, enabling the soaking process to be executed within a short time period and maintaining the soil at high moisture levels constantly is far from attainable as stated by Nelson et al. (2015) [1]. Time is a considerable factor in the achievement of this technique applied in expansive soils, as it may take a long time to see the effect of this method. Since it takes a long time to transmit water to deeper soil particles due to low hydraulic conductivity. Therefore, the sand drain technique has been generally used to solve this problem [3,4].

Lignosulphonates, which are by-products of the paper industry, are materials that are usually used in many different industries from oil production to construction. These waste materials with water-soluble properties are derived from lignin, a wood part. Moreover, the basis of the categorization process depends on the complex polymer of the wood as the properties and chemical composition of lignin vary to wood types. This material is generally categorized as calcium lignosulphonate, magnesium lignosulphonate, sodium lignosulphonate, etc concerning their chemical compositions of them. Annual production of lignosulphonate is 50 million tonnes in the world. However, very little amounts of these materials have been used as agriculture chemicals, industrial binders, and water reducers in different

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areas. For example, the addition of these waste materials into soils results in the reduction of water evaporation. In another example, concrete that includes lignosulphonate is more fluid than concrete without lignosulphonate. They are mostly found in two different types that are powder and liquid in the market [5-8].

Some studies related to the utilization of lignosulphonate in geotechnical engineering have been done for the last decades. Tingle and Santoni (2003) explained that the unconfined compressive strength of low- plasticity clay improved with the addition of lignosulphonate [9]. For example, the unconfined compressive strength of this clay was increased approximately five times with the addition of lignosulphonate. An unconfined compressive strength of marl soil specimens was increased with the addition of lignosulphonate. In addition to this, the improvement percentage occurred of this parameter of marl soils also heightened with the curing period [10]. Tingle (2007) stated that the swelling potential of clay soil decreased with the addition of any type of lignosulphonate [11].

The addition of lignosulphonate into erodible soil resulted in both the rise of critical shear stress and the reduction of soil erosion coefficient [12]. Under cyclic loading, the deformation behavior of sandy silt was enhanced with the addition of lignosulphonate [13]. The lignosulphonate stabilization process of clay soil ended up with both the reduction of diffuse double-layer thickness and the declination of soil dispersivity [14].

The lime pile technique, which has been applied either dry or wet, has been generally used for the improvement of soft soil. Studies related to this technique have been divided into two parts that are soil stabilization and lime diffusion into the soil. Lime diffusion into the soil is the main problem of this technique as diffusion velocity is very slow. For example, the velocity of lime diffusion into soil that has no extensive cracks and fissures was determined as 12.5 mm/year. A study shows that the addition of lignosulphonate into the lime pile increased the velocity of lime diffusion. A study done by Gnana et al. (2022) stated that the fly ash addition to lime pile enhanced the strength properties of expansive soil specimens [15-19].

Geotextile is a material that has been utilized for many geotechnical applications such as reinforcement, drainage, slope stability, and separation. Geotextile application on expansive soil results in the reduction of swelling pressure. For example, the lime-treated coir geotextile reduces the upward swelling pressure of the expansive soil layer by approximately 52.19% in single-layer and 81.89% in double-layer. The percentage swell rate of expansive soil also reduced by 77.59% and 94.53% with a single-layer and double-layer of lime-treated coir geotextile, respectively [20-24].

Soil nails that are referred to as ground anchors have been reinforced for the enhancement of soft soil [25]. In general, the soil nail is not used in the improvement of the stabilization of expansive soil. In this study, the soil nail will be used as a connecting material between the lignosulfonate lime column and the geotextile.

Madhyannapu, R.S., and Puppala, A.J., (2014) studied the effectiveness of Deep Soil Mixing (DSM) technology in mitigating the swell behavior of an expansive subsoil under actual field conditions and found that the DSM technology was effective in mitigating the swell behavior of the expansive subsoil [26].

Techniques of expansive soil stabilization that are mentioned above have been commonly preferred and applied in the field. However, the achievement of these techniques depends on many factors, especially time. An essential aim of this study is the solution of the time factor by combining improvement techniques that are prewetting, lignosulphonate lime column, and geotextile-soil nailing (Figure 1).

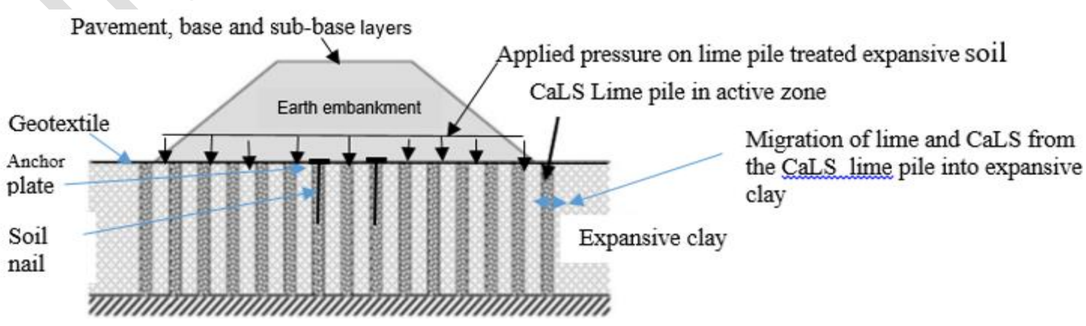

Figure 1. Unified Soil Improvement Technique under the pavement and embankment load

EXPANSIVE SOIL SPECIMEN

The expansive soil specimen used in this study was obtained by mixing kaolinite and bentonite in the laboratory (it is called KB). The dry weight percentages of both kaolinite and bentonite were selected as 85% and 15%, respectively. KB is high plasticity clay according to the Unified Soil Classification System. The dry density and water content of KB were selected as 1.495 Mg/m^3 and 15%, respectively. The properties of KB are given in Table 1.

Table 1. Properties of kaolinite and bentonite (KB) mixture

Properties, (Unit)	**Value**	**Properties, (Unit)**	**Value**
Specific gravity	2.56	Maximum dry density (Mg/m^3)	1.495
Liquid limit (%)	95.2	Swelling potential under 7 kPa (%)	43.95
Plastic limit (%)	23.2	Swelling potential under 25 kPa (%)	29.47
Plasticity index (%)	72.3	Swelling pressure (kPa)	265
Clay content (%)	57	Unsoaked CBR (%)	51.52
Activity	1.27	Soaked CBR (%)	1.31
Optimum water content (%)	26	CBR swell at soaked condition (%) under 7 kPa	40.3

KB is classified as having high swelling potential concerning Seed et al. (1962) [27]. The soaked CBR value and CBR swell value of KB specimens do not fulfill the criteria for the subgrade material specified in Highways Technical Specification (HTS, 2013), and the soil stabilization/improvement required (in a case where the soaked CBR value < 10% and CBR swell % > 3%) [28]. The methods, which consisted of prewetting, calcium lignosulphonate lime pile, and fabric-soil nails, were used to improve the properties of KB.

EXPERIMENTAL WORK

The first part of the experimental work was based on the free swell test and the second part is related to Unified Soil Improvement Techniques (USIT).

The Free Swell Test

The swelling potential is a considerable parameter of expansive soil, free swell tests were done on specimens prepared at this part for measuring the achievement of improvement methods used in this study. All specimens prepared at this part had 63.5 mm diameter and 19 mm height. 7 kPa surcharge pressure was applied to all specimens prepared in this study. All tests were done in this part according to ASTM D4546 [29].

The part of this study formed three subtitles that were prewetting, lignosulphonate lime pile, and fabric-soil nails.

Prewetting

The dry density of KB was prepared at maximum dry density, 15% water content. The water content of KB (15%) is too low considering its optimum water content (26%). For this reason, the water content of KB was increased from 15% to 26.5% (optimum water content) by applying a prewetting process. During the process, a calcium lignosulphonate (CaLS) -water mixture instead of water was added to KB. The water loss of soils that resulted from evaporation could be diminished by adding lignosulphonate [30]. However, the density of this mixture was increased with the addition of lignosulphonate. For this reason, the calcium lignosulphonate-water mixture consisted of 98%

water and 2% calcium lignosulphonate. To investigate the effect of the curing process, the specimens prepared in this study waited in a humid room that maintains a humidity greater than 95% for 1 day, 7 days, and 28 days.

Ca Lignosulphonate Lime Pile (LLP)

Treated specimen with Ca lignosulphonate lime pile (LLP) involved 37 pieces pile that had 4.5 mm diameter and 19 mm height. Each pile was filled with a CaLS lime pile mixture. The properties of lignosulphonate lime piles constructed in KB are given in Table 2.

Table 2. The properties of Ca lignosulphonate lime piles (LLP)

Pile distance center to center (1.9 D) (cm)	Pile diameter (D) (cm)	Pile Length (H) (cm)	Pile area ratio (%)	All piles Volume (cm^3)
0.855	0.45	1.9	20.91	11.18

This mixture consisted of lime, calcium lignosulphonate (CaLS), and water. Figure 2 illustrates both Ca Lignosulphonate LP (LLP) in the oedometer ring and CaLS lime mixture.

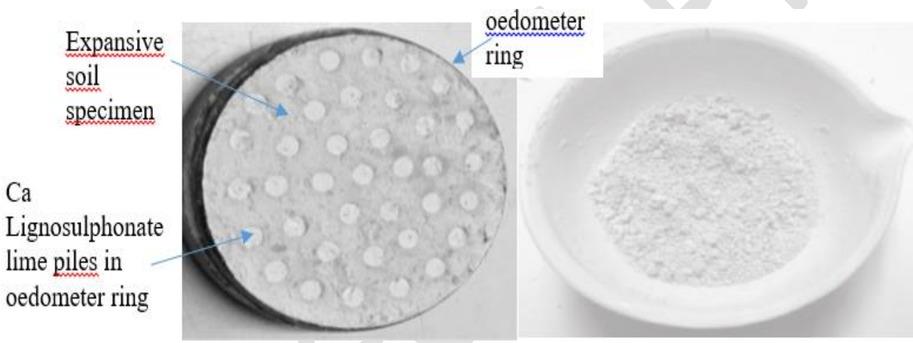

Figure 2. Ca Lignosulphonate lime pile (LLP) (left) in oedometer ring and CaLS lime mixture (right)

The weight percentages of the CaLS lime pile mixture are given in Table 3.

Table 3. The weight percentage of the calcium lignosulphonate lime pile mixture

Percentage by weight (%)	Water	Calcium lignosulphonate (CaLS)	Lime
	30%	3.75%	66.25%

The amount of both water and calcium lignosulphonate in this mixture increased lime diffusion into expansive soil [18]. Treated specimens prepared at this part were waited in the humid room for 1 day, 7 days, and 28 days to observe the effect of the curing period.

Fabric and Soil Fasteners

The free swell test was done on specimens that had 63.5 mm diameter and 19 mm height, these dimensions were very small concerning field conditions. For this reason, a piece of nonwoven fabric instead of geotextile was used to model geotextile. A fastener, which was nonrusting metal and had 8 mm height and 9 mm top diameter, was used to model soil nailing and an anchor plate for connecting fabric and Ca lignosulphonate lime piles. The specimen treated with both fabric and soil fasteners/soil nail+nut was called GSN in this study.

Swelling Potentials of Treated Specimens

The swelling potentials of treated specimens were calculated according to data obtained from the free swell test done under 7 kPa surcharge pressure. These swelling potentials of treated specimens with either prewetting or Ca Lignosulphonate Lime Pile (LLP) techniques are given in Figure 3. It was observed that there are significant changes in the swelling percent of the treated soils due to the clay–lime reactions and clay-CaLS reactions in the Ca lignosulphonate lime pile technique.

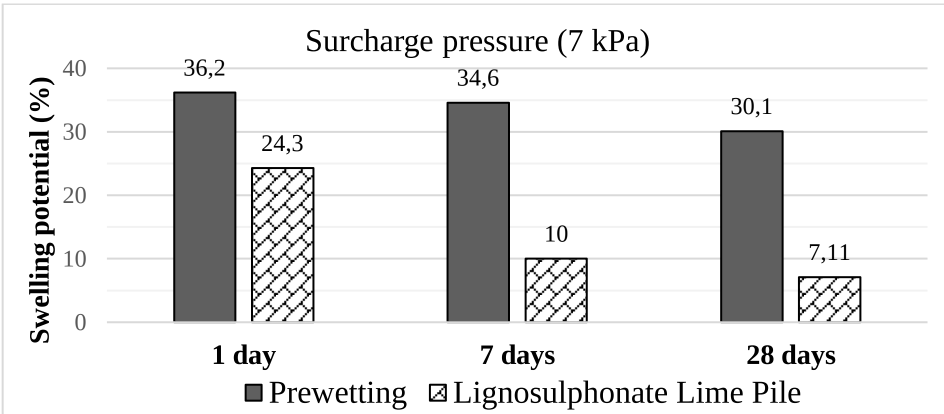

Figure 3. Swelling potentials of treated specimens with either prewetting or LLP

The swelling potentials of KB decreased with both prewetting and LLP techniques. In addition to this, these falls continued with the curing period for both techniques. LLP technique was more effective than prewetting for this study. However, the falls obtained from the 28-day curing period were not sufficient for the stabilization of expansive soils, and do not meet the required criteria.

Unified Improvement Technique (USIT)

The Unified Improvement Technique (USIT) was formed by combining techniques that are prewetting, Ca lignosulphonate lime pile, and fabric+soil fasteners. This technique was named The Unified Improvement Technique (USIT). But, during the installation of soil fasteners to the lime piles, damage occurred to the nearby lime piles, to solve this problem, the number of piles at the LLP technique was reduced from 37 to 19 (Figure 4) and the distance between fasteners was determined as 6D (2.7 cm). Thus, the quantities of piles installed in specimens were felt by half of the LLP technique.

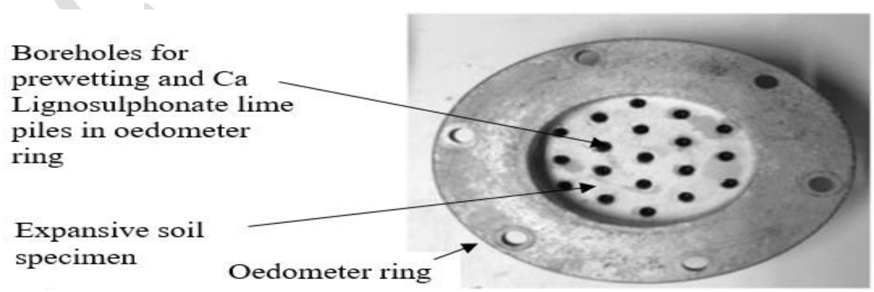

Figure 4. Number of piles in oedometer ring for USIT technique

The reduction of pile number installed in KB causes some parameters related to piles. Table 4 shows the parameters related to piles installed in the USIT specimen in this study.

Table 4. Parameters related to calcium lignosulphonate lime piles installed in USIT specimen

Parameters	USIT
Pile distance center to center (cm)	1.35 (3D)
Pile area ratio (%)	10
All piles volume (cm^3)	5.74

The center-to-center distance of piles installed in the USIT specimen increased concerning the LLP specimen. Thus, both the area ratio and volume of piles installed in the USIT specimen are lower than in the LLP specimen. The installation cost of the USIT specimen is reduced compared to the LLP specimen.

Preparation of USIT specimen

Nineteen boreholes were opened into the USIT specimen before Prewetting, and the LLP and GSN techniques were applied, respectively.

Each borehole was filled with the calcium lignosulphonate-water mixture during the prewetting process. Boreholes were saturated by this mixture (Figure 5). After this process, the water content of KB was increased from 15% to 26% (optimum water content of KB). This process took a while due to the low permeability of KB.

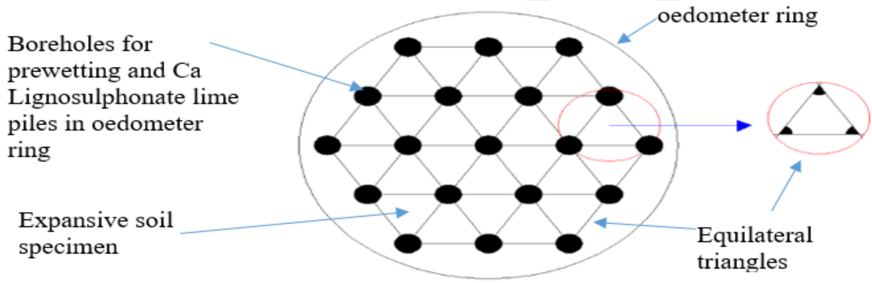

Figure 5. Equilateral triangles into the expansive soil specimen in oedometer ring

Each borehole placed in the USIT specimen was filled with the Ca lignosulphonate-lime mixture. The achievement of the GSN technique of this study depends on the condition that the fastener (to model soil nails and anchor plates) should be installed properly.

The fabric (which model geotextile) was laid down on the treated specimen. The fastener was not installed in each borehole of the USIT specimen. The distance between fasteners was determined as 6D (2.7 cm). Figure 6 illustrates both plans of fasteners and the final top view of the USIT specimen.

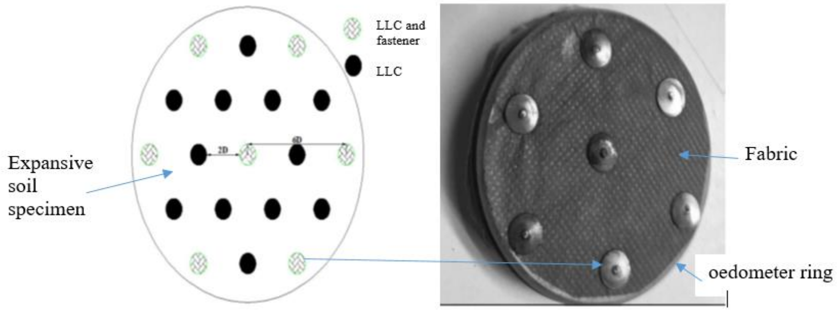

Figure 6. The plan of fasteners and final top view of the USIT specimen in oedometer ring

Swelling Potential of USIT Specimen

Free swell tests were done under both 7 kPa and 25 kPa surcharge pressures. To observe the curing effect, USIT specimens were waited in the humid room for 1 day, 7 days, 28 days, 90 days, and 180 days respectively.

The swelling potentials of the USIT specimens were shown in Figure 7 concerning curing periods.

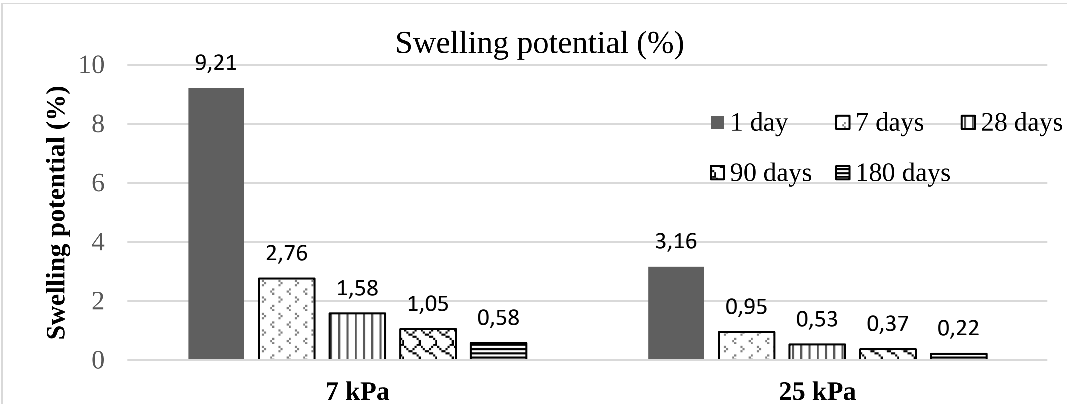

Figure 7. Swelling potentials of USIT specimens

Under 7 kPa surcharge load, the CaLS lime pile case gives 2.63 times higher swell percent (1-day curing), 3.62 times higher swell percent (7 days curing), and 4.5 times higher swell percent (28 days curing) than the USIT case.

Alazigha et al. (2018) stated that CaLS lime pile stabilization is due to the migration of Ca 2+ ions from the lime piles into the clay, flocculation of particles, pozzolanic reactions, and stabilizing mechanisms of CaLS admixture with smearing and agglomeration of clay particles [31]. Additional improvement (decrease in swell percent) in this study in USIT compared to CaLS lime pile stabilization is due to the effect of fabric and soil nailing.

The swelling potential of the USIT specimen was improved with the curing period. While the swelling potential of USIT specimens under 7 kPa was measured as 1.58%, the swelling potentials of treated specimens with prewetting, LLP, and GSN techniques separately were determined as 30.1%, 7.11%, and 41.5%. When the techniques that were mentioned above were separately applied to KB, the reduction of the swelling potential of KB was either very little or insufficient. However, these techniques were applied together and then the swelling potential of KB was decreased from 43.95% to 1.58% after 28 day curing period. Under 25 kPa surcharge pressure, the swelling potential of KB treated with USIT in this study was determined as 0.53% after 28 day curing period.

California Bearing Ratio (CBR) Swell Test

California Bearing Ratio (CBR) swell test has been widely done for determining the swell percent of soil used in pavement design. USIT specimen was tested at the soaked CBR conditions. This test specimen has been waited in the water for four days to measure its swelling potential. Since the test specimen formed high plasticity clay that had high swelling potential. Two different surcharge pressures that are 7 kPa and 25 kPa were applied at both the soaked condition and test stage.

USIT specimen prepared for soaked CBR swell test had 19 pieces of piles that had 1.05 cm diameter and six pieces of nails that had 6 cm length. Both diameters of the pile and the length of the nails have adjusted to the mold of the CBR test. In addition to this, six pieces of nut (to model an anchor plate) are put on the nails to block the tearing of the fabric and to transfer swell pressure to lime piles. The specimen used in this step is illustrated in Figure 8.

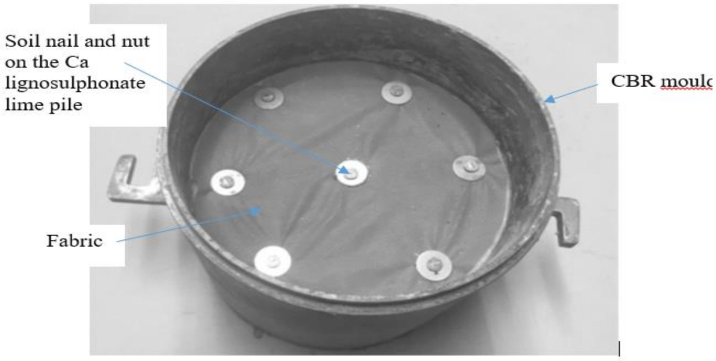

Figure 8. USIT specimen in CBR mold prepared for CBR swell test

These specimens had been kept in the humid room for 7 days, 28 days, and 90 days for investigating the curing effect of this improved method. After the curing period, the CBR swell values of the treated specimens were determined by the data obtained from these tests (Figure 9).

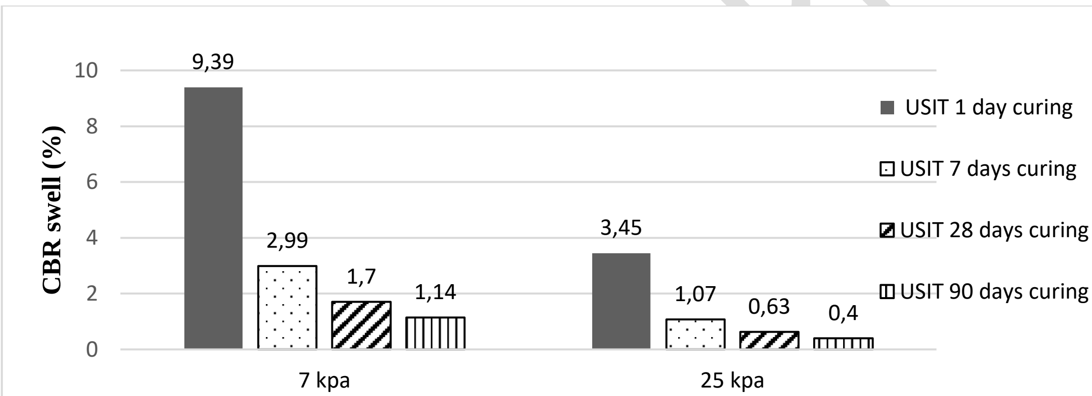

Figure 9. CBR swell values of USIT specimens

The CBR swell values of USIT decreased with the curing period for each surcharge pressure applied in this study. The CBR swell of the USIT specimens (after the soil stabilization/improvement), which waited in the humid room for 90 days, was measured as 1.14% under 7 kPa surcharge pressure and was measured as 0.4% under 25 kPa surcharge pressure and fulfilled the criteria for the subgrade material specified in Highways Technical Specification (HTS, 2013) (i.e. CBR swell % < 3% after 7 days curing) [28].

CONCLUSIONS

Unified Improvement Techniques (USIT) include three techniques that are prewetting, lignosulfonate lime piles, and fabric-soil nails. Firstly, the prewetting technique is the saturation step of the soil specimen with a mixture formed calcium lignosulfonate and water. The lignosulfonate lime pile technique (LLP) forms a rigid layer for fasteners (or soil nails and anchor plates). Then a piece of fabric was laid down over the expansive soil specimen and fasteners were used for the connection between the fabric and the lignosulphonate lime pile. The fabric and soil fasteners are used to ensure both uniform pressures and to transfer some part of the swell pressure to lime piles. To sum up, the expansive soil is improved in both vertical and horizontal directions.

The CBR swell of the USIT specimens which waited in the humid room for 90 days, fulfilled the criteria for the subgrade material specified in Highways Technical Specification (HTS, 2013) (i.e. CBR swell % < 3% after 7 days of curing).

Time is a significant factor for the stabilization of expansive soil with either prewetting or lignosulphonate lime piles methods, to solve this problem, the GSN technique was applied with both prewetting and lignosulphonate lime pile methods alone. Therefore, the improvement process of USIT in this study is faster and more effective than prewetting, lignosulphonate lime piles.

The treated specimen with USIT is more stable and resistant to volumetric change than both the other treated specimens and untreated specimens prepared in this study. The improvement percentage at the swelling potential of expansive soil specimens under 7 kPa surcharge pressure was approximately 96.5 % after 28 day curing period.

The significant drop in the swell potential value suggests that the Unified Soil Improvement Technique's performance is better than CaLS lime piles in the improvement of expansive clays.

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Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this article.

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