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Swell-Shrink Behaviour of Lime Pile and Lime Slurry Treated Expansive Soil

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Abstract. Expansive soils in the field are subjected to swelling and shrinkage due to seasonal moisture variations. Most of the previous studies on swell-shrink were carried out by direct mixing of stabilizer with soil and very few studies have been carried out on swell-shrink behaviour of expansive soil stabilized through permeation. Hence, in the present study an attempt is made to study the swell-shrink behaviour of expansive soil through laboratory tests using lime slurry (LS) and lime pile (LP) techniques and the two results are compared. In laboratory the LS were permeated through the central hole of expansive soil in desiccated state, whereas, the LP was installed in compacted expansive soil. Undisturbed soil specimens were collected from LP and LS treated expansive soil in the test moulds after a curing period of 30 days for evaluation of swell-shrink behaviour at a radial distance of 1.5d (where d = diameter of central hole) and at depths of 0-90 mm and 200-290 mm for LS and LP treated soils. The study shows that in LS treated specimens the volume change increases with increase in number of wet-dry cycles for the specimen taken at a depth of 0-90 mm, which shows the loss of cementation bonds. Whereas, LS treated sample taken at a depth of 200-290 mm and LP treated samples collected at a depth of 0-90 mm and 200-290 mm did not show any improvement in controlling the swell-shrink behaviour of expansive soil.

Keywords: Expansive soil; Swell-Shrink; Lime pile; Lime slurry; Swell-shrink cycles.

1 Introduction

Expansive soils occur all over the world and are found in countries such as Australia, Africa, China, Canada, India, Saudi Arabia, South Africa and USA (Chen 1988; Rao 2000; Ashok et al. 2018). These soils are very much suitable for agriculture and are commonly called as black cotton soil, and occupy 20% of the total land in India (Katti, 1978; Rao 2000; Patil et al., 2013; Ashok et al. 2018). These soils undergo swelling and shrinkage due to changes in seasonal moisture content, as a result it causes severe distress to the structures constructed over them (Thyagaraj and Zodinsanga 2015; Thyagaraj et al. 2016; Kumar and Thyagaraj 2020). Several researchers all over the world have studied the swell-shrink phenomenon of expansive soils. Studies carried out by Popescu (1980), Osipov et al. (1987), Dif and Bluemel (1991), Day (1994) and Rao (2000) showed that the maximum swell occurs during the 2nd wetting cycle and attains equilibrium after 3-4 wetting cycles. The effect of aging on swell-shrink behavior of an expansive soil was studied by Rao and Tripathy (2003). Their study showed that the aging effect is predominant during the 1^{st} wetting cycle which is due to particle rearrangements and formation of bonds. Whereas with increase in swell-shrink cycles the effect of aging slowly nullified and the behaviour of aged specimens almost becomes equal to specimens which were not cured.

Studies by Rao et al. (2001a), Rao et al. (2001b), Rao and Shivanada (2002), Guney et al. (2007) and Khattab et al. (2007) found that the pozzolanic reactions formed between free lime and clay particles was lost with increase in number of swell-shrink cycles. Investigation of Chittoori et al. (2018) showed that the extent of swelling on lime and cement treated expansive soil mostly depends on the montmorillonite content present in the soil. The investigation also showed that the cement treatment is more effective in reducing the swell-shrink behaviour when compared to lime treated expansive soil. Literature review shows that previous research studies on the swell-shrink behaviour of lime stabilized expansive soils by direct mixing with lime is effective. But in the field, lime pile and lime slurry techniques were adopted for the expansive soils extending greater depths. The swell-shrink mechanism involved by direct mixing with lime and through permeation (lime pile (LP) and lime slurry (LS)) is entirely different. Most of the previous studies were carried out by direct mixing of stabilizer with soil and very few studies have been carried out on swell-shrink behaviour of expansive soil stabilized through permeation. Hence, in the present study an attempt is made to study the swell-shrink behaviour of expansive soil through laboratory tests using LS and LP techniques and the two results are compared.

2 Materials

An expansive soil collected from Trichy, Tamil Nadu, India and commercially available $Ca(OH)_2$ were used in the present investigation. The procedures for determination of physico-chemical properties, grain size distribution, index properties and standard Proctor compaction characteristics were described in detail in Kumar and Thyagaraj (2020). The properties of the Trichy expansive soil used for the present laboratory testing are shown in Table 1.

3 Compaction of Soil And Sampling Procedure

LS and LP treatments were carried out in test moulds of diameter 385 mm and height 400 mm. The required quantity of expansive soil was calculated based on OMC (20%), dry unit weight (16.8 kN/m^3) and statically compacted to a thickness of 300 mm in three layers in test moulds for LS and LP treatments using a hydraulic jack. Central holes were made at the centre of the test moulds by statically pushing a 75 mm mild steel pipe. After making the central holes, one test mould was allowed to dry under the direct sun light for development of desiccation cracks and LS was poured into the central hole of desiccated soil. Installation of LP was done by filling the central hole with the lime powder and by adding water in three different stages. After complete permeation of LS and installation of LP in the test moulds, the moulds were allowed to cure for 30 days. Swell-shrink studies were carried out on undisturbed soil specimens collected at a radial distance of 1.5d and depths of 0-90 mm and 200-290 mm for LS and LP treated soils. The detailed procedure of compaction, implementation and sampling programme for LS and LP test moulds were clearly explained in the Kumar and Thyagaraj (2020).

Table 1. Properties of expansive soil (after Kumar and Thyagaraj 2020)

Property	Value
pH	8.52
Pore water salinity (mg/l)	321
Specific gravity (Gs)	2.75
Free swell index (FSI) (%)	270
Initial Consumption of Lime (ICL) (%)	3.5
Atterberg limits	
Liquid limit (%)	92
Plastic limit (%)	22
Shrinkage limit (%)	8
Grain size distribution (%)	
Sand	33
Silt	18
Clay	49
Unified soil classification symbol	CH
Standard Proctor compaction characteristics	
Maximum dry unit weight (kN/m^3)	16.8
Optimum moisture content (OMC) (%)	20

4 Results and Discussion

Fig 1 compares the time-swell plots of LS treated specimen collected at a radial distance of 1.5D and depth of 0-45 mm during different wetting cycles. A nominal swell potential of 0.04% can be observed during the 1st wetting cycle. The swell potential increased to 1.18% and 5.45% during the 2nd and 5th wetting cycles (Fig 1). The initial decrease in swell potential of LS treated specimen during the 1st wetting cycle may be due to the formation of strong pozzolanic bonds between the clay and lime slurry (Rao and Thyagaraj 2003; Thyagaraj and Suresh 2012; Kumar and Thyagaraj 2020). Whereas, the increase in swell potential of LS treated specimens with increase in wetting cycles may be due to partial breakage of these pozzolanic bonds (Rao et al. 2001a; Rao et al. 2001b; Rao and Shivanada 2002; Guney et al. 2007; Khattab et al. 2007; Stoltz et al. 2014; and Kumar and Thyagaraj 2020).

The time-swell plots during different wetting cycles of LP treated specimens sampled at radial distance of 1.5D and 0-45mm depth are plotted in Fig 2. The swell potential of LP treated specimen was compared with untreated specimen compacted to the same dry density and water content (Fig 2). From Fig 2, it can be clearly observed that the second swell potential was the maximum for both LP and untreated specimens in comparison with the swell potential during other wetting cycles. The equilibrium was achieved after 3rd wetting cycle in both LP and untreated specimens. The swell potential of LP and untreated specimen compacted to the same dry density and water content at the 5th wetting cycle was 13.88% and 14.64% (Fig 2).

Symbol	Specimen designation	Radial distance	Cycle	Swell potential (%)
■	LS	1.5D-1	1st	0.04
▲			2nd	1.18
●			5th	5.45

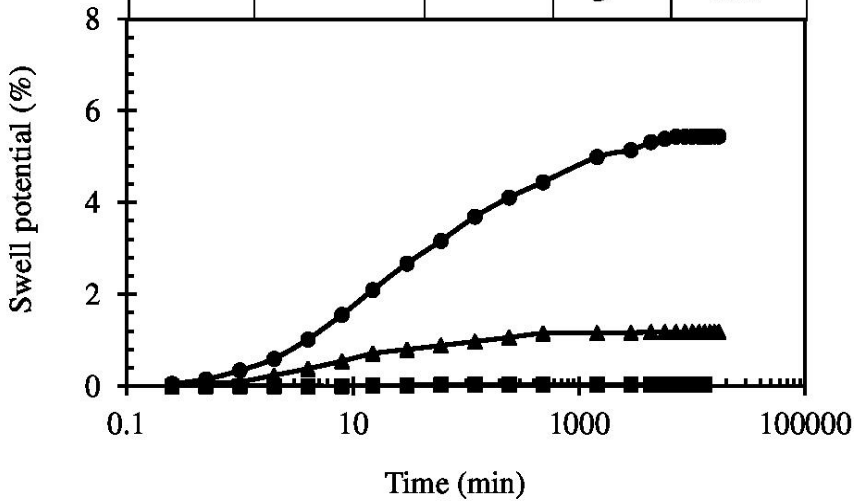

Fig. 1. Swell potential of LS treated specimens sampled at 1.5D and 0-45 mm depth.

Fig. 3 compares the time-swell plots of the LS and LP treated soil specimens sampled at 1.5D radial distance and 200-245mm depth, respectively. The swell potential of LS treated specimens increased from 3.58% during the 1st wetting cycle to 16.12% and 20.67% during 2nd and 5th wetting cycles (Fig 3). In case of LP treated specimens the maximum swell potential is observed during the second wetting cycle (22.21%) and attained equilibrium after 3rd wetting cycle, and exhibits a swell potential of 19.11% during 5th wetting cycle. The weaker pozzolanic bonds that formed in LS treated specimen collected at a depth of 200-245 mm might have lost with increase in wetting and drying cycles and thus increased the swell potential of LS treated specimen (Fig 3). This clearly shows that LS treatment depends on the extent of cracks that was developed with depth. Whereas, the LP treated specimen collected at a radial distance of 1.5D at depths of 0-45 mm and 200-245 mm did not showed any reduction in swell potential with increase in wetting and drying cycle and almost acts like an untreated specimen (Figs 2 and 3). This is due to less permeation of lime into highly impervious expansive soil (Rao and Venkataswamy 2002; Kumar and Thyagaraj 2020).

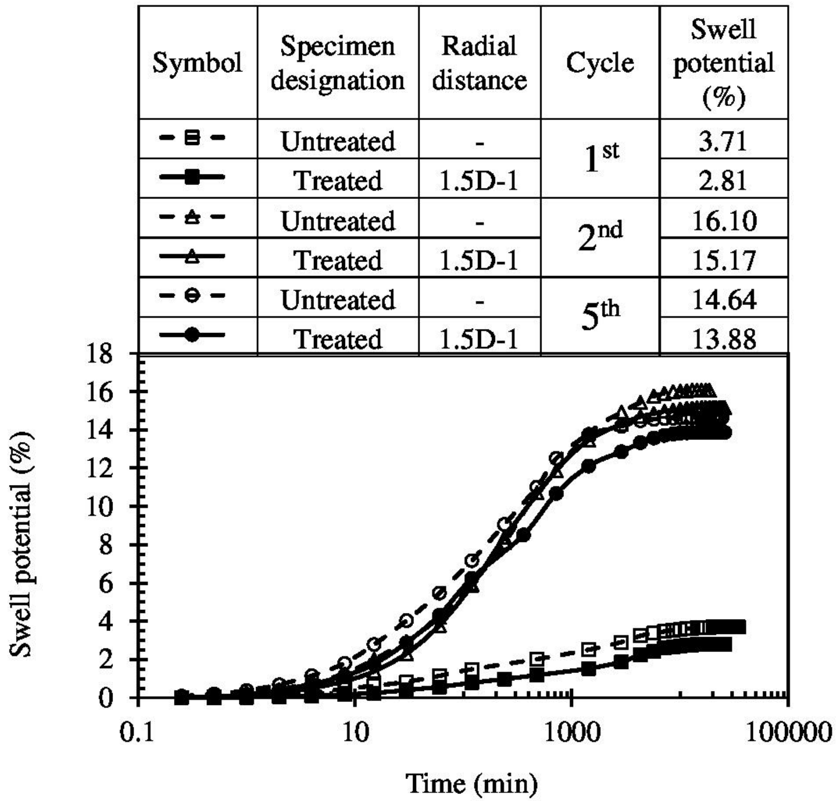

Fig. 2. Swell potential of untreated and LP treated specimens sampled at 1.5D and 0-45 mm depth.

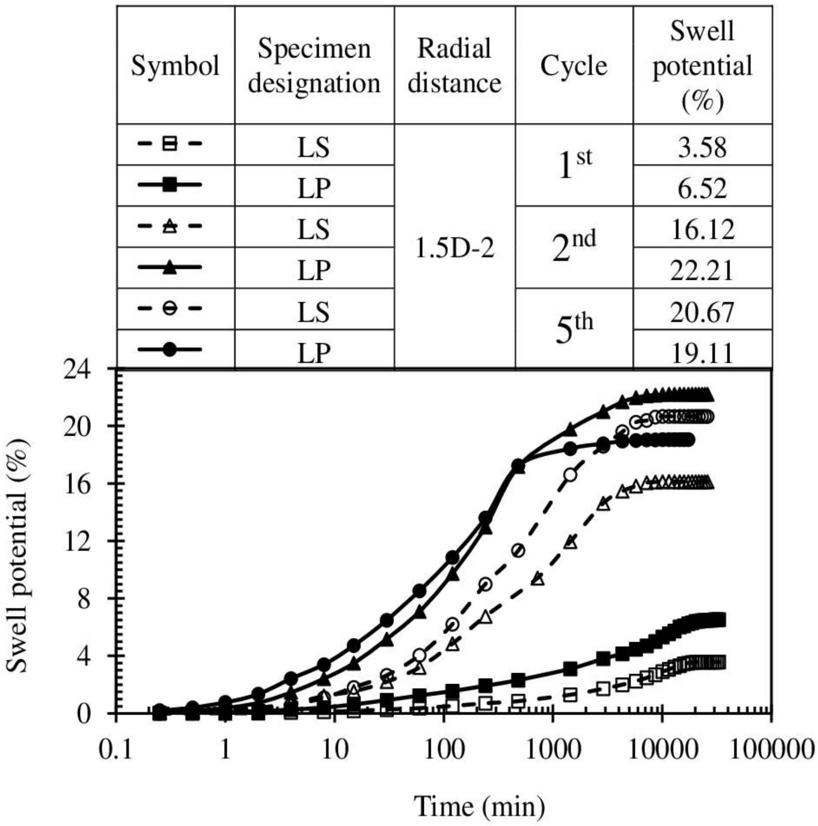

Fig. 3. Swell potential of LS and LP treated specimens sampled at 1.5D and 200-245 mm depth.

4 Conclusions

The swell-shrink behaviour of LS and LP treated expansive soil in compacted state was studied in the present investigation and the following conclusions were drawn from the swell-shrink studies.

1. The LS treated specimen collected at a radial distance of 1.5D and depth of 0-45 mm showed better performance in reducing the swell potential when com pared to the specimen collected at a radial distance of 1.5D and depth of 200-245 mm. This indicates that LS treatment mainly depends on the extent and depth of cracks that was developed in the expansive soil.

2. The LP treated specimens sampled at a radial distance of 1.5D and a depth of

0-45 mm and 200-245 mm did not show improvement and almost behaves like untreated specimen compacted to same density and water content. This shows that lime from LP did not permeate to greater radial distance into highly impervious expansive soil.

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