Swelling and Shrinkage Behaviour of Expansive Soil Blended with Lime and Fibres

Mayakrishnan Muthukumar[1(✉)], S.K. Sekar[2], and Sanjay Kumar Shukla[3]

[1] Department of Structural and Geotechnical Engineering, School of Civil and Chemical Engineering, VIT University, Vellore, India
mmuthukumar@vit.ac.in

[2] School of Civil and Chemical Engineering, VIT University, Vellore, India
sksekar@vit.ac.in

[3] Discipline of Civil and Environmental Engineering, School of Engineering, Edith Cowan University, Perth, Australia
s.shukla@ecu.edu.au

Abstract. Expansive soils are considered to be highly problematic because of their capacity to significant volume change. They swell during the rainy season as they absorb water and shrink when water evaporates from them during the summer season. Because of this dual swell-shrink behaviour, an expansive soil causes severe distress to many civil engineering structures. Several mitigating techniques are adopted to counteract the problems posed by the expansive soils, either by modifying the properties of the soil by adopting stabilization techniques using lime, cement, fly ash, calcium chloride etc. or by adopting special foundation technique such as construction of belled piers, under-reamed piles, etc. In recent years polymeric fibres have also been used to stabilize the soil as well as to improve the strength of the expansive soils. Hence in the present study lime and fibres have been used in different proportions to study the swelling and shrinkage behavior of expansive soils. Swell tests were performed by varying the fibre content and lime with expansive soils. Tests were also conducted by blending fibres and lime together with expansive soils. In a similar way, shrinkage tests were also performed for the various proportions. The test result show that swelling tends to decrease slightly with an increase in the fibre content, whereas shrinkage tends to decrease significantly upon addition of fibres. Both swelling and shrinkage tends to decrease significantly with increasing lime content. The optimum content of fibre was found to be 2%. So the expansive soil specimens blended with 2% fibres and with varying lime content was tested. It is found that blending 2% fibres and 15% lime together in expansive soils is considered to be more effective in controlling the swelling and shrinkage behaviour.

1 Introduction

The problems posed by expansive soils have been recorded worldwide. These expansive soils swell during the rainy season and shrinks during the summer seasons. This cyclic volume change behaviour of expansive soils causes severe damage to the

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lightly loaded structure founded on them (Chen 1988). To minimize the volume change attributes of these expansive soils, several mitigating techniques have been adopted. Stabilization of expansive soil with various additives, including lime, cement, calcium chloride and fly ash has shown promising results in heave reduction and improved strength characteristics (Shanker and Maruthi 1989; Cokca 2001; Sharma 1998).

Al-Rawas et al. (2002) studied the effect of lime, cement and artificial pozzolan and the combination of these three stabilizers at different proportions. Lime, cement and sarooj, an artificial pozzolana produced by burning calcining clay were mixed at different dosages by dry weight of soil. It was observed that swell percentage and swell pressure reduced to zero at 6% of lime. Rice husk ash stabilized with lime or cement was used as cushion between the expansive soil and the foundation to counteract the effect of heaving of expansive soils (Sivapullaiah et al. 2004; Sharma et al. 2008).

Fiber reinforcement of expansive soils is also found to be successful in reducing volume changes and increasing the shear strength of expansive soils. The effect of discrete and randomly oriented polypropylene fibre reinforcement on strength and volume change behaviour of expansive soils was studied by Puppala and Musenda (2000). Fiber reinforced clayey samples were prepared by varying the fibre percentage as 0%, 0.3%, 0.6% and 0.9% by dry weight of soil for the both types of fibers. Test results from their studies showed that the fiber reinforcement enhanced strength and reduces volumetric shrinkage and swelling pressure. Fiber reinforcement also decreases swell potential considerably.

Al-Akhras et al. (2008) carried out investigation on expansive soil with nylon fibres and natural fibres having different aspect ratios to study the influence of fibres on swelling properties of clayey soils. Four aspects ratios (*l/d*) of 25, 50, 75 and 100 and five different fibre contents of 1%, 2%, 3%, 4% and 5% were used in the study. Results revealed that both swelling pressure and swell potential reduced significantly with an increase in the fiber content. From their study it was also observed that natural fibres are more efficacious in controlling heave than nylon fibres. Further, a lower aspect ratio appeared to have a greater effect in reducing swelling pressure in both types of fibres.

The effect of polypropylene tape fibers on swelling behaviour of expansive soils was studied by Viswanatham et al. (2009). One-dimensional swell tests were conducted on remoulded expansive soils without reinforcement and with reinforcement. The percentage range of 0.25% and 0.5% were used with lengths of 30 mm, 60 mm and 90 mm. The study revealed that reduction in heave was proportional to fiber content and maximum heave was observed at a low aspect ratio for both the fibre contents of 0.25% and 0.5%. It was also observed that the length of the fibre was the key factor that influenced the reinforcing effect of fibre. Discrete and randomly distributed fibers were found efficacious in reducing heave.

Puppala (2001) carried out investigation on mixture of fiber and fly ash to stabilize expansive soils. This technique was also found effective in reducing plasticity and free swell characteristics. Kumar et al. (2007) studied the effect of fly ash, lime and polyester fibres on compaction and strength properties of expansive soils. Randomly oriented fibres were introduced in mixes at different percentages and observed that strength increased with increase in curing period.

From the literature review, it is observed that mostly studies are carried out only on reducing the swelling nature of the expansive soils, but there is limited research available on controlling both swelling and shrinkage of expansive soils. In the present study, the swelling and shrinkage behaviour of expansive soils have been studied by adding varying lime content, fibre content and blending both lime and fibres with expansive soils at different percentages.

2 Experimental Investigation

2.1 Test Materials

Bentonite, commercially available clay, was used for the present investigation. The bentonite used was sodium bentonite because it will undergo more volume change when compared to other types of bentonite. Various index properties of the soil were determined and presented in Table 1. Based on liquid limit and plasticity index of the soil, the soil was classified as CH according to Unified Soil Classification System (USCS). The free swell index of the soil was found to be 200%, which is considered to be for a highly swelling expansive soil.

Table 1. Properties of the soil used for this study

Soil properties	Value
Specific gravity	2.68
Liquid limit %	121
Plastic limit %	48
Shrinkage limit %	8
Plasticity index %	82
Free swell index (FSI) %	200
Classification according to USCS	CH

Polypropylene fibres have been used for the present study because of its several advantages like high strength, micro fine reinforcement, chemically inert, noncorrosive and available in varying length. For the present study, fibre length of 6 mm was used.

Commercially available hydrated lime $Ca(OH)_2$ was used for the present study, because of the difficulty in handling quick lime. Fibre has been denoted as ‘F’ and Lime has been denoted as ‘L’ in the present study.

2.2 Swelling Tests

Fibre content was varied as 1%, 2%, 4% and 6% in swelling tests. In another series of tests lime content was varied as 1%, 2% and 4%. The results of the swelling tests with varying fibre content indicated that, the swelling was less with 2%. Hence the effect of swelling behaviour of expansive soil with 2% fibre was studied by varying the lime content (1%, 2% and 4%). The oven dried expansive soil was mixed with initial water content of 10% and with a dry unit weight of 12 kN/m^3 in the mould of 10 cm diameter in three layers of thickness 25 mm. A dial gauge was fitted at the top of the soil layer.

After setting the dial gauge reading to zero, water was added continuously at the top of the clay bed and the swelling was monitoring continuously at various time intervals until an equilibrium heave was attained.

2.3 Shrinkage Limit Tests

The fibre was mixed thoroughly with expansive clays for various percentages. The fibre content was varied as 0, 0.5%, 0.75%, 1% and 2%. The mixture was placed in the shrinkage dish and the specimen was oven dried. Shrinkage limit was determined for varying lime content (2%, 5%, 7.5%, 10% and 15%). Shrinkage limit was also determined on clay blends with 2% fibre and with varying lime content as mentioned earlier.

3 Discussion of Test Results

3.1 Influence of Fibre and Lime on the Swelling Behavior of Expansive Soils

Figure 1 shows the variation of swelling (mm) with varying lime content (%). It is observed that for a given fibre content, the swelling tends to increase with an increase in the time period but the swelling tends to decrease with an increase in the fibre content up to 2%. This is mainly because the fibre-reinforced soils behave like a composite materials in which the fibre having relatively high strength offering more

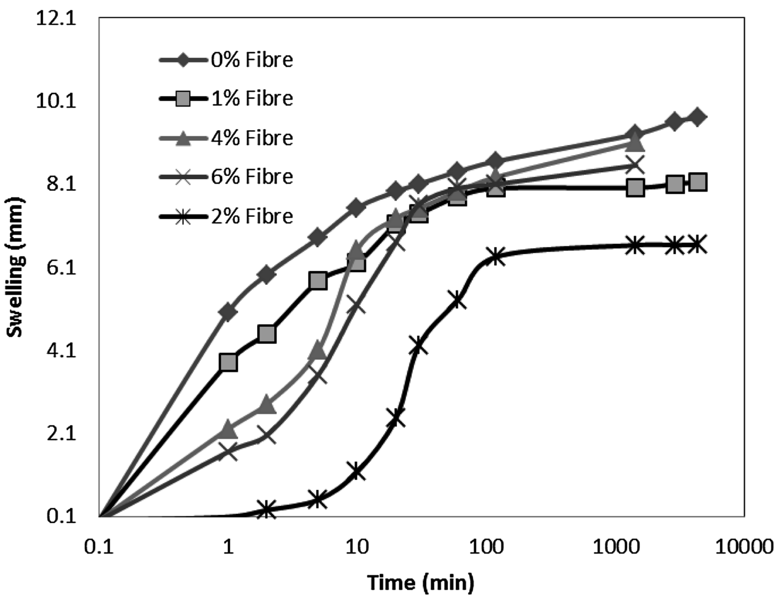

Fig. 1. Rate of heave for varying fibre content (%)

tensile resistance to soil against swelling. For 2% fibre content the initial swelling was less but beyond 2% fibre content swelling tends to increase. This is attributed due to the fact that beyond optimum fibre content further increase in the fibre content fails to offer good bonding between the soil and fibre which leads to an increase in heaving of expansive soil. It is found that the swelling potential of the expansive soil decreased from 21% to 15% with a fibre content of 2%.

Figure 2 shows the rate of swelling of expansive soil blended with varying lime content. The swelling tends to decrease with increase in the lime content. The swelling decreased from 9.5 mm to 2.5 mm, when the lime content was 4%, indicating 74% reduction in swelling. The reduction in swelling is attributed to the ions exchange process and pozzolanic reactions between the soil and lime, resulting in reduced amount of swelling.

Figure 3 shows the comparison of variation of swelling for a lime content of 4% and for a fibre content of 2%. It can be seen from the figure that the initial swelling is controlled effectively by fibres. After certain period of time as the water starts permeating into the soil, the soil get fully saturated and hence the heave tends to increase. In the case of expansive soil blended with lime, the initial swelling is more because of the slow process in the pozzolanic reactions (See Fig. 3). Hence further study has been carried out to reduce the initial swelling of clay lime blends by adding 2% fibre content, so that the total or final swelling will be further reduced.

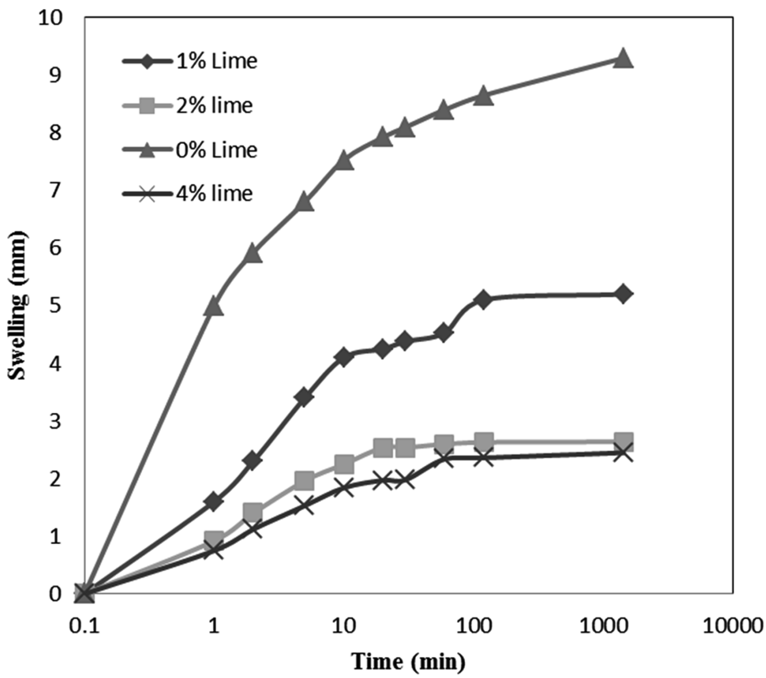

Fig. 2. Rate of heave for varying lime content (%)

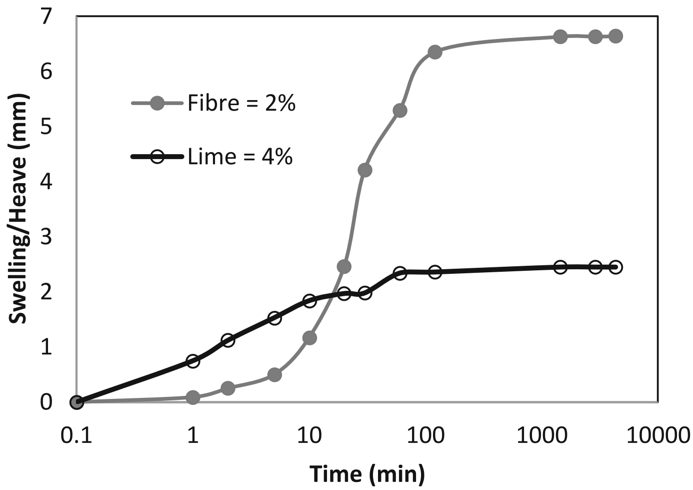

Fig. 3. Rate of heave with time

Figure 4 shows by comparison the variation of swelling with lime and the variation of swelling with lime plus 2% fibre content. It is clearly seen that swelling decreased significantly when 2% of fibre was added to lime-clay blends, indicating a potential decrease in the initial swelling and the further swelling is effectively controlled by lime

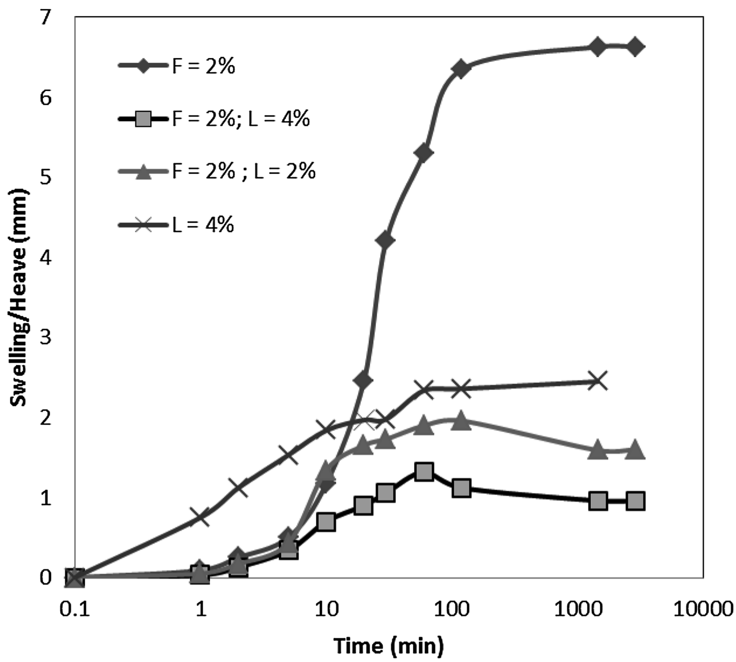

Fig. 4. Rate of heave with time

due to the pozzolanic reaction, resulted in lesser amount of heave when compared to the heave of expansive clay blends with lime.

3.2 Influence of Fibre and Lime on the Shrinkage Behavior of Expansive Soils

Figure 5 shows the effect of fibre content on the shrinkage behavior of expansive soils. It is observed that the shrinkage limit of the expansive soil tends to increase with an increase in the fibre content. The shrinkage limit is an indication of probable volume change of expansive soils. Lesser the shrinkage limit, higher the probable change in the volume of the soil (Holtz and Gibbs 1956). The shrinkage limit of the expansive soil is found to be 8% which is considered to be undergoing severe volume according to Holtz and Gibbs. When the fibre content of 0.5% was added, the shrinkage limit is found to be 38.8% indicating less volume change. The shrinkage limit tends to increase further upon addition of fibre and it is observed that there is no significant increase in shrinkage limit beyond 2% (See Fig. 5). This shows that the fibre reinforcement is proved to be effective not only in controlling the swelling but also the shrinkage of the expansive soil as well.

Figure 6 shows the variation of shrinkage limit for lime-clay blends of different proportions. In lime clay blends, the shrinkage limit also tends to increase with an increase in the lime content. The shrinkage limit is found to be 16.8% for a lime content of 2%, and for a lime content of 15% the shrinkage limit is found to be 36%. Beyond 15% there is no significant increase in the shrinkage limit (Fig. 6). The value of shrinkage limit is relatively less when compared to the fibre-clay blends with a maximum value of shrinkage limit of 58.6%.

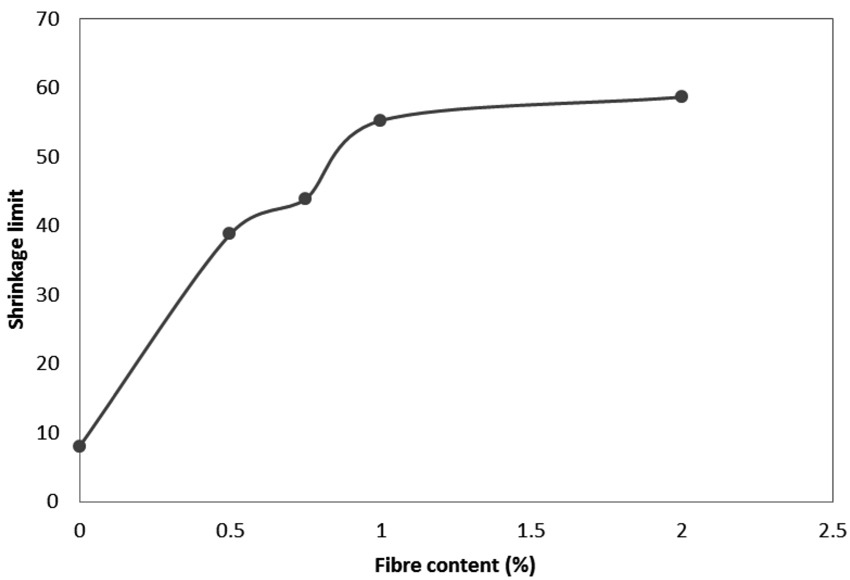

Fig. 5. Variation of shrinkage limit with fibre content

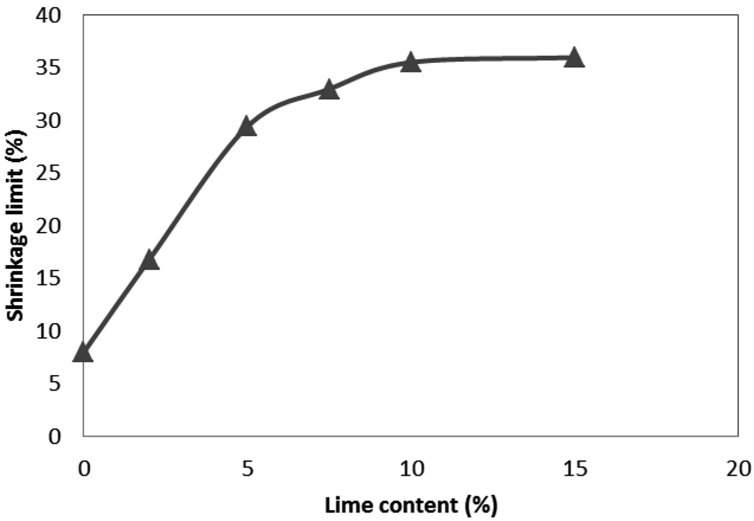

Fig. 6. Variation of shrinkage limit with lime content

Figure 7 shows by comparison, the variation of shrinkage limit for soil blended with lime, fibre and lime with 2% fibre. The shrinkage limit tends to increase significantly upon addition of fibre to any lime content. The shrinkage limit also increases marginally when compared to fibre-clay blends. From the shrinkage limit studies, it is

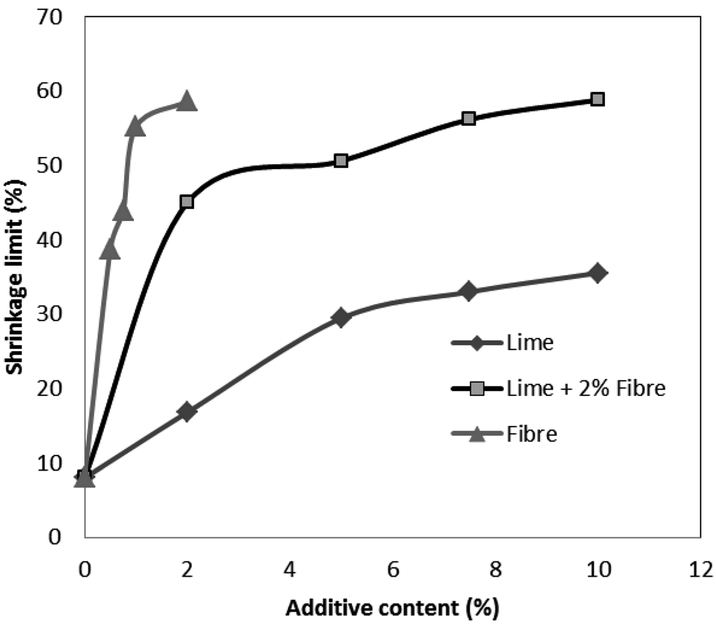

Fig. 7. Variation of shrinkage limit with additives (%)

observed that shrinkage limit is high when expansive soils are blended with fibre and it is true for any amount of additive, on the other hand the shrinkage cracks are more in the case of fibre-clay blends when compared to lime clay blends. The combination of fibre content of 2% and for a lime content of 15%, the shrinkage limit is found to be high (58.63%) and the development of shrinkage cracks also arrested effectively.

4 Conclusions

The following are the main conclusions arrived from the present study:

(1) Addition of fibres up to 2% to the expansive soil causes the heave to decrease. This is mainly because the fibre-reinforced soils behave like a composite materials in which the fibre having relatively high strength offering more tensile resistance to soil against swelling. The swelling potential of the expansive soil decreases from 21% to 15% with a fibre content of 2%.
(2) The swelling tends to decrease with an increase in the lime content. The swelling reduced 74%, when lime of 4% was added to expansive soils. Beyond 4% there is no further reduction in heave because of the initial swelling.
(3) Swelling decreased significantly when 2% of fibre is added to lime-clay blends, indicating a potential decrease in the initial swelling and the further swelling is effectively controlled by lime due to the pozzolanic reaction, resulting in lesser amount of heave when compared to the heave of expansive clay blends with lime.
(4) The maximum value of shrinkage limit is 36% for an optimum lime content, which is relatively less when compared to the fibre-clay blends with a maximum value of shrinkage limit of 58.6%.
(5) With the combination of fibre content of 2% and for a lime content of 15%, the shrinkage limit is found to be high (58.63%) and the development of shrinkage cracks are seen to be arrested effectively. Hence addition of fibre content of 2% and lime content of 15% can control both swelling and shrinkage effectively.

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