Laboratory Study on Natural Fibre Amended Fly Ash as an Expansive Soil Stabilizer

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ABSTRACT: Expansive soil subgrade pose major problems for the pavements due to their volume change characteristics. In the present investigation, the suitability of fibre reinforced fly ash on the stabilisation of expansive soil is studied. Coconut fibre is chosen as natural reinforcing fibre with a cut length of 10 mm and used in different percentages such as 0.25, 0.5 and 1% along with fly ash content of 20% of dry weight of soil. Laboratory tests includes standard Proctor tests, swelling pressure tests and California Bearing Ratio (CBR) tests were conducted to determine the maximum dry density (MDD), optimum moisture content (OMC), swelling pressure and strength of the soil with and without fibre reinforced fly ash matrix. With the addition of admixtures, the OMC is decreased and MDD is increased, the swelling pressure is decreased drastically and CBR values increased with the addition of admixtures showing an optimum improvement for soil with 0.5% fibre and 20% fly ash content. Thus the test results favoured the utilisation of waste materials such as fly ash and natural coconut fibre to enhance the suitability of stabilized expansive soil as subgrade for pavements.

KEYWORDS: Stabilization, Coconut fibre, Fly ash, Expansive soil, Subgrade.

1. INTRODUCTION

Expansive soils have the ability to change in volume in response to changes in its water content. Such soils shrinks when water content decreases and swell when it increases (Chen, 1988). The volume change behaviour of the expansive soil causes large uplift pressures on the structures built on them, specifically lightweight structures (Bell, 1988). Projects such as earthen dam, road embankments, land reclamation require large volumes of borrow earth. This in some cases may not be practically feasible and hence there is a need for stabilization of the in-situ soil. Suitable stabilization of such soils with additives before its application is therefore inevitable and has been used with varying degrees of success.

The most widely adopted technique for stabilization of expansive soil is chemical alteration, as additives (if not leached out over time) permanently control the volume change rather than resisting it. Chemical stabilization methods alter both the physical and chemical properties of the soil rendering it non-plastic or less plastic (Puppala et al., 1996; Al-Rawas et al., 2005). Stabilization of expansive soils by using additives like lime, cement, fly ash and other industrial additives has been practised with great success in curtailment of swelling and shrinkage (Desai and Oza, 1997; Cokca, 2001).

Fly ash is obtained as the by-product from thermal power plants for the combustion of coal. Fly ash production in India is almost 100 million tonnes per year and ash ponds nearly occupy 26,305 acres of land (Das and Yudhbir, 2006). Fly ash reduces soil plasticity and considerably reduces swell potential and swelling pressure. Fly ash stabilizes expansive soil mainly by flocculation and pozzolanic reactions (Phanikumar and Radhey Sharma, 2004, Goswami and Singh, 2005). According to Petry and Little (2002), addition of fly ash improves the soil properties such as stiffness, strength and freeze–thaw durability and reduces plasticity, swelling potential and permeability. Additionally, it finds alternative application in the field of geo-environmental engineering as waste liners and as barrier material (Joshi et al., 1994, Sharma 1996, Cokca, 1997).

The mechanism of fly ash stabilization of expansive soil could be enhanced by addition of fibres to fly ash which helps in increasing the tensile strength of soil, making it more ductile over a range of strain values. Slopes naturally reinforced with randomly oriented plant roots, were comparatively stable (Waldron, 1977), this formed the basis for the concept of fibre inclusions in the soil. Earlier studies by Freitag (1986) and Nataraj and McManis (1997) with inclusion of randomly oriented synthetic fibres in clayey soil considerably increased the strength, ductility and toughness of soil. The reinforced specimens exhibited greater unconfined compressive strength (UCC) over a wide range of moisture contents.

Extensive experimental work was carried out by Kaniraj and Havangi (2001), on polyester fibre inclusions in cement amended local soil. The behaviour of the soil was studied through consolidation, direct shear tests, UCC and compaction tests. The authors found a considerable increase in UCC strength, compression index and found a transition from brittle to ductile behaviour. Kaniraj and Gayathri (2004) further carried out experiments with plastic recycled fibre in geotechnical characterisation of class F fly ash through compaction tests and triaxial shear test.

Studies were carried out to understand the behaviour of combined effect of additives and fibers on stabilization of expansive soil (Punthutaechea et al., 2006, Kumar et al., 2007). Fibres added to expansive soil in combination with ash based stabiliser and lime could be more beneficial in curtailing swell potential and swell pressure. Punthutaechea et al., (2006) carried out studies to understand the stabilising effect of nylon fibres, bottom ash, fly ash and polypropylene fibres. The ash based stabilisers exhibited characteristic reduction in swelling behaviour by ion exchange and pozzolanic behaviour. The swelling severity level of 'high' of control soils were reduced to either 'medium 'or 'low' in severity level for treated soils. However, the fibres presented an inferior behaviour in reduction of swelling characteristics due to the provision of drainage paths by the fibres for pore water dissipation. Nevertheless, the combination of 0.3 % fibres and 10 % to 20 % ash based stabilisers revealed maximum reduction in swell characteristics and also reduced the 'high' severity levels to 'low' severity levels.

Al-Akhras et al., (2008), studied the influence of natural Palmyra fibres and synthetic fibres on the swelling nature of clayey soil with varying aspect ratio and quantity of fibres. They concluded that lower aspect ratio of 25 (compared to 100), and 5 % natural fibres were more effective in controlling swelling potential compared to synthetic fibres. Similar studies by Viswanadham et al., (2009), also revealed analogous results and attributed the resistance to swelling behaviour of clay-fibre contact points.

Studies were carried out by Phanikumar et al., (2016) with nylon fibres on swell-consolidation behaviour of expansive soil. One dimensional swell-consolidation tests were carried out on fibre reinforced expansive soils. The increase in fibre length and fibre content decreased the swell parameters of the soil. The reinforcements also improved the secondary consolidation characteristics of the soil. Over the decades only few studies have been carried out on natural fibres amended ash based stabilizer. The present study uses coconut fibres, a natural fibre in combination with fly ash for stabilization of expansive soil. India is one of the leading producers of coconut. The coir fibres generated from the coir processing industries generate 0.5 million tonnes of coir waste (Leema Peter et al.,2014, Beena and Santhosh, 2013). Thus the present study is focussed on the utilization of coir waste and eco-friendly stabilization of expansive soil.

2. MATERIALS AND METHODS

2.1 Material properties

A laboratory investigation was conducted for studying the efficiency of coconut fibre reinforcement with fly ash matrix in expansive soil. A series of laboratory tests were performed to study the optimum dosage of coconut fibre and fly ash when compared with that of the unreinforced soil specimen. Standard Proctor compaction, CBR and swelling pressure tests were performed for both reinforced and unreinforced soil specimens. The details of the laboratory tests are explained in subsequent sections.

2.1.1 Expansive soil

The natural expansive soil used in the laboratory investigation had a high free swell index and liquid limit. The soil was obtained from a construction area of Anna Nagar site, near Chennai, Tamilnadu, India, at a depth of 1 m from the ground level. The physical properties of the expansive soil were determined according to Indian Standards (IS) and the results are summarized in Table 1. Based on the plasticity characteristics, the soil can be classified as clay of highly plastic (CH) according to unified soil classification system (USCS) classification.

Table 1 Index properties of the expansive soil

Property	Values
% Coarse fraction	8
% Silt	22
% Clay	70
Specific gravity	2.58
Liquid limit (%)	71
Plastic limit (%)	32
Shrinkage limit (%)	10
Plasticity Index	39
USCS classification	CH
Optimum moisture content (%)	16.5
Maximum dry unit weight (kN/m^3)	17.4
Free swell index (%)	100

In order to study the mineralogical composition of expansive soil, X-ray diffraction (XRD) studies were performed to analyse the diffraction pattern (Figure 1) and the minerals present in the soil sample were identified. The XRD graph shows the presence of montmorillonite mineral in expansive soil which is the cause for volume changes in expansive soil and the presence of other minerals such as illite, quartz and calcite are also evidenced.

2.1.2 Fly ash

The fly ash was collected from Ennore thermal power station which is near Chennai, Tamilnadu, India. The physical properties of fly ash are summarized in Table 2. The optimum dosage of fly ash for improving the engineering properties of expansive soils was found to be 20% from the experimental investigation of Phanikumar and Sharma 2004. Based on Punthutaecha et al (2006), the effective percentage addition of fly ash depends on the soil type and lies in the range of 15-20%. Hence, in this research an attempt has been taken to study the effect of different dosages of coconut fibre reinforcement in expansive soil amended with 20 % fly ash by weight of soil.

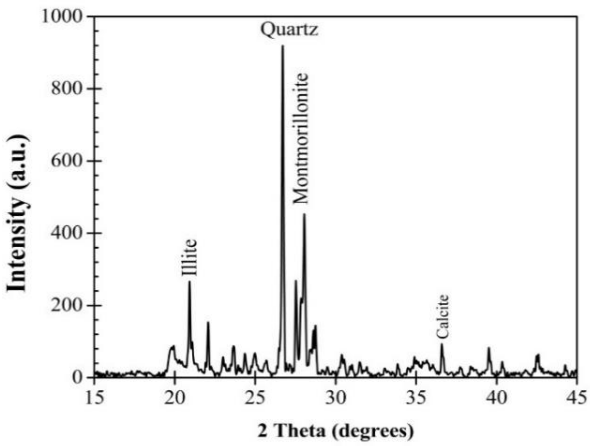

Figure 1 X-ray diffraction curve for soil sample

Table 2 Properties of Class F fly ash used in the study

Physical properties	Values
Specific gravity	2.14
Fineness (m^2/kg)	258
Chemical Composition	**% by mass**
Silicon dioxide (SiO_2)	57.8
Calcium oxide (CaO)	2.58
Aluminium Oxide (Al_2O_3)	25.8
Ferric Oxide (Fe_2O_3)	4.02
Potassium Oxide (K_2O)	1.7
Loss on ignition (%)	0.84

2.1.3 Coconut fibre

The natural coconut fibre obtained from waste dried coconut husk with cut length of 10 mm and width of 1 mm was used to reinforce the expansive soils with varying mix proportions. The l/d ratio of the coconut fibre (CF) was kept constant for all the tests, where l/d ratio is defined as the ratio of length to the diameter of the fibre. The density and percentage water absorption of the fibre is 1.12 g/cc and 5% respectively.

2.2 Tests conducted

All the laboratory experimental studies were conducted according to Indian standards for varying mix proportions of coconut fibre such as 0.25 % CF, 0.5 % CF and 1 % CF on dry mass basis in the expansive soil amended with 20 % fly ash matrix. Standard Proctor compaction tests were performed for varying mix proportions to find out the optimum moisture content (OMC) and maximum dry density (MDD). The specimens were prepared at their respective OMC and MDD to study the strength characteristics and swelling pressure by California bearing ratio (CBR) and constant volume tests method. The test procedure is briefly explained in the following sections.

2.2.1 CBR test

The CBR tests were performed on soil specimens with and without additives at varying mix proportions under soaked conditions to measure the expansion and load-penetration values. The soil sample was blended with 20% fly ash (FA) and mixed with varying proportions of 0.25% CF, 0.5% CF and 1% CF corresponding to the desired OMC and MDD obtained from the compaction curve. The prepared soil sample is filled in the CBR mould by dynamic compaction followed by procedure outlined in IS 2720 (Part 16). A surcharge load of around 2.5 kg was placed on the compacted specimen above the filter paper and the sample was inundated with water in a covered outer tank. A dial gauge of sensitivity 0.01 mm was fixed in the tripod stand to measure the expansion/swelling of the specimen. The initial dial gauge reading and the final dial gauge reading after 96 hours of inundation were noted. Dial gauge readings were monitored and water level was maintained constant throughout the test period. Upon completion of soaking, the dial gauge was removed and the excess water in the mould was removed and the specimen was allowed to drain for 15 minutes. During the removal of water utmost care was taken not to disturb the surface of specimen. Then the drained specimen was placed on the loading machine to measure the penetration resistance by applying load at the rate of 1.25 mm as per IS 2720 Part 16.

2.2.2 Swelling pressure test

The swelling pressure apparatus is used to determine the swelling pressure developed by the specimen compacted to MDD at OMC, when soaked in water. The prepared soil specimen was compacted dynamically in the proctor mould (internal diameter of 102 mm and height 116 mm) and the porous stones were placed on both sides of the compacted specimen separated out by filter paper. The mould was firmly fixed in the frame and placed in a soaking tank facilitating two-way saturation since the base of the mould has channels and radial grooves with connecting holes. A perforated swell plate was mounted over the specimen and a deformation dial gauge of 25 mm travel with least count of 0.01 mm was placed over the plate. After assembling the specimen along with soaking tank in the loading frame of 50 kN capacity, a load measuring proving ring of 5kN capacity was connected to a load transfer bar which in turn is placed over the swell plate. Then the sample was inundated with water and the swelling was monitored by the dial gauge. The initial reading of the proving ring was noted and the load adjustment was done for every 0.1 mm of swell by applying the load by hand operated system. The schematic diagram of swelling pressure test set-up is shown in Figure 2. The load was applied to maintain constant volume of the sample upon inundation and it is confirmed by the test procedure of constant volume method/zero swell method outlined in the IS 2720 (Part 41). From this test, the swelling pressure of the specimen is derived from following equation (1),

$$\text{Swelling pressure } (P_s) = (FL - IL) / A \quad (1)$$

Where,
FL = Final load reading of the proving ring
IL = Initial load reading of the proving ring
A = Cross sectional area of specimen.

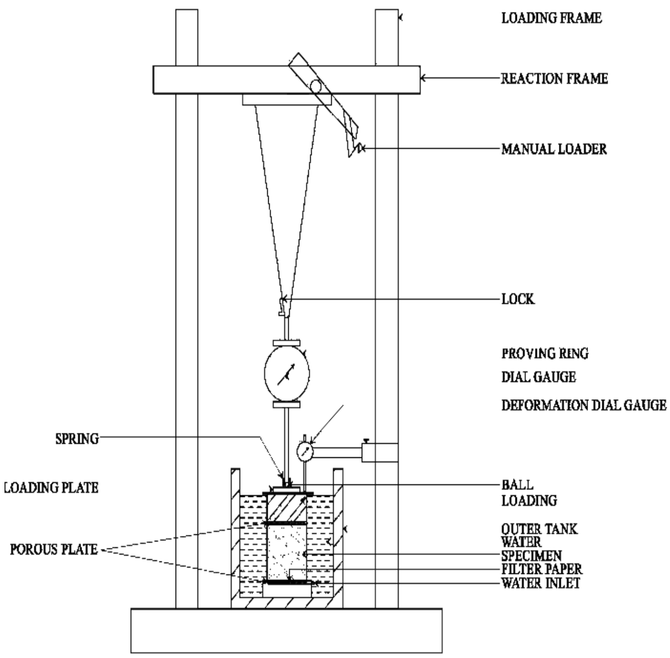

Figure 2 Schematic diagram of swell pressure set-up

3. ANALYSES OF TEST RESULTS

This section summarizes the results of compaction tests, CBR tests, swelling pressure tests for soil with and without stabilizers.

3.1 Compaction Test Results

Figure 3 shows the standard Proctor compaction curves for the soil samples with and without the addition of stabilizers. The compaction curves shift towards lower MDD and higher OMC with the addition of FA and higher CF. The maximum dry unit weight (MDD) and optimum moisture content (OMC) were chosen from the compaction curves and listed in Table 3.

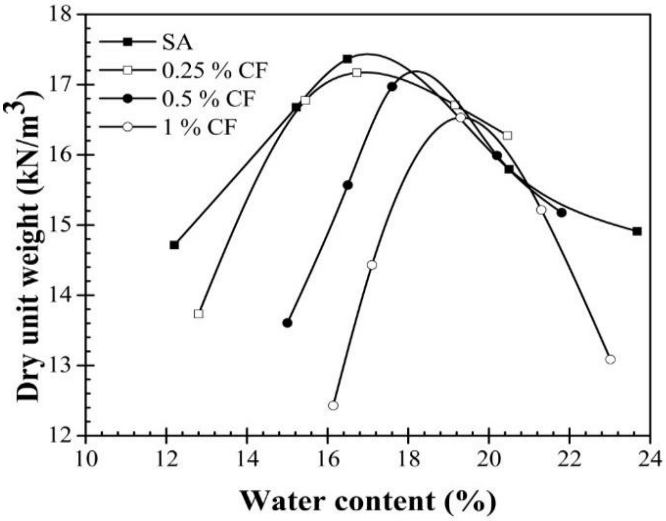

Figure 3 Compaction curves for soil with and without stabilizers

Table 3 Variation of MDD and OMC

Soil Mixture	OMC (%)	MDD (kN/m^3)
SA	16.5	17.4
0.25 % CF	16.7	17.2
0.5 % CF	17.6	17.0
1 % CF	19.3	16.5

From the variation of maximum dry unit weight for virgin soil and soil added with 0.25, 0.5 and 1% of coconut fibres and 20% fly ash upon weight of the soil, it is observed that there is a slight reduction in maximum dry unit weight of the soil upon addition of stabilizers. The percentage reduction of MDD in comparison to the virgin soil is 1.1, 2.3 and 4.8 for soil with 0.25, 0.5 and 1% addition of fibres with 20% fly ash. The reason for the unit weight reduction may be due to the reduction of percentage solids in the mixture of soil with fly ash and fibres. But the reduction is high for 1% addition of fibres and this could be due to the formation of bigger void spaces at higher concentration of fibres (Punthutaecha et al., 2006).

The variation of OMC with the addition of different dosages of stabilizers listed in Table 3 indicates that the OMC of soil is increased upon addition of stabilizers. The percentage increase is 1.3, 6.7 and 17 for soil with 0.25%, 0.5%and 1% addition of fibres along with 20% fly ash when compared to virgin soil. The increase in OMC can be correlated to the high moisture holding capacity of the natural fibre and hence requires additional water to rearrange the particles to achieve the maximum density.

The relationship between OMC and MDD is shown in Figure 4 and it is compared with the correlation obtained by Di Matteo et al. (2009), where it may be seen that there exists a similar pattern between the two findings.

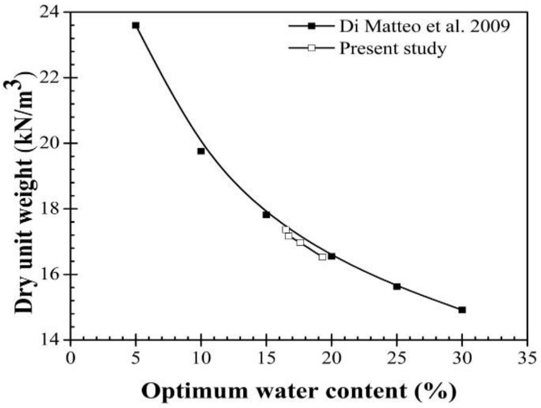

Figure 4 Relationship between OMC and MDD

3.2 CBR Test Results

The strength of the compacted subgrade can be directly evaluated from the CBR values and hence CBR test is highly appropriate to ascertain the suitability of the compacted subgrade (Indraratna, 1994). The penetration curves from the soaked CBR tests for soil with and without stabilizers are presented in Figure 5. Since the curves are initially linear, no corrections to the plots were required. According to Indian roads congress (IRC) 37 guidelines, the soaked CBR values should be considered for expansive soil subgrade. Hence in this investigation, CBR tests were done on soil samples after soaking them in water for 96 hours and the swelling was monitored. The expansion ratio (ratio of increase in soil sample thickness to the initial thickness) expressed in percentage for all the samples after 96 hours is shown in Figure 6.

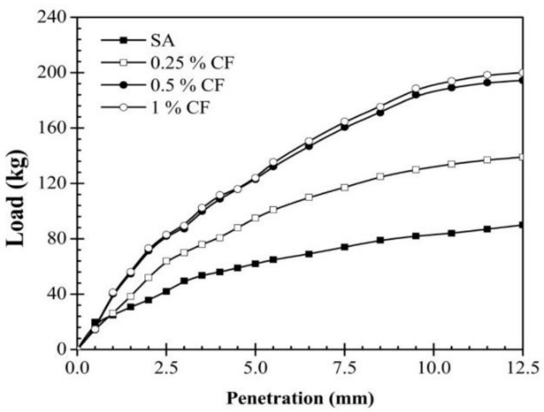

Figure 5 Load vs. penetration curve for soil with and without CF

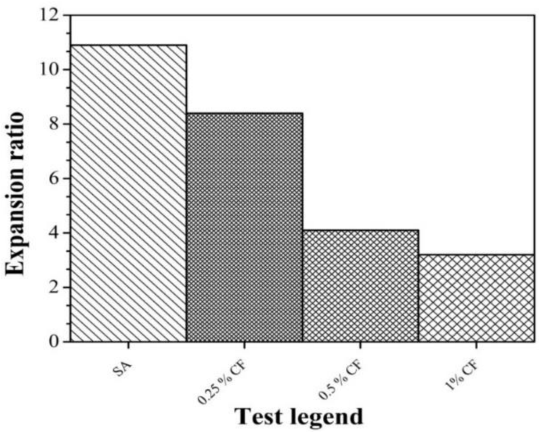

Figure 6 Expansion ratio of specimens under soked condition

The expansion ratio obtained from soaked CBR tests can be taken as the swelling strain of the soil sample. The soil sample expansion is high for virgin soil and the expansion ratio is decreased upon the addition of stabilizers. The data from Figure 6 indicates that the percentage reduction in expansion ratio is 22.9, 62.4 and 70.6 upon addition of 0.25, 0.5 and 1% coconut fibre with 20% fly ash when compared to virgin soil. The variation in expansion reduction is higher (39.5%) when fibre content is varied from 0.25 to 0.5% but the reduction percentage (8.2%) is low when fibre content is varied from 0.5 to 1%. This clearly shows that the control of swelling is more pronounced up to optimum fibre content and further addition of fibres lead to the reduction in performance. The reduction in expansion ratio upon addition of fibres and fly ash is due to the resistance offered by the clay-fibre interaction and also due to the pozzalonic reactions of fly ash with soil (Punthutaecha et al., 2006, Viswanadham et al. 2009, Sabat and Pradhan, 2014).

Table 4 CBR values at corresponding penetration

Soil Mixture	CBR value at 2.5 mm penetration	CBR value at 5 mm penetration
SA	3.1	3.0
0.25%CF	4.7	4.6
0.5%CF	6.0	6.0
1%CF	6.1	6.0

The soaked CBR values corresponding to 2.5mm and 5mm penetration were calculated and it was observed that the values for 2.5 mm are high for all the cases and are listed in Table 4. From the data, it is seen that the soaked CBR value is increased upon the addition of 20% fly ash with different dosages of coconut fibres. The percentage increase in soaked CBR value at 2.5 mm penetration is 50.7, 93.1 and 95.4 upon addition of 0.25, 0.5 and 1% coconut fibre with 20% fly ash. The increased CBR value could be attributed to the combined effect of fly ash and fibres including flocculation by fly ash and tensile strength by fibres. There is a decreasing trend of improvement upon addition of fibres more than 0.5%. Higher the fibre content, the fly ash and fibre contact is more with minimum clay binding which could reduce the performance.

3.3 Swelling pressure Test results

The swelling pressure determined by the constant volume method for stabilized soil in comparison with the soil alone is shown in Figure 7. The virgin soil shows higher swelling pressure when compared to stabilized soils. The percentage reduction of swelling pressure with the addition of 0.25, 0.5 and 1% fibre with 20% fly ash is 40, 57 and 60% respectively. The expansion ratio from soaked CBR tests from Figure 6 is an indication of reduction of swelling upon the addition of stabilizers. As the expansion ratio is decreased, the swelling pressure is also reduced. The variation in swelling pressure reduction is higher (17%) when fibre content is varied from 0.25 to 0.5% but the reduction percentage (3%) is marginal when fibre content is varied from 0.5 to 1%. The effect of addition of fibres being a positive sign of reduction in swelling pressure but the contribution to the reduction by higher dosages of fibres is insignificant.

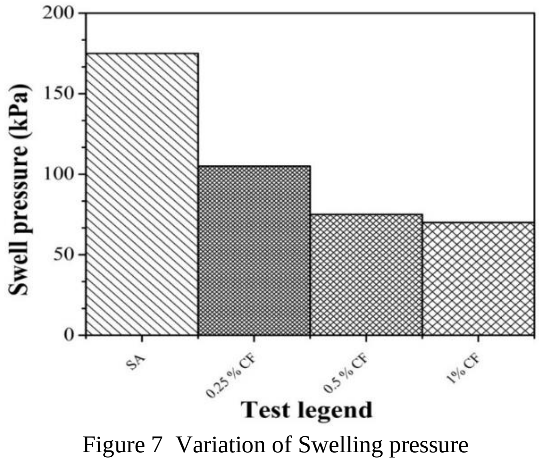

Figure 7 Variation of Swelling pressure

4. CONCLUSIONS

The present study focussed on the effect of different percentages of coconut fibre addition (0.25%, 0.5% and 1% on weight of dry soil) on compaction characteristics, CBR and swelling aspects on the fly ash (20% by weight of dry soil) amended expansive soil. The following conclusions were drawn from the study.

1. The compaction curves shifts slightly towards the right and downwards upon the addition of stabilizers. MDD is decreased and OMC is increased upon increasing the percentage of fibres. The appreciable reduction in density and increase in OMC is noted for the soil blended with 20% fly ash and 1% coconut fibres.

2. Upon addition of fibres in fly ash mixed expansive soil, the soaked CBR values increases. The CBR value is increased by 93% upon the addition of 0.5% fibres and the increase in CBR is not efficient for more than 0.5% fibre addition in fly ash amended expansive soil.

3. The expansion ratio is reduced by 62% upon addition of 0.5% fibres and the reduction in expansion is not pronounced for more than 0.5% fibre addition in fly ash amended expansive soil.

4. The addition of fibres and fly ash causes reduction in the vertical swelling pressure of the expansive soil. The swelling pressure is decreased by 57% upon addition of 0.5% fibre and further increase in fibre content does not significantly reduce the swelling pressure.

From the above results, it is evidenced that the addition of 0.5% fibre along with 20% fly ash is optimum for improving the CBR and reducing the swelling pressure of the expansive soil.

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