SWELLING AND COMPACTION CHARACTERISTICS OF FIBER-REINFORCED EXPANSIVE SOILS

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ABSTRACT: The Foundations which were placed on problematic soils like expansive soils are causing the swell-shrink behavior due to moisture changes and the structures built upon these soils are experiencing failures. There are multiple specified foundation approaches to address the swell-shrink issues brought on by these soils. The current study deals with the volumetric changes of natural fine-grained soils having varying liquid limits (W_L = 58%, 66%, 74%, and 85%) blended with Recron 3s fiber (0.5%, 1%, 1.5%, 2%, 2.5%, and 3%). Swelling potential (S_i) is compared with index properties (Plasticity index and shrinkage index) with variation in fiber percentage. Swell pressure (S_p) tests were conducted by the constant volume method for the optimum fibre content having different compaction energy levels. (IS Light and heavy compaction). For soils having a liquid limit range of 58 to 66%, the S_i decreases and then has an increasing tendency. S_p was not affected to a greater magnitude by the inclusion of optimum fibre content, for varying energy levels compacted at OMC & MDD. Irrespective of the energy levels, an increase in the liquid limit of the soils causes an increase in the optimum fibre content (compacted at the maximum magnitude of MDD).

Keywords: Expansive soil; Fiber; Recron 3s Fibre; Swell potential;

1. INTRODUCTION

Expansive (black cotton) soil is the abundant earth material, which covers almost 1/5th of the area of the Indian subcontinent. Expansive soils are very problematic soil because it changes their volume of water content. This results in problem related to settlement, bearing capacity, shrinkage and cracking. The expansive soil is weak in shear strength and high swell and shrinkage characteristics. Several methods are introduced for stabilizing the expansive soil. As documented in the literature to name a few like replacement of these soils with sand or gravel, blending the lime, Cement etc. and subjecting to different draining techniques like preloading, prewetting and dewatering. But these techniques are not effective for all types of soils and some are time-consuming. Characteristics of the soil can also increase in various methods such as the addition of sand, saltwater, fiber etc. In this, the addition of fiber is the best way to mitigate the consolidation characteristics of expansive soil. There are two types of Fibers available for reinforcement, they are Natural (Bamboo, Jute, Coir, and Sisal) and Synthetic (Polypropylene, Polyester, Polyethylene, and Glass fibers). Numerous academics have conducted extensive research on the stabilization of flexible pavement subgrades and concrete structures in the past using Recron 3s fibers but no study regarding the consolidation or settlement characteristics of the reinforcement of Recron 3s fibers for expansive soils, which had a wide range of liquid limit. The fibers having different aspect ratios will be blended with soil based on design mix proportions with a percentage variation of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%. Four soils reinforced with an optimum fibre content of varying liquid limits are being tested for different energy levels like IS Light and Heavy Compaction. To have a better understanding of the swelling characteristics, swell pressure tests were performed at OMC on plain and reinforced soil and the swell potential was calculated by using the empirical formulas of Seed et al. (1962) and Ranganathan et al. (1965) for the soils under study.

2. LITERATURE REVIEW

Basma. A and Homoud (1996) investigate the four soils of various plasticity and swelling cycles. The findings demonstrated that clays' expansive behavior is significantly influenced by cyclic swelling and shrinking. When the soils were alternatively wetted and partially shrunk, a general decline in the clays' ability to swell, correlating to a reduced water absorption capability, was found. On the other side, when the soils shrank completely, there was a rise in the swelling potential. After multiple cycles, equilibrium can be reached in either situation.

Rao A S et.al (2004) determined the Free Swell index, like other index characteristics of clays, is applied to soil fractions less than 425 microns. In the equation between swell potential and swell pressure, it serves as a parameter. In the study, swell potential and swelling pressure of remolded and compacted expansive soils were forecasted using the correlations developed between the free swell index and placement conditions.

Viswanadham et.al (2009) showed how discrete, randomly placed geofibers are effective at reducing the propensity of pricey soil to swell. They performed a 1-D consolidation test and concluded that the low aspect ratios and fiber contents of 0.25% and 0.50% have resulted in the greatest reduction in swell pressure and heave.

Tripathy. S and Subba Rao (2009) conducted an experimental study on the soil samples, to carefully analyze the effects of modifications in the shrinkage pattern and the swell-shrink behavior of compacted expansive soil. The results of the experiment demonstrated that if the suction during the shrinkage cycles was smaller than the prior suction, the soil could immediately reach an equilibrium state in terms of its capacity to swell and shrinkage; otherwise, due to weariness of the swelling the state of equilibrium was achieved. It was found that the soil specimen that had shrunk more is exhibiting the volumetric deformation that was noticeably greater than the corresponding vertical deformation. It is demonstrated that suction has a significant impact on shrinkage cycles.

Phanikumar B.R and Singla R (2013) studied the swelling characteristics of expansive soils reinforced with artificial fibers (using nylon fiber) with varying percentages of fibre (F_c) ranging from 0 to 0.30% with an increment of 0.05% by weight. The results showed that up to F_c=0.25%, the swell potential, and swell pressure declined, but when F_c = 0.30%, they mildly increased. Additionally, it was discovered that the fiber-reinforced specimens' secondary consolidation properties were superior to those of the unreinforced specimen.

Sharma A.K and Sivapullaiah P.V (2017) examined the ability to stabilize expansive soils using a binder created by industrial waste like blending fly ash and GGBS. The test results demonstrated that soil swelling behavior decreased as binder content increased. The binder was shown to be efficient and cost-effective for stabilizing expansive soil with fewer chemical additives, it is minimizing the swelling and compressibility after the addition of lime to the optimum percentage i.e 1%.

Soltani. A et.al., (2018) investigated the fiber's ability to reduce an expanding soil's tendency to swell. The reinforcements consisted of two different kinds of tape-shaped fibres, namely Fiber A (width fw = 2.5 mm) and Fiber B (fw = 7 mm). Each of the three fibre contents of fc = 0.5%, 1%, and 1.5%. The findings indicate that fc = 0.5% was the indicated best case for both fibre types. Higher inclusions up to 1%, however, could potentially be a suitable option if compressional deformations are not the main issue.

Selvakumar S and Soundara B (2019) studied the recycled expanded polyester (EPS) beads and geofoam granule columns (GGC) affecting the expansive soil by treating it with it. A soil sample was placed in two different placement settings with changing moisture contents to test the effectiveness of GGC inclusion in expansive soil. The test findings demonstrated a considerable reduction in swelling percentage, pressure, and time rate with the addition of GGC.

Ali. N and Raj. V. S (2020) have evaluated the effectiveness of expansive soil reinforced with polypropylene fibre. The results show that discrete, randomly placed polypropylene fibre is effective in reducing expansive soils' propensity to swell. We investigated the swelling properties of expanded soil specimens that had been remoulded and reinforced with varied fibre contents (f = 0.2%, 0.3%, 0.4%, and 0.5%) and aspect ratios (l/b = 15, 30, and 45). There is a decrease in the swelling and heave when it is subjected to consolidometer for different percentages of fibre and aspect ratio.

Shukla. T. et.al., (2021) investigated how tyre fibres affected the way expansive soils swelled when they were subjected to consolidation, for the variation in the percentage of fibers (from 0.25 to 1%) and soil size (aspect ratio). It was found that as fibre length increases, the ideal fibre content decreases and vice versa. As a result, shorter fibres are required as fibre content increases to lessen the risk of swelling while longer fibres are required as fibre content decreases.

3. MATERIALS

3.1 Selection of Soils

The liquid limit of the soils is an important factor to decide the selection of soils for the current experimental study. The selected soils which are having a liquid limit ranging from 50 to 90%. Four soil samples were taken from various sites in the districts of Mysuru and Chamarajanagar, and they were then put through a preliminary laboratory inquiry that included liquid limit and free swell tests. The Casagrande percussion method was used to calculate the liquid limits (IS: 2720 - Part 5, 1985). Finally, it was decided to use the following soils in the present experimental study.

1. Field soil-1 from Devanur, Govt polytechnic college Devanur, Mysore district, which contains a dominant clay mineral i.e., kaolinite montmorillonitic (K-M).
2. Field soil-2 from sutturu, Kabini canal, Nanjangud taluk, Mysuru district, which contains a dominant clay mineral i.e., Montmorillonitic (M).
3. Field soil-3 from ramasamudram, Chamarajanagar, Chamarajanagar district, which contains a dominant clay mineral i.e., Montmorillonitic (M).
4. Field soil-4 from Kuntur, Chamarajanagar district, which contains a dominant clay mineral i.e., Montmorillonitic (M).

The physical and index properties of soils is shown in Table 1.

Table 1: Physical and index properties of Soils

Sl. No	Soil	Free Swell Ratio	Specific Gravity	Liquid limit (w_L): %	Plastic limit (w_P): %	Plasticity index (I_p): %	Shrinkage limit (w_S): %	*Shrinkage index (I_s): %	Grain Size Distribution: %			Type of Clay Mineral	IS classification
									Clay size	Silt size	Sand Size		
1	Soil-1	1.78	2.69	58	27	31	17.6	9.4	24	48	28	K-M Soil	CH
2	Soil-2	1.5	2.6	66	27.5	38.5	16.8	10.7	31	46	23	M-Soil	CH
3	Soil-3	2.30	2.87	74	26	48	8	18	26	52	22	M-Soil	CH
4	Soil-4	1.58	2.72	85	28.5	56.5	16.7	11.8	60	31	9	M-Soil	CH

3.2 Selection of Fiber

In the present experimental study, the selected soils were reinforced with synthetic fibre to enhance the characteristics of the expansive soil. Potential benefits for waste reduction come from using synthetic fibres like polyester can be used for the reinforcement technique. One of a kind is Recron 3s Fibre.

Table 2 shows the properties of the Recron 3s fibre.

Table 2: Recron 3s fiber properties

Property	Value
Density in gram/cm^3	0.91
Cut length in mm	12
Diameter in mm	0.033
Color	white
Humidity (%)	Less than 0.1
Acid resistance	Very good
Alkali resistance	Very good
Water absorption (%)	80

4 METHODOLOGY

4.1 Preparations of natural soils for investigation

The collected soils were are dried, powdered and sieved through IS Sieve size 0.425mm to remove the coarser fraction.

For the selected plain and reinforced soils, the tests have been conducted were Physical, index properties and IS Proctor compaction. The categorization of index properties is indirectly affecting the degree of swelling, were used to infer the swell potential. For the best fibre content, the swell pressure test is also carried out using the constant volume method on both plain and reinforced soil.

4.2 Compaction

The IS light and heavy compaction tests were conducted (IS: 2720, Part-7, 1980; IS: 2720, Part-8, 1983) for the soils under study. About 6 to 8 samples, each weighing 2.5 kg, were fully mixed with various water contents for the moulding process for each of these tests, namely the light and heavy compaction tests. For the maturation period, these samples were covered in plastic covers; After achieving the required moisture content, the samples were tested for compaction.

4.3 Swell pressure (Sw)

It is the stress exerted by the soil under constant volume when it's swelling due to water immersion is prevented.

The swell pressure can be measured by the consolidometer testing method and the constant volume method.

Constant volume method

The disturbed soil sample is compacted to the desired compaction characteristics in the Proctor apparatus. The specimen prepared was made in contact with the loading block and put the whole assembly over the platen of the loading frame. The proving ring was attached firmly to the loading frame and positioned centrally over the specimen. The dial gauge was fit to the cell and the soil specimen was submerged under the water for swelling. The initial reading of the proving ring and dial gauge was recorded for reference. As the specimen swells, the increase in volume is reflected in terms of the reading of strain measuring load gauge.

The total load is the change in the proving ring reading from initial divisions (Total load = Proving ring constant * change in proving ring reading); From the Total load to the area of cross-section, Sw is obtained.

4.4 Swell potential (Sp)

The swell potential is the proportional volume change that can be anticipated with the variation in moisture content.

One can predict swelling potential using the one-dimensional swell-consolidation test in an oedometer or by using classification index qualities such as the plasticity index, clay content, activity, and shrinkage index, which only indirectly affect swelling.

Seed et al. (1962) proposed an equation for swell potential concerning plasticity index under a surcharge of 6.9 kPa as follows:

$$\mathbf{S = 2.16 \times 10^{-3}(\boldsymbol{PI})^{2.44}} \qquad \textbf{(1)}$$

Ranganatham and satyanarayan (1965) proposed an equation of the form

$$\mathbf{S = \boldsymbol{m_1}(\boldsymbol{SI})^{2.67}} \qquad \textbf{(2)}$$

Where,

m_1 = Constant = 41.13×10^{-5}

SI = Shrinkage index = (Liquid limit – Shrinkage limit)

The swell potential was estimated through the defined equations of (1) & (2) by substituting the values of the Plasticity index and shrinkage index from the defined index properties and it was compared for the soils under study.

5 RESULTS AND DISCUSSIONS

5.1 Results of Variation in compaction characteristics with varying percentages of fiber

Figures 1 through 8 shows that the variation of compaction characteristics (Optimum moisture content (OMC) and Maximum dry density (MDD) with addition of different percentage of fibers for the soils having different liquid limit range.

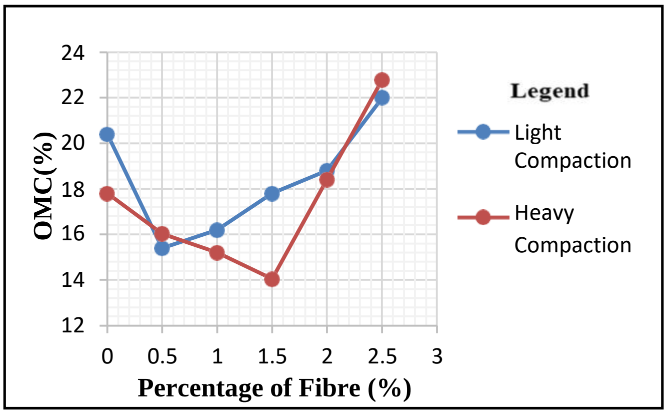

Fig. 1. Variation of OMC for Soil 1

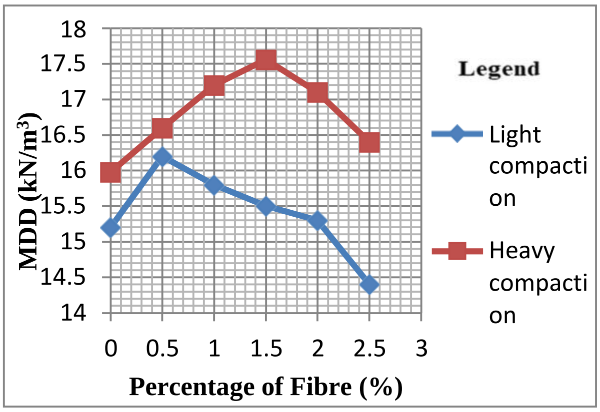

Fig. 2. Variation of MDD for Soil 1

From the figures 1& 2, it is observed that, the magnitude of MDD was achieved at 0.5% blending of fiber for light compaction and 1.5% blending of fiber for heavy compaction of the soil having liquid limit 58%.

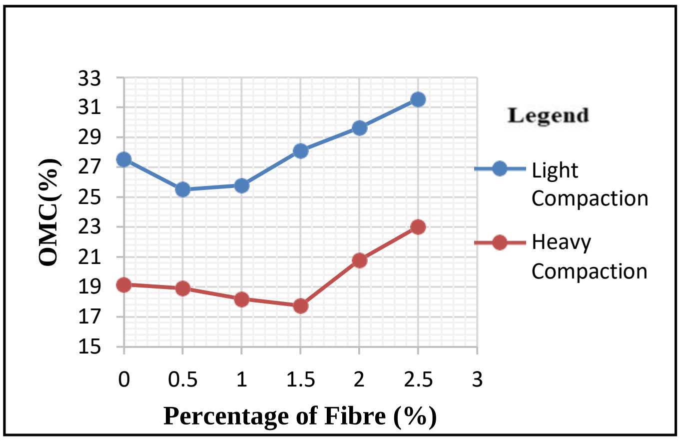

Fig.3. Variation of OMC for soil 2

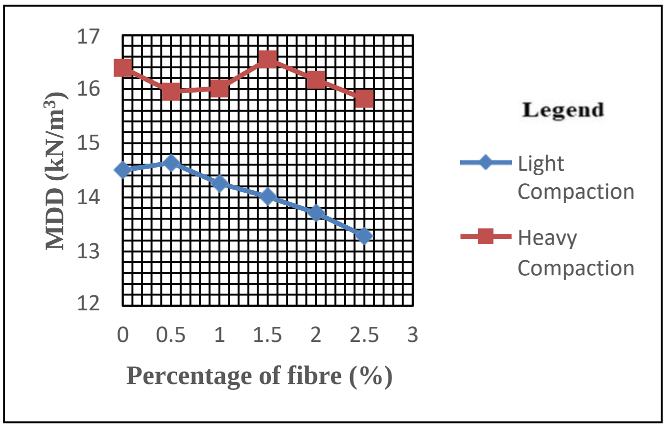

Fig.4. Variation of MDD for soil 2

From figures 3&4, it can be observed that, the magnitude of maximum dry density was achieved at 0.5% blending of fibre for light compaction and 1.5% blending of fibre for heavy compaction of the soil having liquid limit 66%.

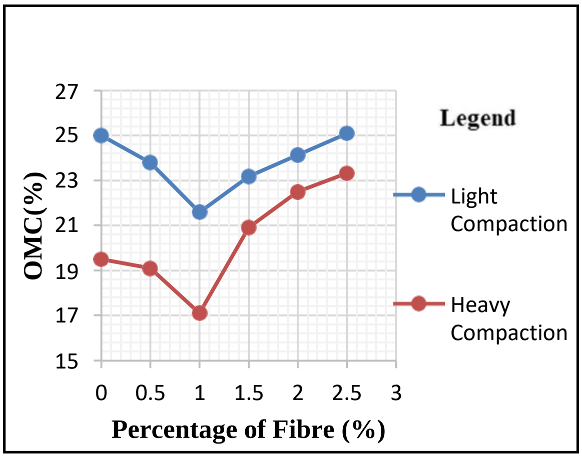

Fig. 5. Variation of OMC for Soil 3

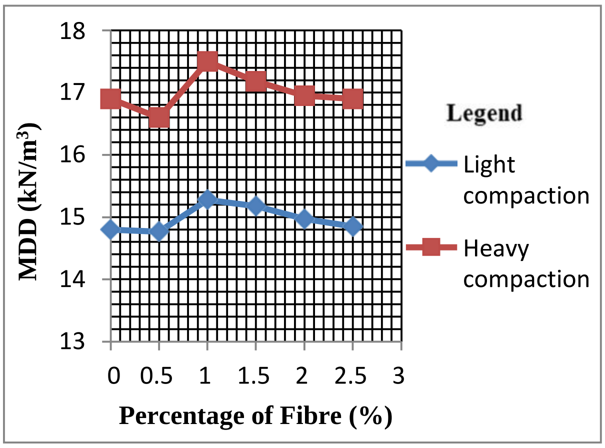

Fig. 6. Variation of MDD for Soil 3

From the figures 5&6, it is observed that, the magnitude of MDD was achieved at 1% blending of fiber for both standard proctor compaction and modified proctor compaction of the soil having liquid limit 74%.

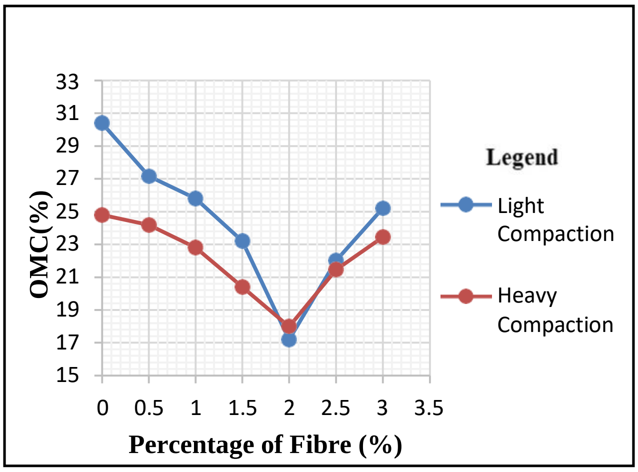

Fig. 7. Variation of OMC for Soil 4

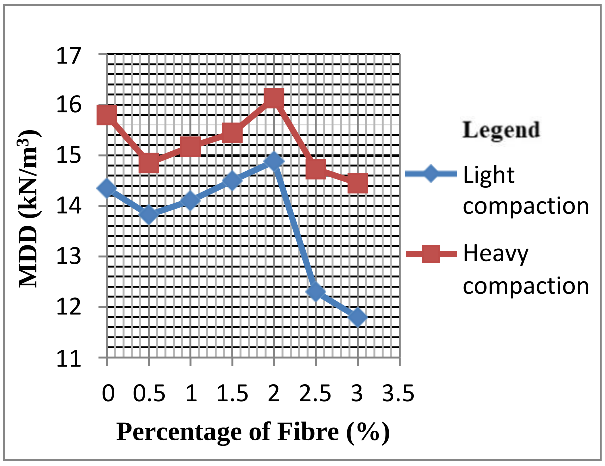

Fig. 8. Variation of MDD for Soil 4

From the figures 7&8, it is observed that, the magnitude of maximum dry density was achieved at 2% blending of fiber for both Standard and Modified Proctor compaction tests of the soil having liquid limit 85%.

From the figures 1, 3,5 & 7 it can observed that, there is a reduction in OMC up to optimum percentage of fiber i.e up to maximum magnitude of MDD. According to Proctor's capillarity and lubrication theory from 1933, water has a dual effect of lubrication and capillarity (or suction), which explains this behaviour. The dry density of dry soil is noted to be lower due to strong capillarity, and as water is added, the capillarity decreases and the water also lubricates the particle contact, the dry density increases up to the maximum dry density. The fibres that have been incorporated into the soil are filling the internal spaces between soil particles to reach the highest dry density level. The extra fibres present in the soil fabric blended with fibre, cannot occupy in the intra void spaces after the optimal fibre content has been reached due to a lack of internal flow channels. This will enhance the soil's surface area and the contact between soil particles and fibres, both of which will result in an increase in the soil's ideal moisture content.

The practical application of IS Light and Heavy Compaction tests for the soils under study blended with artificial fibres explicitly demonstrates the significant increase in the MDD values associated with OMC values which strongly comprehends the behaviour of a strong subgrade for pavements subjected to higher intensity of dynamic loadings and there by achieving the overall economy in the design criteria. Similarly for the shallow foundations, the soil bearing capacity can be improved and swell-shrinkage behaviour can be controlled when it is compacted to the wet of optimum placement condition; For the earthen embankments, it was compacted to dry optimum placement condition of to control the permeability of the soil.

From the Figures 1 through 8, it can be also observed that, the variation of percentage of fiber to the soils having different liquid limit range, the ideal percentage of fibre with the highest MDD value increased as the soil's liquid limit increased, from 0.5 and 1.5% for soils with liquid limits of 58% and 66% to 1% and 2% for soils with liquid limits of 74% and 85%.

5.2 Variation of swell pressure with and without inclusion of fibre

Figures 9&10 presents the variation of swell pressure with percentage fines and liquid limit respectively.

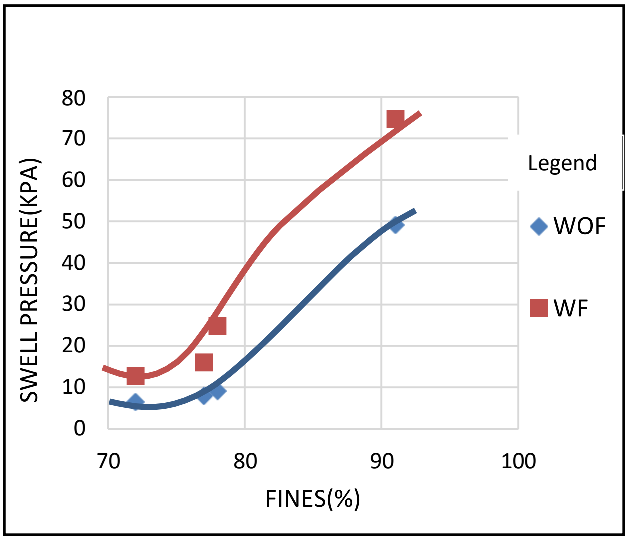

Fig.9. Variation of Sw with percent fines

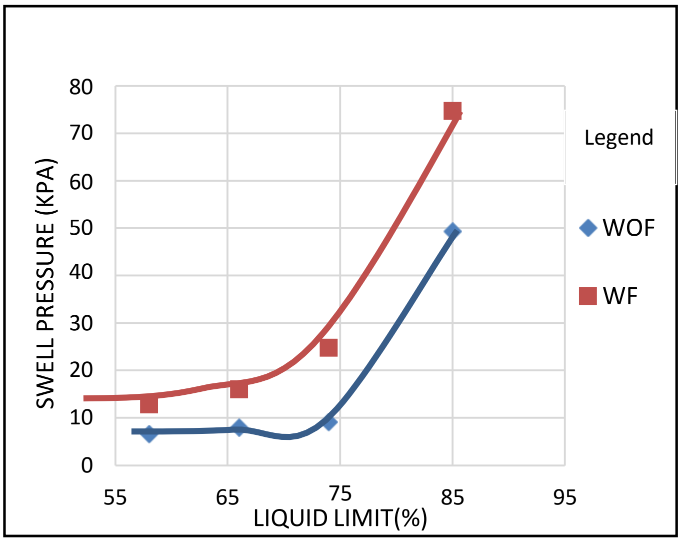

Fig.10. Variation of Sw with Liquid limit

From figure 9 it can be observed that the swell pressure increases with an increase in the percentage of fines, this is due to the fact that, increase in the specific surface area of the soil particles which in turn increases the reactivity of the soils.

From figure 10 it can be observed that the swell pressure of the soils increases with the increase in the liquid limit of the soils, it is due to the fact that, the fibre having 80% of water absorbing capacity which in turn increases the swell pressure of the soils.

5.3 Variation of swell potential with different percentage of fibre using variation in plasticity index:

Figures 11 through 14 shows the variation of swell potential for soils having different liquid limits calculated by empirical formula using plasticity index.

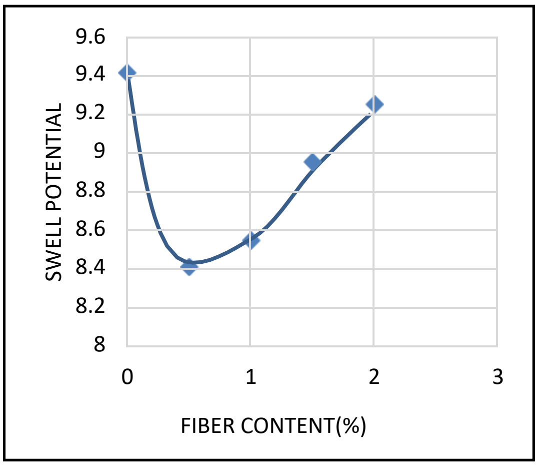

Fig.11 Variation of Sp with fibre content for soil 1

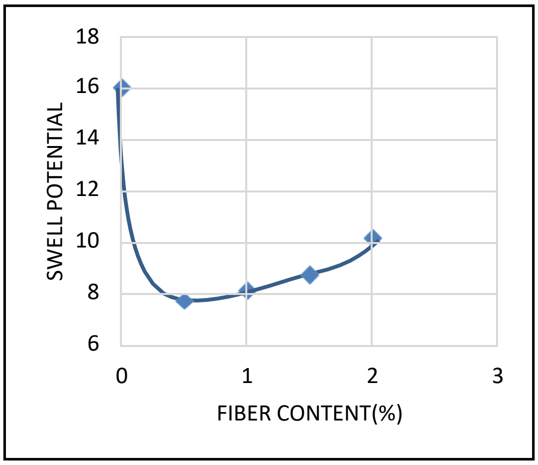

Fig.12. Variation of Sp with fibre content for soil 2

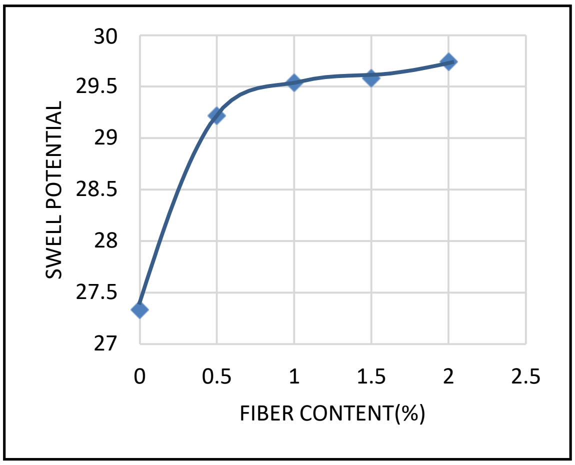

Fig.13. Variation of Sp with fibre content for soil 3

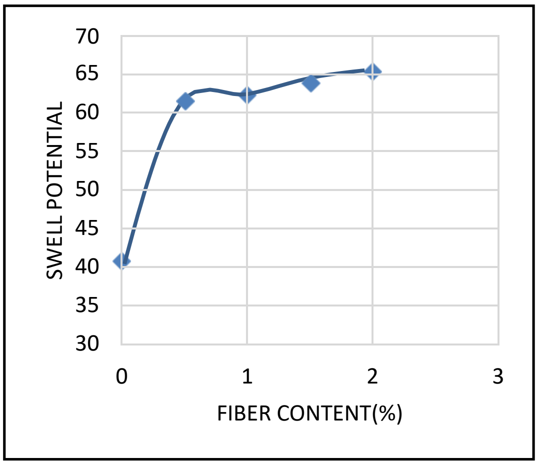

Fig.14. Variation of Sp with fibre content for soil 4

5.4 Variation of swell potential with different percentage of fibre using variation in shrinkage index:

Figures 15 through 18 shows the variation of swell potential for soils having different liquid limits calculated by empirical formula using shrinkage index.

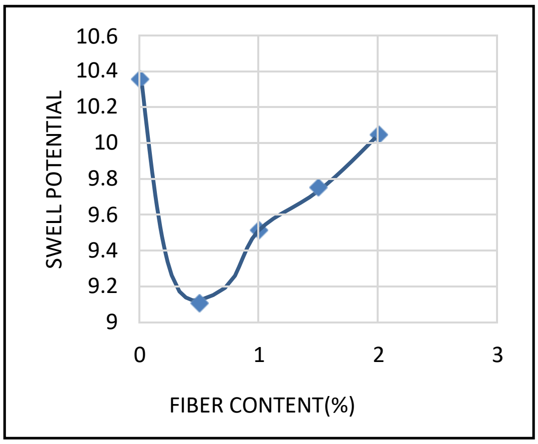

Fig.15. Variation of Sp with fibre content for soil 1

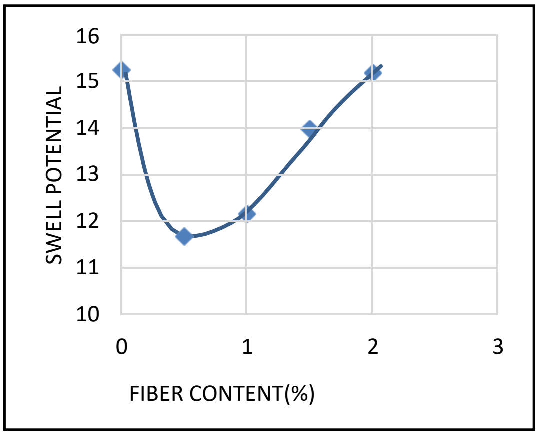

Fig.16. Variation of Sp with fibre content for soil 2

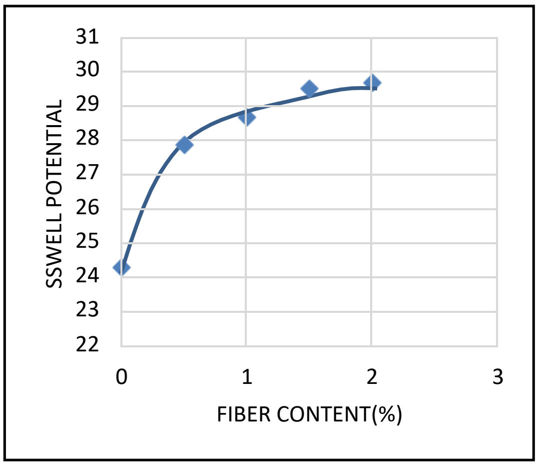

Fig.17. Variation of Sp with percentage fibre for soil 3

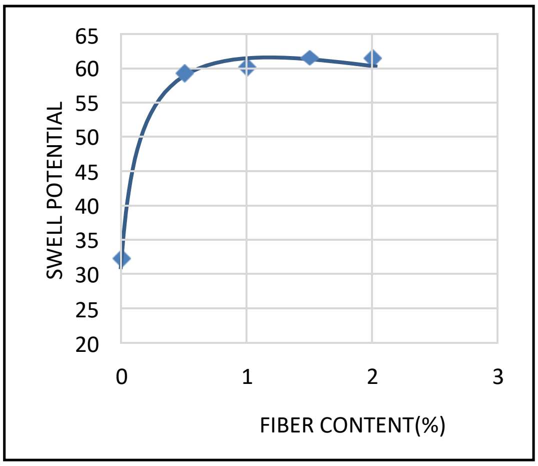

Fig.18. Variation of Sp with Percentage fibre for soil 4

From figures 11 through 18, it can be also observed that, for soils 1 & 2, 0.5 % fibre content which is optimum, results in lower swell potential. For soils 3 & 4 beyond 1 % of fibre, the variation is more or less constant. For both the plasticity index and shrinkage index the variation is the same i.e for the optimum fibre content of 0.5% fibre, there is a decrease in swelling potential up to 66% liquid limit. This is because the increase in the percentage of clay fraction and montmorillonite clay mineral dominance is leading to an increase in inter-particle attraction which decreases the magnitude of particle flocculation and also the amount of void space available for water entrapment at liquid limit [Dispersed soil fabric structural arrangement i.e no face to face orientation] [Sridharan 1990], There is the low magnitude of difference (23%) in plasticity characteristics of soil (W_L,W_P and W_S) for the Soil 1 and 2, whereas for the soils 3&4 it is higher (66%) with the addition of fibers is leading to decrease in I_P, I_s and when compared with soil 1 and 2. With the addition of Recron 3s fibres from 0.5 to 3%, expansive soils with liquid limits between 58% and 66% showed improved plasticity characteristics. This is due to the percentage of clay and silt in the fines having a lower particle size (high specific surface area), which contributes to more water entrapment in the soil voids and an increase in the repulsive force of action between soil particles as the liquid limit rises. This is owing to the fact that the soil's liquid limit range of 66% can be regarded as the ideal liquid limit range for enhancing the plasticity qualities of expansive soil when fibres are added, and it was leading a decrease in swelling potential.

6 Conclusions

Based on the detailed experimental study, the following conclusions were made

- The optimum percentage of fiber with a maximum value of MDD was increasing with an increase in the liquid limit of the soil i.e from 0.5 and 1.5 % for the soil having liquid limit 58% & 66% whereas, for 74% and 85%, it is 1% and 2% respectively.
- The swell pressure increases with an increase in the percentage of fines.
- As the soil's liquid limit rises, the swell pressure of the soil also rises.
- For the 0.5% of fiber content, the swelling potential decreased with an increase in the liquid limit (up to 66%).

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