Determination of characteristic water contents of fiber reinforced expansive soils – A fundamental approach

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Abstract: Conventionally liquid, plastic and shrinkage limits are considered as plasticity characteristics of natural fine -grained soils. Different approaches to estimating liquid limits itself demonstrate that the concept of a liquid limit and the mechanism governing it are not the same [Prakash and Sridharan, 2002]. In the present experimental study five natural fine-grained expansive soils having liquid limit range (50% to 100%) were used. The three characteristic water contents i.e., It was feasible to calculate the free swell limit (W_{FS}), setting limit (W_{SL}), and shrinkage limit for plain and fiber-reinforced expansive soils for different percentages by adjusting the initial water content. There are relationships between starting and final water contents as well as sediment volume and liquid limit.. The experimental study's measurement of the equilibrium sediment volume shows good agreement with the established procedure for determining liquid limits. Using linear regression analysis, correlations were developed between index properties, plasticity characteristics with the compaction characteristics for varying water contents along the compaction curve for different energy levels.

Keywords: Compaction curve; fiber; regression analysis; sediment volume; settling limit.

1 Introduction

The topography, geology, climatic conditions, and vegetation of India are all diverse. As a result, India has several different types of soil that are all very different from one another. The main soil types in India are alluvial, black (expansive), red, laterite and lateritic, forest, and arid/desert soils. India has broad soil that covers a sizable chunk of the country. Clayey soils with the propensity to expand when the moisture content is higher or contract when the moisture content is lower are known as expansive soils. These qualities are brought about by the presence of clay minerals that can swell when the moisture content is higher. Much of south India is covered in expansive soils.

Because of their weak strength, considerable compressibility, and significant potential for swelling and shrinking, expansive soils are often considered to be unattractive building materials for use in civil engineering applications. Finding a practical way to enhance engineering behavior at a lower cost is essential. The strength and bearing capacity of the expansive soils are directly impacted by the swelling properties, including swell potential, swell pressure, and free swell index.

As a result, such soils typically need to be changed before application in order to match design criteria. Expansive soils can be stabilized using either chemical techniques or mechanical techniques. Utilizing compaction with reinforcing assistance, mechanical modification increases soil porosity and inter-particle friction. Fibers of synthetic (like polypropylene and nylon) and natural (like coir and palm) origin are frequently used as reinforcements, in addition to other fiber-like materials like plastic waste strips and shredded tyres.

This experimental program's major goal was to find out how the fibre (Recron 3s) reinforcement affected the mechanical and physical characteristics of soil samples taken from expansive clay deposits in Kollegala taluk and Yalandur taluk of Chamarajanagar district, Suttur village of Mysuru district, Ramasamudram and Kuntur of Chamarajanagar district. The effects of liquid limit, plastic limit, one-dimensional settlement, and other physical features are discussed. The experimental program was run on soil samples that had Recorn 3s fibre, with the fibre content between 0% to 3%, with an interval of 1%.

2 Literature Review

Stadtbaumer's study (1976), demonstrated that both low- and high-swelling clay minerals' liquid limits were not governed by common physicochemical parameters.

Sridharan A and Sudhakar Rao (1990), shown that the soil expansivity potential is determined by the ratio of the soil sediment volumes in a 0.025% solution of sodium chloride to those in kerosene and categorised the expansive soils based on this ratio.

Sridharan & Prakash (1998), acknowledged the existence of the three water contents, free swell limit, settling limit, and shrinkage limit that characterise any soil water system.

Sridharan and Prakash (2000), for fine-grained soils, a correlation between sediment volume and liquid limit has been demonstrated without altering the standard definition of the soil's liquid limit, which is the point at which the soil has essentially no shear strength.

Rao A S (2004), et.al determined the free swell index on the soil fraction less than 425micron sieve. It is used as a parameter in the relationship for swell potential and swell pressure.

Kameshwar Rao, et.al (2009), reported that the inclusion of synthetic fibre lowers the swelling pressure caused by the expanding soil.

Tripathy S and Subba Rao (2009), conducted an experimental inquiry on samples of the soils to thoroughly investigate the effects of changes in shrinkage pattern on the swell-shrink behavior of compacted expansive soils.

Sridharan and Prakash (2010), further report, the stress history of fine-grained soils has a definite influence on permeability values apart from void ratio effect and this is attributed to fabric effect.

Saravan Ramaswamy and Arumairaj P D (2013), analysed the effects of adding polypropylene fibre to clay soil experimentally and found that the fibre improves the ductility behaviour of soils, minimising shrinkage settlements after desiccation.

Anju C A, et.al (2016), showed that a decline in the soil's water-holding capacity occurs as the amount of fibre increases.

Krishnagouda H, et.al (2018), carried out a comparative analysis of soil strength by adding Recron 3s and discovered that the soil's UCS value rises, but only to a limited degree beyond (0.25% of Recron 3s).

Muthulakshmi and Ammaiappan (2018), attempted to inculcate the relationship between the percentage of fibre and maximum UCC strength of the reinforced and unreinforced soils.

Muhammad Al, et.al (2019), indicated that the swelling potential is significantly reduced by addition of polypropylene fibres up-to 0.6%.

Poonam Tripathi and Ray D S (2020), have explicitly stated that the soil crushed thickness reduces on addition of admixtures (Recron 3s fibre) when compared to non-admixture soil.

Prasanna H S, et.al (2021), have shown that soil volumetric shrinkage reduces as the size of the applied compactive energy increases.

3 Materials and Methods

3.1 Materials

Soils from roughly 25 places near the Mysuru district were initially considered in the current experimental study. Then, five soils were selected based on the liquid limit and free swell index criteria, and samples were taken from each location.

Field soil - 1 from Yalandur, near a construction site, nearby Mysuru district. It has a dominant mineral kaolinite (K).
Field soil - 2 from Kollegal, close to a gas station, nearby Mysuru district. It contains montmorillonite (M).
Field soil - 3 from Suttur, located near Nanjangud taluk, Mysuru district. This has a high-water content.
Field soil - 4 from Chamarajanagar district, which contains a dominant clay mineral i.e, Montmorillonite (M)

Field soil - 5 from Kuntur, neighbouring Kollegal and Yelandur, nearby Mysuru district.

Selection of fibre

In this experiment, expansive soils are given a synthetic fibre addition to enhance their engineering qualities. The opportunity to reduce waste and thus the carbon footprint exists when synthetic fibres like polyester are used as reinforcement materials. Polyester fibre from Recron 3 is utilised as a reinforcing material. Due to their non-toxicity, resistance to corrosion, and high tensile strength, one of the most used synthetic materials for soil reinforcement is polyester fibres. Table 1 lists the properties of Recron 3's fibre.

Table 1. Properties of Recron 3s fibre

Density	0.91 g/cm³
Water absorption	80%
Diameter	34 μm
Cut length	12 mm
Colour	White
Humidity	< 0.1%
Acid resistance	Very good
Alkali resistance	Very good
Water absorption	80%

Preparation of soil for investigation

The field soil samples are taken, oven dried, crushed, and sieved through a 0.425 mm IS sieve to remove the coarser fraction.
An extensive investigation of soil samples was conducted to identify the index qualities with and without treatment with fibres.

3.2 Methods

Index properties of soils

On the various soils under investigation, the subsequent experiments were run;

Test for specific gravity: The density bottle method and distilled water were used to ascertain the soils' specific gravities (IS: 2720-Part-3, 1980).

Test for liquid limit: To determine the soils' liquid limitations, the Casagrande percussion method and the cone penetrometer method were both utilized (IS: 2720 - Part 5, 1985).

Test for plastic limit: The standard 3 mm thread rolling technique was used to determine the soils' plastic limitations (IS: 2720-Part 5, 1985).

Test for shrinkage limit: We determined the soil shrinkage limits using the mercury displacement method (IS:2720 Part 6, 1972).

Grain size analysis: The distribution of particle sizes in the soil, as discovered by sifting (IS:2720, Part 4, 1985).

Hydrometer analysis: (IS:2720, Part 4, 1985).

Test for free swell: The Bureau of Indian Standards' recommendation (IS: 2720, Part 40, 1977) refers to the soil's free swell index.

Compaction characteristics of soils

On soils, IS tests for mild and high compaction were performed (IS: 2720, Part-7, 1980; IS: 2720, Part-8, 1983).

The main inputs for the majority of the field procedures used to compress soil are the outcomes of laboratory compaction tests, either traditional or modified proctor compaction tests. Maximum dry density (γ_{dmax}) and optimal moisture content (OMC) are the two crucial compaction properties. Greater compactive effort for a given soil will result in higher γ_{dmax} values and lower OMC values.

Table 2. 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): %	Shrinkage index (I_S): %	Grain Size Distribution: %			IS classification
									Clay size	Silt size	Sand Size	
1	Soil-1	1.5	2.688	64.46	25.52	38.94	9.7	11.28	11	77	12	CH
2	Soil-2	1.4	2.686	67.4	26.51	40.89	7.8	11.37	22.5	34.2	43.3	CH
3	Soil-3	1.5	2.6	66	24.03	41.97	16.8	10.7	31	46	23	CH
4	Soil-4	2.30	2.87	74	23	51	8	18	26	52	22	CH
5	Soil-5	1.58	2.72	85	28.5	53.5	16.7	11.8	60	31	9	CH

Procedure

Five 100 ml weighing jars were filled with soil samples, each weighing 25 g in dry weight. Each of the jars received a variable amount of distilled water to create soil-water suspensions with various starting water volumes (Wi). After completely blending, the soil-water suspensions were left to settle without being disturbed. The sediment volume in each jar was measured after a 24-hour equilibration period. Each sediment's final water content (W_f), beginning dry weight, and soil specific gravity were calculated using the final sediment volume. The result was a graph between W_f and log10 W_i. The $W_f = W_i$ line was used as the settling limit water content of the soil, and the best fit line that took into account the experimental points was used to compute the soil's ultimate water content.
By changing the fibre content in the expanding soils, the process is repeated.
Sridharan & Prakash (1998) utilised the following equations(1,2,23,4) to statistically link the traditional liquid limit with the water content of the settlement border

$$W_L\,(\%) = 0.68\ W_{SL}\,(\%) \quad (1)$$

It was found that the liquid limit determined by the percussion cup method, W_L (%), and the equilibrium sediment volume in cm^3/g were related. With a correlation coefficient of 0.95, the following equation which is the most suitable linear regression equation is generated.

$$W_L\,(\%) = 43.15\ S_V - 10.21 \quad (2)$$

According to statistical analysis, when two integers are connected by a formula with a correlation coefficient of 0.94, there is no discernible loss of precision.

$$W_L\,(\%) = 37.17\ S_V \quad (3)$$

The following relationship between the soil liquid limit and the equilibrium sediment water content, W_{SV}(%), has a correlation coefficient of 0.94.

$$W_L\,(\%) = 0.473\ W_{SV}\,(\%) \quad (4)$$

Sediment volume method

The beginning water content of the soil-water suspension has been demonstrated to affect the equilibrium sediment volume if $W_{SL} < Wi < W_{FS}$, and for Wi > WFS, the equilibrium sediment volume takes on a separate value.

Numerous observations of the sediment formation process show that the soil clay mineralogy significantly affects the sediment equilibrium volume of soils produced in various physicochemical situations as well as the texture of soft sediments (Sridharan & Prakash, 1999). Diffuse double-layer repulsion controls the volume change of montmorillonite soils, whereas particle-level shearing resistance controls the volume change of kaolinite soils during settling and sediment formation. The increase in the amount of equilibrium sediment in kaolinite soil is brought on by an increase in the net attractive forces between particles. On the other hand, in montmorillonite soils, the net inter-particle repulsion is what causes the increase in sediment volume at equilibrium. As a result, even if the equilibrium sediment amount of both sediments were increased, the control mechanisms would still be in conflict based on the dominant clay mineral in the soil.

The current experimental investigation focuses on the relationship between several physical characteristics of fiber-reinforced expansive soils and the settling limit by altering the soil's fibre concentration. The settlement limits were compared with liquid limit of different soil samples, both of which contribute to the settlement of the plain soils. The soils' maximum liquid limit determines the maximum dry density. The settling volume of the expansive soils were also compared with free swell ratio.

4 Results and discussions

From the equations mentioned in the methodology (equation 2,3 and 4) it can be stated that $W_L < W_{SL} < Wsv$ as documented in the literature. The relation between sediment volume at equilibrium and the soil liquid limit is shown in figures 1 and 2.

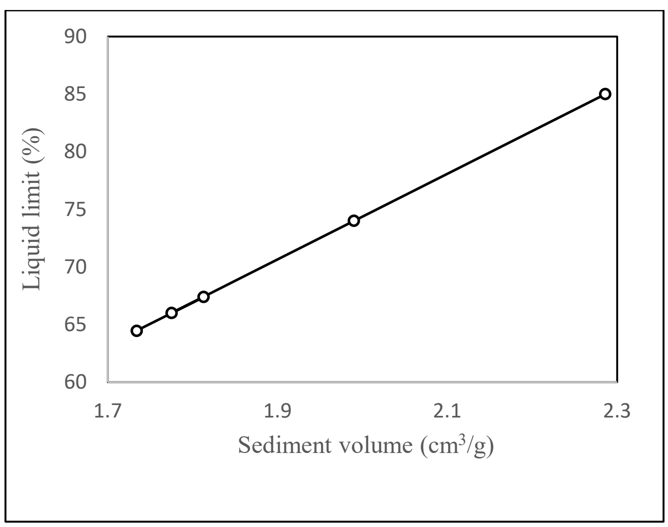

Fig. 1. Relation between liquid limit and sediment volume (with a correlation coefficient of 0.94)

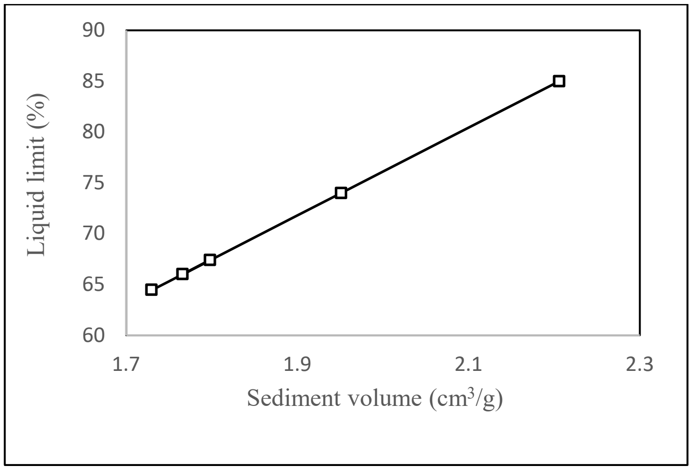

Fig. 2. Relation between sediment volume and liquid limit (with a correlation coefficient of 0.95)

Figures 1 and 2 show the link between the equilibrium sediment volume and soil liquid limit determined by equations (2) and (3). It has been observed that as the liquid limit of expansive soils rises, the comparable sediment volume rises as a result of the rise in void spaces. The volume of the sediment has a direct impact on the soil's liquid limit. For the same liquid soil constraints, the sediment volume computed with a correlation coefficient of 0.95 is somewhat lower than that obtained with a correlation coefficient of 0.94.

Figure 3 represents the relation between settling limit and free swell index of the expansive soil, with and without fibres.

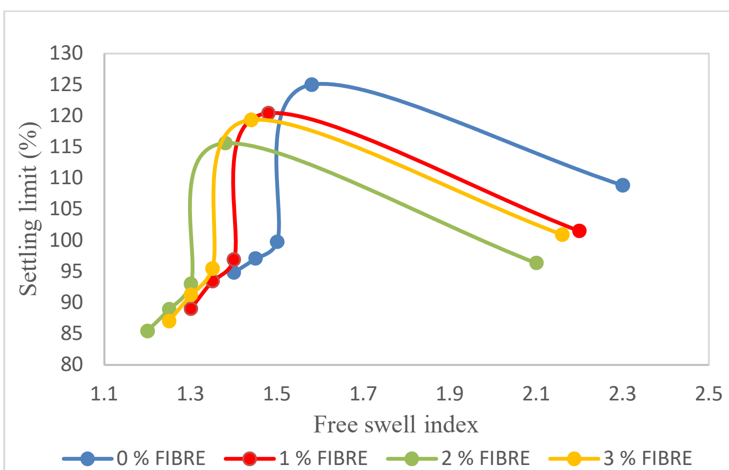

Fig. 3. Relationship between settling limit and free swell index of the soil

According to Figure 3, when the amount of fibre added increases between the ranges of 1%, 2%, and 3%, the amount of swelling of the soil decreases as a result of the fibre absorbing moisture, until the addition of 2% fibre, after which any further fibre will cause swelling. The settling limit drops as the percentage of fibre goes up, and there is a noticeable drop at 2% fibre content. The ideal fibre content to minimise settling is thought to be 2%.

Figure 4 represents the relation between the initial and final water content of expansive soils.

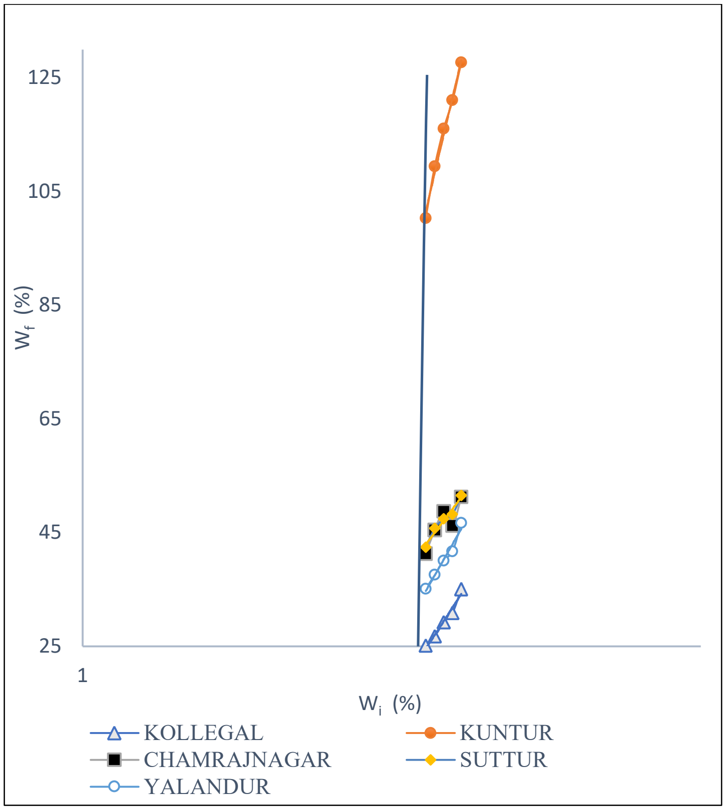

Fig. 4. Initial water content v/s Final water content

Figure 4 demonstrates how the equation can be used to relate the initial water content and the final water content. The amount of equilibrium sediment produced by settling depends on the initial water content of the soil-water suspension.

$$W_f = 80.337\ W_i - 123.23 \quad (5)$$

The final water content was determined in accordance with the experimental results and the best fit line.

Figure 5 depicts the link between the optimal soil moisture level and the expansive soil's plastic limit both with and without the addition of fibres.

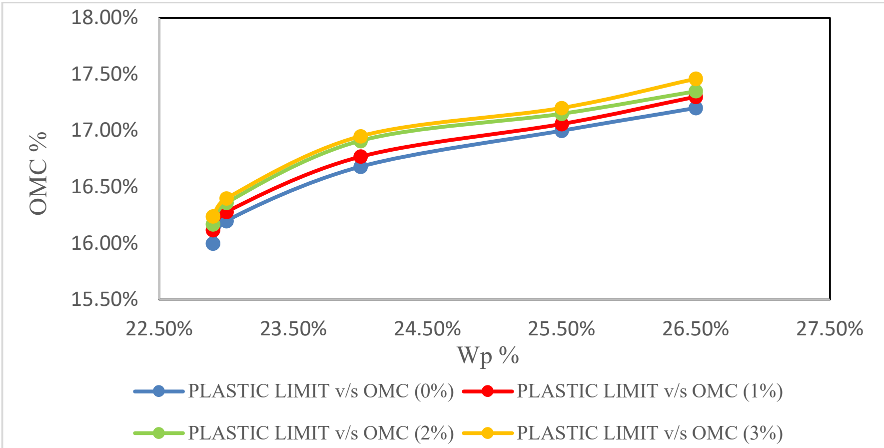

Fig. 5. Relation between OMC and plastic limit

According to figure 5, the reason why the values of OMC and plastic limit increase when fibres are added to the soil at increasing percentages (1%, 2%, and 3%) is due to the fibres' propensity to absorb water.

The relationship between MDD and the plastic limit of the expanding soil, both with and without the inclusion of fibres, is depicted in Figure 6.

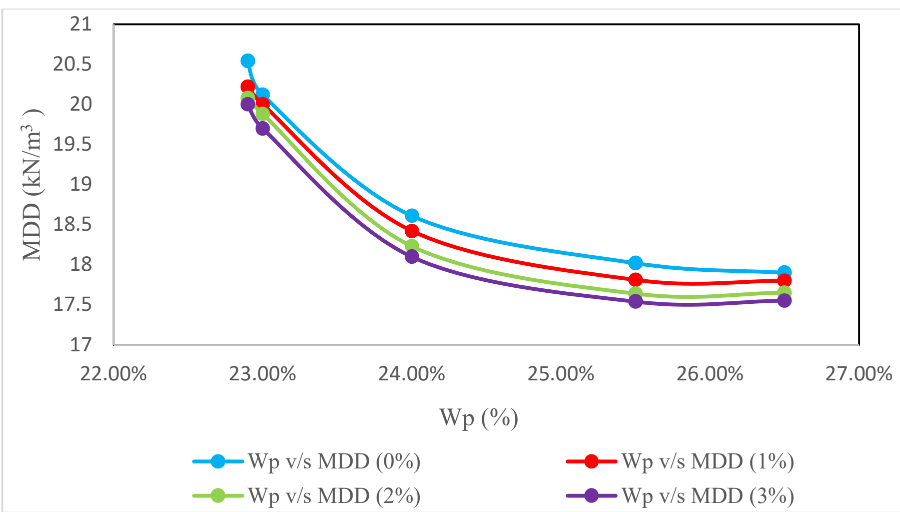

Fig. 6. Relation between MDD and plastic limit

From figure 6, because the weight of the fibre that replaces the soil particles is smaller than that of the soil itself, the maximum dry density of soil decreases as the amount of plastic component increases.

The link between MDD and the optimal moisture content, with and without the inclusion of fibres, is shown in figure 7.

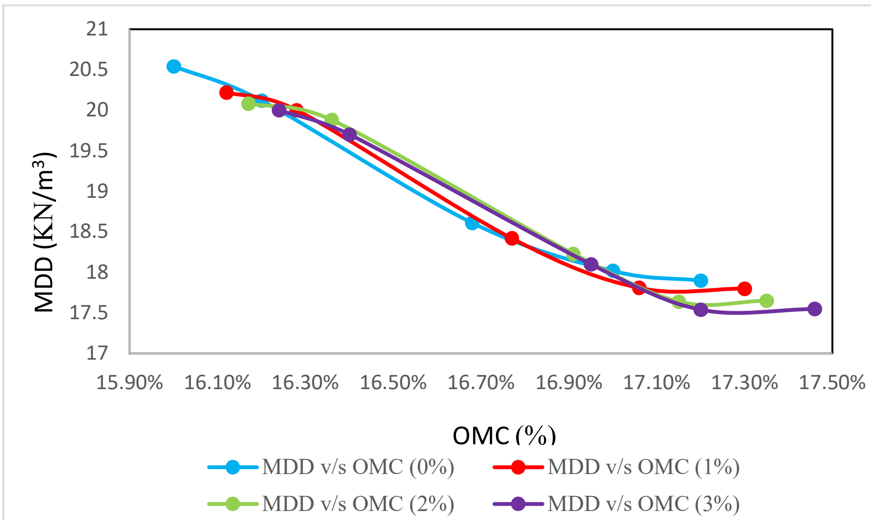

Fig. 7. Relation between the MDD and OMC for fibre reinforced and unreinforced soil

Figure 7 shows that as soil is replaced with fibre, the MDD of the fibre reinforced soil reduces with increasing fibre percentages (1%, 2%, and 3%) while the OMC of the soil increases with fibre addition (1%, 2%, and 3%) due to an increase in surface area. When compared to the comparable OMC values, the MDD of reinforced soil acquires an inverse relationship.

5 Conclusion

The following conclusions are drawn from the current experimental study:

1. By introducing Recron 3s fibre, the expansive soil's swelling potential is decreased.
2. By using Recron 3s fibre, the expansive soil's settling capacity is decreased.
3. The expansive soil's liquid limit and sediment volume are connected; the liquid limit rises as the soil's sediment volume rises.
4. Plastic limit increases with the inclusion of fibre.
5. When fibres are added, the maximum dry density drops because the fibres replace the soil particles, lowering the overall unit weight of the soil.
6. OMC rises when more fibre is incorporated into the soil and moves in the opposite direction of the MDD of the soil.

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