Effect of coir fiber on compressibility behavior of clayey soil

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Abstract. The significant high compressibility and low shear strength of clayey soil impose challenges to the civil engineers. Use of coconut coir fiber for improving soil property was advantageous because they are cheap, locally available and eco-friendly and used as a reinforcement material. Coconut fiber is a natural fiber extracted from the husk of a coconut. This paper focuses on the experimental investigation on the effect of coir fiber on the compressibility characteristics and permeability behavior of the clayey soil. Coir fiber was added in different percentages (viz 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%) to the soil sample with 10mm length and the effect of coir fiber in compressibility and permeability characteristics of the soil was studied. Results show that compressibility decreased and the coefficient of consolidation increased on the addition of the coir fiber. Coir fiber of different percentage is used for the study and optimum moisture content and maximum dry density was used for preparing the soil sample. An optimum percentage of coir fiber for the enhanced properties of soil was found out and also the coefficient of consolidation, compression index is found out from consolidation test with different loading rates. The compression index (c_c) decreases with the inclusion of coir fibers in the soil up to certain fiber content and increases thereafter.

Keywords: Consolidation, clayey soil, coir fiber

1 Introduction

Consolidation characteristics as well as, settlement characteristics are the most problematic topics in the field of geotechnical engineering. This property is directly related to the total settlement of any structure. Excess and non-uniform settlement of foundation soil may cause a high amount of imbalance moment in the entire joint of the existing structure, which may cause the failure of the structure. Therefore it is required to understand the process properly which will eventually help to mitigate the problems related to the settlement. Consolidation settlement is the vertical displacement of the surface corresponding to the volume change at any stage of the consolidation process. Consolidation settlement will result if a structure is built over a layer of saturated clay or if a water table is lowered permanently in a stratum overlying a clay layer. On the other hand, if excavation is made in a saturated clay, heaving will result in the bottom of excavation due to the swelling of clay. In any field of engineering science, researchers have concentrated their studies on the development of new materials through the elaboration of composites. In the case of geotechnical engineering, the idea of inserting fibrous material in a soil mass to improve its consolidation behavior has been known since ancient times (Abdi M R 2008). That is some modifications can be done to the soils by providing reinforcements using locally available natural fibers (coir fiber). Reinforcing with such material in the soil will provide an easy drainage path so that more and more water will dissipate through the pores and improves the compressibility and permeability characteristics of the soil and reduces the time required to reach the primary consolidation (Rabindra kumar .K 2012).

2 Experimental program

One dimensional consolidation tests were conducted to evaluate the effect of coir fiber on the consolidation and permeability characteristics of the soil. Materials used for the study is illustrated below.

2.1 Materials used

Soil. The clayey soil was collected from Erumapetty Thrissur District, Kerala. The geotechnical properties of clay are given in Table 1. The clayey soil is classified as high plastic clay (CH) according to IS Plasticity chart.

Table 1. Geotechnical properties of soil

Properties	Clay
Specific gravity	2.76
Percentage of gravel (%)	5
Percentage of sand (%)	12
Percentage of fines (%)	83
Liquid limit (%)	52
Plastic limit (%)	25
Shrinkage limit (%)	16
Plasticity index (%)	27
Soil classification system	CH
Optimum moisture content (%)	18
Maximum dry density (kN/m^3)	16.1

Coir fiber. The use of natural fibers was widely adopted in the ancient period due to the eco-friendly behavior of natural fiber. The use of coir fiber for the soil improvement is highly attractive in countries like India where such materials are locally and economically obtainable, in view of preservation of the natural environment and cost-effectiveness. The coir fiber is one of the hardest natural fiber available because of its high content of lignin and has low density. The coir fiber is collected from Irinjalakuda coir manufacturing factory, Thrissur District, Kerala. The physical properties of coir fiber from the manufactures manual are shown in the Table.2

Table 2. Physical properties of coir fiber (Manufactures Manual Irinjalakuda, Thrissur, Kerala)

Properties	Values
Density(g/cc)	0.6-1.4
Elastic modulus(N/m^2)	$3.79x10^9$
Tensile strength(N/m^2)	$165x10^6$

(a) Clayey soil

(b) Coir fiber

Fig. 1. Materials used for the study

3 Sample preparation

The collected natural clayey soil in the form of a wet condition placed in an oven for 24 hours and then crushed into dry powder form suitable for the work. The light compaction tests were conducted to determine the optimum moisture content and maximum dry density of the soil sample. The measured quantities of soil sample and the corresponding quantity of water content is mixed together and placed in a desiccator to ensure that uniform distribution of moisture content within the soil mass.

The fibers were cut into an average length of 10mm for preparing the sample. These fibers were added to the soil sample at different percentages varying from 0.4%, 0.5%, 0.6%, 0.7% and 0.8% at an increment of 0.1% of coir fibers. The soil samples were prepared by initial dry mixing of oven-dried soil and the corresponding quantity of fiber content (according to the percentage by weight of oven-dried soil). The optimum water content obtained from the compaction test was added gradually and mixed until the water spread all over the soil. The mix was used for the preparation of consolidation test specimens. The test was also conducted on unreinforced soil specimens. The variation in compressibility and permeability characteristics of unreinforced soil and soil reinforced with fiber content was compared.

4 Testing program

Fig. 2. Experimental set up of consolidation test

The compaction test results were used for preparing the soil samples. The consolidometer of 20mm thickness and 60mm in diameter was used for conducting the test. The porous stones were saturated by immersing them into the water. After assembling the consolidometer, bottom porous stone, bottom filter paper, specimen, and the top porous stone are placed one by one. The loading block is positioned centrally on the top porous stone. The assembly was mounted on the loading frame and centered such that the axial load was applied. The dial gauge was set in position and the mould assembly was connected to the water reservoir. The water was allowed to flow into the specimen until it was fully saturated. A seating pressure of 25 kPa was applied an initial load was set to give a pressure of 25kPa and the initial reading of the dial gauge were taken and after note the dial gauge readings at the time interval of 0, 0.25, 2.25,4, 6.25, 9, 12.25, 16, 20.25, 25, 36, 49, 64, 81, 100, 120, 180 and 240 minutes and allow this load to 24 hours. The load increment of 50, 100,200, and 400 kPa was applied and the same procedure was repeated. After completing the loading stage the specimen preferably within the ring was weighed and thereafter placed in an oven for 24 hours for drying. The oven-dried mass of the sample was taken.

The compression dial guage readings in thousands of mm are plotted against the square root of time in the pressure range of 200-400kPa from which the time required for 90% consolidation (t_{90}) is found out which is used to find the coefficient of consolidation (c_v).Void ratio (e) vs log p curves are plotted from which the compression index (c_c) is found out as slope of straight line portion of e log p curve. From the values of void ratio, the coefficient of volume change (m_v), coefficient of compressibility (a_v) is found out.

5 Results and discussions

The variation of coefficient of consolidation with different loading rates is illustrated in the Fig.3 below. The void ratio- pressure relationship curves for both unreinforced and reinforced soils are given in the Fig.4. The values of compression index (c_c) were calculated from e- log P curves and the variation of compression index with varying percentage of fiber is shown in the Fig.5.

From the Fig.1, the values of the coefficient of consolidation (c_v) increased on adding a different percentage of coir fibers, thereafter with the addition of coir fiber coefficient of consolidation shows a decrease. This is mainly due to the fact that the fibers provide a drainage path to drain out the water from the soil (Rabindra kumar et. al.;(2012), Abdi et. al.;(2008). So that more water will dissipate through the pores and reduces the time required to achieve primary consolidation. The void ratio vs pressure curve is given in the Fig.4. The void ratio decreases with the percentage inclusion of coir fibers since the void spaces are occupied by fibers (Augustine korli lawer 2011).

The compression index vs percentage of fiber graph is given in the Fig.5. The value of compression index (c_c) decreases on adding coir fibers up to 0.6% and thereafter with the addition of coir fiber compression value shows an increase. The decrease in the compression index value is due to the fact that the tensile strength of coir fiber induces cohesion in clay particles. The confinement effect, friction angle and shear strength increases on adding fiber content and hence decrease in compressibility (Jayasree et. al 2014).

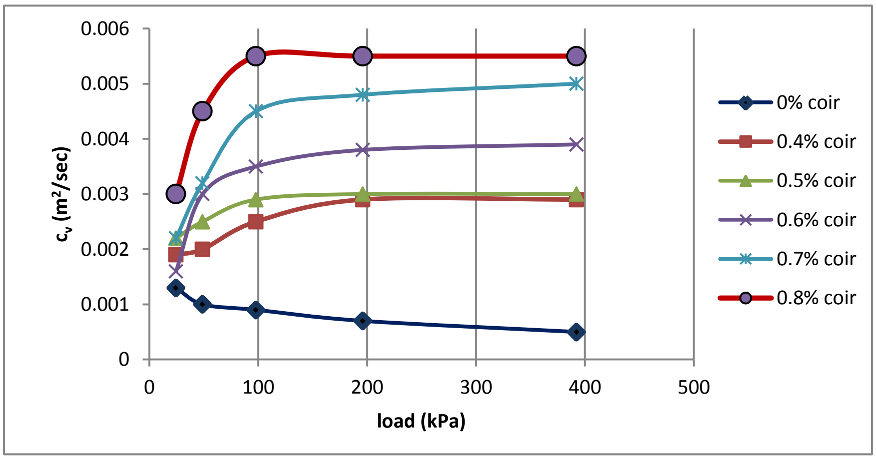

Fig. 3. Variation of the coefficient of consolidation with different percentage of coir fiber

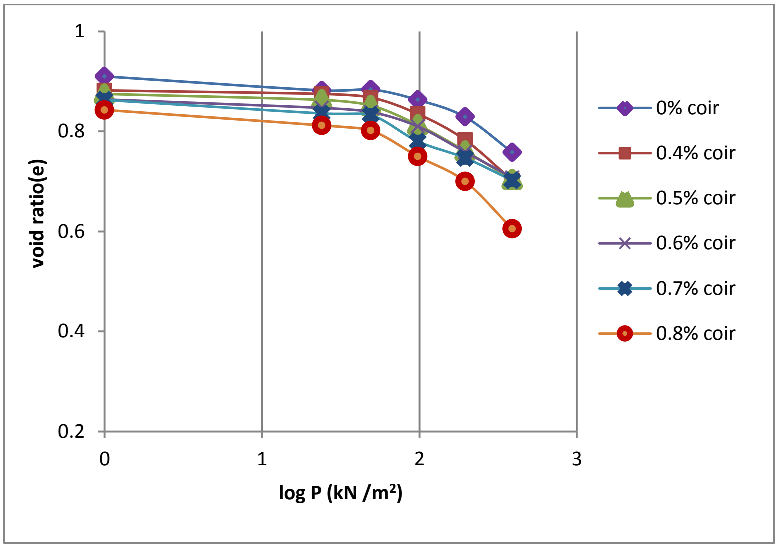

Fig. 4. Void ratio vs pressure curve

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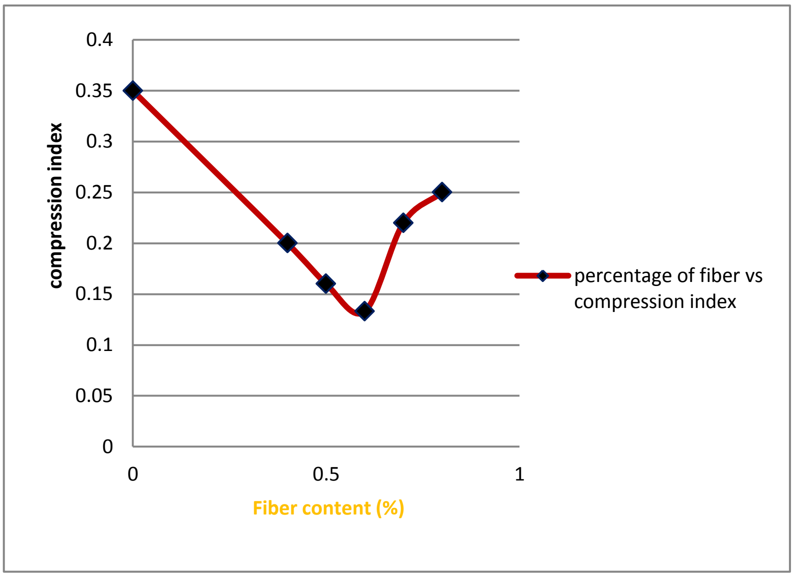

Fig. 5. Compression index vs percentage of fiber

Table 3. Consolidation parameters of soil reinforced with coir fibers

Percentage of coir fiber	Load (kN/m^2)	Coefficient of compressibility(a_v) in (m^2/kN) $a_v = \frac{de}{d\sigma}$	Coefficient of volume change(m_v) in (m^2/kN) $m_v = \frac{a_v}{1+eo}$	Coefficient of permeability(k) (m/sec) $k = c_v\, m_v\, \gamma_w$
0 %	24.52	$3.93x10^{-2}$	$2.05x10^{-2}$	$3.93x10^{-6}$
	49.05	$4.32.x10^{-2}$	$2.26x10^{-2}$	$4.32.x10^{-7}$
	98.10	$4.58x10^{-2}$	$2.39x10^{-2}$	$4.28x10^{-7}$
	196.2	$2.41x10^{-2}$	$1.26x10^{-2}$	$2.41x10^{-7}$
	392.4	$3.01x10^{-2}$	$1.57x10^{-2}$	$2.01x10^{-7}$
0.4%	24.52	$1.46x10^{-3}$	$7.76x10^{-3}$	$1.46x10^{-5}$
	49.05	$1.14x10^{-3}$	$6.02x10^{-3}$	$1.14x10^{-5}$
	98.10	$6.72x10^{-3}$	$3.57x10^{-3}$	$6.72x10^{-5}$
	196.2	$6.30x10^{-3}$	$3.35x10^{-3}$	$6.30x10^{-5}$
	392.4	$6.27x10^{-3}$	$3.33x10^{-3}$	$6.27x10^{-5}$
0.5%	24.52	$6.23x10^{-4}$	$3.33x10^{-4}$	$6.08x10^{-4}$
	49.05	$6.21x10^{-4}$	$3.32x10^{-4}$	$6.12x10^{-4}$
	98.10	$6.10x10^{-4}$	$3.26x10^{-4}$	$6.18x10^{-4}$
	196.2	$6.08x10^{-4}$	$3.25x10^{-4}$	$6.24x10^{-4}$
	392.4	$6.05x10^{-4}$	$3.23x10^{-4}$	$6.31x10^{-4}$
0.6%	24.52	$7.95x10^{-5}$	$2.45x10^{-5}$	$9.25x10^{-3}$
	49.05	$7.91x10^{-5}$	$2.32x10^{-5}$	$9.35x10^{-3}$
	98.10	$7.88x10^{-5}$	$1.18x10^{-5}$	$9.42x10^{-3}$
	196.2	$7.82x10^{-5}$	$9.98x10^{-5}$	$9.49x10^{-3}$
	392.4	$7.66x10^{-5}$	$9.90x10^{-5}$	$9.58x10^{-3}$
0.7%	24.52	$7.59x10^{-3}$	$4.13x10^{-3}$	$9.69x10^{-3}$
	49.05	$7.45x10^{-3}$	$4.04x10^{-3}$	$9.72x10^{-3}$
	98.10	$7.42x10^{-3}$	$4.03x10^{-3}$	$9.78x10^{-2}$
	196.2	$7.33x10^{-3}$	$3.98x10^{-3}$	$9.85x10^{-2}$
	392.4	$7.25x10^{-3}$	$3.94x10^{-3}$	$9.89x10^{-2}$

Percentage of coir fiber	Load (kN/m^2)	Coefficient of compressibility(a_v) in (m^2/kN) $a_v = \frac{de}{d\sigma}$	Coefficient of volume change(m_v) in (m^2/kN) $m_v = \frac{a_v}{1+eo}$	Coefficient of permeability(k) (m/sec) $k = c_v\, m_v\, \gamma_w$
	24.52	7.18×10^{-4}	3.86×10^{-4}	9.92×10^{-2}
0.8%	49.05	7.05×10^{-4}	3.79×10^{-4}	9.94×10^{-2}
	98.10	7.85×10^{-5}	4.22×10^{-5}	9.95×10^{-2}
	196.2	7.52×10^{-5}	4.04×10^{-5}	9.97×10^{-2}
	392.4	7.20×10^{-5}	3.87×10^{-5}	9.99×10^{-2}

From Table 3. The values of coefficient of compressibility (a_v), coefficient of volume change (m_v) and were decreased as the addition of coir fibers. This is mainly due to the presence of fiber increases resistance to compression (Abdi M R 2008). The coefficient of permeability increased on adding fiber content and provides drainage path.

6 Conclusions

A series of one-dimensional consolidation test was conducted to evaluate the effects of coir fiber with varying percentages on the consolidation characteristics and permeability behavior of clayey soil.

- The compression index (c_c) decreased with the inclusion of coir fibers in the soil up to 0.6% fiber content and increased thereafter. Thus minimum c_c value is observed at 0.6% for soil reinforced with the coir fibers.
- The value of the coefficient of volume change (m_v) was increased with the fiber content up to 0.6% fiber content and thereafter increases.
- The coefficient of consolidation (c_v) increases with the inclusion of coir fibers. Thus the time required to achieve primary consolidation decreases for fiber reinforced soil for a given degree of consolidation and a given drainage path. Thus c_v increased by 74% on adding 0.6% fiber and thereafter on increase in fiber content c_v increases.
- Compression index (c_c) decreased on adding fiber content. Thus c_c decreased to 63% on adding 0.6% fiber content.

Based on the results obtained, it is recommended that coir fiber can be used as a reinforcing material for improving the consolidation characteristics and permeability behavior of the soil.

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