ABSTRACT: Soft clay deposits pose major problems to the geotechnical engineers because of poor shear strength and high compressibility and cannot be neglected as these geologically young deposits are distributed predominantly along the narrow coastal plains all over the world. In view of the industrial activities along the coastal line it has become necessary to utilize these areas after suitably improving the ground so that various structures could be safely supported. Cochin is no exception to this. Reinforced soils can be obtained by either incorporating continuous reinforcement inclusions within a soil mass in a certain pattern or mixing discrete fibres randomly with a soil. In recent times, randomly distributed fibre reinforced has attracted the attention of engineers in many geotechnical engineering applications. In this paper, an attempt has been made to study the effect of inclusion of coir fiber on the shear strength of marine clay. Results indicate that the shear strength increases considerably by the inclusion of the coir fibers by about four times.

INTRODUCTION
Clayey soils pose great challenges to geotechnical engineers and consultants, as structures on soft compressible clays create number of problems. Construction without soil improvement is usually impractical due to anticipated large settlements and long coastline covered with thick soft clay deposit. In view of the increased industrial activities along the coastline, it has become necessary to utilize these areas, after suitably improving the ground, so that various structures can be safely supported.

Reinforcement of soil using fibers has been a subject of research for a long time. The concept of reinforcing soil with tensile resisting elements has been widely accepted in engineering practice. Construction using reinforced soil is known to have existed in the fourth and fifth millennium B.C. This concept is used to improve the soil properties such as bearing capacity, shear strength etc. This concept was first developed by Henry Vidal [1], by which he demonstrated that the introduction of reinforcing elements in a soil mass increases the shear resistance of the medium. Reinforced earth technique is considered to be an effective ground improvement method because of its cost effectiveness and easy adaptability.

An earth mass stabilized with discrete randomly distributed fibers resembles traditional earth reinforcement in many of its properties [2]. Many test results had proved the effectiveness of fiber reinforcement [3-5]. The use of continuous polymeric filaments, rather than discrete short fibers mixed randomly with the sandy soils under the proprietary name “Texsol”, was an early established method in retaining walls and slope protections. However, randomly distributed fiber-reinforced soils have recently attracted increasing attention in many geotechnical engineering application. It was observed that unconfined compressive strength of clay increases with the addition of fibers and it further increases when fibers are mixed with clay sand mixture [6].

In comparison to systematically reinforced soils, randomly distributed fiber reinforced soils exhibit some advantages. Preparation of randomly distributed fiber reinforced soils is similar to soil stabilization by admixture. Discrete fibers are simply added and mixed with the soil, much like cement, lime, or other additives. Randomly distributed fibers offer strength isotropy and limit potential planes of weakness that can develop parallel to oriented reinforcement in systematically reinforced soils.

The use of natural materials such as jute, cotton, coir, sisal etc. as reinforcing materials in soil started in the early nineties. The main advantage of these materials is that they are locally available with practically little cost. They are biodegradable and hence will not create environmental problems. This ability of natural fibers to absorb water and to degrade with time is its prime property which gives them an edge over the synthetic materials.

In this paper an attempt has been made to study the effect on the shear strength variation of soil by the inclusion of randomly distributed coir fiber. The reason for the selection of the natural fibers was that they are easily available, biodegradable, less costly etc. India accounts for more than two-thirds of the world production of coir and coir products. Kerala is the home of Indian coir industry, producing 60% of the total world supply of white coir fiber and over 85% of coir products. Hence coir is selected for this study as it is abundantly available in Kerala. Also, coir is one of the hardest natural fibers because of its high content of lignin.
Of all the natural fibers, coir possesses the greatest tearing strength, retained as such even in very wet conditions. Coir as a biodegradable and environmental friendly material is virtually irreplaceable by any of the modern synthetic substitute.

MATERIALS AND METHODOLOGY

Soil
The soil used in this study is marine clay collected from Munadamveli in Cochin City, which is situated on the western coast of India. Representative soil samples collected from the same depths, but from different boreholes at various locations were mixed thoroughly into a uniform mass and preserved in polyethylene bags so as to retain its natural water content.

The properties of marine clay used for this study were determined and are given in the Table 1.

<table>
<thead>
<tr>
<th>Properties of marine clay</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>2.65</td>
</tr>
<tr>
<td>Grain size distribution</td>
<td></td>
</tr>
<tr>
<td>Sand (%)</td>
<td>17.5</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>41</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>41.5</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>120</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>55</td>
</tr>
<tr>
<td>Shrinkage limit (%)</td>
<td>17</td>
</tr>
<tr>
<td>Plasticity index (%)</td>
<td>65</td>
</tr>
<tr>
<td>Natural water content (%)</td>
<td>60</td>
</tr>
<tr>
<td>IS Classification</td>
<td>CH</td>
</tr>
</tbody>
</table>

Reinforcement
Coir fibers used for this study were procured from a local manufacturing unit near Alappuzha. Three fiber lengths are used in this investigation, 10mm, 20mm and 30mm. Different percentages of fibers are also used.

Experimental Investigations
For the preparation of unreinforced sample, required quantity of water was added to air dried sample. Fiber reinforced soil samples were prepared at natural water content equal to that of unreinforced soil. The fibers were taken out individually, and straightened out. The fibers were then cut into the desired lengths of 10mm, 20mm and 30mm, and then air dried before mixing. The quantity of fiber to be added to the soil was taken as a percentage of dry weight of the soil. The fibers were weighed according to the prescribed reinforcement content and mixed into the clay in small increments until all the fibers were effectively distributed within the soil. The added fibers were mixed thoroughly by hand to achieve a fairly uniform mixture. The mixing of fiber into the soil became more difficult as reinforcement content increased. Proper care was taken at each stage of mixing to obtain a homogeneous mixture.

In the present study, Unconfined Compressive Strength tests were conducted as per IS 2720 part 10-1973 and load deformation behaviour of unreinforced marine clay and marine clay reinforced with fibres at different percentages were studied.

RESULTS AND DISCUSSIONS
A series of unconfined compression tests were carried out in the laboratory on unreinforced marine clay and marine clay reinforced with the natural fiber coir, at natural water content and at different lengths (10mm, 20mm and 30mm).

EFFECT OF FIBER INCLUSION ON SHEAR STRENGTH
Figure 1 shows the stress strain behaviour of marine clay reinforced with various percentages of coir fiber length of 10mm. It may be noted that the maximum strength is achieved at a fibre content of 0.8%.

The effect of fiber addition in soil on shear strength shows that the stress-strain curves are similar to that of the unreinforced sample. For all samples, the shear strength increases with increase in fiber content up to a fiber content of 0.8%. Further increase in fiber content reduces the shear strength.

The mechanism by which fibre inclusion increased the shear strength could be explained by the development of interfacial friction between soil particles and fibers. This can be attributed to the increase in bonding resistance with the increase in fiber content. Beyond a fiber content of 0.8%, the decrease in shear strength could be due to the reduced contact area between the soil particles and fiber. It
Effect of inclusion of coir fiber on the shear strength of marine clay

is clear that the fiber reinforced soil is able to hold more deformation and higher strain at rupture.

To express the results in terms of a dimensionless quantity, a parameter 'strength ratio' (Rf) which is defined as the ratio of shear strength of reinforced soil to the shear strength of unreinforced soil has been selected. ie. Mathematically,

\[ R_f = \frac{q_u(\text{reinforced})}{q_u(\text{unreinforced})} \]

EFFECT OF FIBER CONTENT ON SHEAR STRENGTH

Table 2 shows the shear strength variation of marine clay reinforced with coir fiber having a length of 20mm. The strength ratio is maximum at 0.8% of fiber which is 4 times as compared to that of the unreinforced sample.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Fiber content (%)</th>
<th>q_u (kg/cm²)</th>
<th>Rf</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>16</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>29</td>
<td>1.81</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>44</td>
<td>2.75</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>60</td>
<td>3.75</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>64</td>
<td>4.00</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>23</td>
<td>1.44</td>
</tr>
<tr>
<td>7</td>
<td>1.5</td>
<td>19</td>
<td>1.19</td>
</tr>
</tbody>
</table>

The variation of unconfined compressive strength of marine clay reinforced with coir fiber at different fiber content is shown in figure 2. It is seen that the shear strength increases initially with increase in percentage of fiber. It has been found that the optimum percentage is 0.8, beyond which there is a decrease in shear strength even after the increase of fiber content. Hence it may be concluded that 0.8% is the optimum fiber content.

EFFECT OF LENGTH OF FIBER ON SHEAR STRENGTH

Figure 3 shows the stress strain characteristics of marine clay reinforced with different lengths of coir fiber at a fiber content of 0.8%. It has been found that the maximum shear strength is obtained for fiber length of 20mm.

Fig 2 Variation of unconfined compressive strength of coir fiber reinforced marine clay with length at different fiber content

Fig 3 Stress - strain characteristics of marine clay reinforced with different lengths of coir fiber at 0.8% fiber content

Fig 4 Variation of unconfined compressive strength of marine clay reinforced with coir fiber for different lengths.
Figure 4 shows the effect of length of fibre and fibre content on the unconfined compressive strength of marine clay. For any particular percentage of fiber content, the shear strength increases with increase in fiber length up to 20mm, beyond which an increase in length decreases the shear strength. It is seen that the maximum strength is obtained at a length of 20mm. There has been an increase of 300% with respect to the unreinforced sample.

FAILURE PATTERN OF UNREINFORCED MARINE CLAY
Figures 5a and 5b show the failure pattern of unreinforced soil specimen and soil specimen reinforced with coir fiber of length 20mm at 0.8% fiber content. It is noticed that the specimen of unreinforced soil sample has failed by a combination of shear and tensile splitting. The inception of tensile cracking can be attributed to possible stress concentrations within the specimens, specimen end effects, and anisotropic deformations during axial compression. Such induced weaknesses reduce the apparent strength. The inclusion of the random, discrete fibers resists the propagation of these cracks across the entire specimen and confines them locally.

CONCLUSIONS
The stress strain variation of marine clay with and without the inclusion of fibers was found out by conducting a series of unconfined compression tests. The test results show that:

- The inclusion of random fibers in marine clay increases the shear strength of marine clay significantly.
- The shear strength increases with increasing fiber content up to 0.8% by weight for the coir fiber.
- The shear strength increases non-linearly with length up to 20mm beyond which an increase in length decreases the shear strength.
- As compared to the unreinforced soil sample, the shear strength of soil sample reinforced with coir fibers is almost 300%.

The natural fibers are less expensive when compared to synthetic fibers, which may also cause environmental concerns. These features have attracted the attention of researchers and field engineers and coir reinforced soil finds increased applications in civil engineering practice. The findings of this study have practical significance as a ground improvement technique, with respect to embankment, sub grade and other such problems.

REFERENCES