Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Influence of Rainfall on the Interface Shear Strength of Unsaturated Lateritic Soil with Geosynthetics

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Abstract. Seasonal variations in the soil moisture content can result in significant changes in soil suction. Rainfall infiltration can cause loss of matric suction in the unsaturated lateritic soil. Several failures are reported in lateritic soil slopes in Kerala, associated with rainfall. Geosynthetics are generally used for improving the stability of soil structures constructed with poorly draining soils. Shear strength at the interface of unsaturated lateritic soil with geosynthetics plays a crucial role on the internal stability of geosynthetics reinforced structures. The present study investigates the influence of rainfall induced wetting on shear strength of lateritic soil as well as lateritic soil-geosynthetics interface. Lateritic soil was collected from a site in Kerala which was subjected to rainfall induced slope failure. Geotechnical characterization of the soil was carried out. Shear testing was conducted on soil samples of size 305 x 305 x 200 mm. When the moisture content was increased by 4% due to wetting, the shear strength of the lateritic soil was reduced by 20%. Whereas, the corresponding reduction in strength at the interface for the soil-geosynthetic system was only 3%. Similarly, an increase in moisture content by 8% due to wetting resulted in a reduction in strength by 30% and 4% for soil-soil and soil-geosynthetic system, respectively.

Keywords: Rainfall, Geosynthetics, Reinforced soil, Unsaturated soil, Lateritic soil.

1 Introduction

Primary reason for failures in most of the geotechnical structures like embankments, reinforced soil walls, slopes etc. is the development of high pore water pressure due to the lack of drainage. Failures can happen if water accumulate within the geotechnical structures faster than the drainage rate. Granular soils with fine content less than 15% are ideally used as a fill material in various geotechnical applications. Of late, locally available marginal soils with poor drainage characteristics are being increasingly used in bulk geotechnical applications such as a structural fill in embankments, reinforced soil slopes etc.

Major part of Kerala is covered with lateritic soils which are highly sensitive to wet and dry climate. Lateritic soils are formed under sub-tropical and tropical monsoon climates with a well-defined wet and dry climatic condition. Chemical composition and mineralogical characteristics depend on the parent rock and the degree of weathering. In general, the soil stratification consists of hard laterite at the surface of about 3 m and a lithomargic lateritic layer which is generally classified as sandy silt/silty sand above the parent rock. Locally available lateritic soils are increasingly used in the construction of highway embankments.

Several failures are reported in lateritic soil slopes in Kerala, associated with the rainfall. Rainfall is one of the most important triggering factors for failures in geotechnical structures. It can change the hydrological and geotechnical behaviour of the soil resulting in massive destruction. When rainfall infiltration occurs, negative pore water pressure or the matric suction decreases and shear strength of the soil reduces.

Many places of Kerala have been witnessing internal erosion along with landslides, in the recent years, associated with intense rainfall. Dhanya and Divya (2019) reported a recent evidence of soil piping due to internal erosion in a lateritic soil slopes associated with heavy rainfall, in northern part of Kerala. Drainage helps in reduction of pore water pressure which otherwise can affect shear strength of the material. Slopes and embankments need to be provided with proper drainage facilities and erosion control measures.

It is well known that geosynthetics can be used for the repair of failed slopes as well as for the construction of new embankments. Permeable geosynthetic inclusions help to dissipate the excess pore water pressure within the poorly draining fill material. Several authors (Mitchell and Zornberg, 1995; Miki, 1997; Iryo and Rowe, 2003; Iryo and Rowe, 2005) reported the application of non-woven geotextile layers installed within the fill material, to contribute to the stability of the soil structure, by dissipating excess pore water pressures during the construction. They also minimize the build-up of pore pressure in the future, which can be caused by rainfall infiltration. Application of composite geosynthetics which combine the function of reinforcement and drainage in poorly draining soils are also reported by some investigators (Iryo and Rowe, 2005; Bhattacherjee & Viswanadham, 2015; Mamaghanian et al. 2019; Vibha and Divya, 2019, 2020). These types of composite geosynthetics generally have a non-woven geotextile which is attached with a strengthening component such as geogrids or polyester yarns.

In many applications, soil structural fill is compacted at its maximum dry density and optimum moisture content, and remains practically unsaturated. Role of suction in increased shear strength of the soil is well recognized (Fredlund et al. 1978). Seasonal variations in the soil moisture content can result in significant changes in soil suction. Rainfall infiltration cause loss of matric suction in the unsaturated lateritic soil. The present study investigates the influence of rainfall induced wetting on shear strength of lateritic soil as well as lateritic soil-geosynthetics interface. The interface between geotextiles and soil fill has long been identified as one of the important factors affecting the stability of geosynthetic reinforced soil structures. This is particularly important in the design of geosynthetic reinforced soil structures with marginal fills with poor drainage properties.

2 Materials Used

Lateritic soil was collected from a site in Kerala which was subjected to rainfall induced slope failure. Geotechnical properties of the soil were determined by conducting various laboratory tests as per standard procedures. Particle size analysis has been carried out to obtain grain size distribution of the soil (ASTM D422). Figure 2 shows the grain size distribution of the lateritic soil. Percentage fines in the soil was observed to be 33.4%. According to USCS classification, soil was categorized as silty sand (SM).

Fig. 1 Lateritic soil used for the study

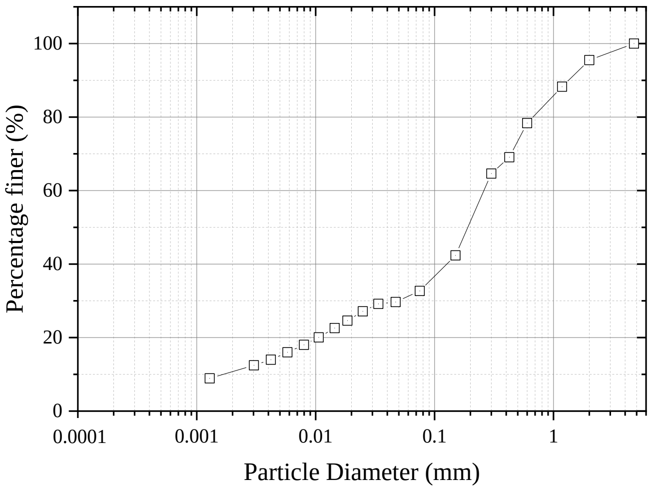

Fig. 2. Particle size distribution curve of soil

The maximum dry unit weight and optimum moisture content of the soil was 17.2kN/m^3 and 15% respectively as obtained from standard Proctor tests (ASTM D698). Compaction characteristics of the lateritic soil is as shown in Fig. 3.

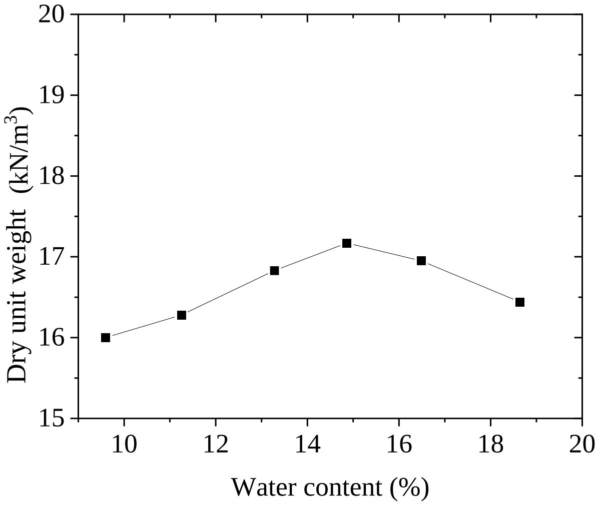

Fig. 3. Compaction curve of the soil

Various geotechnical properties of the soil are summarized in Table 1.

Table 1. Properties of the soil collected

Properties	Values
Specific gravity	2.58
Sand sized (%)	66.6
Percentage fines (%)	33.4
Silt sized (%)	21.63
Clay sized (%)	11.77
Liquid limit (%)	38
Plastic limit (%)	Non-plastic
Soil classification as per USCS	SM
Maximum dry unit weight	17.2 kN/m^3
Optimum moisture content, OMC (%)	15

Geosynthetics used in the present study was non-woven polypropylene geotextile. It has a tensile strength of 30.5 kN/m in the machine direction and 28.5 kN/m in cross machine direction. Transmissivity of the geotextile at a normal stress of 20 kN/m^2 corresponds to 8.5 x 10 $^{-6}$ m^2/sec.

3 Testing Procedure

3.1 Influence of rainfall induced wetting on the soil-soil shear strength

A series of direct shear tests were carried out to evaluate the influence of rainfall induced wetting on the shear strength properties of the lateritic soil. Soil samples for each test were mixed with a water content corresponding to optimum moisture content (15%) and stored in an airtight polyethylene bag wrapped with a wet cloth for at least 24 hours to attain moisture equilibrium. This was verified by determining the water content of soil at the end of moisture equilibrium, by oven drying method.

Soil was compacted in 3 layers in shear test box to attain 95% maximum dry density. Saturated direct shear tests were conducted on soil samples compacted at optimum moisture content at three different normal stresses i.e, 50 kN/m^2, 100 kN/m^2 and 200 kN/m^2 to determine the shear strength parameters. As per ASTM D3080, soil samples were consolidated for 24 hours under each normal stress prior to shearing. Shearing rate was computed according to ASTM D3080, from the time corresponding to 90% consolidation. This was done to ensure the dissipation of excess pore water pressure at failure. Figure 4 shows the equipment used for carrying out tests. Shear loading was applied with a help of a computer-controlled unit that utilizes a micro stepper motor. Displacement transducers of 100 mm travel was used for measuring the shear displacements as well as vertical displacements. Both horizontal and vertical displacement were measured using displacement transducers. The effective angle of internal friction of the soil was found to be 37°.

Fig. 4. Large direct shear testing equipment

In order to study the influence of rainfall induced wetting on the shear strength properties of the lateritic soil, constant water unsaturated direct shear tests were conducted on soil samples adopting the procedure reported by Jotisankasa and Mairaing (2010). Initial compacted conditions of all the samples were maintained uniform. The moist compacted samples were prepared similar to that of saturated testing. The samples were compressed one dimensionally at a normal stress of 100 kN/m^2 for one day.

Water was sprinkled prior to shearing in order to induce wetting due to rainwater infiltration, to simulate the field condition. Thus, the moisture content in the soil was altered prior to shearing. Samples were kept undisturbed and wrapped for 3 days such that the sprinkled water distributes uniformly within the samples and the suction equilibration is achieved. Samples were sheared at a rate of 0.5 mm/min. After completion of the test, gravimetric water content was determined by taking three representative samples from top, middle, and bottom of the soil sheared specimen to estimate suction from soil water characteristics curve (SWCC) of the soil. Filter paper method as per ASTM D5298-10 was used to determine the soil water characteristics curve of the soil as shown in Fig.5.

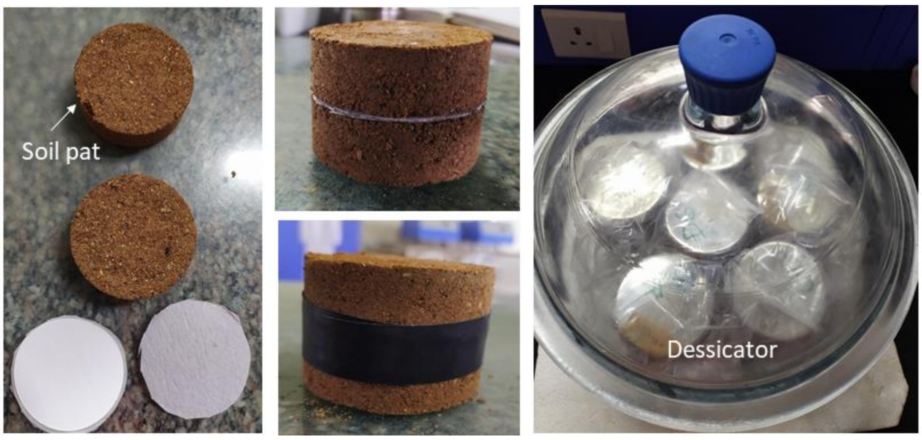

Fig. 5. Filter paper method for the determination of SWCC of the soil

The shear strength of unsaturated soil can be represented by Equation 1 (Vanapalli et al. 1996).

$$\tau = c' + (\sigma_n - u_a) \tan \phi' + c^s \quad (1)$$

where c' is the cohesion intercept of saturated soil, σ_n is the normal stress at failure plane, u_a is the pore-air pressure, ϕ' is the effective friction angle of soil and c^s is the apparent cohesion due to soil suction. It is a function of degree of saturation and soil suction.

3.2 Influence of rainfall induced wetting on the soil-geosynthetics interface strength

The interface testing was conducted as per ASTM D5321. Non-woven geotextile was laid over the substrate in the lower test box as shown in Fig. 6.

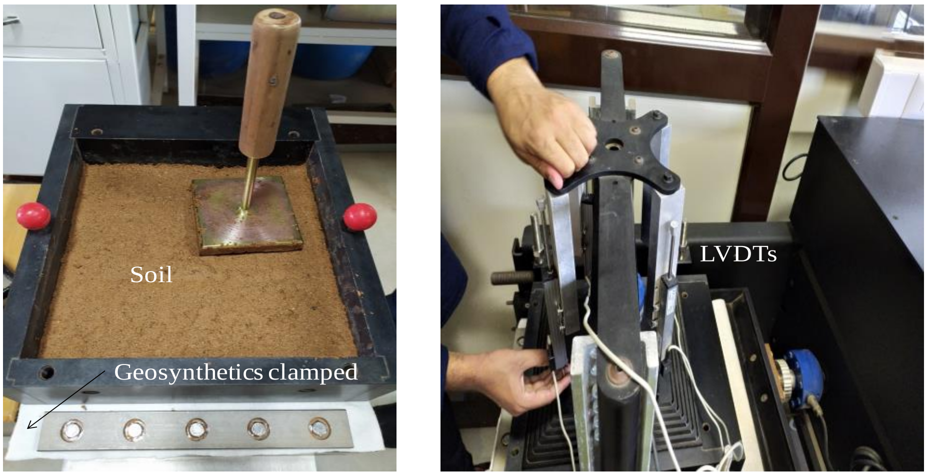

Fig. 6. Interface shear testing using large direct shear equipment

Geotextile was clamped to the lower box. Soil was compacted in 3 layers in shear test box to attain 95% maximum dry density. The sample preparation procedure and initial compacted condition of the soil was maintained same as explained before.

4 Results and Discussions

The results of constant water unsaturated direct shear tests in order to study the influence of rainfall induced wetting on the shear strength properties of the lateritic soil are shown in Fig. 7. The wetting induced altered water content is represented herein as *w*. Results shows that apparent cohesion is highly influenced by water content. A strain softening behavior was observed for the samples with lower moisture content due to breakage of bonding provided by water menisci (Jotisankasa and Mairaing 2010).

As the wetting is induced, reduction in shear stress was observed. This is because, for unsaturated soil condition, initially an apparent cohesion exists within the soil mass due to soil suction. This contributes to a higher shear strength for the soil. But as the degree of saturation increases, initial suction (at OMC) within the sample decreases and thus reducing its strength. Soil suction was determined from the soil water characteristics curve of the lateritic soil from the measured gravimetric water content. Figure 8 shows the variation of suction within the soil samples due to wetting. A reduction of 30% in strength was observed as the water content increased from 15%

(OMC) to 23.10% (OMC+8). Also, dilation of the samples was observed during shearing at higher suction (low water content). But as the suction decreases (high water content), contraction behavior was observed. Apparent cohesion, c^s was computed and the variation of c^s due to soil suction with water content is shown in Fig. 9.

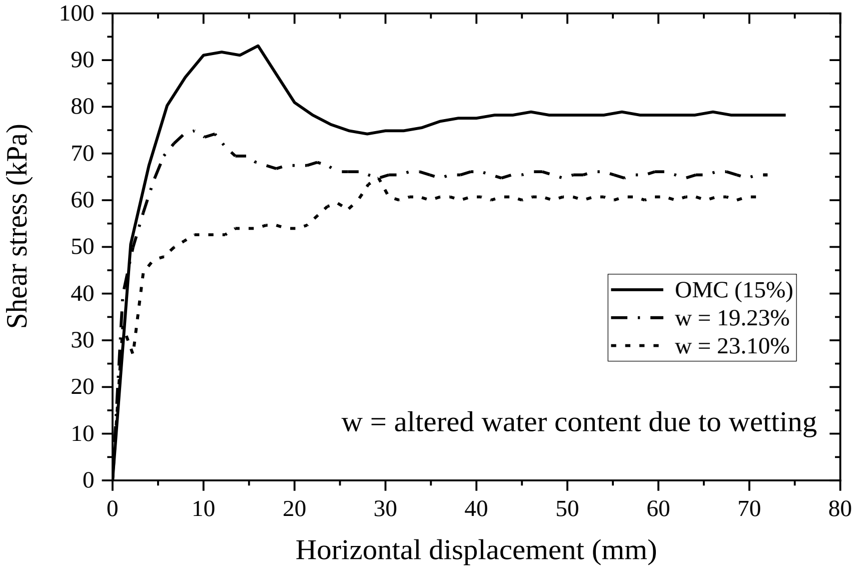

Fig. 7. Shear stress vs horizontal displacement graph for each water content

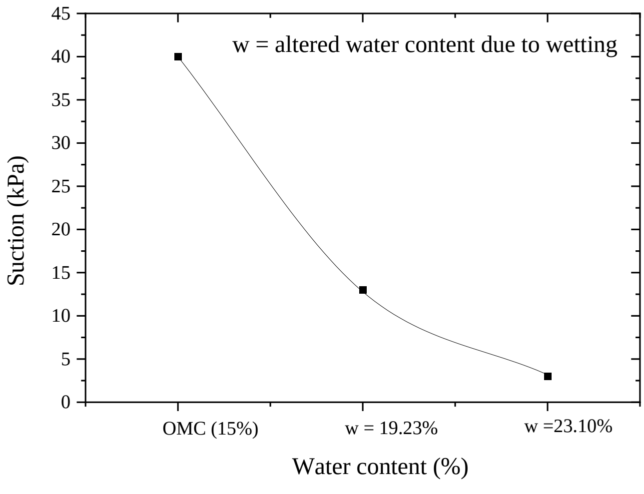

Fig. 8. Variation of soil suction due to wetting

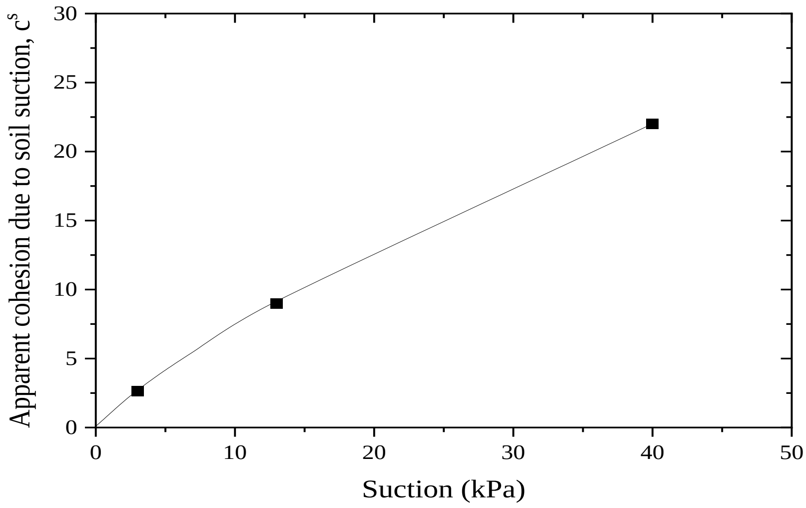

Fig. 9. Variation of apparent cohesion with suction

It was observed that during rainfall infiltration, degree of saturation in the soil is increased. Thus, the matric suction in the soil mass reduces and thereby the apparent cohesion (contribution of matric suction to shear strength) decreases. In a similar manner, the results of interface shear testing were analyzed. The results are summarized in Table 2. Here, adhesion factor corresponds to the ratio of shear strength of soil-geosynthetics system to shear strength of soil and its value was observed to be varied between 0.7 to 1.2. As can be observed, the adhesion factor is increasing as the water content is increased.

Table 2. Summary of interface shear strength properties

Parameter	OMC (15%)	w= 19.23%	w = 23.10%
Soil-Geotextile interface shear stress (kPa)	72	70	69
Adhesion factor	0.75	0.9	1.2

Figure 10 shows the percentage reduction of shear strength for both soil and soil-geosynthetic system. A significant reduction in the shear strength of soil was observed as the water content is increased due to wetting.

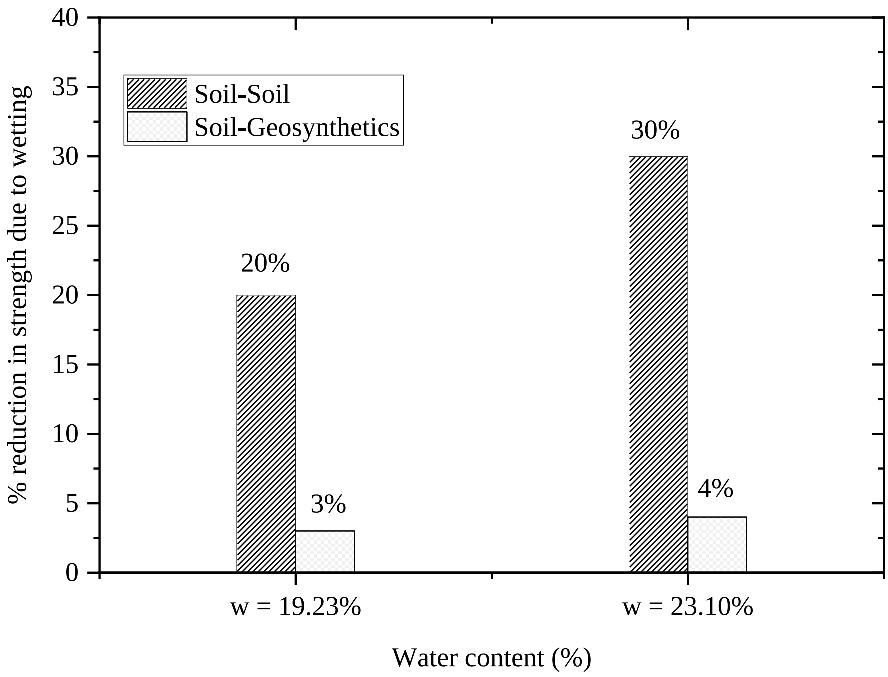

Fig. 10. Percentage reduction in strength due to wetting

When the moisture content was increased by 4% due to wetting, the shear stress of the lateritic soil was reduced by 20%. Whereas, the corresponding reduction in strength at the interface for the soil-geosynthetic system was only 3%. Similarly, an increase in moisture content by 8% due to wetting resulted in a reduction in strength by 30% and 4% for soil-soil and soil-geosynthetic system, respectively. The reduction in shear strength at the interface for a soil-geosynthetic system due to wetting induced increase in water content was significantly less. This can be due to the transmissivity of the geotextile at the interface resulting in drainage of water during shearing. Thus, the bond strength can be increased. Thus, high transmissivity non-woven geotextiles can effectively drain and hence reinforce the poorly draining soil, even in undrained condition. Thus, rainfall induced wetting will have less influence in the interface properties of lateritic soil-non woven geotextile interface owing to the high transmissivity.

5 Conclusions

Present study investigates the influence of rainfall induced wetting on shear strength of lateritic soil as well as lateritic soil-geosynthetics interface. Apparent cohesion due to the suction in lateritic soil was found to decrease by 70% and 93% when the moisture content was increased by 4% and 8% respectively. Reduction in suction can lead to loss of shear strength of unsaturated lateritic soil. It was observed that, when the moisture content was increased by 4% due to wetting, the shear strength of the lateritic soil was reduced by 20%. Whereas, the corresponding reduction in strength at the interface for the soil-geosynthetic system was only 3%. Similarly, an increase in moisture content by 8% due to wetting resulted in a reduction in strength by 30% and 4% for soil-soil and soil-geosynthetic system, respectively. Thus, rainfall induced wetting is observed to have less influence in the interface properties of lateritic soil-non woven geotextile interface owing to the high transmissivity.

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