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Effect of a Coarse Material Sandwich Technique on the Behavior of Geotextile Reinforced Clay

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Abstract. The usage of natural geotextile have been found to be effective in improving geotechnical characteristics of soil and are being extensively used due to its several distinct advantages such as cheap, locally available, eco friendly and is used as reinforcement material. In this study jute geotextile is used as reinforcement for increasing the strength properties of soil. In the sandwich technique, sand is used as coarse material. This study presents the results of unconsolidated undrained triaxial compression tests for determining the shear strength and stiffness behavior of geotextile reinforced clay and the effects of sandwiching geotextile in a thin layer of sand on improving the shear strength and stiffness of reinforced clay. The test variables include confining pressures, number of geotexile layers and thickness of sand layers. The test results showed that the shear strength and stiffness behavior of reinforced clay considerably increased as the number of geotextile layers was increased. Regarding the sandwich technique, the test results showed that layers of sand encapsulating the geotextile can effectively enhance the soil-geotextile interaction. The shear strength and stiffness behavior of reinforced clay considerably increased as the thickness of sand layer was increased.

Keywords: Triaxial test, Sandwich technique, jute geotextile

1 Introduction

A large part of our world consists of weak cohesive soil deposits. These soils are unsuitable for construction purposes, both as a foundation material and as a construction material. However, this type of soils can be strengthened by the inclusion of various type of synthetic and natural materials and make it in to suitable for construction purposes. Ground improvement using geosynthetic materials are in which geosynthetic reinforcements are embedded in a soil mass, have several distinct advantages because of their ductility, high tolerance to differential settlement without structural distress, rapid method for construction and cost effectiveness. Since Natural materials are biodegradable, eco-friendly, locally available and cost effective, these materials are widely using in various soils improvement projects. One of the most common geosynthetic materials used to reinforced soil is geotextiles. The main function of these elements is to redistribute stresses within the soil mass in order to enhance the internal stability of reinforced soil structures. Thin sand-layer inclusions could increase the interface interaction between the clay and reinforcement, resulting in improving the overall shear strength of the reinforced clay. The sand also acted as a lateral drainage layer to dissipate excess pore water pressure during shearing. In addition to its mechanical function, the sandwich technique has been demonstrated to increase a soil-geotextile or soil-geocomposite system's lateral drainage capacity, accelerate pore water pressure dissipation within reinforced soil.

2 Experimental Program

A series of unconsolidated undrained triaxial compression tests were conducted for investigating the shear strength and stiffness behaviour of unreinforced clay, jute geotextile reinforced clay. The effects of jute geotextile sandwiched in sand layer of varied thickness is assessed in terms shear strength and stiffness of reinforced clay. The tests were performed under different confining pressures (50 kPa, 100 kPa and 150 kPa) and various numbers of geotextiles (one, two and three layers). For sandwich technique the thickness of sand layers are 2 mm, 4 mm, 6 mm and 8 mm respectively.

3 Materials

3.1 Clay

The clayey soil sample was collected from Kannapuram, Thaliparamba Taluk, Kannur District, Kerala, India. Table 1 presents the basic properties of clayey soil.

Table 1. Properties of clay

Properties	value
Specific gravity	2.6
Liquid limit (%)	67
Plastic limit (%)	38
Shrinkage limit (%)	21
Plasticity Index (%)	29
IS classification	OH
Optimum moisture content (%)	27
Maximum dry density (kN/m^3)	14

3.2 Sand

Sand is used as the coarse material for the sandwich technique. River sand is used for the study. The sand was collected from Mambaram, Thalassery Taluk, Kannur District, Kerala, India. Table 2 presents the basic properties of sand.

Table 2. Properties of sand

Properties	value
Coefficient of uniformity (C_u)	2.875
Coefficient of curvature (C_c)	0.96
Specific gravity	2.63
IS classification	SP
Maximum dry density (kN/m^3)	17

3.3 Geotextile

Use of waste material and natural geotextile for improving soil property is advantageous. Commercially available woven Jute geotextile is used for this study. It was collected from Weldone Industries, kannur district, kerala, India. Properties of woven jute geotextile obtained from National jute board are shown in Table. 3

Table 3. Properties of jute geotextile (National jute board)

Properties	Value
Thickness (mm)	2
Weight (gm/m^2)	760
Permittivity (m/s)	0.5
Strength (warp x weft) (kN/m)	20x20

4 Sample Preparation

The collected clayey soil in the form of wet condition was placed in an oven for 24 hours and then crushed into dry powder form. Soil sample was allowed to sieve through 425 micron IS sieve. Fig.1 represents the diagram showing location of geotextile layers and the sandwich specimen. The cylindrical soil specimens with 38 mm diameter and 72 mm height were prepared. The diameter of geotextile layer and sand layer was taken as 32mm. For unreinforced soil, the sample was filled in layers and compacted by using standard compaction approach, so as to attain the maximum dry density obtained from compaction test. For reinforced soil, the samples were filled in several layers keeping same density of unreinforced specimens. For the sandwich specimens, clay was placed into a mould. After the clay was compacted and leveled to a desired height, half of the predetermined quantity of dry sand was placed and compacted with a small tamper to achieve the required thickness and density. Afterward, the reinforcement layer was introduced above the lower part of the sand. Then the remaining portion of sand and clay was placed. Fig. 2 shows the preparation of reinforced soil specimen with one layer of geotextile. Where geotextile layer was placed at the center of specimen and compacted to same density obtained for unreinforced specimens.

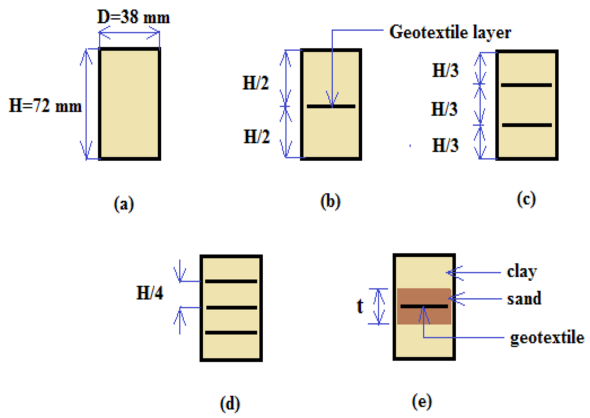

Fig. 1. Arrangement of geotextile layers in reinforced soil (a) Plane soil (b) Soil specimen with one-layer geotextile (c) Soil specimen with two-layer geotextile (d) Soil specimen with three-layer geotextile (e) sandwich specimen

Fig. 2. Specimen preparation with one-layer of geotextile

5 Testing Program

Triaxial tests were performed on the unreinforced, reinforced clay and the sandwich specimen under different confining pressures (50,100 and 150 kPa). The axial loading was increased gradually at the rate of 1.2 mm per minute. The loading was continued until strain level of reinforced specimen reached 20 %. This strain is known as strain at failure.

6 Results and Discussion

6.1 Triaxial Test Results of clayey Soil Reinforced with Geotextile Layers

Type of failure. Fig. 3 shows photos of deformed failure specimens. In unreinforced samples, failure was observed as bulging failure at the center of the specimen. In reinforced samples, bulging occurred between two adjacent geotextile layers. As the number of geotextile layers increased, the bulging gets reduced. Thereby deformation become comparatively less.

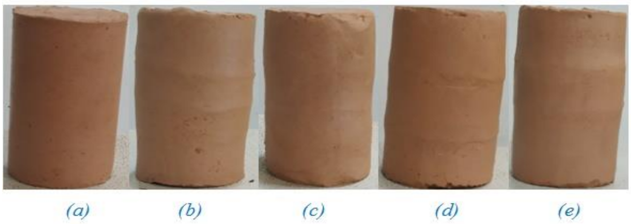

Fig. 3. Soil specimen before and after loading with and without geotextile (a) Plane soil specimen before loading (b) Plane soil specimen after loading (c) Soil specimen with one-layer geotextile after loading (d) Soil specimen with two-layer geotextile after loading (e) Soil specimen with three-layer geotextile after loading.

Stress-Strain behavior. The fig. 4 shows comparison of Stress-Strain behavior of unreinforced and reinforced clayey soil on confining pressure of 150 kPa. The deviator stress and axial strain at failure was increased as the number of geotextile layers was increased.

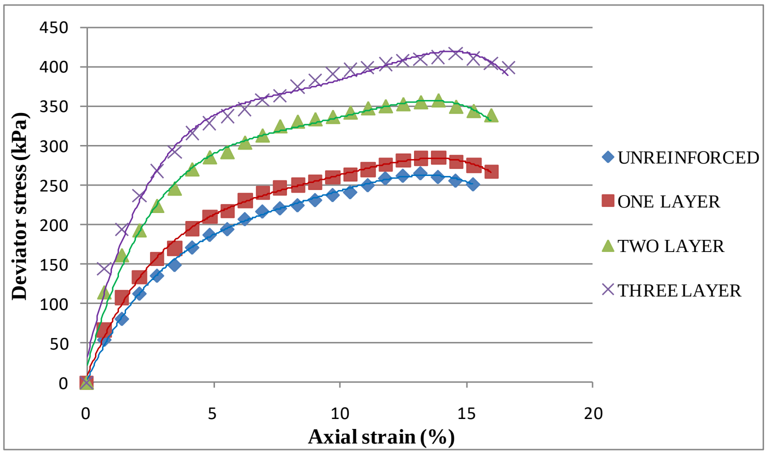

Fig. 4. Deviator stress Vs Axial strain on confining pressure 150 kPa

Table 4 presents the values of deviator stress at failure in unreinforced and reinforced clayey soil specimens. The deviator stress at failure was increased with number of geotextiles due to good soil geotextile interaction.

Table 4. Deviator stress at failure of reinforced clay specimens

Configuration	Deviator stress at failure (kPa) Confining pressure (kPa)		
	50	100	150
Unreinforced clay	173.5	211	265.4
One layer	187.2	227.8	284.2
Two layer	236.8	278.2	357.2
Three layer	275	328.5	416.3

Improvement in deviator stress. The strength improvement was expressed as improvement factor. The improvement factor is defined as the ratio of deviator stress of reinforced soil to that of unreinforced soil. Table 5 presents the improvement in deviator stress at failure of reinforced clayey soil on three confining pressures. The improvement factor was increased with number of geotextile layers.

Table 5. Strength improvement of reinforced clayey soil

Configuration	Improvement factor Confining pressure (kPa)		
	50	100	150
One layer	1.07	1.08	1.07
Two layer	1.36	1.31	1.34
Three layer	1.58	1.55	1.56

Modified failure envelope. The shear strength characteristics such as undrained cohesion (C_u) and angle of internal friction (ϕ) of soil samples can be determined from modified failure envelopes. Fig. 5 presents comparison of modified failure envelopes of unreinforced and reinforced clayey soil specimens.

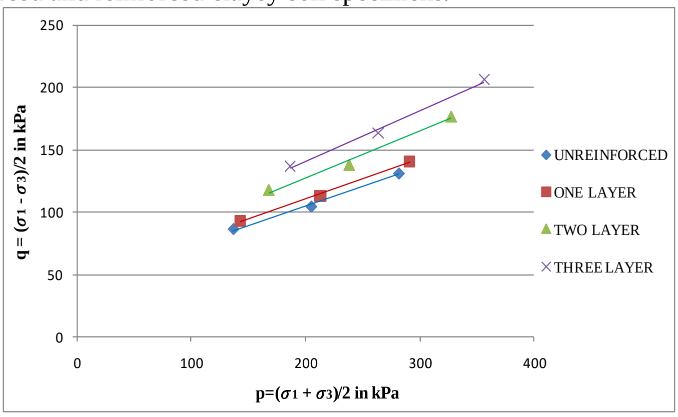

Fig. 5. Comparison of modified failure envelope of clayey soil

As the number of geotextile layers was increased, the failure envelope of reinforced specimens shifted upward. The undrained cohesion was increased because of development of pseudo cohesion on confining soil layers from geotextile layers and angle of internal friction also increased due to the increased passive resistance as the confining pressure were increased. The increase in shear strength of reinforced clay is mainly due to the increase in undrained cohesion of the clay.

Modulus of Elasticity, E. Modulus of elasticity is a measure of soil stiffness. It is calculated by taking the slope of initial tangent drawn to the stress-strain curve. Table 6 presents the Modulus of elasticity obtained for unreinforced and reinforced clay specimens on three confining pressures. The Modulus of elasticity was increased as the number of geotextile layers and confining pressures were increased.

Table 6. Modulus of elasticity (kPa) of reinforced clayey soil

Configuration	Modulus of Elasticity (kPa)		
	Confining pressure (kPa)		
	50	100	150
Unreinforced clay	3125	4375	4667
One	4000	4600	6500
Two	7500	8000	11111
Three	9285	11250	13333

6.2 Triaxial Test Results of Clay Reinforced with a Geotextile Encapsulated in Thin Layer of Sand (Sandwich Specimen)

Type of failure. Fig. 6 presents a typical image of the deformed sandwich specimen. The failure was caused by a bulging of the clay and a discontinuous deformation at the sand-clay interface. The bulging and deformation were attributed to a lateral expansion of clay restrained by the sand-clay interface. Because the sand particles were prone to penetrate the clay, the sand-clay interface shear strength could be stronger than the shear strength of the clay itself. Thus, the zone of maximum lateral deformation moved away from the sand geotextile interface to the clay.


(a) (b)

Fig. 6. (a) Sandwich specimen before loading (b) sandwich specimen after loading

Stress-Strain behavior. The fig. 7 shows comparison of Stress-Strain behavior of unreinforced clay, clay reinforced with one layer geotextile and sandwich specimen of clayey soil on confining pressure of 150 kPa.

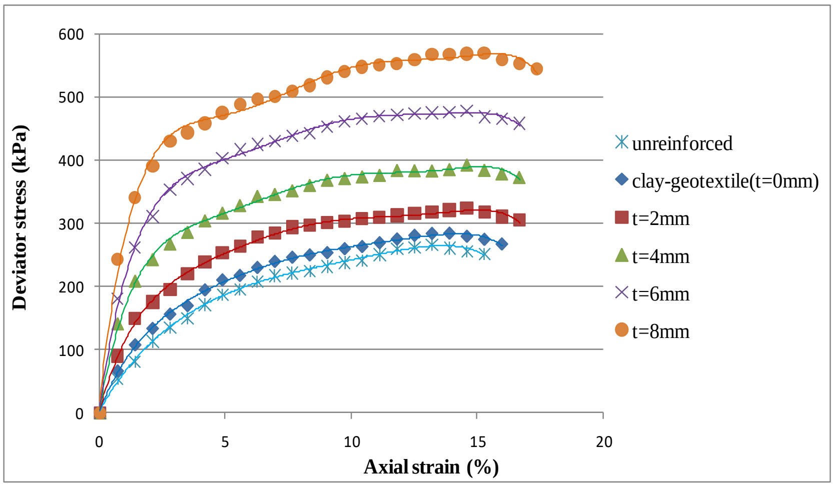

Fig. 7. Deviator stress Vs Axial strain on confining pressure 150 kPa

The sandwich soil specimens reached peak deviator stress at specified confining pressure than that of clay-geotextile specimen and unreinforced soil specimens. The deviator stress and axial strain at failure was increased as the thickness of sand layer was increased due to good soil geotextile interaction.

Table 7 presents the values of deviator stress at failure of unreinforced clay, clay-geotextile specimen and sandwich specimen of clay on three confining pressures. The deviator stress and axial strain at failure increased with thickness of sand layers and with confining pressures. The maximum value of deviator stress was found to be 569.4 kPa with a sand thickness of 8mm on confining pressure of 150 kPa.

Table 7. Deviator stress at failure of sandwich specimen

Configuration	Deviator stress at failure (kPa)		
	Confining pressure (kPa)		
	50	100	150
Unreinforced clay	173.5	211	265.4
Clay-geotextile (t=0mm)	187.2	227.8	284.2
t=2mm	204.5	257	323.2
t=4mm	242.1	310.1	393
t=6mm	291	372.8	478.4
t=8mm	341.7	445.7	569.4

Improvement in deviator stress. The strength improvement was expressed as improvement factor. The improvement factor is defined as the ratio of deviator stress of reinforced soil to that of unreinforced soil. Table 8 presents the improvement in deviator stress at failure of sandwich specimens under three confining pressures.

The improvement factor was increased with increase in thickness of sand layers. The maximum value of improvement factor was found to be 2.14 when sand thickness is 8mm on confining pressure of 150 kPa. The improvement factor for the sandwich specimen is more when compared to the improvement factor of clay reinforced with one layer geotextile.

Table 8. Strength improvement of sandwich specimens

Configuration	Improvement factor Confining pressure (kPa) 50	100	150
Clay-geotextile (t=0mm)	1.07	1.08	1.07
t=2mm	1.17	1.21	1.22
t=4mm	1.39	1.46	1.48
t=6mm	1.67	1.76	1.8
t=8mm	1.96	2.11	2.14

Modified failure envelope. The shear strength characteristics such as undrained cohesion (C_u) and angle of internal friction (ϕ) of soil samples can be determined from modified failure envelopes. Fig. 8 presents comparison of modified failure envelopes of unreinforced, clay-geotextile specimen and sandwich specimens. The slopes of the failure envelopes steepened as the thicknesses of the sand layers were increased, resulting in increases in the friction angles and slight decreases in the cohesion. The inclusion of sand layer increases the interface interaction between clay and geotextile. Regarding the sandwich technique, the increase in shear strength of clay is mainly due to the increase in friction angle of the clay.

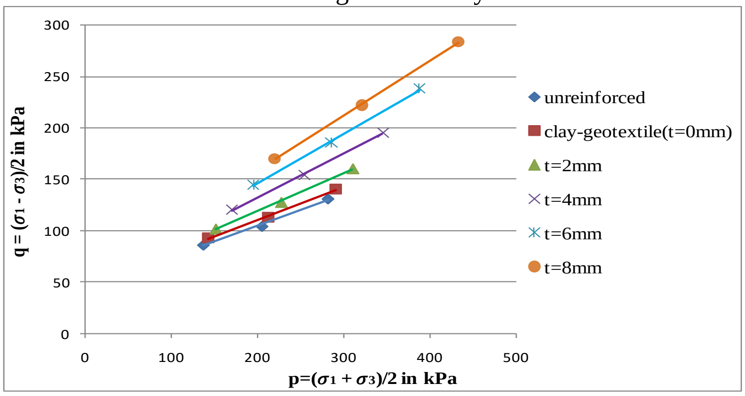

Fig. 8. Comparison of modified failure envelope of sandwich specimen

Modulus of Elasticity, E. Modulus of elasticity is calculated by taking the slope of initial tangent drawn to the stress v/s strain curve. Table 9 presents the Modulus of elasticity obtained for unreinforced clay, clay-geotextile specimen and sandwich specimens on three confining pressures. The Modulus of elasticity were increased as the thickness of sand layer and confining pressure were increased.

Table 9. Modulus of elasticity (kPa) of sandwich specimen

Configuration	Modulus of Elasticity, E		
	Confining pressure, kPa		
	50	100	150
Unreinforced clay	3125	4375	4667
t=0mm	4000	4500	6500
t=2mm	6667	8333	10666
t=4mm	10000	11000	16000
t=6mm	12500	14000	26000
t=8mm	17000	20000	35000

7 Conclusions

The conclusions of this study can be summarized as follows:

1. The reinforced clay specimens failed when bulging occurred between two adjacent reinforcement layers. The sandwich specimens failed because of the bulging of the clay and discontinuous deformation at the sand-clay interface.
2. Both the reinforced clay and sandwich specimens enhanced the peak shear strength of the clay. The deviator stress was increased as the number of geotextile layers, confining pressures and the thickness of the sand layer was increased.
3. The Axial strain at failure also increased as the number of geotextile layers, confining pressures and thickness of sand layers were increased. The maximum deviator stress at failure occurred in sandwich specimen of clayey soil compared to reinforced clay with geotextile layers.
4. The improvement factor was increased with number of geotextile layers and thickness of sand layers on different confining pressures. The improvement factor of sandwich specimen was found to be 2.14 on confining pressure of 150 kPa, which is more compared to reinforced clay.
5. The undrained cohesion and angle of internal friction were increased as the number of geotextile layers and thickness of sand layer was increased. In

sandwich specimen of clay a slight decrease in cohesion and an increase in friction angle was found out when it compared with reinforced clay.

6. The modulus of elasticity was increased with number of geotextile layers, confining pressures and thickness of sand layers. The modulus of elasticity of sandwich specimen was found to be more compared to reinforced clay.

From this study, it is clear that small reinforcement spacing and thick sand layers can effectively strengthen the soil-geotextile interaction. Therefore, as a practical application, low permeability and fine-grained soils can be strengthened by using permeable geotextile layers and providing layers of coarse grained soil around reinforcement.

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