Shear Behavior of Marginal Soil & Non-Woven Geotextile System under UU & CU Triaxial Conditions

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Abstract. Backfill material is one of the major constituents of Geosynthetic reinforced soil (GRS) structures. Current design guidelines conventionally recommend the use of free draining granular material as a backfill material. Owing to the fact that difficulty in finding these materials has increased the use of locally available marginal soil for the construction site as an alternative backfill. Use of marginal fill can reduce the transportation cost and environmental impact due to soil excavation and thereby reducing the overall construction cost of GRS structures. Major concern in using marginal soils as backfill is the build up of positive pore water pressure during construction, which reduces the internal shearing resistance of the soil. It also reduces the interface shear strength between the reinforcement and fill materials. The current study focuses on the shear behavior of marginal soil (SC type) and non-woven geotextile system under UU and CU triaxial testing conditions. Specimens were prepared at their maximum dry density (MDD) and optimum moisture content (OMC) with the change in number of geotextile layers. The test results revealed that the shear strength of reinforced soil increased with the number of geotextile layers in both UU and CU triaxial testing conditions. The pore pressure evolution showed the increased contractive response of marginal soil-geosynthetics system with the addition of geotextile layers. Failure pattern of the geotextile reinforced specimens exhibited bulging/barrel failure patterns between adjacent geotextile layers unlike shear band formations in unreinforced soil specimens.

Keywords: Non-woven geotextile, Marginal soil, UU and CU triaxial.

1 Introduction

Use of geosynthetics enhances the performance of geotechnical structures and has been used since several past years. Geosynthetic reinforced soil structures (GRS) are widely used in many places such as slope and bridge abutments and other geotechnical applications. Understanding the behavior of soil and reinforcement as a composite material is important. Current design guidelines recommend the use of free draining material as a backfill material for the construction of GRS (geosynthetic reinforced soil) structures. Locally available soils called marginal soils are not generally used due to its low permeability, fine grained nature and poorly draining property. To reduce the transportation cost and environmental issues associated with the excavation of soil, locally available marginal soil has been chosen as an alternative backfill material. Main issue in using marginal soil is the development of positive pore water pressure which can weaken the soil reinforcement interface. However, few researchers [1-3] suggested that adopting proper drainage system could solve this problem. Fabian and Fourie [4] investigated the performance of silty clay samples with various permeability coefficients. Al Omari et al. [5] and Noorzad & Mirmuradi [6] studied the performance of geo-mesh reinforced clay. Unnikrishnan et al. [7] examined the behavior of reinforced clay in triaxial compression under static and cyclic loading conditions. Cheng-Wei Chen [8] examined the behavior of fiber reinforced clay under compression and extension loading. Grey & Al-Refeai [9] and Latha & Murthy [10] studied the behavior of reinforce sand under triaxial compression conditions. Zhang et al. [11] studied the behavior of reinforced sand with 3D inclusions. In the present study, an experimental investigation was conducted to see the effect of inclusion of non-woven geotextile layers with the marginal soil (SC type) under unconsolidated undrained (UU) and consolidated undrained (CU) triaxial testing conditions.

2 Material Properties

2.1 Marginal Soil

The basic geotechnical properties of locally available Palaj soil were determined by conducting specific gravity, liquid limit, plastic limit, grain size analysis, standard proctor and consolidation tests. The soil used for the study was collected from Palaj, Gandhinagar and was classified as SC type as per Indian Soil Classification System (ISCS). Basic geotechnical properties of Palaj soil are shown in Table 1. The specific gravity was found to be 2.67. The optimum moisture content and maximum dry density were obtained to be 11.66% and 1.92 g/cc respectively. Grain size analysis signified 53% sand, 35% silt and 12% clay. The soil was classified as marginal soil as per provisions given by several codes and guidelines (Yang et al. [3]), as shown in Fig. 1.

Table 1. Basic geotechnical properties of marginal soil

Properties	Values
Specific Gravity	2.67
Liquid Limit	26%
Plastic Limit	16%
Plasticity Index	10%
Sand	53%
Silt	35%
Clay	12%
Soil Classification	SC

Optimum Moisture Content (OMC)	11.66%
Maximum Dry Density (MDD)	1.92 g/cc
DFSI	10%
Compression index (C_C)	0.11
Recompression index (C_r)	0.008
Visual appearance	Brown

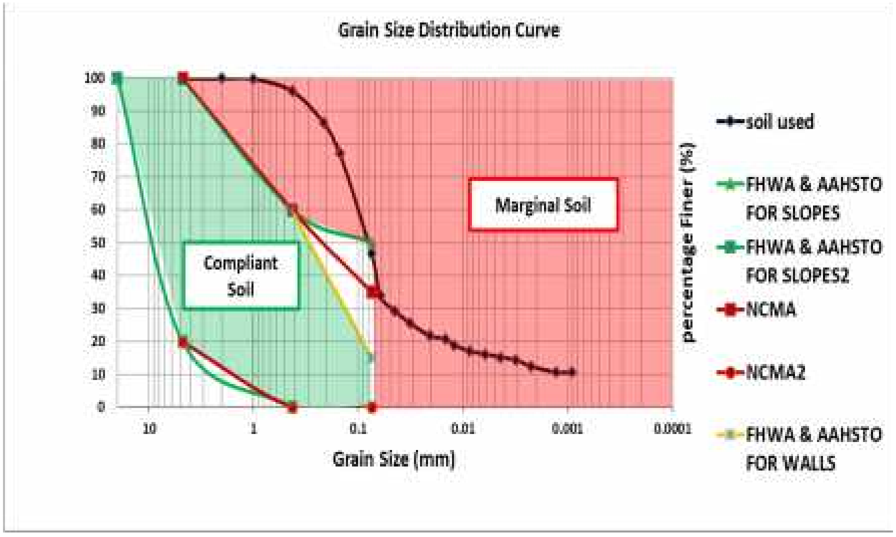

Fig. 1. Grain size distribution of backfill for GRS structures as recommended by design guidelines and soil used for the present study

2.2 Non-Woven Geotextile

Commercially available non-woven geotextile was used for the present study. The technical data provided by Techfab India is summarized in Table 2

Table 2. Properties of Non-woven geotextile

Properties	Values
Tensile strength (MD/CD)	16.0/18.5 kN/m
Grab strength (MD/CD)	1080/1180 N
Grab elongation (MD/CD)	60/60%
Permeability	0.21 cm/sec
Permittivity	1.1 s^{-1}
Apparent opening size	150 µm
Color	White

3 Experimental Program

In the present study, a series of UU (unconsolidated undrained) and CU (consolidated undrained) triaxial tests were performed on unreinforced and reinforced specimens of marginal soil at confining pressure of 100 kPa with varying number of non-woven geotextile layers (i.e. zero, one, two, three and four layers). The specimens were prepared at OMC (Optimum Moisture Content) and MDD (Maximum Dry Density) of marginal soil. The soil was compacted in equal layers such that after compacting each layer of soil the reinforcement was placed horizontally. The soil specimens of 100 mm diameter and 200 mm height were prepared by moist tamping method using three-piece mould supported by collar at the top and base plate at the bottom (Fig. 2). For CU triaxial tests, the specimens were water flushed before forced saturation followed by isotropic consolidation prior to shear deformation of the marginal soil specimens. For complete saturation of the specimens Skempton's pore pressure parameter (B) was checked after every increment and was assured to be 0.95 before consolidation. The specimen was saturated at back pressure of 470 kPa during CU triaxial testing. UU triaxial tests were performed at strain rate of 0.4 mm/min and CU triaxial tests were conducted at strain rate of 0.05 mm/min.

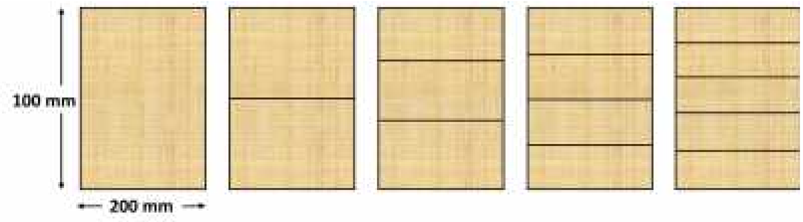

Fig. 2. Reinforcement arrangement for testing

4 Results and discussions

4.1 UU triaxial test

The stress-strain response of unreinforced and reinforced specimens of marginal soil with different number of non-woven geotextile layers at confining pressure of 100 kPa under UU triaxial conditions is presented in Fig. 3. Inclusion of reinforcement greatly enhanced the shear strength of the marginal soil as compared to unreinforced specimens [2] as shown in the Fig. 4. The shearing was continued till 20% of axial strain for reinforced specimens as no well-defined peak was observed in its stress-strain response. It was observed that the deviatoric stress increased significantly from 544 kPa for unreinforced specimen to 911 kPa with 4 layers of reinforcement (Table 3). As the layers of non-woven geosynthetics in the form of soil reinforcement increased in the soil mass, the peak deviatoric stress was observed to increase indicating stronger response of soil with increasing reinforcement. The stiffness of Palaj soil specimens before and after reinforcement at lower strain level (1%) was observed to be similar. It could be attributed due to the smaller mobilization of tensile strength of reinforcement at lower strain level. On loading the reinforced soil specimens (σ_1), tensile loads in the reinforcement were generated which resulted into the additional compressive lateral stresses at the soil/reinforcement interface and thereby induced additional confining stresses ($\Delta\sigma_3$) in the soil apart from externally applied confining stress (σ_3) as shown in the Fig. 5. The soil and reinforcement interaction caused the increased shear strength of reinforced specimens due to the additional confinement effect.

Table 3. Increment in shear strength of marginal soil with the inclusion of reinforcement

Specimens	Peak deviatoric stress (kPa)	Increase in peak deviatoric stress (%)
Unreinforced	544	-
1 layer	594	9
2 layer	699	28
3 layer	828	52
4 layer	911	67

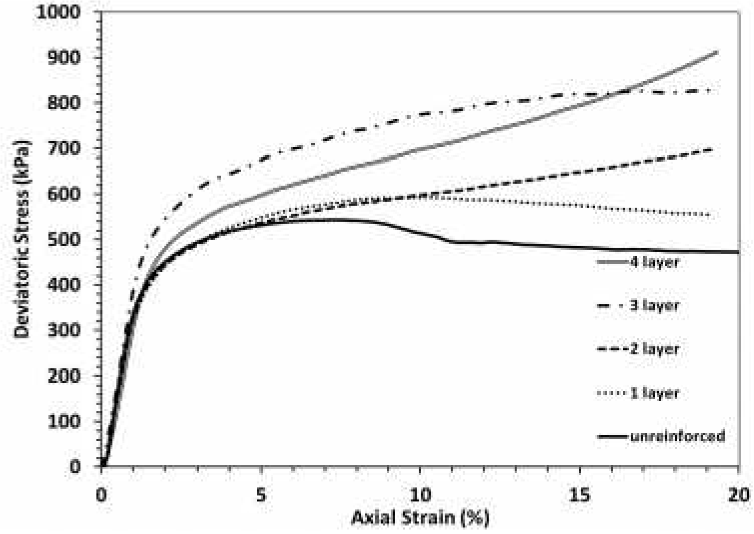

Fig. 3. Stress-strain response of reinforced and unreinforced specimens of marginal soil under UU triaxial conditions

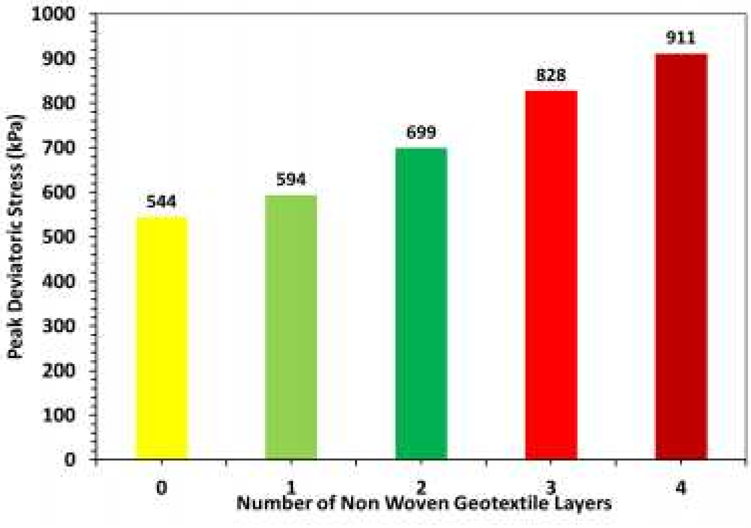

Fig. 4. Stress-strain response of reinforced and unreinforced specimens of marginal soil

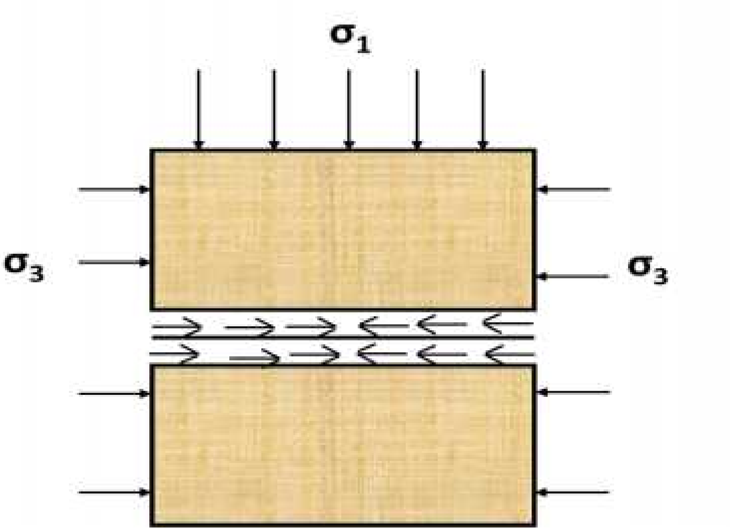

Fig. 5. Mechanism of reinforcement inclusion on soil mass

4.2 CU triaxial test

Stress-strain and pore water pressure response

The stress-strain behavior of unreinforced and reinforced specimens of marginal soil with different number of non-woven geotextile layers (one and three layers) at confining pressure of 100 kPa under CU triaxial conditions is shown in the Fig. 6. All the specimens exhibited hardening response and no well-defined peak was observed. Hence, shearing was continued till 20% axial strain and was considered as the failure criteria. It was observed that the specimen with three layers of geotextile exhibited higher peak shear strength as compared to the unreinforced marginal soil specimen [3]. However, specimen with 1 layer of geotextile indicated decreased shear strength as compared to the unreinforced specimen. The increase in shear strength for the specimen with 3 layers of geotextile was observed due to the mobilization of tensile strain in the reinforcement which generated frictional force between soil and reinforcement. The specimen with 1 layer of reinforcement did not acted as a monolithic system and behaved as a two different soil mass separated by a layer of reinforcement which resulted into decreased shear strength as compared to the unreinforced marginal soil specimen. Very small variation was observed in the deviatoric stress of 3-layer reinforced specimen and unreinforced specimen till 2% axial strain.

The excess pore water pressure response for the unreinforced and reinforced specimens at confining pressure of 100 kPa is shown in the Fig. 7. For unreinforced specimen, the pore water pressure increased till 2% of axial strain and after it decreased gradually. For reinforced specimen, pore water pressure response increased till 2-3% axial strain and after that it became constant. With the inclusion of reinforcement, marginal soil specimen showed more contractive behavior as compared to unreinforced. Fig. 7 indicated increased contractive response with increase in number of reinforcing layers. Till 2% of axial strain, there was not much difference in pore water pressure response for all the specimens as reinforcement required some deformation to mobilize its tensile strength. Inclusion of reinforcement prevented the lateral deformation due to mobilized tensile forces, and hence decreased dilative behavior was observed with the increasing number of reinforcement layers as compared to the unreinforced marginal soil specimens.

Effective stress path (ESP)

Effective stress paths plotted as per MIT stress model for the unreinforced and reinforced specimens are presented in Fig. 8. For the unreinforced marginal soil specimens, the ESP moved away from the origin indicating dilative behavior of marginal soil. However, ESP for reinforced specimens moved towards the origin upto certain level of axial strain, which indicated increased contractive behavior. After this, it showed no further development in positive pore water pressure, however deviatoric stress increased continuously.

4.3 Failure of specimens

The failure of unreinforced and reinforced marginal specimens is shown in Fig. 9. The well-defined shear band was observed during failure in unreinforced marginal soil specimen. However, bulging of the soil mass between the reinforcements was observed during failure for reinforced specimens. Also, it was observed that 3 layers of reinforcement and more were able to make the monolithic system of composite of soil and reinforcement better.

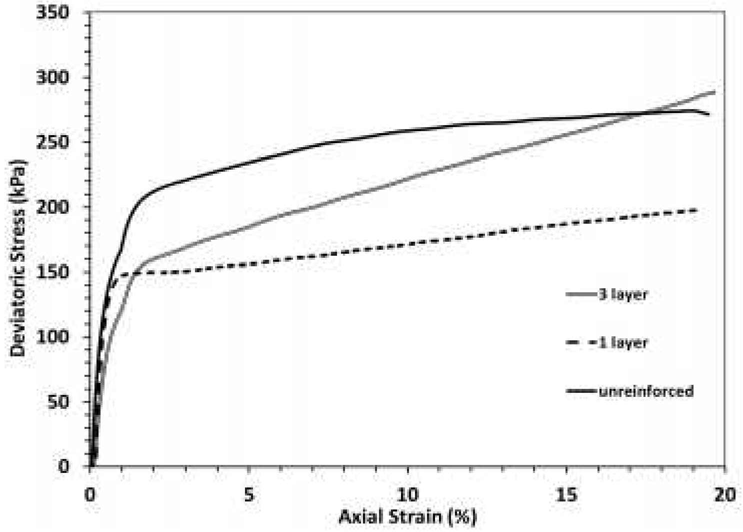

Fig. 6. Stress-strain response of reinforced and unreinforced specimens of marginal soil under CU triaxial conditions

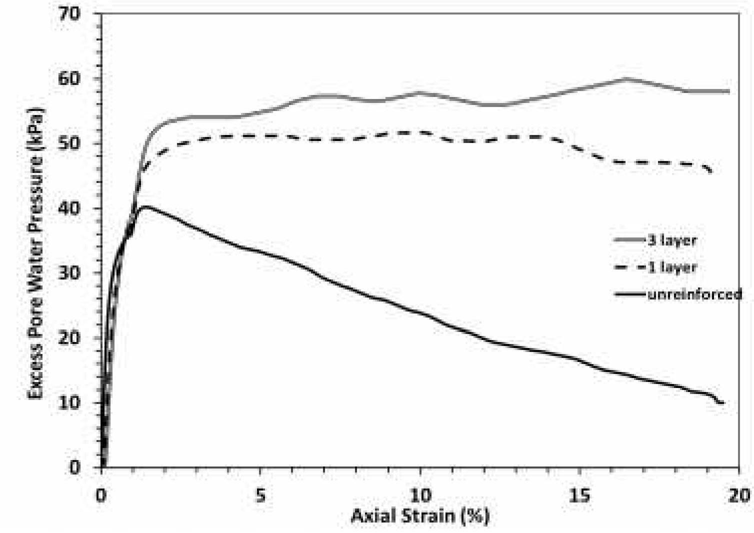

Fig. 7. Pore water pressure response of reinforced and unreinforced specimens of marginal soil under CU triaxial conditions

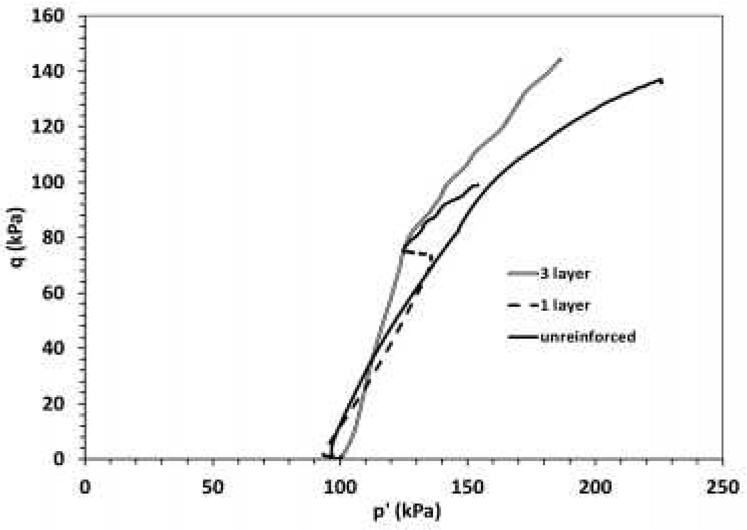

Fig. 8. Effective stress path of reinforced and unreinforced specimens of marginal soil under CU triaxial condition

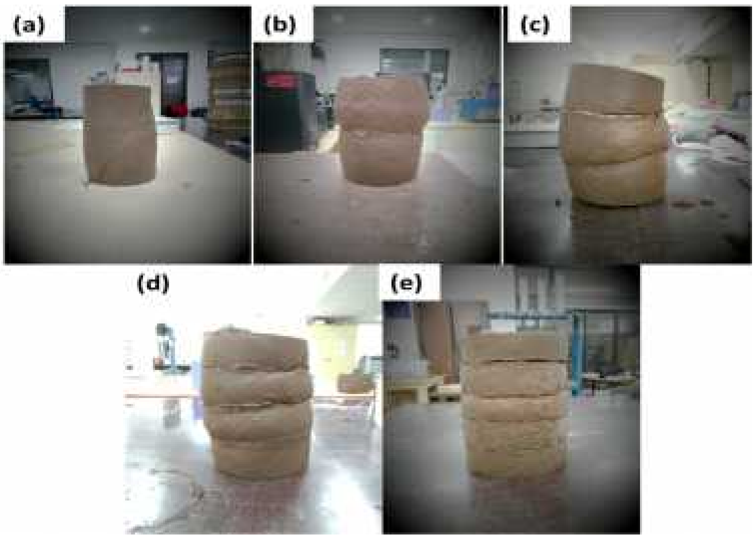

Fig. 9. Failure of specimens under UU triaxial condition varying number of geotextile layers inclusion: (a) unreinforced (b) 1 layer (c) 2 layer (d) 3 layer (e) 4 layer

5 Conclusions

A series of UU and CU triaxial compression tests were performed on marginal soil (SC type) with varying number of non-woven geotextile layers to investigate the effect of reinforcement on shear behavior of marginal soil. The conclusion of the present study is as follows:

- Under UU triaxial conditions, the addition of non-woven geotextile layers greatly increased the shear strength of the marginal soil as compared to the unreinforced specimen and it increased with the increasing number of geotextile layers.
- UU triaxial tests also signified that initial stiffness of both the unreinforced and reinforced specimens till 1% was obtained to be same indicated that mobilization of reinforcement strength required some amount of deformation.
- CU triaxial test results indicated the hardening response for both the unreinforced and reinforced specimens of marginal soil. It was observed that reinforcement specimens with 3 layer of non-woven geotextile showed increased shear strength as compared to the unreinforced specimens whereas specimens with 1 layer of non-woven geotextile showed decreased shear strength.
- Pore water pressure response showed that inclusion of reinforcement exhibited increased contractive behavior as compared to the unreinforced specimen. However, the contractive behavior increased with the increasing number of geotextile layers.
- Failure of specimens indicated the shear band formation clearly for the unreinforced specimens whereas reinforced specimens showed bulging effect during failure.

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