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Study on Shear Strength Properties of Reinforced Soil under TC and TE Stress Path Tests

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Abstract

At the present time a multistage loading triaxial test has been widely implemented in the laboratory of geotechnical engineering as a substitution of the conventional triaxial test. This investigation assesses the possible effects of TC and TE stress path on unreinforced and nonwoven geotextiles reinforced soil. The testing program concentrated on a series of consolidated-drained triaxial compression and extension tests of unreinforced and reinforced soil specimens on 50 mm diameter and 100 mm high samples at consolidating pressures ranging between 100-500 kPa. The stress-strain and volume change properties, elastic parameters and failure envelopes of the unreinforced and reinforced soils for different stress paths were calculated. The stress-strain behavior of the compacted soil for different stress path is non-linear and stress path dependent. The shear strength parameters of the unreinforced soil are different for compression (c'=27.42 kPa, ϕ'= 28 .02^{o}) and extension paths (c'=23.5 kPa, ϕ'= 27^{o}). The reinforced soils exhibit an improvement in shear strength characteristics (higher angle of internal friction and cohesion intercept) under various loading conditions over that of unreinforced soil. This is due to the pseudo confinement caused by the lateral restraint and shear stress mobilization along the soil-reinforcement interface.

Keywords: *Reinforced soil; Triaxial Compression; Triaxial Extension tests; Model parameters; Stress path.*

1 Introduction

In tropical or semi-tropical area, compacted clayey soil has been widely used as fill material for different geotechnical structures such as road pavements, embankments, retaining structures, land reclamation and landfills. The assessment of the shear strength properties and prediction of the behavior of such fills have often been based on limited information. In spite of various semi-empirical test methods developed to correlate engineering experience, proper design and construction uncertainty still remains. The variation of strength parameters and compressibility of clayey soils are mainly due to differences in moisture contents. This results in seasonal variation in strength which have considerable influence on the geotechnical structures. However, the failure mechanism, effect of moisture, strength, and expansion-contraction behavior of tropical soil composites are not yet well understood due to limited studies. The safe and economical design of geotechnical structures require a good understanding of the behavior of clayey soils under various loading conditions. This study is aimed at improving our understanding of the behavior of such soil and to develop a simplified approach for solving some geotechnical engineering problems. Some existing soil at a construction site may not always be totally suitable for supporting structures such as buildings, bridges, road pavements, railway subbase, embankments, and dams. For example, in some soil deposits, the in situ soil may be very loose and will result in a large elastic settlement when loaded. In that case, the soil needs to be densified to increase its unit weight and thus the shear strength. In some instances the top layers of soil are also very weak or undesirable and must be removed and replaced with a better soil so that the structural foundation can be built. The use of reinforced earth is one of the developments in the design and construction of geotechnical structures. Reinforced earth is a composite material formed by using appropriate reinforcement into the soil which is relatively durable and stable. The basic principle of reinforced soil involves the generation of frictional forces at the soil-reinforcement interface. Thus, to design any geotechnical structure involving the application of reinforced earth, it is also essential to understand the friction generated at the interface of the soil composites. In the present research study an attempt have been made to evaluate the stress-strain and volume change behavior of unreinforced and georeinforced soil under various stress paths. It is hoped that this research investigation will play significant roles in the reduction of uncertainties related to the design of unreinforced and reinforced soils in Bangladesh.

2 Material Properties and Testing Program

In this research work, undisturbed clay of 75 mm tube samples was used for stress path test. The basic soil properties were determine following the ASTM Standard (2017). The soil is blackish in color and classified as CH in Unified Classification System (USCS). The soil particle contains about 75 % clay, 19 % silt, 06 % sand and no gravels. The other soil properties are: liquid limit 69%, plastic limit 35% plasticity index 34%, and specific gravity 2.63. From the plasticity chart, as suggested by Head (1980), the soil can be classified as CH i.e. high plasticity clay. The natural moisture content was about 34.2%. The coefficient of permeability of compacted soil was found to be approximately 2.462 x 10^{-9} m/sec and it indicate that the permeability of the soil is very low (Terzaghi and Peck, 1948; Whitlow, 1995). In this research work, geotextiles were used as the reinforcement material. Non-woven types geotextiles was used throughout this research work. The non-woven geotextiles properties were determine following the ASTM Standard (1992). The testing program was performed by hydrostatic compression stress path (HC) tests on clay. This stress path is followed using the conventional 50 mm dia and 100 mm high cylindrical triaxial samples. Hydrostatic compression tests were conducted for clay to simulate the bulk modulus properties of the clay. In this program, three tests were done. In this stress path, the testing was done at initial consolidation pressure 100 kPa and then increases stepwise to 500 kPa by following the ASTM Standard (2020). In triaxial compression TC stress path test, the stress is applied such that it remains always on the octahedral plane. In this case σ_1 is increased, whereas σ_2 and σ_3 are reduced such that σ_{oct} remains constant. In other words, if there is an increase in σ_1 of $\Delta\sigma_1$, then σ_2 and σ_3 are decreased by equal amounts of $\Delta\sigma_1/2$. In triaxial extension TE stress path test, σ_2 and σ_3 are increased by equal amounts of $\Delta\sigma_1/2$ but σ_1 is decreased such that σ_{oct} remains constant.

3 Research Methodology

In this investigation, three hydrostatic compression tests were performed on the undisturbed barind soil. The hydrostatic triaxial compression specimens were prepared by trimming from 75 mm tube samples. The specimens were set up between a porous disk at its bottom and a porous disk at the top in the triaxial cell. A rubber membrane was placed over the specimen using a membrane stretcher and O-rings were placed over the membrane on the bottom pedestal and upper cap. Saturation of the test specimens was achieved by continuously increasing the cell pressure and back pressure. The computer controlled triaxial (GDS) system was adapted to carry out the HC stress path tests that were described by Menzies (1989). A microprocessor collects the data from transducers automatically at prescribed intervals. The data were transmitted by the controlling microprocessor for recording, processing and production of results, which could be displayed on the screen, tabulated or plotted by a plotter.

4 Results and Discussion

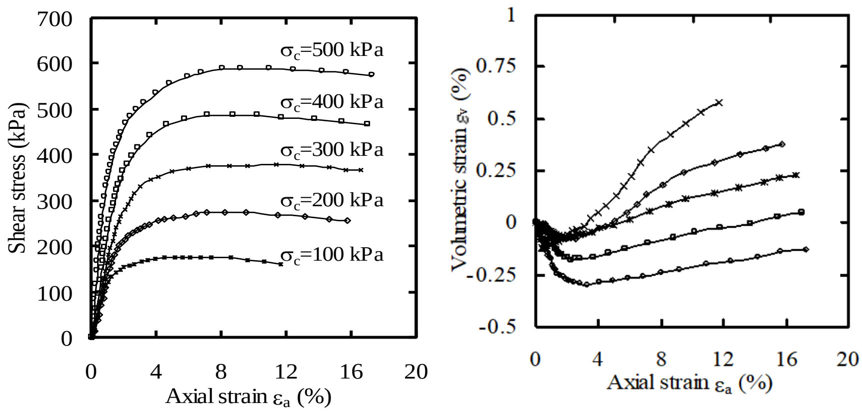
In this section, the experimental triaxial stress path test results are presented. The stress-strain and volume change characteristics, prediction of shear strength parameters of unreinforced and reinforced soil under different stress paths are discussed. The effects of stress paths on the elastic properties of unreinforced and reinforced soil are described in addition to the effect of reinforcement on the strength properties of soil composites. The shear strength parameters of the unreinforced soil are different for compression (c' = 27.42 kPa, ϕ' = 28 .02^o) and extension paths (c'= 23.5 kPa, ϕ'= 27^o). Dìaz-Rodrìguez et al. (1992) reported from the 17 clays, the full range of effective stress friction angle on natural clays ranges from 17^o to 43^o. Comparisons of the strength characteristics between unreinforced and reinforced soil are also made. Corfdir, A. and Sulem, J. (2008) described similar behavior for extension and compression triaxial tests for dense sand and sandstone. Two series of stress path tests were conducted, one on the compression side and one on the extension side.

4.1 Compression Loading

In this investigation, triaxial compression stress paths test, i.e. TC stress paths for unreinforced and reinforced soil were conducted. The shear stress versus axial strain and volumetric strain versus axial strain for the various stress paths at consolidation pressures (σ_c) of 100 kPa to 500 kPa are shown in Figure 1, Figure 3 and Figure 5 respectively. The test results shows that the stress-strain relationships are non-linear and the failure strains increases with the increase in confining pressure for all the stress paths. It was observed that there were no distinct peak points in the σ-ε curves. The curves levels off at higher strains until failure. The volume change characteristics for the triaxial compression (TC) path exhibits contraction behavior at lower stress levels and expansion at higher stress levels. In general, it was observed that the various stress paths show contraction and expansion behavior but the shapes are significantly different. The failure of the specimens was observed at mid height by bulging for TC path. It can be concluded that the failure stress and the volume change behavior are stress path dependent. Similar behavior was reported by Vaid and Sasitharan (1992). Atkinson et al. (1987) also observed that the strength and stress-strain behavior of kaolin clay are significantly affected by both compression and extension stress path.

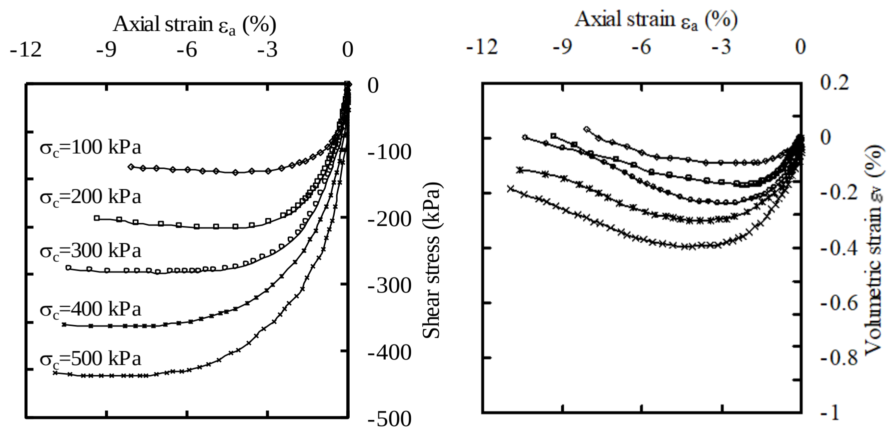
4.2 Extension Loading

Triaxial extension stress path tests (TE) for unreinforced and reinforced soil were conducted. The shear stress versus axial strain and volumetric strain versus axial strain for the various stress paths at consolidation pressures (σ_c) between 100 kPa to 500 kPa are shown in Figure 2, Figure 4 and Figure 6 respectively. As in the case of compression loadings, the stress-strain relationships are non-linear and the failure strains increases with the increase in confining pressure for all the stress paths. Similarly, the σ-ε curves do not produce any distinct peak points. The volume change characteristics for the triaxial extension (TE) paths exhibits contraction volume change behaviour at lower stress levels and the rate of contraction decreases at higher stress levels. In these cases, the volume contraction is more noticeable than other stress paths. The main reason of this behaviour may be due to gradual increase of confining pressure until failure. Taha et al. (1999) reported similar behaviour in drained triaxial extension test on residual granite soil. Thus, the failure stress and the volume change behaviour for triaxial extension tests are also stress path dependent. The failure of the test specimens is observed at the mid height due to necking for all the triaxial extension tests.



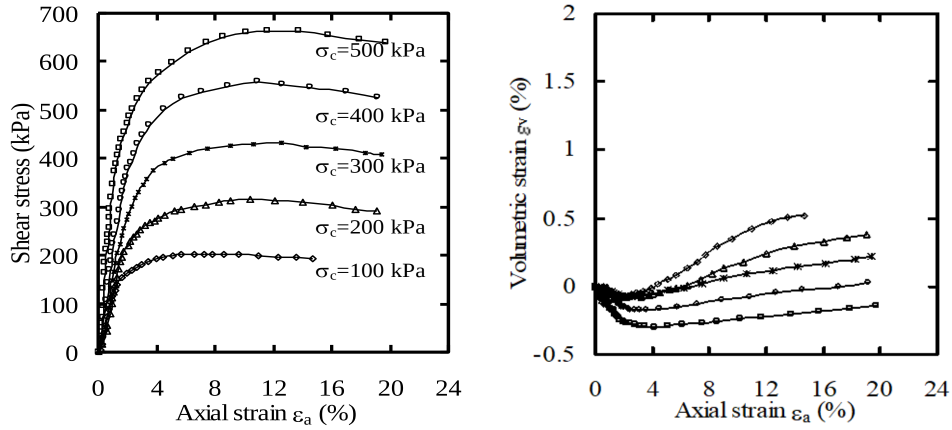
(a) (b)

Figure 1. Stress-strain characteristics of unreinforced soil for TC stress path: (a) shear stress vs. axial strain (b) volumetric strain vs. axial strain.



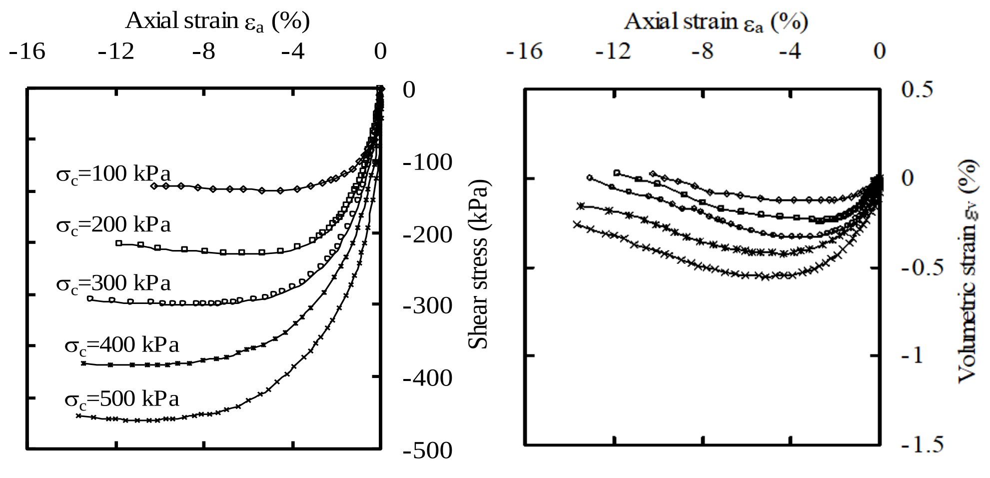
(a) (b)

Figure 2. Stress-strain characteristics of unreinforced soil for TE stress path: (a) shear stress vs. axial strain (b) volumetric strain vs. axial strain.



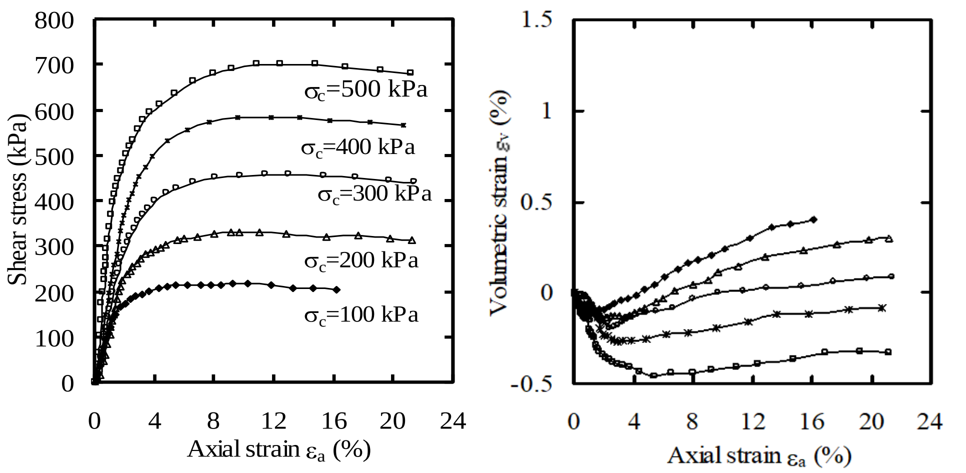
(a) (b)

Figure 3. Stress-strain curves of a single layered non-woven geotextile reinforced soil for TC path: (a) shear stress vs. axial strain (b) volumetric strain vs. axial strain.



(a) (b)

Figure 4. Stress-strain curves of a single layered non-woven geotextile reinforced soil for TE path: (a) shear stress vs. axial strain (b) volumetric strain vs. axial strain.



(a) (b)

Figure 5. Stress-strain curves of a two layered non-woven geotextile reinforced soil for TC stress path: (a) shear stress vs. axial strain (b) volumetric strain vs. axial strain.

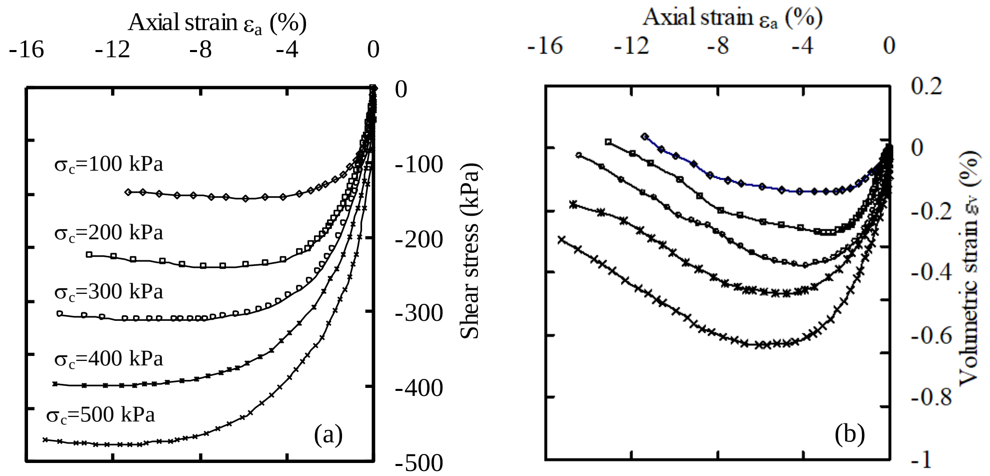


Figure 6. Stress-strain curves of a two layered non-woven geotextile reinforced soil for TE stress path: (a) shear stress vs. axial strain (b) volumetric strain vs. axial strain.

The comparison of the stress-strain and volumetric strain characteristics of unreinforced and reinforced soil for various stress paths are presented. The failure strains at 200 kPa (consolidation pressure) for the different paths are summarized in Table 1. From the results, it is observed that the reinforced soils exhibit higher failure strains and shows about 26 % to 38 % higher than that of unreinforced soils. The failure strains also increases with the increase of reinforcement layers. However, the increase in failure strains over unreinforced soil is not proportional to the number of layer. In general, the increase in failure strains over unreinforced soils is observed for all the stress paths. The failure shear strength of the unreinforced and reinforced soils for the different stress paths are presented in Table 2.

Table 1.Comparison of failure strains of unreinforced and reinforced soil at consolidation pressure σ_c = 200 kPa.

Stress paths	Failure Strain of unreinforced soil (%)	Failure strains of reinforced soil (%)		Increase of failure strains over unreinforced soil (%)	
		1NWG	2NWG	1NWG	2NWG
TC	7.15	9.01	9.69	26.01	35.52
TE	4.95	6.24	6.87	26.06	38.78

Table 2.Comparison of shear strength of unreinforced and reinforced soil at consolidation pressure σ_c =200 kPa.

Stress paths	Shear strength of unreinforced soil (kPa)	Shear strength of reinforced soil (kPa)		Increase of shear strength over unreinforced soil (%)	
		1NWG	2NWG	1NWG	2NWG
TC	266	303	328	13.91	23.31
TE	203	216	226	6.40	11.33

The reinforced soils exhibit higher strength for all the stress paths and increase in strength of reinforced soils depends upon the number of reinforcement layers and stress path followed. The non-woven geotextile reinforced soils show higher strength than the woven geotextile and geogrid reinforced soils. The percentage increase in the shear strength of reinforced soils is stress path dependent. In the compression side, the percentage increase in strength is 13.91% to 23.31% for TC path. However, in the extension side, the percentage increase in strength is 6.40% to 11.33% for TE stress path. The percentage increase in the strength of reinforced soil over unreinforced soil for different stress paths are stress path dependent. Reinforced soils show higher volume contraction than that of unreinforced soil. The reinforced soils exhibit higher cohesion and angle of internal friction than the unreinforced soils. The non-woven geotextile reinforced soils show higher angle of internal friction than the unreinforced soil in the compression side but marginal variation is observed in extension path. The increase in the angle of internal friction and cohesion for a two layered non-woven geotextile over a single layer is significant in compression path but marginal in extension path.

5 Conclusion

Two different stress paths, one on the compression side and one on the extension side were considered. Drained triaxial tests were conducted on the unreinforced and reinforced soil samples using stress or strain computer controlled triaxial testing machine. Non-woven geotextiles were used as the reinforcement. For reinforced soil, a single layer and two layer reinforcement were used. The stress-strain and volume change properties, elastic parameters and failure envelopes of the unreinforced and reinforced soils for different stress paths were investigated. The conclusions that may be derived from the experimental investigation are:

- The stress-strain behavior of the compacted soil for different stress path is non-linear and stress path dependent. The shear strength parameters of the unreinforced soil are different for compression (c'= 27.42 kPa, ϕ'= 28 .02^o) and extension paths (c'= 23.5 kPa, ϕ'= 27^o).
- The reinforced soils exhibit an improvement in shear strength characteristics (higher angle of internal friction and cohesion intercept) under various loading conditions over that of unreinforced soil. This is due to the pseudo confinement caused by the lateral restraint and shear stress mobilization along the soil-reinforcement interface.
- The reinforced soils exhibit higher failure strain and volume contraction than unreinforced soils for all stress paths. The stress-strain and volume change behavior for reinforced soils are also highly stress paths dependent.
- The shear strength parameters of the unreinforced and reinforced soils are independent of the various stress paths followed.

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