Undrained Shear Behaviour of Fly Ash-Geosynthetic System with Woven and Non-Woven Geotextile

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Abstract. The use of geosynthetic reinforced soil structures in various geotechnical engineering applications is increased in recent times. Conventionally, free-draining materials such as coarse to medium sands are used as reinforced fill material. However, the availability of sands are decreasing rapidly, and that raised certain economical and environmental issues. Fly ash is a good alternative to the sand as reinforced fill material. It is a by-product generated due to coal combustion and contains silt-sized hollow spherical particles having very low specific gravity. In the current research, an attempt has been made to evaluate the shear behaviour of the fly ash-geosynthetic system under undrained triaxial conditions. A series of undrained triaxial compression tests were performed on 100mm diameter and 200mm height specimens of fly ash having zero to four layers of woven and non-woven geotextiles at 100, 200, and 300 kPa confining pressures. The peak deviatoric stress was enhanced with the insertion of geotextile layers due to an increase in effective confining pressure within the specimen, generated by the mobilisation of large tensile forces at fly ash-geotextile interfaces. The rise in shear strength was more prominent in the case of woven geotextile as compared to non-woven due to its high stiffness and high load carrying capacity. The post-peak softening response was reduced, and the hardening response was increased as the number of geotextile layers increased. The values of shear strength parameters (c and φ) had been increased from unreinforced to four layers of geotextile-fly ash system except for a single layer system.

Keywords: Woven Geotextile, Non-Woven Geotextile, Fly Ash, Stress-Strain, Undrained Shear Strength

1 Introduction

The use of geosynthetic products in the geotechnical engineering applications are elevated from the past several decades. The low cost and ease of application are some advantages of this reinforced-soil system. Geotechnical structures such as retaining wall, bridge approach embankment, road and railway embankment, ground improvement structures, erosion control structures, landfills are being constructed with the help of various geosynthetic products such as geotextiles, geogrids, geomembranes, etc. Several authors [1-10] in the past explored the beneficial effect of these products on the strength enhancement of soil by performing direct shear, triaxial and plain strain tests. Athanasopoulos [3] investigated the effect of particle sizes on the geotextile-reinforced sand by performing a series of direct shear tests and concluded that the aperture size of geotextiles governs the dilatancy behaviour of sand. Chandrasekaran et al. [5] and Haeri et al. [6] performed triaxial compression tests on two different diameter specimens of sand reinforced by geotextiles and determined that the shear strength and axial strain at failure increased with decrease in the spacing of reinforcements. Latha and Murthy [7] conducted triaxial compression tests on sand reinforced with woven geotextile, geogrid and polyester film. They concluded that the reinforcement enhanced the apparent cohesion of the system but had a negligible effect on the internal friction angle. Tafreshi and Asakereh [9] evaluated the strength ratio and strength enhancement of silty sand reinforced by geotextiles at various strain levels during triaxial compression tests and recommended to use the field specific strain level for the strength comparison of unreinforced and reinforced specimens. Nguyen et al. [10] performed triaxial compression tests on reinforced sand and investigated the mobilization and distribution of reinforcement strain, and soil-geotextile interface shear stresses through digital image analysis technique.

All the previous investigations mainly focussed on the shear behaviour of sand with geosynthetic products, as sand is widely used in the construction of reinforced-soil structure due to its high angle of internal friction and high permeability. However, the availability of sand is decreased nowadays, and that raised certain economical and environmental issues. Hence, it is essential to determine the alternative material of sand, and fly ash can be a good alternative solution to that. Fly ash is a by-product of coal combustion generated from thermal power plants. Fly ash contains silt-sized hollow spherical particles having low specific gravity and can be used as reinforced fill material. Hence, the undrained shear behaviour of a fly ash-geotextile system is evaluated in the current study. A series of unconsolidated undrained triaxial compression tests were carried out on fly ash specimens reinforced with zero to four layers of woven and non-woven geotextiles at three different confining pressures. The results were analysed in terms of deviatoric stress-axial strain behaviour with variation in shear strength parameters.

2 Material Properties

The material used in the current research was fly ash obtained from Gandhinagar thermal power plant. The grain size distribution curve of fly ash was obtained through a dry sieve and hydrometer analysis, as shown in Fig. 1. Fly ash contains 20% sand-size particles and 80% silt size particles with very low specific gravity (Gs) of 2.11. Fig. 1 shows the compliant soil zone (green zone), which was specified by various codes [11-13] for the reinforced fill material. Fly ash GSD curve was not fallen to that category, and hence it is important to check its suitability as rein-forced fill material. The maximum dry density (MDD) and optimum moisture content (OMC) of fly ash were obtained through standard Proctor test, and their values are 1.16 g/cc and 31%, respectively. The geotextiles used in the current study was brought from TechFab India Ltd. The physical and mechanical proper-ties of woven and non-woven geotextiles are presented in Table 1. The woven and non-woven geotextiles were manufactured from polyester and polypropylene as a raw polymeric material. Tensile strength of woven geotextile was found higher than that of non-woven geotextile.

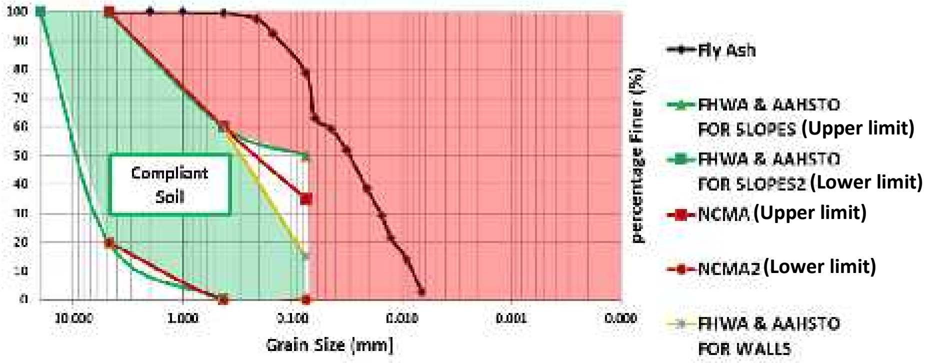


Fig. 1. Grain size distribution curve of Gandhinagar fly ash

Table 1. Properties of Geotextiles

Geotextile Type	Woven Geotextile	Non-woven Geotextile
Product Detail	TFI 3300 TechFab India	PR-25 TechFab India
Physical Characteristics	Woven multi-filament yarns	Staple fiber needle-punched
Polymer Used	Polyester	Polypropylene
Tensile Strength (MD/CD)	300/50 kN/m	16/18.5 kN/m
Water Flow Normal to Plane	8 L/m^2/s	55 L/m^2/s
Characteristic Opening Size O_{90}	205 µm	90 µm

3 Sample Preparation and Testing Program

A total of 27 unconsolidated undrained (UU) triaxial compression tests were performed at three different confining pressures of 100, 200 and 300 kPa and having a number of geotextile (woven and non-woven) layers as zero, one, two, three and four. Triaxial specimens were prepared of size 100 mm diameter and 200 mm height. Moist tamping method was used to prepare the specimen at 95% of MDD (1.10 g/cc) and OMC (31%). The required amount of oven-dried fly ash was taken and mixed uniformly with a calculated amount of water. Then the specimen was prepared in six layers of equal thicknesses by tamping in the three-piece metal mould with a wooden rammer. Geotextile layers were cut in a circular shape and arranged in such a manner that they divide the specimen in equal thicknesses, as shown in Fig. 2. Each textile layer was placed horizontally after properly compact and levelled the underlain fly ash surface. After preparing the specimen, it was carefully transferred to the base plate of the triaxial setup. It was then covered with a latex rubber membrane and 'O' rings. The cell was filled with water, and appropriate confining pressure (100, 200 and 300 kPa) was applied. Shearing was then done by loading the specimens axially at the strain rate of 0.4%/min till the strain level reached 20%. The experimental data were recorded by the automatic data acquisition system (DAQ) through the load cell of 10kN capacity and LVDT of 50mm capacity. For higher confining pressure of 200 and 300 kPa, digital load cell was replaced by manual proving ring of 20 kN capacity, and LVDT was replaced by a dial gauge. The experimental observations for that were taken manually. The detailed experimental program is denoted in Table 2.

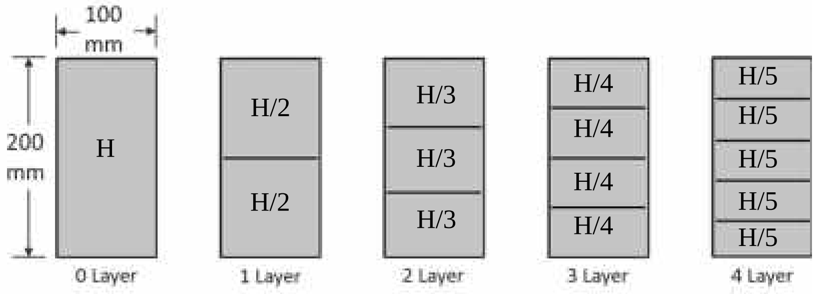


Fig. 2. Geotextile arrangement for triaxial compression test

Table 2. Detailed experimental program

Geotextile	**Confining Pressure**	**Number of Layers**	**Number of Tests**
Unreinforced	100 kPa, 200 kPa & 300 kPa	0	3
Woven	100 kPa, 200 kPa & 300 kPa	1	3
		2	3
		3	3
		4	3
Non-Woven	100 kPa, 200 kPa & 300 kPa	1	3
		2	3
		3	3
		4	3
		Total Tests=	27

4 Result and Discussion

4.1 Deviatoric Stress-Strain Behaviour

Figure 3a-3c and 4a-4c show the deviatoric stress-strain response of fly ash specimens reinforced with woven and non-woven geotextiles at 100, 200 and 300 kPa confining pressures, respectively. It is observed that the peak deviatoric stress was increased with increased in confining pressure for all the number of geotextile layers due to a reduction in void ratio as confining pressure increases. Peak deviatoric stress was chosen as a failure criteria for the analysis. For unrein-forced and single layer fly ash specimens, a well-defined peak was observed in the stress-strain curve at low strain level between 2 to 3% for all the confining pressures. Whereas, for a higher number of geotextile layers more than one, the strain hardening response was observed and no visible peak was obtained. Hence, the test was continued till 20% strain, and failure was assumed at the highest strain level. The peak deviatoric stress value was increased as the number of woven and non-woven geotextile layers increased for all the three confining pressures except for a single layer system. For a single layer system, the specimen did not behave as a homogeneous specimen and acted as a specimen of 1:1 aspect ratio. That might be the reason for non-uniform strain generation inside the specimen and hence, showed less shear strength than unreinforced one. For other specimens having a higher number of layers, as the axial strain increases, the friction might be generated between fly ash and geotextile interfaces due to K_0 condition at the interface. As a result of this, the tension was generated inside the reinforcement and this tension in the reinforcement could have been increased the effective confinement of the specimen. Hence, the undrained shear strength of reinforced specimens was observed to be higher than that of unreinforced specimen for both the woven and non-woven geotextiles. The schematic diagram of the possible mechanism is shown in Fig. 5. The initial stiffness of the specimen was found highest for the unreinforced specimen and decreased for the reinforced specimen. This behaviour is consistent for both the woven and non-woven geotextiles. The reason for that could be the imperfect or uneven setting of fly ash on the surface of geotextiles at the specimen preparation stage. The smaller voids could be left at the interfaces, and that leads to lower stiffness at low strain levels. As soon as the strain level increases, the voids were compressed, and the proper bonding between geotextile and fly ash could be established. This further leads to increase in strength for reinforced specimens at higher strain levels. The common bifurcation point in the stress-strain response of two, three and four layer system was observed between 2% to 3% strain level for both woven and non-woven geotextiles. It indicated that strain level for the end of linear response was almost similar, irrespective of a number of geotextile layers. The peak deviatoric stress and percentage increase in shear strength are presented in Table 3.

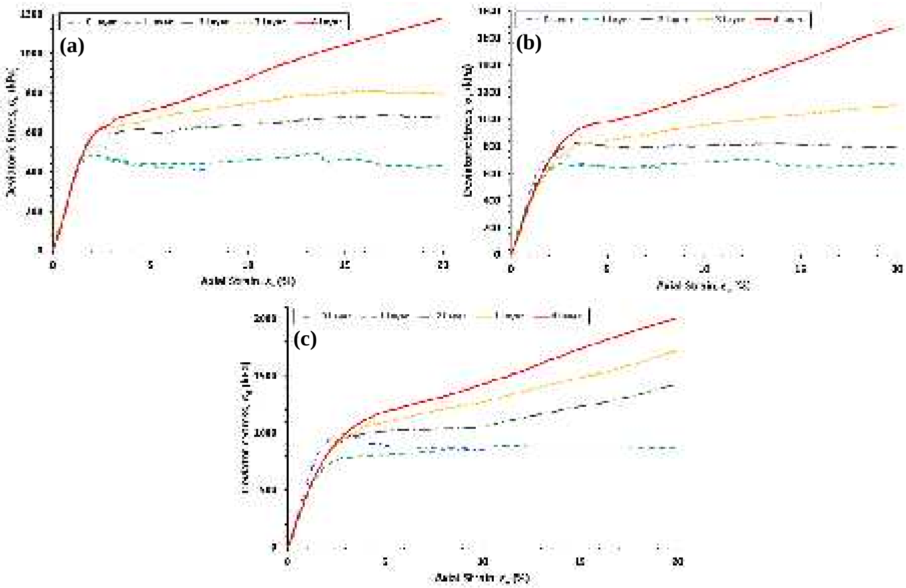


Fig. 3. Stress-strain response of woven geotextile reinforced fly ash: (a) 100 kPa confining pressure (b) 200 kPa confining pressure (c) 300 kPa confining pressure

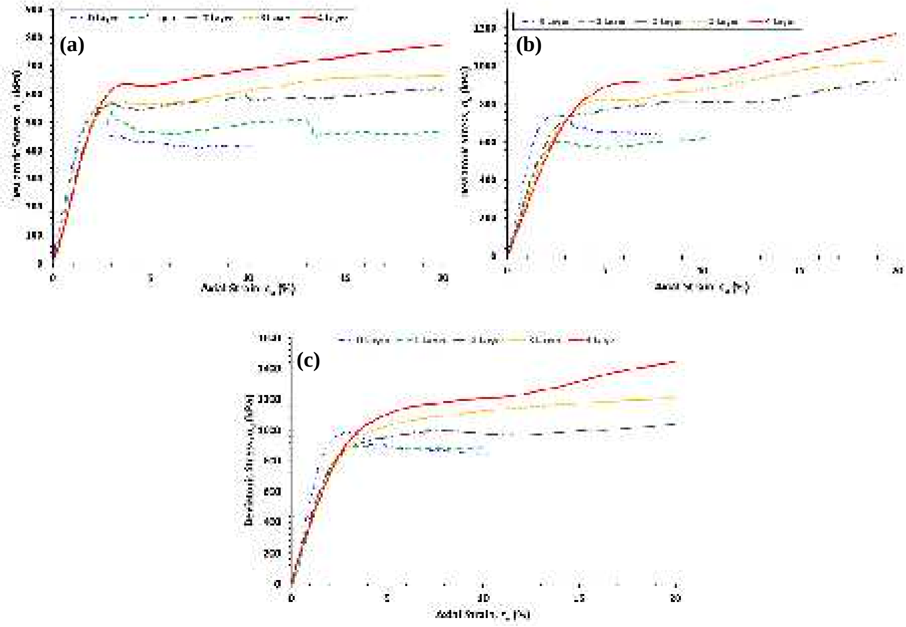


Fig. 4. Stress-strain response of non-woven geotextile reinforced fly ash: (a) 100 kPa confining pressure (b) 200 kPa confining pressure (c) 300 kPa confining pressure

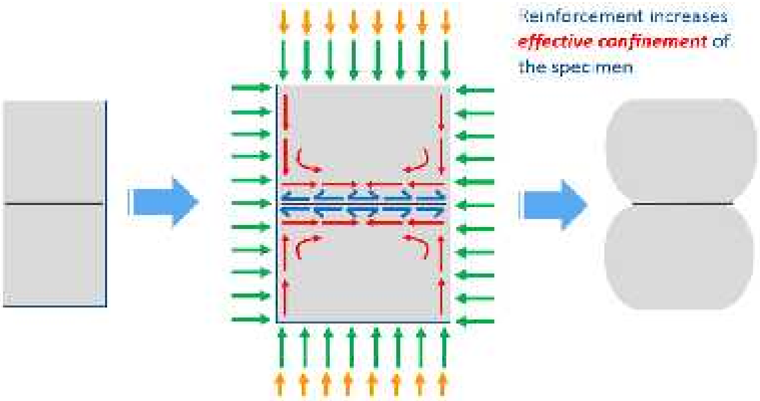


Fig. 5. Mechanism of reinforcement during shearing process

Table 3. Peak deviatoric stress, percentage strength increase and total shear strength parameters of unreinforced and reinforced fly ash

Woven Geotextile								
Geosyn-thetic Layer	Peak Deviatoric Stress (kPa)			Percentage Increase in Strength (%)			c	φ
	100 kPa	200 kPa	300 kPa	100 kPa	200 kPa	300 kPa	kPa	Degree
0	535	745	985	-	-	-	84	32
1	492	712	889	-8	-4	-10	87	30
2	686	831	1425	28	12	45	41	42
3	808	1104	1717	51	48	74	58	44
4	1179	1682	2006	120	126	104	173	43

Non-Woven Geotextile								
Geosyn-thetic Layer	Peak Deviatoric Stress (kPa)			Percentage Increase in Strength (%)			c	φ
	100 kPa	200 kPa	300 kPa	100 kPa	200 kPa	300 kPa	kPa	Degree
0	535	745	985	-	-	-	84	32
1	561	621	899	5	-17	-9	100	28
2	619	931	1036	16	25	5	120	31
3	677	1031	1209	27	38	23	111	35
4	776	1171	1442	45	57	46	110	39

4.2 Effect of Confining Pressure on Peak Deviatoric Strength

Figure 6a and 6b show the variation of peak deviatoric stress with confining pressure and number of geotextile layers for woven and non-woven geotextiles, respectively. It is evident from the graph that increases in the peak deviatoric strength for woven geotextile is higher than that of non-woven geotextile for all the confining pressures. The increase in strength for woven geotextile is from 985kPa to 2006kPa for 300kPa confining pressure, whereas it increased from 985kPa to 1442kPa for same confining pressure in the case of non-woven geotextile. This could be due to the higher strength and stiffness of woven geotextile as compared to non-woven geotextile. Woven geotextile can generate higher force at the very low strain level. The percentage increased in peak deviatoric strength was highest for four layers woven geotextile system as 126% at 200 kPa confining pressure and 57% for four layers non-woven geotextile system at same confining pressure. The percentage increase in strength from unreinforced to four layers reinforced is increased from 100 kPa to 200 kPa confining pressure, after which it decreased for 300 kPa confining pressure.

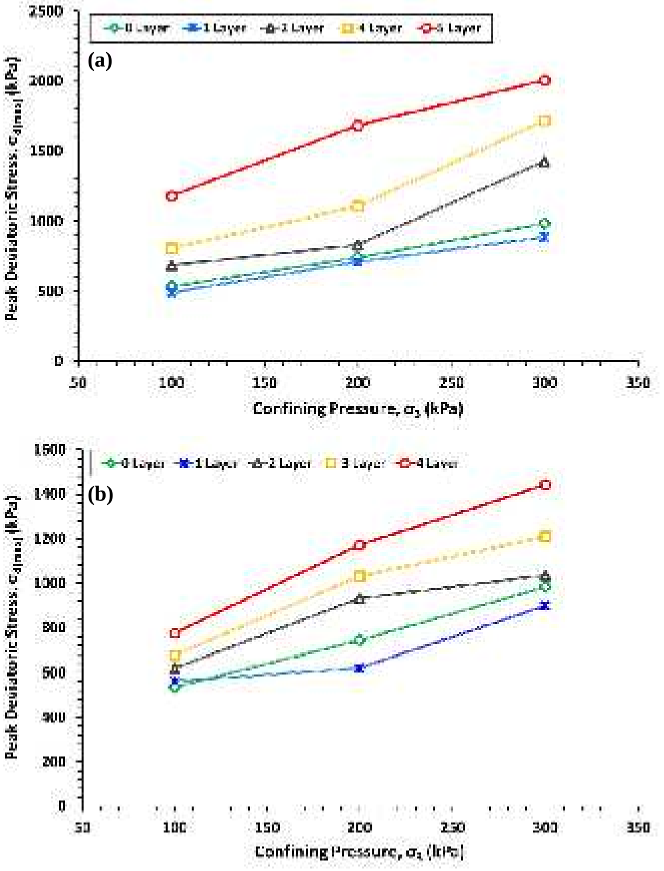


Fig. 6. Peak deviatoric strength variation with confining pressure and number of geotextile layers (a) Woven geotextile (b) Non-woven geotextile

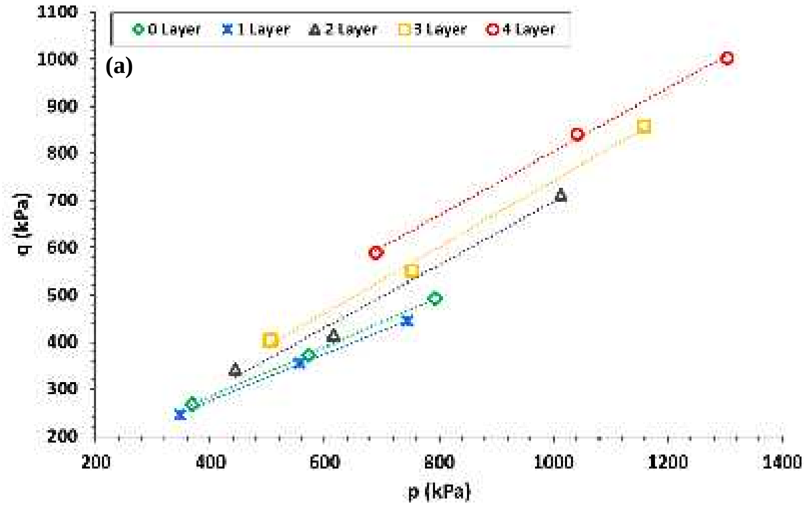
4.3 Variation in Shear Strength Parameters (c & φ)

The shear strength parameters (c & φ) for all the cases was determined through modified failure envelope (q-p plot) as shown in Fig. 7a and 7b for woven and non-woven geotextiles, respectively. The MIT definition of q and p was used for the analysis and that defined as follows,

$$q = \frac{(\sigma_1 - \sigma_3)}{2} \tag{1}$$

$$p = \frac{(\sigma_1 + \sigma_3)}{2} \tag{2}$$

Where q is peak shear stress, and p is mean confining stress. The q-p plot was almost linear for all the layers of woven and non-woven geotextiles. The variation of undrained cohesion (c) and angle of internal friction (φ) with a number of geotextile layers is shown in Fig. 8a and 8b, respectively. The angle of internal friction (φ) was found to increase from 32^o to 44^o for zero to four layer of woven geotextile and from 32^o to 39^o for zero to four layer of non-woven geotextile. Increase in 'φ' for woven geotextile is higher than that of non-woven. Undrained cohesion for non-woven geotextile increased from 84 to 120 kPa for zero to two layer and then decreased till 110 kPa for four layers. A reverse trend was observed for woven geotextile as 'c' was decreased from 84 to 41 kPa for zero to two layer and then increased till 173 kPa for four layer system.



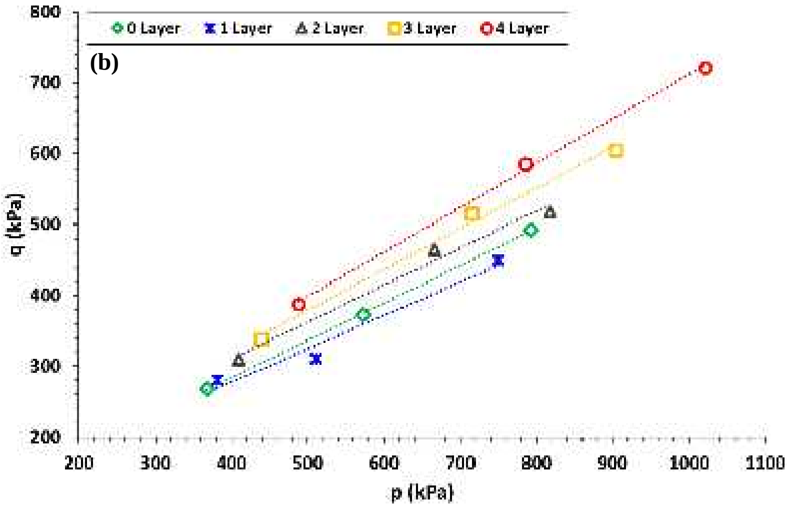
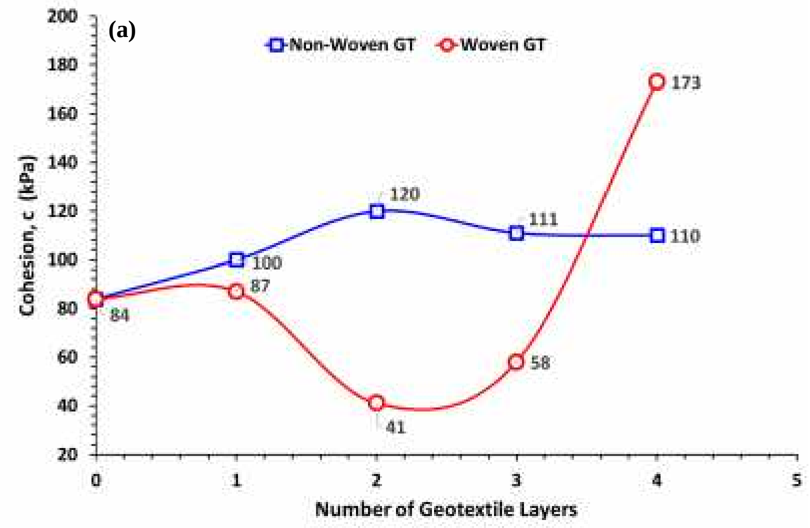


Fig. 7. Total stress failure envelope for: (a) Woven geotextile (b) Non-woven geotextile



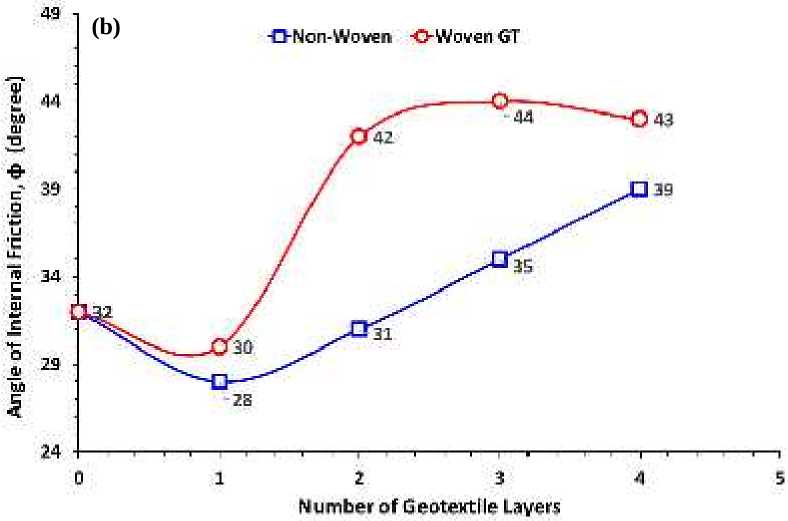


Fig. 8. Variation in shear strength parameters (a) Cohesion, c (b) Angle of internal friction, φ

5 Conclusions

The major conclusions derived from the current study can be summarised as follows:

- The undrained shear strength (σ_{dmax}) of fly ash increased with increase in number of woven and non-woven geotextile reinforcement layers, except for the single layer fly ash-geotextile system.
- The increase in shear strength with woven geotextile was higher as compared to non-woven geotextile due to higher stiffness and strength of woven geotextile.
- A well-defined peak deviatoric stress (σ_{dmax}) was attained for zero & single layer system whereas, strain hardening response (bi-linear response) was observed for two, three & four layer system for both woven and non-woven geotextiles.
- Initial stiffness of the sample was highest for the unreinforced fly ash and reduced with insertion of geotextile layers.
- Angle of internal friction (φ) was found to increase consistently with number of layers from 32^o to 39^o for non-woven geotextile and from 32^o to 44^o for woven geotextile.
- Undrained cohesion (c) was observed to increase for non-woven geotextile whereas, no particular trend was obtained for woven geotextile.
- For both the geotextiles, the percentage increase in peak strength was increase with increase in confining pressure till 200 kPa, after which it reduced.
- The strain at failure (ε_f) was lowest for unreinforced system and increased as number of reinforcement layer increased.

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