Interfacial Behavior of Reinforced Clay-Sand Sandwich Model

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***Abstract*— A comparative study with the suitability of usage of geotextiles in Kaolinite clay and sand is conducted. Also the impact of number of geotextiles and reinforcement spacing in strength of clay material is studied. This is compared with a sandwich model by including a thin layer of sand in between clay surrounding geotextile, in order to improve the interfacial strength varying sand layer thickness.**

Keywords*— *Geotextile, Sand, Sandwich Model

I. INTRODUCTION

Economically and environmentally acceptable geotechnical structures are on increasing demand nowadays. But for the construction of such structures, some limitations are faced due to the high cost and the problems caused during the extraction of aggregates. Usage of locally available cohesive soils can be a solution to such problems, but it may not have the ability to meet the specified geotechnical requirements. In such cases, some modifications can be done to the clay, like providing reinforcements such as geotextiles, geonets etc. which has got renowned functions in aiding drainage and reducing seepage pressure.

There are many advantages of using low permeable, low quality soils in geotechnical constructions, which includes mainly of transportation, purchase costs for aggregates and environmental problems that can be caused during extraction as well as disposal of the aggregates. But due to its low permeable nature, pore water pressure increases and there will be considerable volume changes in the soil, which in turn it affects the strength of the entire structure. Usage of geotextiles in these cases can provide drainage to an extent. But it will not be sufficient to provide the required strength. Thus sand inclusions of varying thickness can be provided in addition to these geotextile for better enhancement of drainage in structures made with cohesive soils. When thin sand layers are provided around the geotextiles that act as a reinforcement in clay matrix, the deformation and strength behaviors are found to be improved. This strength improvement method using sand and geotextile is known as sandwich technique and the model is termed as sandwich model.

1.1 Interfacial Behavior of reinforced Sand

During 1970s, the concept of using geotextiles to reinforce soil structures has been proposed. It has got wide applications in Geotechnical and Transportation engineering. But the geotextiles applications are usually done with non-cohesive materials such as gravel and sand as they can provide high frictional resistance, better drainage and lower water susceptibility.

The effective performance of geotextiles reinforced structures can be ensured with mobilization of interfacial shearing resistance. The backfill material has to be highly frictional as well as well graded coarse grained material. Generally fine grained soils are not recommended for important structures as it loses its adhesion under large strains. Rate of corrosion will be increased due to the interference of water with the cohesive materials. When geotextile reinforced soil slopes are considered, the soil-geotextile interface will act as the weakest plane which will lead to post construction deformation and failures. Tests are to be conducted to determine the coefficient of friction values of the soil-geotextile interfaces to assess failure realistically. Thus in order to design a geotextile reinforced geotechnical structure, for better stability, it is recommended to study the interaction of soil-geotextile interfaces.

1.2 Interfacial Behavior of Reinforced Clay

The use of geotextiles in reinforcing non cohesive soil was found to be successful, which lead to the study of geotextile reinforced clay materials. When high quality backfills were required to use in embankments, earth walls and foundations, it provides an economical alternative by reinforcing it with geotextiles. Thus by considering economy and feasibility, interfacial behavior studies of clay-geotextiles interface are to be conducted using large scale pullout tests, direct shear tests and triaxial tests to analyze its application in the field.

From the previous studies, many advantages of using geotextile reinforcements in earth walls, foundations and retaining walls were highlighted like the reduction of total costs, aesthetics, simplicity, more reliable and adaptability in different site conditions. But some limitations were also there in using reinforced cohesive materials like pore water pressure build up, creep potential, construction cost is higher, compatibility and low frictional strength. By using good quality geotextiles, it allows the drainage and the successive pore water pressure buildup can be avoided. Thus by using compacted locally available clay material, better improved geotechnical structures can be made by reducing the total cost.

When sand is used around the geotextile layer, it provides more drainage and the buildup of pore water pressure during the loading can be reduced. It also provides better strength and stability than simple geotextile reinforced structures. A thin layer of sand ranging from 8-16mm is only required to build an improved structure. The thin sand layer can provide the weak clay-geotextile interface high frictional strength and more drainage. The cost will be much lower than entirely using the costly and high strength sand material in the constructions.

1.3 Interfacial Behavior of Reinforced Clay-Sand Sandwich Model

Reinforcement elements are generally used in cohesive soil earth structures to redistribute stresses which means the transfer of load from highly unstabilized areas to the stabilized areas, thus maintaining the equilibrium by redistribution of stresses within the soil mass. But these redistribution largely depends on the soil strength properties and the stress transfer generally takes place at the soil geotextile interface, which will be a weak plane when cohesive soils are used. Thus the usage of cohesive soils will be highly unsuitable when such reinforcing elements are provided. Thus the better and effective solution will be to provide a thin layer of sand cushion around the geotextile to provide good soil-geotextile interface properties. Thus sandwich technique is an effective technique for strength improvement and it also proved to be economical.

II. EXPERIMENTAL PROGRAM

2.1 *Materials*

2.1.1 *Kaolinite Clay*

Kaolinite clay is collected from English Indian clay factory from Veli and the basic engineering properties evaluated along with their graphical representations are given below:

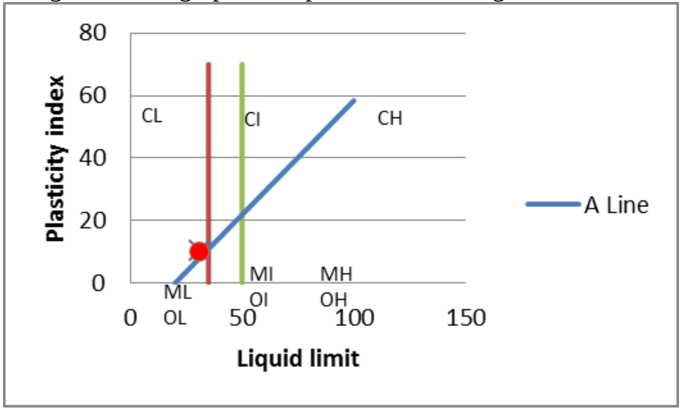

Fig 1. Plasticity Chart

From the plasticity chart, it can be analyzed that the clay selected for the study belongs to the low permeable Clay category. The particle distribution curve is plotted which indicates predominantly clay and silty type. This describes the basic characteristics of the clay selected for the study.

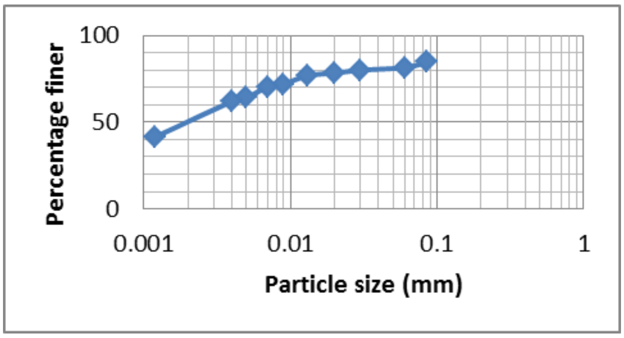

Fig 2. Particle Size Distribution Curve of Kaolinite clay

2.1.2 Locally Available Sand

Locally available sand was collected from the premises of Marian Engineering College. Poorly graded sand is obtained from the local regions. The basic engineering properties determined are mentioned in table 2. From the analysis of engineering properties of sand, it can be concluded that it belongs to the category of poorly graded sand from IS Standards.

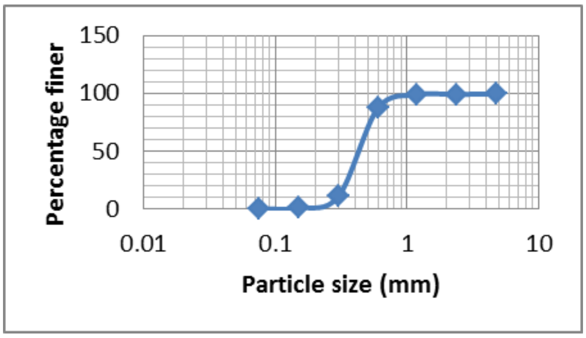

Fig 3. Particle Size Distribution Curve of Sand

2.1.3 *Woven Coir Geotextiles*

Woven coir geotextiles were collected from Charangattu coir factory, Alappuzha as reinforcement to be provided in Kaolinite as well as sand in order to improve strength.

Properties	Values
Mass (g/m^2)	900
Thickness at 20 KPa	6.5
Percentage elongation at break	30
Aperture size (mm)	4.2 × 5.2
Initial tangent modulus at 5mm deformation (KN/m)	65-75

Table 3. Properties Of Geotextiles

Properties	Values
Liquid limit (%)	32
Plastic limit (%)	21.9
Shrinkage limit (%)	20
Plasticity Index	10.1
Optimum moisture content (%)	24
Maximum dry density (g/cc)	1.48
Percentage silt (%)	39
Percentage clay (%)	51
Percentage sand (%)	10
Unconfined compressive strength (KN/m2)	0.65
Specific Gravity	2.61
IS Classification	CL

Table. 1. Properties of Clay

2.2 *Test Apparatus*

Cohesion and angle of internal friction values were obtained by conducting unconsolidated undrained triaxial compression tests as per IS 2720 Part 11. Tests were conducted using Kaolinite clay, geotextile reinforced Kaolinite, geotextile reinforced clay- sand sandwich model and stress- strain graphical representations are plotted to compare the strength characteristics.

2.3 *Test Procedure*

The materials for the study are collected from the respective places mentioned above. Tests are conducted based on the IS codes and the basic engineering properties of the Kaolinite clay, sand and geotextiles are clearly defined in the results with their corresponding graphical representations. In case of unconsolidated undrained Triaxial Compression tests, which are conducted to compare the strength characteristics of clay-geotextile, sand-geotextile, clay-geotextile with varying confining pressures and reinforcement spacing. Sandwich model test is conducted by placing a thin layer of sand in between clay layers and the geotextile is placed at the central layer in between the sand layers.

3. RESULTS AND DISCUSSIONS

Triaxial compression tests are conducted to compare the strength characteristics of clay-geotextile, sand-geotextile, clay-geotextile with varying confining pressures and reinforcement spacing. The stress- strain graphical representations are plotted from the results and maximum deviatoric stress values are compared using the concepts of Strength Ratio and Strength Difference. The effects of including geotextiles and providing thin layers of sand around reinforcements on shear strength improvement were evaluated using the strength ratio and strength difference. The strength ratio (SR) is defined as the ratio of the maximum deviator stress of reinforced specimens to that of unreinforced specimens under the same confining pressure. The strength difference (SD) is defined as the shear strength difference between reinforced specimens and unreinforced specimens at a specific confining pressure, which also indicates the net strength improvement from applying a reinforcement or sand layer.

$SR = (\sigma_{d,max})_{re} / (\sigma_{d,max})_{un}$

$SD = (\sigma_{d,max})_{re} - (\sigma_{d,max})_{un}$

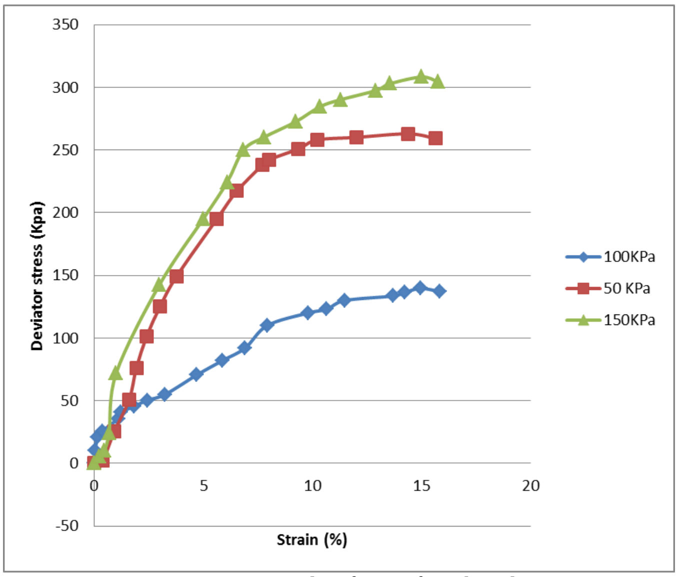

Fig. 4 Stress – Strain plot of unreinforced Kaolinite

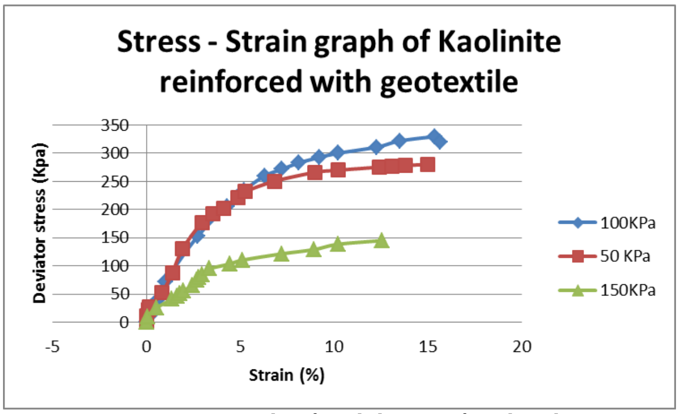

Fig. 5. Stress – Strain plot of single layer reinforced Kaolinite

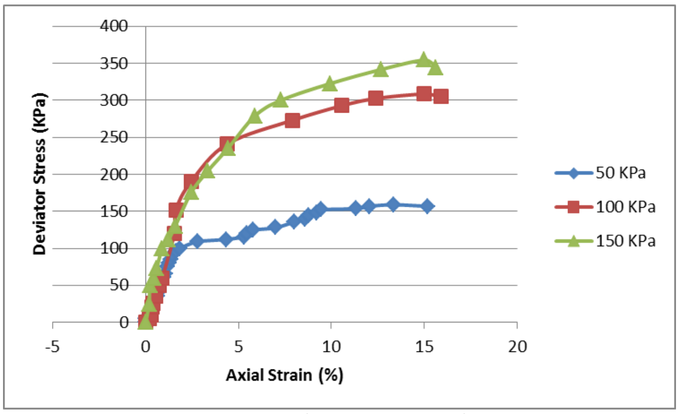

Fig. 6. Stress- Strain plot of double layer reinforced Kaolinite

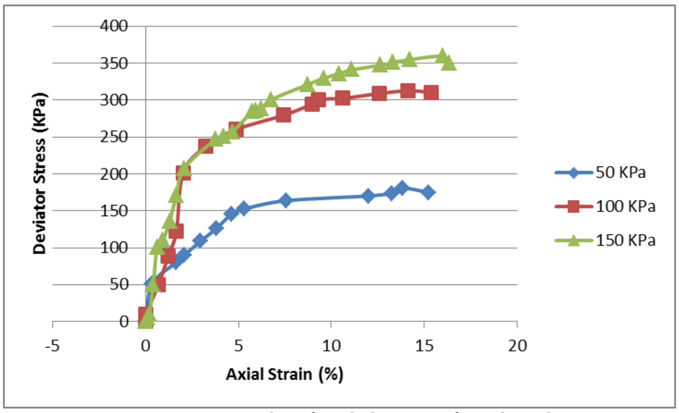

Fig. 7. Stress- Strain plot of triple layer reinforced Kaolinite

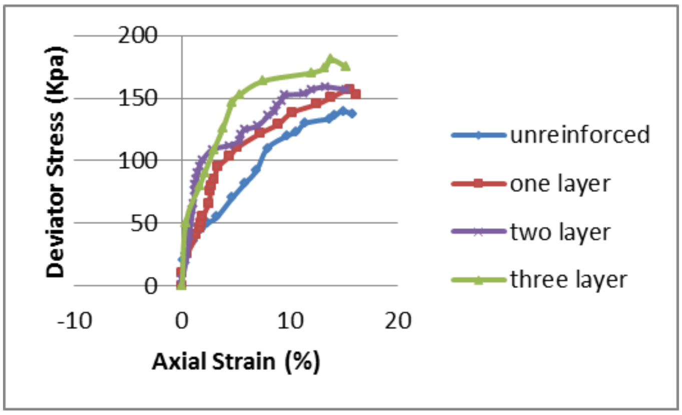

Fig. 8. Stress strain plot of geotextile reinforced clay specimens with different reinforcement layers compared with unreinforced specimen at confining pressure of 50 KPa.

Different stress-strain plots on unreinforced and reinforced Kaolinite at different confining pressures and different layers of geotextile which includes one layer, two layers and three layers or different reinforcement spacing is plotted as in Fig. 8 for 50Kpa, Fig. 9 for 100KPa and Fig. 10 for 150KPa.

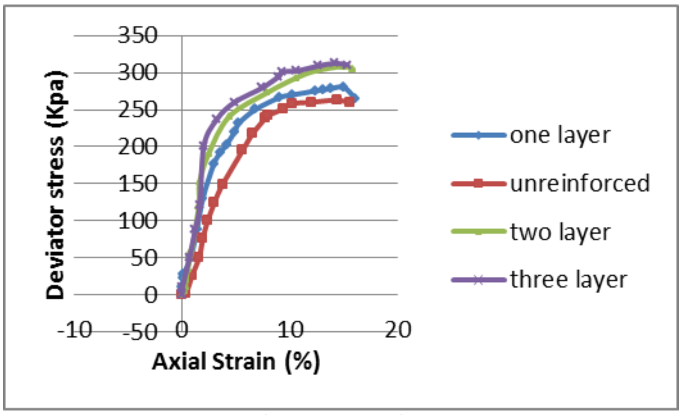

Fig. 9. Stress strain plot of geotextile reinforced clay specimens with different reinforcement layers compared with unreinforced specimen at confining pressure of 100 KPa.

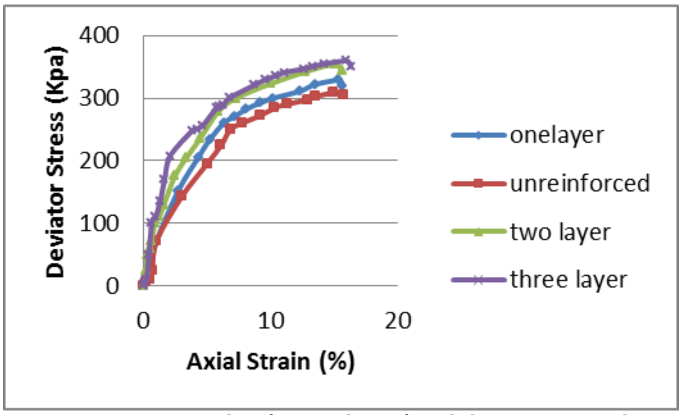

Fig. 10. Stress strain plot of geotextile reinforced clay specimens with different reinforcement layers compared with unreinforced specimen at confining pressure of 150 KPa.

From all the three graphs, it can be analyzed that for a particular confining pressure, the reinforced specimen is found to attain more strength than the unreinforced specimen. Also as the number of geotextile layers is increased, or as the reinforcement spacing is decreased, strength is found to be increasing. This shows the suitability of coir geotextiles as reinforcement for earth structures.

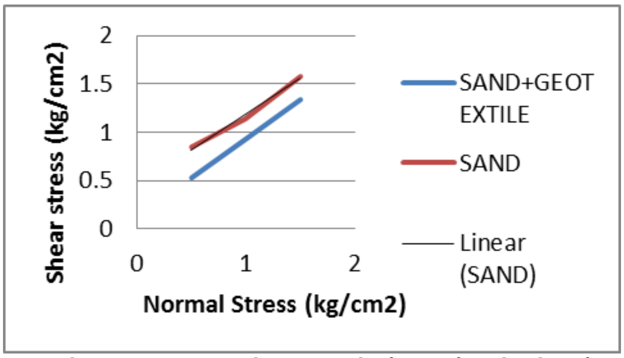

Fig. 11 Shear stress Vs Normal Stress graph of unreinforced and reinforced sand

From Fig. 11, direct shear tests were done with sand alone and the 'φ' value obtained is 36°. Then direct shear tests were conducting after keeping a layer of geotextile in the middle layer and the value of 'φ' obtained is 39.9°. After comparing the values, it was found that there has been a considerable increase in angle of friction values which implies strength improvement. Thus the sand acts well with the geotextile and they are less likely to be rearranged during shearing. But in case of clay, the cohesion value is obtained as 20KPa and 'φ' value obtained is 16° for unreinforced soil and for reinforced soil, and cohesion value for reinforced is 28KPa and 'φ' value is 18°. Thus the better utilization of reinforcement can be made when reinforced with sand when compared to Kaolinite.

Fig. 12 shows the failure envelopes (p-q plot) of unreinforced and reinforced clay specimens in the principal stress space. The maximum stress achieved before failure is defined as failure deviator stress. As the reinforcement spacing is reduced (as number of geotextile layer is increased), failure envelope is found to be shifted upwards. The failure envelopes are found to be parallel to each other.

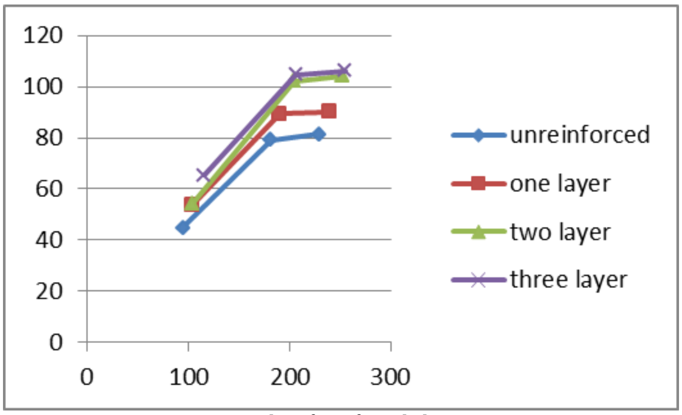

Fig. 12. P-q plot of reinforced clay specimens

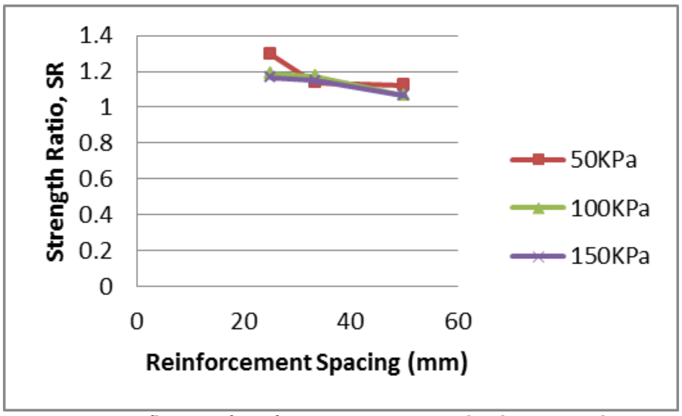

Fig. 13. Influence of reinforcement spacing on the shear strength improvement for reinforced clay specimens – Strength ratio Vs Reinforcement spacing

From the strength comparison using the parameters strength ratio and strength difference, as in fig.12 and fig. 13, it can be seen that as reinforcement spacing increased or number of geotextiles decreased SR and SD is found to be decreasing which shows better strength characteristics as the number of geotextile layers are increased.

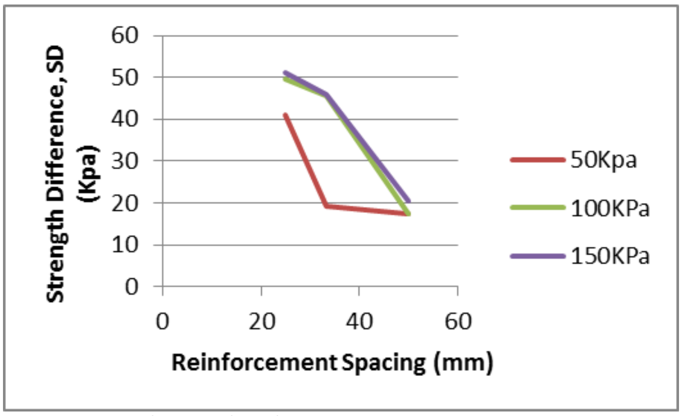

Fig. 14. Influence of reinforcement spacing on the shear strength improvement for reinforced clay specimens – Strength difference Vs Reinforcement spacing

The angle of friction and cohesion values obtained from plotting the p and q values, which are the modified failure envelope are tabulated below:

	C	φ
Unreinforced	20.89	16.72
One layer	22.529	16.61
Two layer	28.66	20.45
Three layer	33.837	19.90

Table 4. Cohesion and angle of friction values of different number of layers of geotextile

A sandwich model is created by sandwiching geotextile surrounded by sand with varying thickness in clay layer. The stress strain graph is plotted as in fig. 12 for 50KPa confining pressure with varying thickness of sand layer, which comprises of 5mm, 10mm, 15mm and 20mm thickness. The maximum deviator stress is found to be highest as the thickness increases when compared to unreinforced and singly geotextile reinforced. The stress – strain plots with 5 mm, 10 mm, 15 mm and 20 mm thickness with varying confining pressure is shown in figures below.

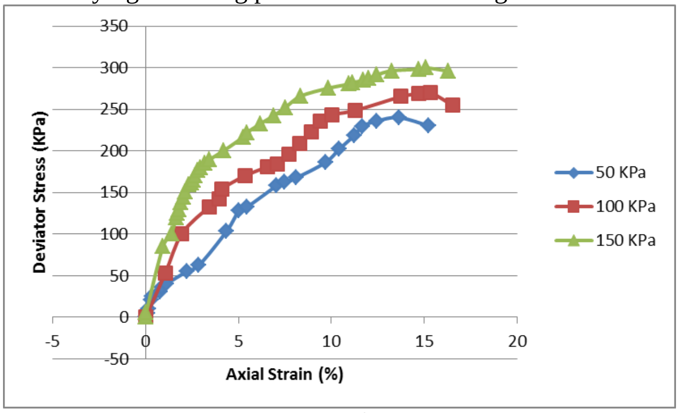

Fig. 15. Stress- Strain plot of sandwich model with 5mm sand layer thickness

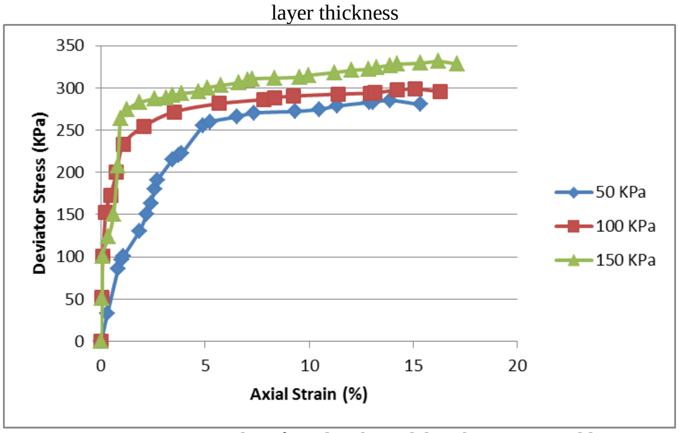

Fig. 16. Stress- Strain plot of sandwich model with 10 mm sand layer thickness

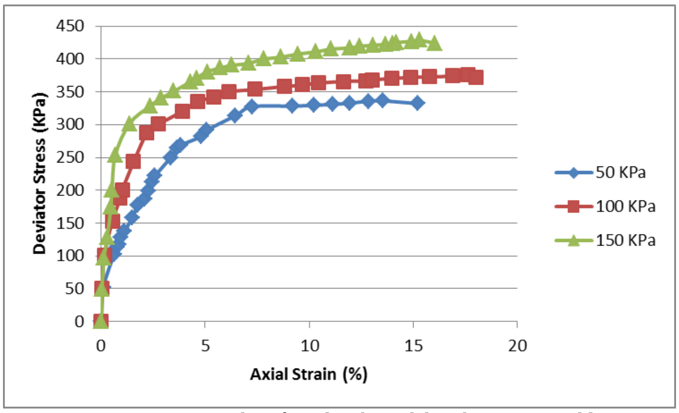

Fig. 17. Stress- Strain plot of sandwich model with 15 mm sand layer thickness

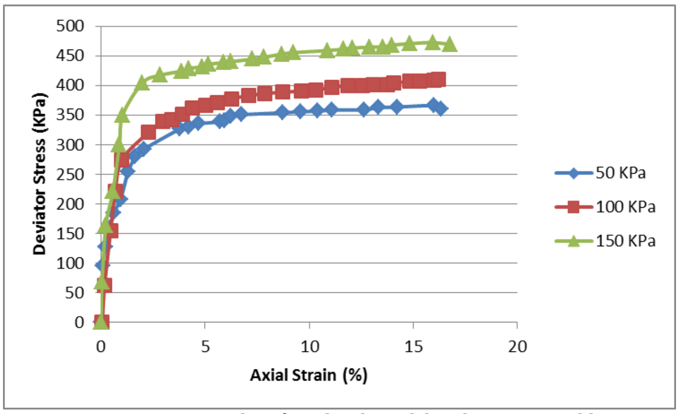

Fig. 18. Stress- Strain plot of sandwich model with 20 mm sand layer thickness

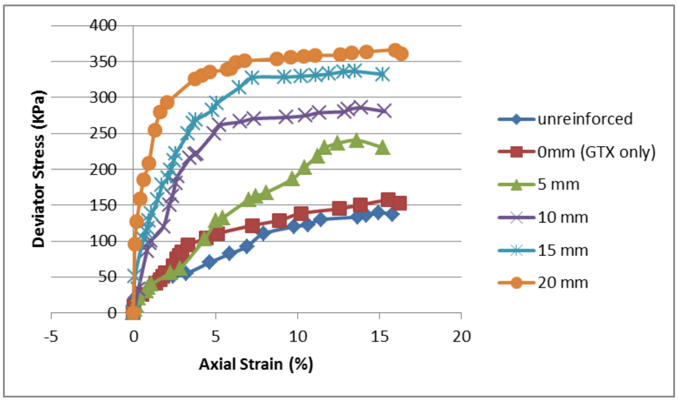

Fig. 19. Stress-Strain graph of reinforced Kaolinite with sand and geotextile at 50 KPa confining pressure

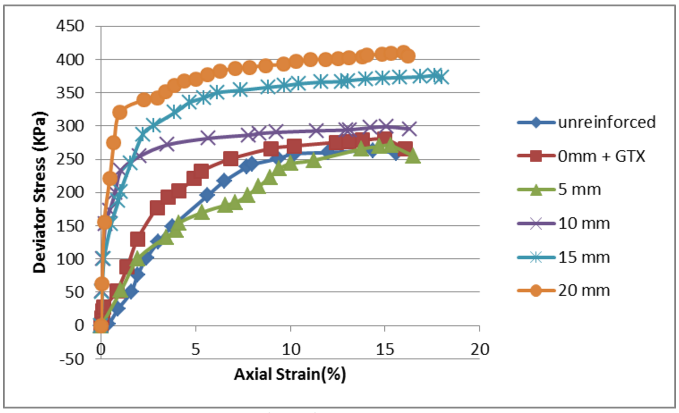

Fig. 20. Stress-Strain graph of reinforced Kaolinite with sand and geotextile at 100 KPa confining pressure

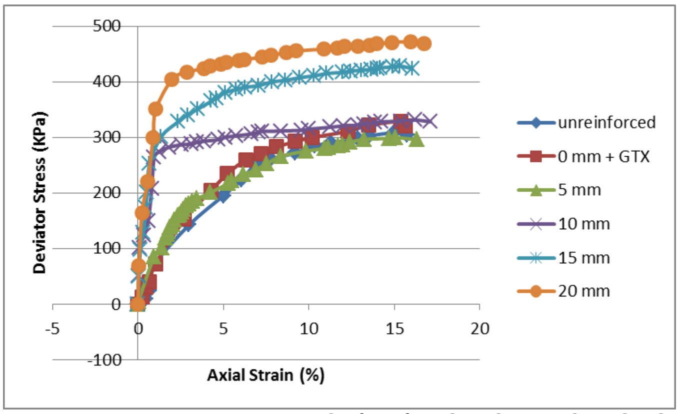

Fig. 21. Stress-Strain graph of reinforced Kaolinite with sand and geotextile at 150 KPa confining pressure

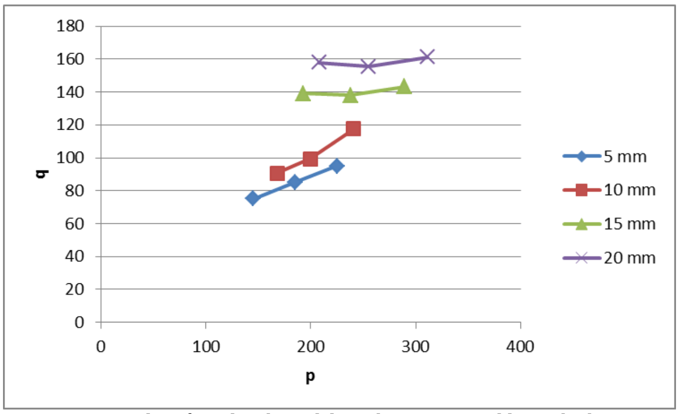

Fig. 22. P-q plot of sandwich models with varying sand layer thickness.

The modified failure envelope is plotted for varying sand layer thickness ranging from 5 -20 mm thickness which shows the top one of 20 mm thickness and the bottom one as of 5 mm thickness which implies the higher strength values for the sand layer with 20 mm thickness..

4. CONCLUSIONS

- In Clay, the value of cohesion and angle of internal friction is found to have a slight increase when it is reinforced with geotextile.
- This behavior is an indication that the clay-geotextile interface resistance is low which results in premature failure of the interface before full strength of the reinforcement is mobilized.
- Due to failure of interface, strength of reinforcement may be largely under- utilized when geotextiles used with cohesive soils.
- When geotextile is used in sand, value of angle of internal friction is found to be increasing, which shows better strength and better utilization of reinforcement.
- Due to the high frictional characteristics of sand, the particles in sand are less likely to be rearranged during shearing.

- When clay-sand-geotextile sandwich model is made, the peak value is found to be increased when compared to clay and clay-geotextile graphical representations.

- The maximum deviator stress is found to be increasing with the variation of confining pressure and as number of geotextiles is increased. As the number of geotextiles is increased and the reinforcement spacing is reduced, the strength is found to be increasing significantly. But as it increases the overall cost of the project, sandwich model is found to provide more strength than the multiple geotextile layer strength.

- When sandwich model is made with varying thickness of sand layer, it was found that as the thickness of sand layer increases, the strength also increases.

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