Comparison of Behaviour of Sand and Clay with Woven and Non- Woven Geotextile – A Numerical Study

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***Abstract*—Soils are strong in compression but weak in tension. This weak property of soil is improved by introducing reinforcing elements in the direction of tensile stress. Geosynthetics are man-made products manufactured from synthetic polymeric materials and sometimes from natural materials. Due to good tensile strength, geotextiles can increase bearing capacity of soil and will reduce excessive settlement. This paper investigates the effect of woven and non-woven geotextiles on sand and clay by numerically modelling in Plaxis 2D. Analysis is conducted for the cases, (i) Drained (ii) Undrained (iii) Partially drained conditions. The characteristics considered in the present analysis are (a) California Bearing Ratio, and (b) Bearing capacity ratio values. The results show that the characteristics of soil increased with the addition of geotextiles.**

Keywords— Plaxis 2D, California Bearing Ratio, Bearing capacity ratio.

I. INTRODUCTION

Generally, soil is a weak structural material in tension. Availability of good soil, for development of civil infrastructure is scarce due to the ever-increasing population. In such cases, it is required to increase the strength properties of these weak soils. To enhance these strength properties, the soil can be stabilized by different methods such as Chemical stabilization and Mechanical stabilization. Chemical stabilization involves the use of chemicals as stabilizing materials. Mechanical stabilization involves the improvement of soil properties by addition of soil reinforcement or non-reactive fibers to the soil. The addition of geosynthetics as soil reinforcement as a mechanical stabilization method has been proven to improve the mechanical properties of soil. So, here we analyze the use of 'Geosynthetics' for soil reinforcement.

Madhu Sudan Negi and S.K Singh (2017) studied the effect of geotextile for subgrade reinforcement using experimental and numerical studies. Two types of geotextiles, woven and non-woven geotextiles were used to reinforce the soil (i.e., sand and clay). The experimental results were analysed numerically using ABACUS software. Woven geotextiles which had higher tensile capacity showed better reinforcement than non-woven geotextiles. Also soils with low CBR (California Bearing Ratio) value showed higher strength (Bearing Capacity Ratio, BCR) than soils with higher CBR value. [1]. Sadok Benmebarek, etal. (2014) evaluated the effect of geosynthetic reinforcement on settlement of the embankment over locally weak zone using Plaxis 2D. The numerical showed that the inclusion of geosynthetic reinforcement decreased the settlement at the embankment base, at both ends of construction and at the end of consolidation stages. Also, the intensity of displacement in the locally weak zone for unreinforced embankment was very significant compared to reinforced embankment. [2]. Salahudeen, A.B and Sadeeq, J.A (2016) investigated the use of geosynthetics for ground improvement based on numerical analysis using Plaxis 2D software. Here the geosynthetic used for reinforcement was geogrid. The total displacement in unreinforced slope was reduced when reinforced with geogrids. It showed that the use of geogrid is very useful in reducing settlement of embankment of slopes. The use of geogrid layers for reinforcement at suitable locations within the slope increased the load carrying capacity of footings. [3]. Binanda Khungur Narzary, etal. (2018) estimated and characterized CBR soil sample using regression and finite element model. Plaxis 2D software was used to calculate CBR and load required for 12.5 mm penetration numerically using finite element technique. The CBR model incorporated Mohr-Coulomb model which converts nonlinear behavior of soil into bilinear characteristics. The validation of the model suggested the use of estimated elastic modulus in numerical studies of CBR tests. [5].

Geosynthetic-reinforced soil technique has been widely used in civil engineering practice over the last few decades. It has proven to offer reliable and cost-effective solution to many soft and unstable ground problems. Nowadays, geosynthetics has been recognized as effective means of soil reinforcement. They are having good tensile and compressive strength. Geosynthetic materials are suitable for performing various functions such as reinforcement, separation, filtration and lateral drainage. Most common types of geosynthetics include geotextiles, geomembranes, geogrids, geocomposites, geofoams, geocells and geotubes. This project mainly focuses on the use of geotextiles (Woven and Non-woven geotextiles) for reinforcing two different types of soils, i.e., sand and clay. Here we are numerically analyzing geosynthetic reinforced soil samples by using PLAXIS 2D software. Strength

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improvement in the soil samples by varying the number and spacing of geotextiles is also analyzed.

II. MATERIALS

A. Sand

Sandy soils are characterized by less than 18% clay and more than 68% sand in the first 100 cm of the solum. Sandy soils are often considered as soils with physical properties easy to define weak structure or no structure, poor water retention properties, high permeability, high sensitivity to compaction with many adverse consequences.

B. Clay

Clay is the densest and heaviest type of soil which does not drain well. The particles in these soils are tightly packed together with each other with very little or no airspace. Generally, clayey soils have low strength, high compressibility, high plasticity, and high volumetric changes.

C. Geotextiles

Among the different geosynthetic products, geotextiles are the ones that present the widest range of properties. Geotextiles are permeable, polymeric textile products in the form of flexible sheets. Geotextiles are manufactured from polymer fibers or filaments that are later formed to develop the final product. The most common types of fibers or filaments used in the manufacture of geotextiles are monofilament, multifilament, staple filament, and slit film. If fibers are twisted or spun together, they are known as a yarn. Woven geotextiles and non-woven geotextiles are used in this study. Woven geotextiles are made from yarns by conventional weaving process with regular textile structure and have visible distinct construction pattern having high tensile strength. Non-woven geotextiles are made from directionally or randomly oriented fibers into a loose web by bonding with partial melting, needle punching or chemical binding agents and have a random pattern and have low tensile strength.

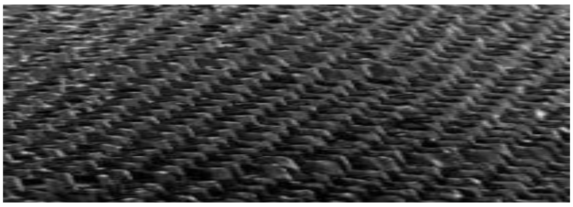


Fig.1. Woven geotextile

Fig. 2. Non-woven geotextile

III. CBR TEST USING PLAXIS 2D SOFTWARE

The California Bearing Ratio (CBR) test is performed in construction materials, to evaluate the strength of soil sub grades and base course materials in design of flexible pavement. This test helps to characterize the subgrade soil in terms of CBR value, which relates the strength parameter of soil. In this study, the CBR test is numerically analysed in PLAXIS 2D software by developing a finite element model. Test sample is modelled according to the CBR test. Here, sand and clay is used as samples; different cases of each sample with and without geotextile (woven and non-woven) are considered. Drained, undrained and partially drained conditions of the soil are also considered. The CBR model obtained from the analysis produce a load-penetration curve. The load required for 12.5 mm depth of penetration and CBR value of the modelled soil is calculated from this load-penetration curve.

A. Case 1: Model without mould and annular disk

Geometry model consists of soil sample which is modelled by a 6 nodded triangular element. Characteristics of soil were modelled by Mohr coulomb model with undrained condition and the required parameters are inserted. Each soil sample (sand & clay) are considered with different cases. The input procedures enable a quick generation of finite mesh. A prescribed load is applied on the model and undergoes some calculations to generate a deformed mesh and load displacement curve. The properties of the geotextiles and soil samples which are used in this case are given in Table I and Table II respectively.

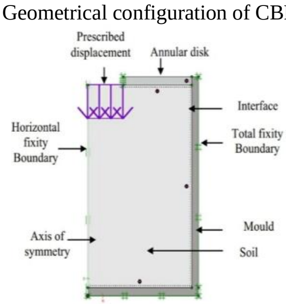
TABLE I. PROPERTIES OF GEOTEXTILE

Properties	Woven Geotextile	Non Woven Geotextile
Material Type	Elastic	Elastic
Weight (g)	400	150
Poisson's Ratio	0	0.35
Modulus of Elasticity E(MPa)	80	20
Tensile Strength (kN/m)	30	13

TABLE II. PROPERTIES OF SOIL

Properties	Clay	Sand
Material Model	Mohr-Coulomb	Mohr-Coulomb
Material Type	Undrained	Undrained
Unit Weight (unsat)	16.6 kN/m^3	18 kN/m^3
Unit Weight (sat)	17.31 kN/m^3	23 kN/m^3
Permeability K_x	1.15x10^{-8}m/s	1.15x10-8m/s
Permeability K_y	3.31 X 10-^{10}m/s	2.8 x 10^{-5}m/s
Elastic Modulus E_{ref}	2000 kN/m^2	30000 kN/m^2
Poisson's Ratio (nu)	0.23	0.333
Cohesion c_{ref}	0.54 kg/cm^2	0.01 kg/cm^2
Angle of Internal Friction (phi)	1°	33°
Dilatancy Angle (psi)	0°	3°

Fig. 3. Geometrical configuration of CBR model



B. Case 2: Model with mould and annular disk

Numerical analysis of CBR test is conducted with mould and annular disk. Here the interface is provided between (i) annular disk & soil (ii) mould & soil (iii) annular disk and mould. Vertical fixities are provided and deformation of mould and annular disk were restricted by total fixity boundary conditions. For allowing vertical deformations, axis of symmetry is associated with horizontal fixity.

Geotextile is provided at varying heights and number of layers. Dimensions of mould and annular disk were as per Indian Standards IS: 2720 (Part XVI) - 1987.Mohr-Coulomb model was used to model the characteristics of soil with drained, undrained and partially drained conditions. Load required for 12.5 mm deformation is observed at the end. Properties of soil and geotextiles are given in Table III.

TABLE III. PROPERTIES OF MOULD AND ANNULAR DISK [4]

Properties	Mould	Annular Disk
Material Model	Linear Elastic	Linear Elastic
Material Type	Non-Porous	Non-Porous
Unit Weight (unsat)	840 kN/m^3	650 kN/m^3
Elastic Modulus E_{ref}	110x10 ^{6}kN/m^2	200x10 ^{6}kN/m^2
Poisson's Ratio (nu)	0.35	0.3

The numerical modelling of CBR test is conducted for the samples at drained and undrained conditions with the different layers of geotextiles and spacings: CBR model with soil, CBR model with geotextile reinforced soil at centre, CBR model with geotextile reinforced soil at 1/3rd distance from bottom, CBR model with geotextile reinforced soil at 2/3rd distance from bottom, CBR model with 2 geotextile reinforced soil at centre and 1/3rd from bottom, CBR model with 2 geotextile reinforced soil at centre and 2/3rd from bottom, CBR model with 2 geotextile reinforced soil at 1/3rd and 2/3rd distance from bottom ,CBR model with 3 geotextile reinforce soil at centre, 1/3rd and 2/3rd distance from bottom.

IV. RESULT AND DISCUSSIONS

A. Case 1:Model without mould and annular disk

Each soil sample (sand and clay) is modelled by considering different cases. These cases are considered for woven as well as non-woven geotextile reinforcements. And corresponding to these cases we got 4 different graphs as shown in Figure 4, Figure 5, Figure 6 & Figure 7

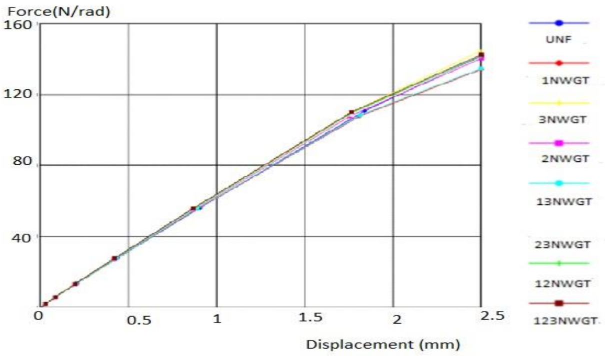


Fig. 4. Clay with non-woven geotextile

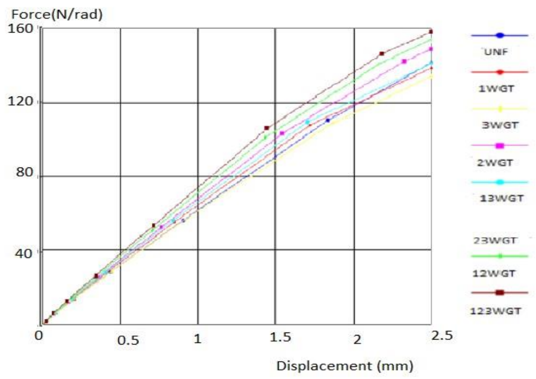


Fig. 5. Clay with woven geotextile

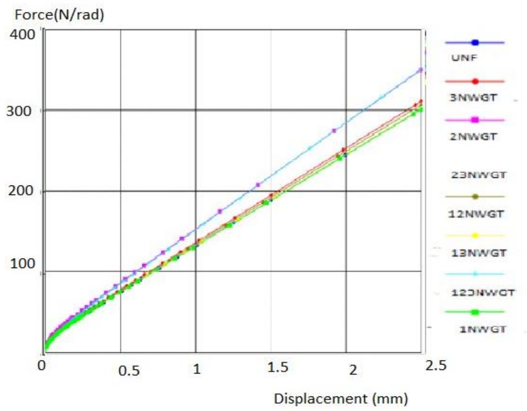


Fig. 6. Sand with non-woven geotextile

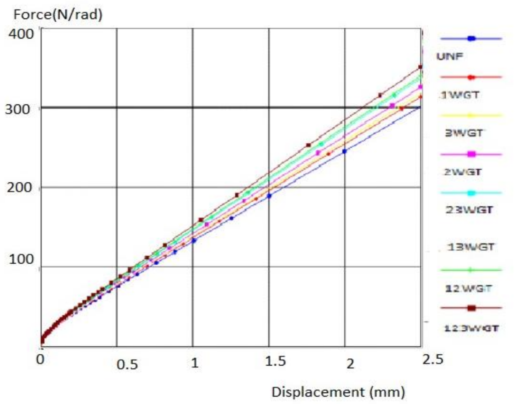


Fig. 7. Sand with woven geotextile

From the above graphs, it was found that good CBR values are obtained for the following cases:

i. CBR model with non-woven geotextile reinforced clay at 1/3rd
ii. CBR model with 3 non-woven geotextile reinforced clay at 1/3rd, 2/3rd & centre
iii. CBR model with non-woven geotextile reinforced sand at 2/3rd as well as CBR model with 3 non-woven geotextile reinforced sand at 1/3rd, 2/3rd & centre
iv. CBR model with 3 woven geotextile reinforced sand at 1/3rd, 2/3rd & centre.

B. Case 2:Model with mould and annular disk

From the graphs, the load corresponding to 2.5mm and 5mm penetration is obtained. And corresponding to that load CBR values was found out using the formula.

$$\text{CBR value of soil at 2.5mm} = \frac{P_T}{P_S} \times 100 \qquad (1)$$

Where Pt= load applied at 2.5mm penetration and Ps= Standard load (kg).

And corresponding BCR values are found by using the formula.

$$\text{BCR value} = \frac{CBR_{unreinforced}}{CBR_{reinforced}} \qquad (2)$$

Notations used in this study for various combinations for placement of geotextile in CBR mould are given in Table IV.

TABLE IV. NOTATIONS FOR DIFFERENT COMBINATIONS FOR PLACEMENT OF GEOTEXTILE

Sl. No	Placement of geotextile at height	Woven Geotextile(wgt)	Non-woven geotextile (nwgt)
1	Unreinforced	unf	
2	Reinforcement at the center	1wgt	1nwgt
3	Reinforcement at 1/3 rd from top	2wgt	2nwgt
4	Reinforcement at 2/3 rd from top	3wgt	3nwgt
5	Reinforcement at 1/3 rd from top and at centre(double layer)	12wgt	12nwgt
6	Reinforcement at 2/3 rd from top and at centre(double layer)	13wgt	13nwgt
7	Reinforcement at 1/3 rd and at 2/3rd from top (double layer)	23wgt	23nwgt
8	Reinforcement at 1/3 rd , 2/3 rd from top and at centre(triple layer)	123wgt	123nwgt

The results of CBR tests on soils are given in Table V, VI and VII. To analyse the effectiveness of geotextile in increasing the strength, the BCR is calculated for all the cases (Table V) and is compared.

TABLE V. CBR RESULTS OF SOILS AT UNDRAINED CONDITIONS.

Sl. No	Placement of geotextile	Sand		Clay	
		CBR	BCR	CBR	BCR
1	unf	60.43		48.80	
2	1wgt	59.49	0.98	49.04	1.00
3	2wgt	59.82	0.99	49.02	1.00
4	3wgt	60.51	1.00	49.08	1.01
5	12wgt	59.54	0.99	49.04	1.00
6	13wgt	60.62	1.00	49.08	1.01
7	23wgt	60.57	1.00	49.08	1.01
8	123wgt	60.67	1.00	49.08	1.01
9	1nwgt	59.44	0.98	48.91	1.00
10	2nwgt	59.80	0.99	48.91	1.00
11	3nwgt	60.39	1.00	48.97	1.00
12	12nwgt	59.46	0.98	48.91	1.00
13	13nwgt	60.42	1.00	48.97	1.00
14	23nwgt	60.42	1.00	48.97	1.00
15	123nwgt	60.48	1.00	48.97	1.00

TABLE VI. CBR RESULTS OF SOILS AT PARTIALLY DRAINED CONDITIONS.

Sl. No	Placement of geotextile	Sand		Clay	
		CBR	BCR	CBR	BCR
1	unf	60.44		49.02	
2	1wgt	83.56	1.38	55.31	1.13
3	2wgt	81.07	1.34	55.02	1.12
4	3wgt	78.96	1.31	55.03	1.12
5	12wgt	80.97	1.34	55.33	1.13
6	13wgt	80.97	1.34	55.32	1.13
7	23wgt	79.01	1.31	55.09	1.12
8	123wgt	79.01	1.31	55.09	1.12
9	1nwgt	80.94	1.34	56.13	1.14
10	2nwgt	81.06	1.34	55.78	1.14
11	3nwgt	78.89	1.31	55.00	1.12
12	12nwgt	80.95	1.34	56.14	1.15
13	13nwgt	80.95	1.34	56.14	1.15
14	23nwgt	78.93	1.31	55.04	1.12
15	123nwgt	78.93	1.31	55.04	1.12

TABLE VII. CBR RESULTS OF SOILS AT DRAINED CONDITIONS.

Sl. No	Placement of geotextile	Sand		Clay	
		CBR	BCR	CBR	BCR
1	unf	78.13		54.18	
2	1wgt	80.95	1.04	56.12	1.04
3	2wgt	81.01	1.04	55.74	1.03
4	3wgt	79.06	1.01	55.01	1.02
5	12wgt	80.94	1.04	56.14	1.04
6	13wgt	78.98	1.01	55.08	1.02
7	23wgt	78.93	1.01	55.03	1.02
8	123wgt	78.97	1.01	55.07	1.02
9	1nwgt	80.93	1.04	56.13	1.04
10	2nwgt	81.01	1.04	55.75	1.03
11	3nwgt	78.86	1.01	54.98	1.01
12	12nwgt	80.92	1.04	56.11	1.04
13	13nwgt	78.86	1.01	55.04	1.02
14	23nwgt	78.88	1.01	54.99	1.02
15	123nwgt	78.88	1.01	55.02	1.02

In undrained condition, the CBR value of 2.5mm was found larger value, hence the test results are fine and no further correction is required. In the case of clay, the reinforced soil samples have higher CBR value compared to the unreinforced soil samples. The woven and non- woven geotextiles are placed at different locations within the soil samples, and it was found that maximum CBR value was obtained for woven geotextile, when it is placed as three layers. In the case of sand, a similar trend was obtained as maximum CBR value was obtained when woven geotextile is placed in 3 layers. Considering the pore water pressure and partially drained condition, higher CBR value is obtained for 2.5mm displacement. From the above table, in both cases of clay higher CBR value is obtained when 2 layer of geotextile is placed at centre and 1/3rd and drained up to 1/3rd height of CBR model. In case of sand, the highest CBR value is obtained for sand with woven geotextile placed at centre and drained up to 1/2 of CBR model whereas using non- woven geotextile, it is observed that when the CBR model is drained up to 1/3rd of the height and non- woven geotextile is placed at 1/3rd of height gives good CBR value. Considering the CBR model at fully drained condition and also the pore water pressure, the highest CBR value is obtained for 2.5mm displacement. In both cases of sand, it is observed that when 1 layer of geotextile is placed at 1/3rd gives highest CBR value. In the case of clay with woven geotextile it is observed that when 2 layer of woven geotextile is placed at centre and 1/3rd gives highest CBR value whereas for clay with non- woven geotextile, the highest value is obtained when non- woven geotextile placed at centre.

V. CONCLUSION

In this study, CBR test is numerically modelled using Plaxis 2D software. Analysis was conducted on sand and clay at drained, undrained and partially drained conditions with geotextiles at different layers and spacing. CBR model generated from the analysis provided CBR value of the soil and a satisfactory prediction of load required against the penetration of 12.5 mm depth of the sample. In undrained conditions, the maximum CBR value obtained was when woven geotextile used as 3 layers. The BCR value obtained for clay as 1.005 and for sand as 1.0039 shows that there is sufficient improvement in the strength characteristics with the usage of geotextiles. When effect of water table and pore-pressure was considered, the variations in the strength characteristics goes on changing but the CBR values were increased. Geotextile reinforcement is an effective method to improve the CBR of soils. Geotextiles could be effective in reducing settlement of soil and it can complement low strength soils.

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