

An Experimental Study on The Effect of Geopolymeric Composite Reinforcement on Soil Subgrade for Flexible Pavements

Gnana Prasanna G^{1,*}, Mahesh V², Dinesh Kumar Reddy N³, Srikanth T⁴, Tharun Kumar Maddileti⁵

Abstract

The use of geo-synthetics, such as geotextiles, has the potential to enhance the inherent engineering and geotechnical properties of subgrade soils that exhibit poor conditions. The use of geotextiles in pavement construction has many advantages, including enhanced subgrade strength and the ability to construct flexible pavements that are both efficient and cost-effective since it reduces the pavement thickness. In the realm of flexible pavement system development, the significance of subgrade soils and their inherent characteristics, including permeability and strength, is well acknowledged. The study included conducting experiments to investigate the use of geo-polymeric materials like geo-textiles on improving the mechanical properties of the subgrade soils under varying moisture conditions. Geotextiles possess good tensile resistance as it is made up of good polymeric material like polyester, polypropylene and polyethylene. Geotechnical tests including grain size analysis, Atterberg limits, California bearing ratio test, and compaction tests, were conducted. CBR tests and UCS tests were conducted by placing the geotextiles in a singular arrangement at various depths and subjecting them to both soaked and unsoaked conditions to assess the soil's strength. The results demonstrate that the use of geosynthetic reinforcement in the soil effectively enhances the strength of the subgrade across various soil types. The optimal performance of geo-synthetics in relation to their placement inside the CBR mold was found to be at a distance of 1/3 of the mold's height from the top. This placement outperformed the alternative distances of 1/2 and 2/3 of the mold's height.

Keywords: Geopolymers, CBR value, UCC, mechanical properties, flexible pavements, polymer composites

INTRODUCTION

The soil reinforcing technique is a frequently used methodology in efforts to improve the condition of degraded soil. Various reinforcing materials, including metal strips, synthetic geotextiles, geogrid sheets, geosynthetic membranes, natural geotextiles, and randomly scattered synthetic and natural fibers, are being used to enhance the stability and resilience of soil. Furthermore, the act of reinforcing the soil leads to a significant enhancement in various properties such as tensile strength, shear strength, and other relevant characteristics. Additionally, it also contributes to an improvement in the bearing capacity and overall cost-effectiveness. The presented approach offers a viable means of enhancing the subgrade, exhibiting significant potential as a cost-efficient and effective solution for a diverse range of geotechnical challenges.

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Desirable characteristics of sub-grade materials include high compressive and shear strength, resistance to weather and loading conditions, permanent and easy compaction, efficient drainage, and low susceptibility to volume fluctuations and frost action. Research has shown the beneficial use of geosynthetic materials for reinforcing subgrade soils in road construction, leading to enhanced functioning of both paved and unpaved highways. The strength of the geosynthetic materials depend on the type of polymer used to manufacture it. Various polymers used to prepare geosynthetics are polypropylene (PP), polyester, and high-density polythene (HDPE). Researchers used rubber-based polymeric materials, natural or glass fiber-based polymeric materials which are derived from waste materials to enhance the performance of flexible pavements sustainably [1, 2].

Reinforced soils are often conceptualized as composite materials, whereby the reinforcement is anticipated to endure tensile stresses and engage with the soil via frictional interactions. Geosynthetic materials may use four distinct techniques to enhance the performance of subgrade soils. The measures used include the prevention of localized shearing of the subgrade, enhancement of load distribution throughout the base course, reduction or reorientation of shear forces on the subgrade, and the utilization of the tensioned membrane effect. Geosynthetics, when positioned either between the subgrade and base course or inside the base course, serve the purpose of reinforcing and improving the performance of paved roads.

In this area of study, various researchers have made a remarkable contribution by their numerous and important works. Neves et al [3]. used numerical analysis to elucidate the implications of using geosynthetics for subgrade reinforcement in road pavement design. Perkins and Ismeik [4]. made an effort to improve the characteristics of pavement thickness by integrating geo-synthetics into flexible pavements. The study findings were released in the year 1997. Perkins [5]. primarily focused on laboratory-based investigations conducted on pavement test sections using aggregate base layers and a geosynthetic reinforcing layer, as documented in published literature. The experiments were carried out on pavement test sections. The primary emphasis of Nithin et al [6]. was directed at evaluating the performance of the inter layer system.

The objective of this research was to examine the basic engineering and geotechnical characteristics of substandard subgrade soils and explore the potential use of geo-synthetic materials, such as geotextiles, to augment the soil's mechanical properties. Within the realm of civil engineering, this has considerable importance. The Indian Highways system mostly consists of flexible pavement, which may be constructed using several methods. The California Bearing Ratio (CBR) test is a widely used empirical method for the construction of flexible pavements. Surface load testing is a kind of assessment conducted on soil surfaces, primarily used in soil investigations to aid in the construction of pavements. The design of a novel structure should be predicated upon the strength analysis of samples that have been prepared at the Optimum Moisture Content (OMC), as determined by the Proctor Compaction test, and thereafter subjected to a three-day immersion in water prior to conducting any tests. It is important to do this task prior to the finalization of the design.

The study included conducting experiments to investigate the use of geosynthetics on subgrade soils under varying moisture conditions. Various geotechnical tests were conducted, including grain size analysis, consistency limits, California Bearing Ratio test, and compaction testing. The soil was subjected to CBR (California Bearing Ratio) testing by implementing a geotextile membrane with different thicknesses of CBR mold in a singular arrangement. The experiments were conducted under two conditions: one with the immersion of the soil specimen in the water and the other without. This approach aimed to get precise measurements of the soil's strength. The findings of this study suggest that the inclusion of a geotextile membrane reinforcement in the soil results in a significant enhancement of the inherent strength of the subgrade. The use of this technology necessitates reduced maintenance efforts, exhibits resistance to corrosion, extends the lifespan of road pavement, and concurrently diminishes the required thickness of the pavement.

MATERIALS AND METHODOLOGY

Materials

The poor subgrade soil and the geopolymeric material are the main materials required for the study.

Soil

Soil samples that are used for experimentation was collected from Kottala village, Chandragiri Mandal,

Chittoor Dist. Laboratory tests were done on the soil to determine the various properties of soil like Specific gravity, Grain size analysis, Liquid Limit, Plastic Limit, Compaction Properties, and shear parameters. All the tests were conducted as per IS 2720 [7]. The soil properties and classification is given in Table 1.

Table 1. Soil Classification.

S N.	Description	Values
1	Specific gravity	2.31
2	% of Coarse fraction	14
3	% of clay	53
4	% of silt	33
5	Liquid limit (%)	48.15
6	Plastic limit (%)	26.66
7	Plasticity Index (%)	21.49
8	I.S. Soil classification	CI

Geosynthetics

Geosynthetics are one of the polymeric materials which are used to increase the performance of the soil. This petroleum based product exists in the market in many forms such as geotextiles, geonets, geogrids, geomembranes and geocells. In this study, geotextiles are used for enhancing the subgrade deformation.

METHODOLOGY

The performance of the geopolymeric reinforcement on soils is evaluated by conducting tests like California bearing ratio test and Unconfined compressive strength test by varying the position of the reinforcement membrane in the soil sample. Firstly, modified proctor's test is conducted to know the optimum moisture content and the maximum dry density of the virgin soil to prepare soil specimens for conducting test.

Modified proctors test

Heavy compaction test was performed as per IS 2720-8 (1983) [8]. A soil sample of 6 kg was taken and sieved through 19 mm IS sieve. The soil retained on the sieve was discarded and 5 kg of soil passed through the sieve was collected for the testing. The required amount of water is added, mixed thoroughly, divided into 5 equal portions and compacted in 1000 cc mold in five layers by giving 25 no. of blows with 4.89 kg rammer from 45 cm height of fall for each layer. The weight of sample is checked and the process is followed by adding 2 % of water till the weight of the sample reduced. The graph is given below Figure 1.

California bearing ratio (CBR) test

CBR test was conducted on the soil sample as per IS 2720-16 (1987) [9]. A representative soil sample of 6 kg was taken and mixed it thoroughly with OMC and compacted it in a 2250 cc mold using heavy compaction. A placer disc was placed over the mold base and a filter paper was placed below and above the soil sample.

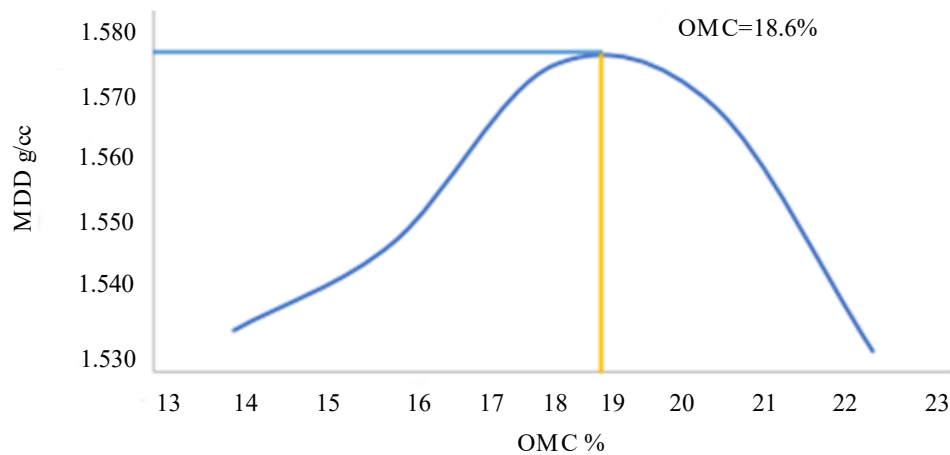


Figure 1. Compaction curve of subgrade soil.

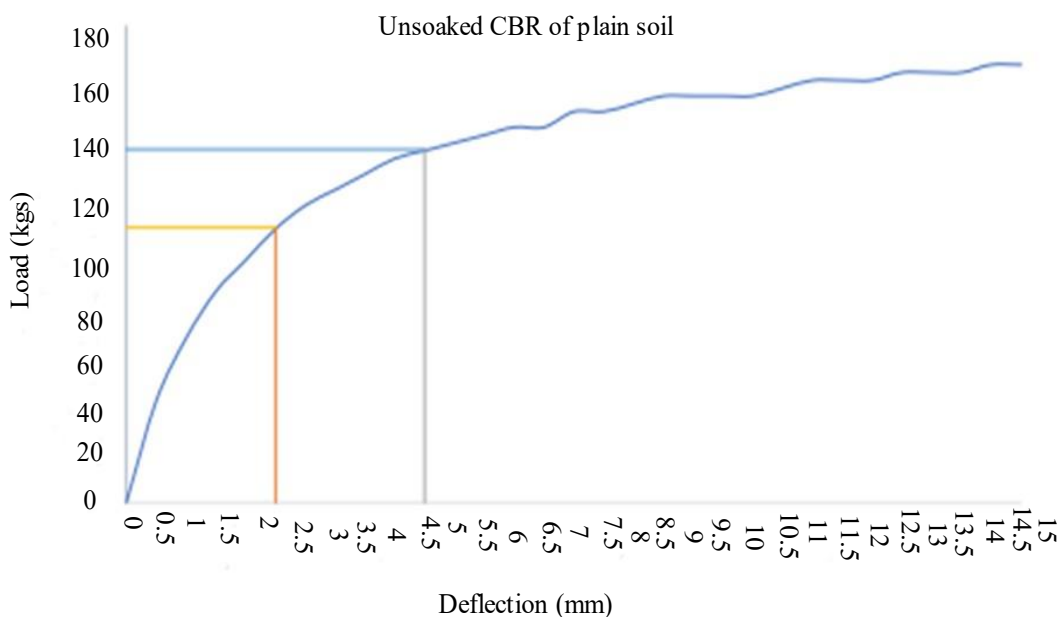
Unsoaked CBR test: The mold with compacted soil sample was reversed, placer disc was removed and the sample was placed under CBR testing machine. Surcharge loads were applied above the sample. The load was applied at the rate of 1.25 mm per minute and the load was recorded at 2.5mm, 5 mm, 7.5mm and 12.5 mm penetrations. The CBR value was calculated as per the formula below.

$$\text{California Bearing Ratio} = (\text{Penetration load } (P_T) / \text{Standard Load } (P_S)) * 100$$

Soaked CBR test: The prepared soil sample along with mold, base plate and surcharge loads was placed under the water for 96 hours and tested the sample similar to the above procedure and the CBR value is determined by drawing graph between load and penetration. Load versus Penetration graphs for unsoaked and soaked conditions of the soil samples are shown in the Figure 2.

Unconfined Compressive Strength

The soil samples are extruded from prepared soil sample of the CBR mold with a cylindrical soil sampler of size 36 mm Dia and 72 mm height after trimming and tested under UCS testing machine according to IS 2720- 10 (1991) [10]. The stress-strain curve of plain soil obtained in the UCS test is shown in Figure 3.



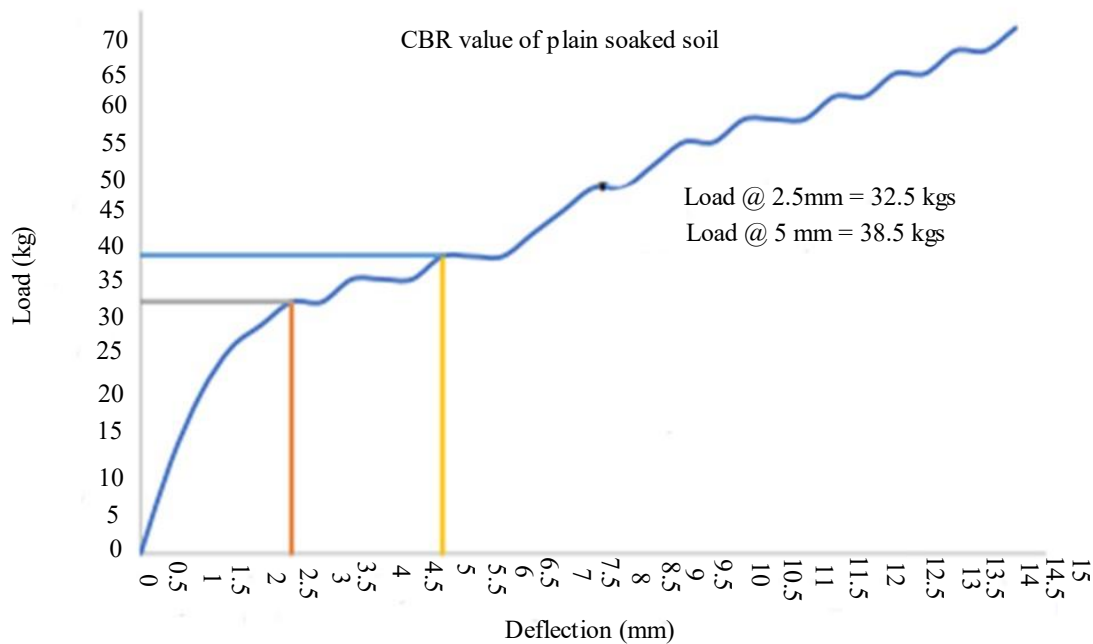


Figure 2. Load Vs penetration graphs for unsoaked and soaked conditions.

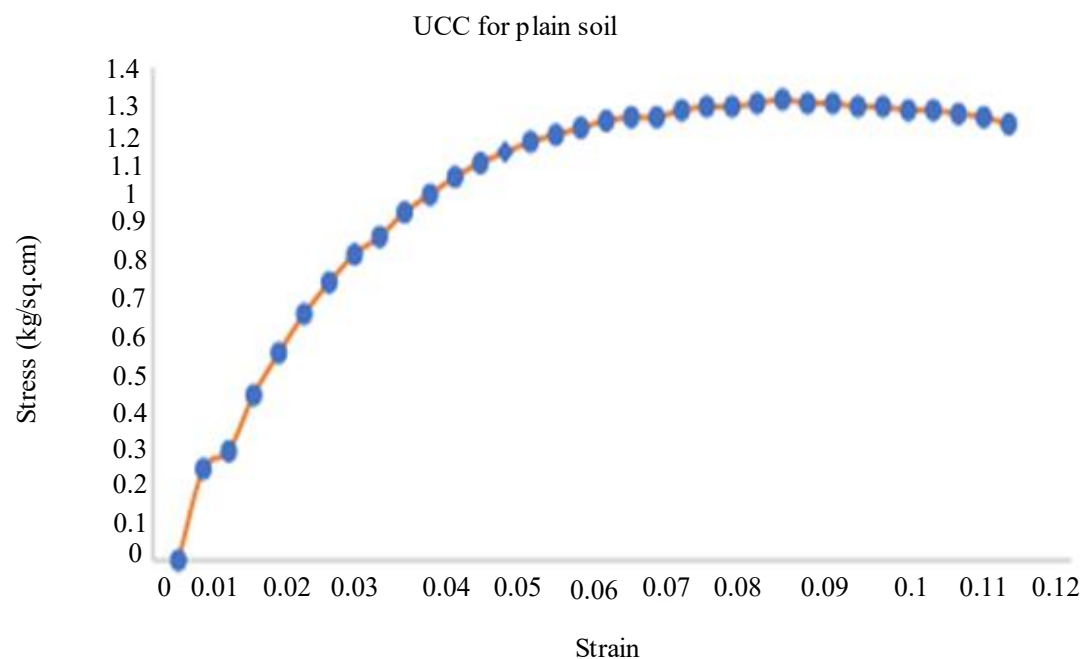


Figure 3. UCS stress-strain graph for plain soil.

The results of the tests are presented in the Table 2.

Table 2. Soil Engineering Properties.

S.N.	Soil properties		Values
1	Compaction Characteristics	OMC (%)	18.6
		MDD(g/cc)	1.574
2	CBR	Unsoaked (%)	7.57
		Soaked (%)	2.37
3	Unconfined Compressive Strength (kg/cm ²)		1.306

Geotextile Positioning

The CBR and UCS soil samples were tested placing the geotextile at $1/3$ rd, $1/2$ and $2/3$ rd of the depth of the sample from the top surface of the sample as shown in Figure 4 to determine the effect of reinforcement.

RESULTS AND DISCUSSIONS

California Bearing Ratio and Unconfined compressive strength tests were performed on the samples by placing a layer of geotextile at $1/3$, $1/2$ and $2/3$ height of the sample from the top of the sample. CBR tests are conducted on the samples on both soaked and unsoaked conditions.

CBR Test at Various Positioning of Geotextile

Unsoaked condition

Unsoaked CBR tests are conducted on the samples prepared by placing a layer of geotextile at $1/3$, $1/2$ and $2/3$ of the depth from the top of the sample. The results are presented as load vs deformation graphs presented in the Figure 5 and the values clearly representing that the geotextile inclusion improves the CBR value and the maximum value occurs at $1/3$ positioning of geotextile. The variation of CBR value for different positioning of geotextile is showed in Figure 6.

Soaked condition

Soaked CBR tests are conducted on the samples prepared by placing a layer of geotextile at $1/3$, $1/2$ and $2/3$ of the depth from the top of the sample. The results are presented as load vs deformation graphs and the values clearly representing that the geotextile inclusion improves the soaked CBR value and the maximum value occurs at $1/3$ positioning of geotextile. The variation of CBR value for different positioning of geotextile is showed in Figure 7.

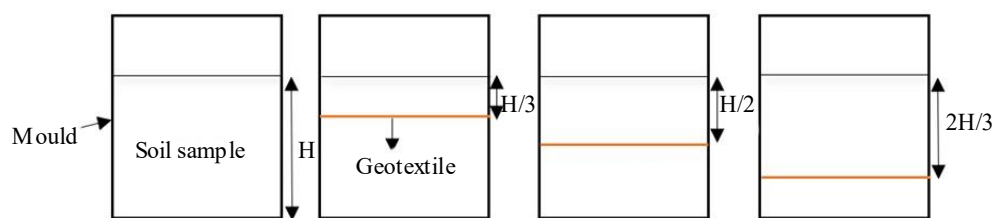


Figure 4. Soil sample with various geotextile position.

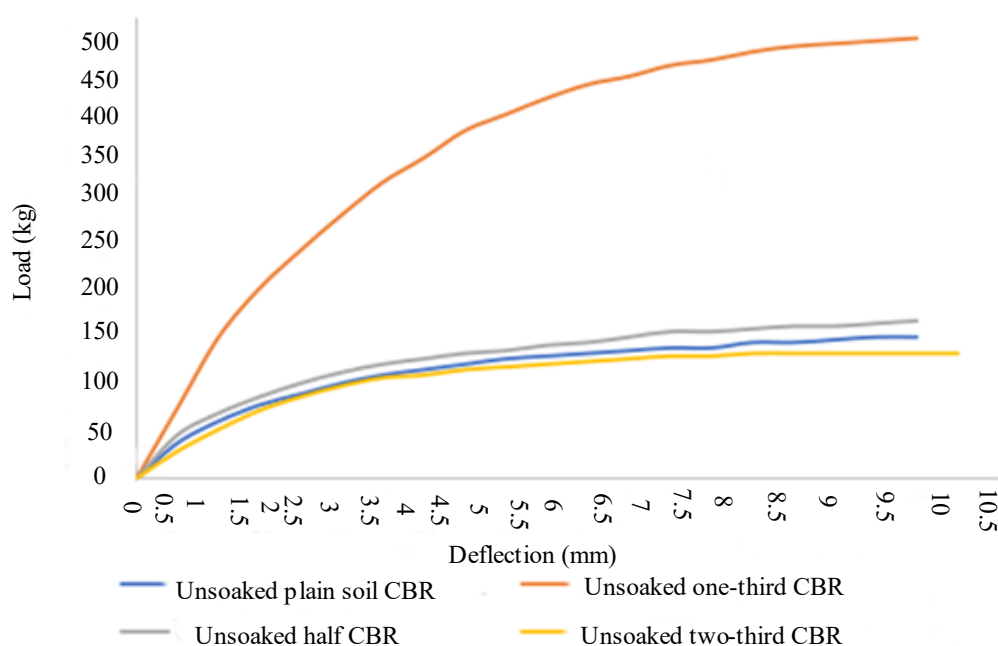


Figure 5. Load vs penetration graph for various positions of geotextile for unsoaked condition.

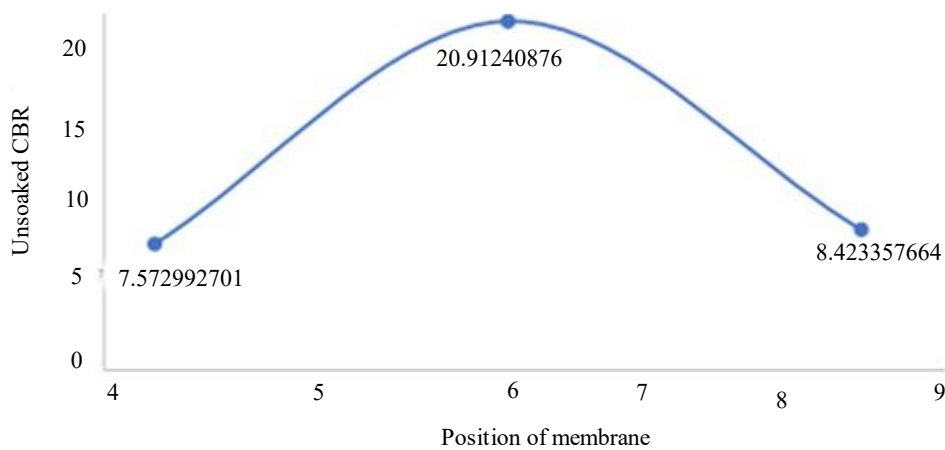


Figure 6. Variation of CBR value for different positioning of geotextile.

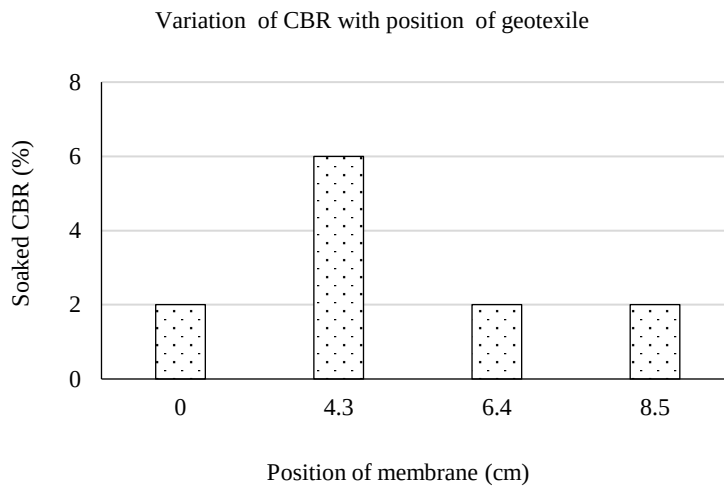


Figure 7. Variation of soaked CBR for various geotextile placement positions.

The increase in the CBR value is attributed to the resistance offered by the geotextile reinforcement to the penetration of the plunger. The resistance is more when the geotextile is placed at near to the surface of the sample and it is reduced with the depth of the geotextile reinforcement. The reinforcement also offered tensile resistance to the soil specimen [11]. The variation of the CBR values with the position of the geotextile is given in the Table 3 for unsoaked and soaked condition.

Table 3. Variation of the CBR values and % increase with the position of the geotextile.

S N.	Depth of geotextile from the top surface sample	CBR (%) (Unsoaked)	% increase of UCBR	CBR (%) (Soaked)	%increase of SCBR
1	Normal soil sample	7.6	--	2.37	--
2	4.3	20.9	175	6.49	173.8
3	6.4	8.4	10.52	2.57	8.43
4	8.5	7.3	-3.94	2.12	-10.54

*UCBR=unsoaked CBR and SCBR=soaked CBR

UCS For Various Positions of Geotextiles

Unconfined compressive strength of the prepared soil samples using geotextile reinforcement with different positioning i.e., 1/3, 1/2 and 2/3 depth from the top of the soil sample were tested and the results are presented as stress-strain graphs. The UCS of the soil samples with geotextile placed at 1/2 of the depth was higher than the remaining positions of the geotextile. The stress-strain curves of all the samples with various geotextile placement is given in Figure 8.

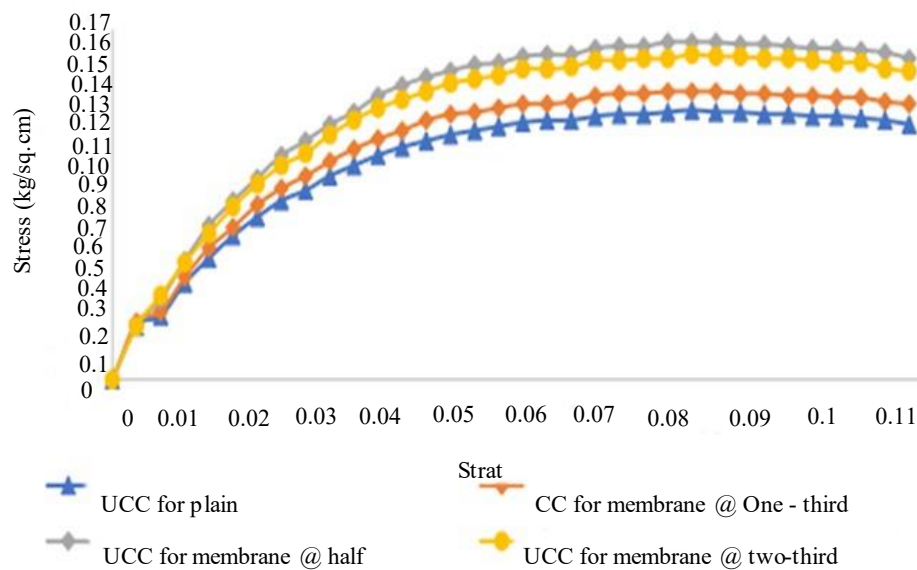


Figure 8. Graph showing stress-strain curves of various geotextile placement.

The failure pattern of the soil sample was changed by the placement of the geotextile. It is also observed by Parihar NS and Shukla RP who performed UCS with geosynthetic reinforcement and found that the maximum strength of the soil specimen is increased and the penetration of the failure plane is obstructed by the reinforcement [12]. The increase of UCS at $\frac{1}{2}$ depth of the geotextile encasement might be attributed to the obstruction of the development of the shear failure in the soil sample. The UCS values at various geotextile positioning and the percentage of increase of UCS with geotextile inclusion are given in Table 4.

Table 4. UCS values at various geotextile positioning and the percentage of increase of UCS.

S.N.	Position of geotextile from top of the sample (cm)	UCS (kg/cm ²)	% increase
1	Normal sample	1.3	--
2	2.4	1.4	7.7
3	3.6	1.64	26.15
4	4.8	1.6	23.0

The Figure 9 shows the variation of UCS of soil samples with the position of Geotextile. The graph clearly shows that the UCS is higher for geotextile placement at 3.6 cm i.e., at $\frac{1}{2}$ depth of the sample.

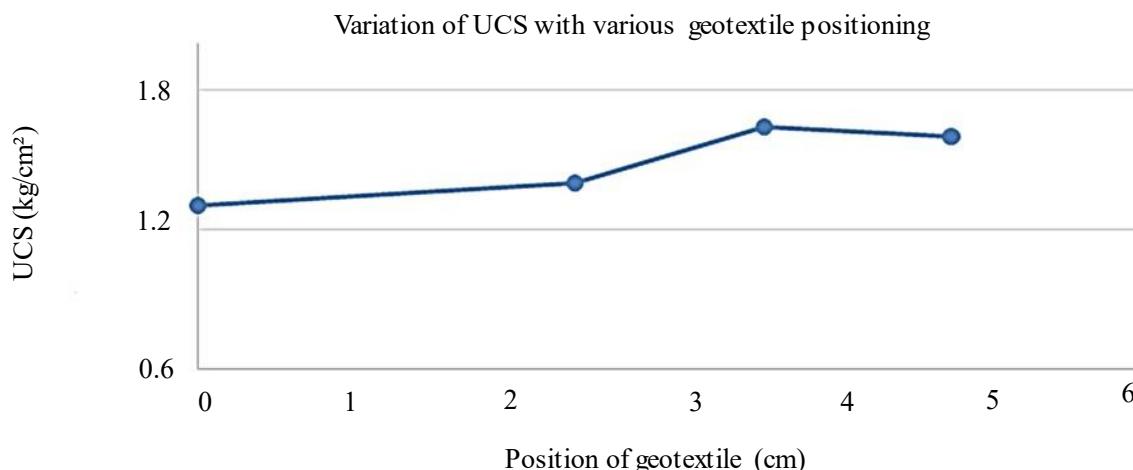


Figure 9. Variation of UCS of soil sample with the position of geotextile.

CONCLUSIONS

An experimental investigation on the effect of geotextile reinforcement was studied through California bearing ratio tests and unconfined compressive tests by placing the geotextile at different positions i.e., $1/3$, $1/2$ and $2/3$ from the top surface of the sample. The following conclusions are drawn from the tests performed on the reinforced and unreinforced soil sample.

1. The geo-polymeric reinforcement improves the CBR characteristics and unconfined compressive strength of the soil.
2. Geotextile placed at $1/3$ depth of the sample had improved the unsoaked CBR and Soaked CBR by 175 and 174 percentage when compared with the normal soil sample.
3. Unconfined compressive strength of the soil sample is increased by 26.15% with the inclusion of geotextile at the depth of half of the sample.

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