Optimization of Tensile Strength of Geosynthetic Reinforcement for CBR Value of Low Plastic Soil

BY

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A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science in Geotechnical Engineering

NUST Institute of Civil Engineering (NICE)
School of Civil and Environmental Engineering (SCEE) National
University of Sciences and Technology (NUST)
H-12 Sector, Islamabad, Pakistan
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DEDICATED

TO

MY BELOVED PARENTS

WHO GAVE ME A LOT OF SUPPORT

AND

ENCOURAGEMENT

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ABSRTACT

The geotextiles are used in the globe for the civil and geotechnical engineering applications. Extensive studies implemented on geotextiles' applications but little effort spent for optimization of geotextiles' tensile strength. Most of the previous researchers used 2 or 3 different tensile strength geotextiles for their respective research. In this study, the effect of inclusion of ten different tensile strength (commonly available in market) of non-woven geotextile for optimization of California bearing ratio (CBR) value of soil was investigated. A comparison was made among the soaked and unsoaked silty-clayey soil through the usage of the needle-punched nonwoven (NW) geotextiles as a reinforcement and optimization had been achieved. The needle-punched NW geotextiles had different tensile strengths (10, 25, 35, 50, 65, 80, 100, 115, 123 and 140 kN/m) corresponding to local unit of (150, 350, 500, 700, 900, 1100, 1300, 1500, 1600 and 1800 GSM) respectively. For the soaked condition of soil, the CBR value was increased from 6.66% to 161.765% and for unsoaked condition, the CBR value of the soil was increased from 5.40% to 153.65% after using geotextiles. The maximum enhancement of the tensile strength for the CBR value was at the value of 115 kN/m or 1500 GSM at both soaked as well as unsoaked conditions and beyond 115 kN/m or 1500 GSM, there wasn't any increase in CBR value.

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Chapter 1

1 Introduction

1.1 Background

The pattern and growth of pavement is very confrontable and Engineers have difficulties due to shaky and brittle soils. The mentioned difficulty is due to the existence of profoundly compressible clayey soils, which makes the pavement existence regularly affected. The Geo-grids and Geo-synthetics are famous as support and reinforcement for improving designing execution. Subsequently the use of alternative construction techniques such as reinforcement allows for an improvement in the pavement life [1] . The types and Applications of Geo-synthetics have incorporated an enormous assortment of items made out of polymers and are intended to take care of numerous issues related to geotechnical and transportation. The Geo-synthetic support is normally positioned in the boundary between the aggregate base course and the subgrade [1] . As generally the geo-synthetics are formulated into Geo-textiles (woven and non-woven), Geo-grids, Geo-net, Geo-membranes and Geo-strips etc. There are numerous utilizations of geo-synthetics has been highlighted in the literature. The primary applications for the improvement of weak soils is reinforcement. The incorporated reinforcement multiplies strength and expands CBR value of soils.

The efficiency or productivity of soil reinforcement relies upon soil-reinforcement association, which could be measured through testing models regarding methods of complex research center[2]. The layer of a geo-synthetic as a support or reinforcement could be utilized viably to build up the unpaved construction on the subgrades of soft soil, bringing about enhanced value of strength for the road. The advantages acquired from the utilization of geo-synthetic layers regarding the unpaved streets or roads, which could be anticipated as for execution, performance and strength as well as for development and economy. As the idea of utilizing geo-synthetic for the reinforcement in paved/unpaved road development began during the phase of 1970s [3] . As due to that point forward, numerous experimental and mathematical investigations have been accounted for in the writing to assess the advantages of utilizing the geo-synthetics in road development. It has represented that due to the fruitful utilization of geo-synthetics in roads, there are multiple types of geo-synthetics, which have been created globally and its market has been consistently developing. A few scientists have discovered the advantages of geo-synthetic reinforcement for the unsurfaced roads to enhance durability of those roads. The geo-textiles have become dependent extensively for the need of reinforcements to maintain the durable selection of constructions(roads, retaining walls, slopes and embankments)[4].

The woven geo-textiles are formed through weaving together to the tight portions of film, which fills the functions of detachment and reinforcement. The woven geo-textiles are passed through tensile strength, which is the opposition of a material needs to be broken under strain or tension.

The first-generation or the initial woven geo-textiles has been manufactured through cut tapes. As the cut tapes are barred level yarns woven, which are at the degree of 90 angles to produce a strong material. It is significant to mention that due to wide smooth surface of them, it has been the reason that it contains poor water coercivity and properties of low soil association. The enhancement of the high-quality superior woven geotextiles has provoked a more durable material.

As the non-woven geotextiles are porous geo-synthetics made of nonwoven materials utilized through soil, rock, or some other geotechnical-related material as a vital piece of a structural designing undertaking, construction, or framework[5].

Like woven, non-woven geotextiles are produced through utilizing synthetic material. Moreover, it contains much of random structure, which is formulated through the interlocking of filaments. The woven and nonwovens are consumed for the reasonable applications. The most straightforward approach to distinguish the contrast among the woven and nonwoven geotextile is through its original properties. As the non-woven geotextiles has been felt for the close resemblance through the specialties of "fluffy" look to the material [6]. and figure 1.1 shows the comparison of woven and non-woven geotextile.

(a) Woven Geotextile (b) Non-woven Geotextile (c) Knitted Geotextile

Figure 1.1 Different geotextile; (a) woven geotextile, (b) non-woven geotextile and (c) knitted geotextile

1.2 Problem Statement

The precedent literature has the limitations not to address an appropriate optimization of tensile strength of geosynthetic reinforcement for CBR value of soil. Since the 1970s, the utilization of geotextile as reinforcement has become more famous because of more good execution, which has been accounted for in a numerous instance[7]. Most of the research has been carried out on the comparison of the effect of reinforced and unreinforced soil using the geosynthetic material. In this research, the author focuses on the optimization of tensile strength of geosynthetic reinforcement for CBR value of soil by using the geotextile (non-woven) of different tensile strengths. The Comparison of reinforced and unreinforced soil using

Geotextile (non-woven) with different tensile strength values (10, 25, 35, 50, 65, 80, 100, 115, 123, 140 kN/m) or (150, 350, 500, 700, 900, 1100, 1300, 1500, 1600 and 1800 GSM) for both soaked and unsoaked conditions has been done. Adding layer of non-woven geotextile enhances the strength of the subgrade soil in terms of CBR value and improved the CBR value of soil more than that of the unreinforced soil.

1.3 Aim and Objective

The aim of the present research is to study the effect of geo-synthetic inclusion on the strength characteristics of the subgrade soil and analyze the effect of tensile strength of material on its strength characteristics of subgrade soil for unreinforced and reinforced cases. The aim of this research can be achieved by following objectives:

- Improve the CBR value of soil
- Comparison of reinforced and unreinforced soil using Geotextile (non-woven) with different tensile strength values (10, 25, 35, 50, 65, 80, 100, 115, 123, 140 kN/m) for both soaked and unsoaked conditions.
- Look for the optimization of tensile strength of geo-synthetic reinforcement For the CBR value of soil.

1.4 Research Scope

A detailed study of the previous literature had been conducted on Geo-textile reinforcement. The critical analysis of the previous research articles worldwide has been focused to understand the methodologies and procedure followed through them. As through the literature, the author come to know that the optimum adjustment or height of the Geo-textile material is H/4 from the top of standard mould of CBR[3]. To achieve the set goals, the Geotextile reinforcement of different tensile strength would be taken and CBR tests would be performed.

The soil utilized in this research has been available locally that has been obtained from the Top City Housing Society Islamabad, Pakistan. As the soil is silty clay when it was examined. It is significant to mention that according to AASHTO, up to A4 or maximum A5 soil is used for the construction of the road. If we have to use A6 or A7 that is composed of silt and clay mostly, we have to improve CBR. So, we use Geo-Synthetic Reinforcement.

1.5 Outcome

To have the optimization of tensile strength of Geo-synthetic reinforcement for the Geotextile (Non-woven), this research has been done. The Comparison of reinforced and unreinforced soil using Geotextile (non-woven) with different tensile strength values (10, 25, 35, 50, 65, 80, 100, 115, 123, 140 kN/m) or (150, 350, 500, 700, 900, 1100, 1300, 1500, 1600 and 1800 GSM) for both soaked and unsoaked conditions has been done. The performance of soils in soaking condition can be improved using geotextiles. The CBR value of soil for soaked conditions and unsoaked conditions has increased by adding the layers of geotextile. But the soaked parameter is more reliable as it is the worst condition in comparison of unsoaked soil. Non-woven geotextile has been added in the soil in the increasing order of Tensile strength. At about 115 kN/m of tensile strength of geotextile, the optimization has been achieved. There is not further increase in the value of CBR of soil after 115 kN/m. So, 1500 GSM or 115 kN/m tensile strength of needle-punched non-woven geotextile is the maximum value up to which the CBR value of soil has increased. For the soaked condition of soil, the percentage increase in the CBR value of the soil is 6.7% to 161.8%.

Chapter 2

2 Literature Review

2.1 General

The Geo-synthetics plays a significant role in the growth of the pavement industry since it has been introduced. The scientists have represented the advantages of the use of geo-synthetic reinforcement over weak subgrades of roads to improve their execution and effectiveness The Geo-textiles have been used immensely as a reinforcements for the massive variety of structures (roads, retaining walls, slopes and embankments) [4]. As somewhat recently, a broad exploration concentrate for the geo-synthetics in the pavement applications has been led in the need of economy and improved CBR.

2.2 Silty clay

The Silt is known as the granular particles of a size between the sand and clay as its mineral origin is located in the quartz and feldspar. As according to the AASHTO, up to A4 or maximum A5 soil is used for road construction. If we have to use A6 or A7 that it has to be mostly composed of silt and clay, we have to improve CBR value. So, we have used Geosynthetic Reinforcement.

2.3 Woven and Non-Woven Geo-synthetics

The woven geotextiles are produced by weaving together tight portions of film. As they fill the roles of detachment and reinforcement. The woven geotextiles are alluded to by the tensile strength, which is the opposition a material needs to breaking under strain or tension.

The first-generation or Original woven geo-textiles has been made up of cut tapes. As the cut tapes are the barred level yarns woven at 90-degree angles to yield a durable and long-lasting material. These elements used to settle on them, which is the poor decision for the common applications particularly in the wet conditions. As with the passage of time the improvement of superior woven geotextiles has prompted a durable powerful material.

The nonwoven geotextiles are porous geo-synthetics made of nonwoven materials utilized through the soil, rock, or other geotechnical-related materials as a vital piece of a structural designing undertaking, construction, or framework [5].

Like wovens, non-woven geo-textiles are made for utilizing a synthetic material. However, they contain more arbitrary structure which is delivered by the interlocking of filaments. The most straightforward approach to distinguish the contrast between a woven and non-woven geotextile is by its actual properties. The non-woven geotextiles closely resemble with the characteristic of "fluffy" look to the material [6]. Table 2.1 showed properties of NW geotextiles.

Table 2.1 Physical and mechanical properties of needle-punched non-woven geotextile

Properties	NW10	NW25	NW35	NW50	NW65	NW80	NW100	NW115	NW123	NW140
Weight, g/m2	150	350	500	700	900	1100	1300	1500	1600	1800
Thickness, mm	1	1.5	1.9	2.3	2.7	3.1	3.5	4	4.3	4.7
Tensile strength, kN/m	10	25	35	50	65	80	100	115	123	140
Elongation at break, %	40-55	40-55	40-55	45-55	45-55	50-55	60-65	60-65	65-70	65-70
CBR, puncture resistance, N	1800	4500	6200	8000	9500	11500	13600	15800	17200	19300

The cost of geotextiles is of prime concern. Although the price of NW geotextiles has been varied due to some factors like site and climate variations, availability, transportation and quality. The cost of geotextiles is related to mass per unit area. Heavier geotextiles cost more than that of lighter ones. Table 2.2 showed the cost of NW geotextiles.

Table 2.2 Cost of Geotextiles

NW (kN/m)	NW (GSM)	Price (USD)
10	150	0.6
25	350	1
35	500	1.8
50	700	2.4
65	900	3
80	1100	3.6
100	1300	4.1
115	1500	4.7
123	1600	5.1
140	1800	5.5

2.4 Applications of Geotextile Reinforcement

Soil Stiffness (in term of secant modulus, Es) is increased with the provision of all type of reinforcements. With the provision of all kind of reinforcements, the shear strength in all types of soils improved and geotextile reinforcement is the most effective. CBR value of the soil has also been increased by using the Geotextile reinforcement. In the recent decades, geotextile reinforcement has widely been used to improve the CBR value of subgrade to improve the life and efficiency of road. Applications of non-woven geotextiles are shown in Figure 2.1.

(a)Applications of non-woven geotextiles on Roads (b)Applications of non-woven geotextiles on Roads

(c) Applications of non-woven geotextiles on tunnel Roads (d)Applications of non-woven geotextiles on Tunnel road

Figure 2.1 Applications of non-woven geotextiles; (a) Applications of non-woven geotextiles on Roads, (b) Applications of non-woven geotextiles on Roads, (c) Applications of non-woven geotextiles on tunnel Roads and (d)Applications of non-woven geotextiles on Tunnel road

2.5 Advantages

- This research is used to analyze the effect of geo-synthetic inclusion about the strength parameters of the subgrade soil.
- Check the effect of tensile strength of material about the strength parameters of subgrade soil through the usage of the Geotextile (non-woven) with different tensile strength values.
- Due to this study, one will come to know the optimization of the tensile strength of soil using Geo-textile (non-woven).
- The use of Geo-synthetic reinforcement is an economical way to improve the CBR value of soil.
- Most of the researches have been carried out on the comparison of the effect of reinforced and unreinforced soil using the geosynthetic material. In this research, the author focuses on the optimization of the tensile strength of geosynthetic reinforcement for CBR value of soil by using the geotextile (non-woven) of different tensile strengths for both soaked as well as unsoaked conditions.

The literature study of a paper reports an examination on valuable impacts of reinforcement on a fine soil with a geo-synthetic reinforcement (geo-composite) and their reaction under stacking [4]. Table 2.3 shows the summary of CBR test results and figure 2.3 shows Force-penetration curves from the CBR tests.

Table 2.3 Summary of the CBR tests results

Sample	Reinforcement No. of layers	W (%)	Wreal (%)	CBR 2.5 (%)	CBR 5 (%)	Fmax (kgf)
Soil	0	11.9	11.9	9.5	10.0	374.4
	0	13.9	13.8	4.7	4.7	185.8
	0	15	15.1	3.2	3.5	142.2
Soil+GC	1	11.9	11.9	12.3	12.2	464.0
	1	13.9	13.6	4.7	4.9	192.6
	1	15	15	3.4	3.7	161.1
	2	11.9	11.9	13.6	13.9	533.0

2.6 Limitations

- Availability of the required tensile strength geotextile.
- Often geo-grid has been used instead of geotextile because geo-grid has a bit better result.
- It has been seen that a higher concentration of fibres brought about a higher increment in CBR values and, independent of the kind of the fibres the CBR values have expanded through expanding the fiber amount.

2.7 International Researches

One of the preferred materials examined for various types of soil subgrades has reinforced with the geo-grids. The tests are directed on soil in lab and field simultaneously as the CBR value is figured through the studies. The outcomes acquired have presented the impact of the plasticity and fines (%) and conceivable use of the geo-grid in improving the soaked CBR execution, which without geo-grid is extremely poor [1].

The geo-synthetic reinforcement layers are frequently used to enhance and assess the performance of the subgrade soils through laying single and double layers of the geo-synthetic reinforcements (Glasgrid, Tenax 3D grid, and Tenax multimat) horizontally at the various heights. The results revealed that the Tenax 3D grid reinforcement should be positioned between 0.3H and 0.36H, where H is the height of the soil specimen, for the best performance. The highest impact of reinforcement is attained for Glasgrid and Tenax multimat reinforcements when they have been positioned between 0.41H and 0.62H [3].

The CBR value is evaluated by installing geo-grid and geotextile at the different heights, and it has been discovered that one layer geo-grid , which has been placed at H/4 and two layer geotextile placed at H/4 & 2H/4 the distance from the top of the CBR mould reveals larger values of 2.38 and 2.03 times even more than the soil alone [8]. Figure 2.2 and 2.3 [8] show Comparison of CBR values of geogrid and geotextiles.

Figure 2.2 Comparison of CBR values at different positions of geogrid [8]

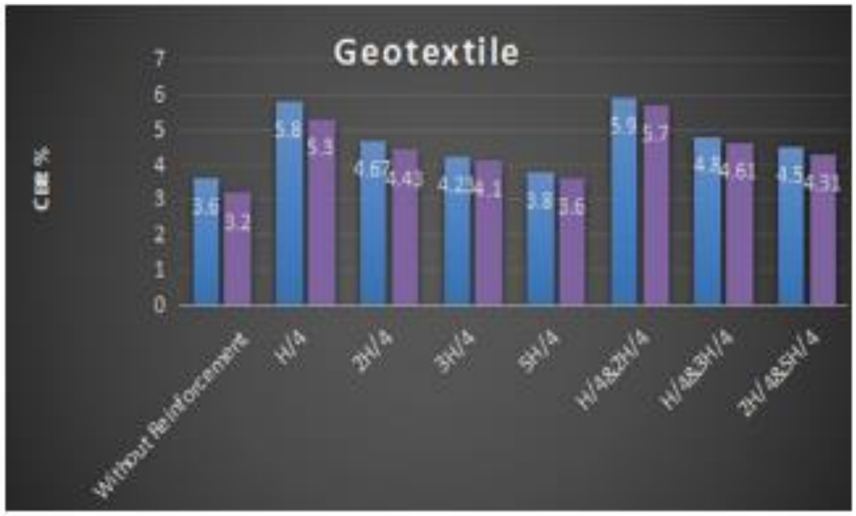


Figure 2.3 Comparison of CBR values at different positions of geotextiles [8]

The goal of the study is to investigate the feasibility of decreasing the discomfort triggered through expansive soil on the pavement structures. This report has presented that the trial results of an expansive soil sub-grade, which has strengthened with and without coir geo-textile mat. The lime and silica fumes, as well as treated and untreated coir geo-textile mat with polypropylene fiber net has been used in the study. In a cleared design, the increased property of reinforced expansive soil subgrade could potentially contribute to decrease the thickness of the sub-base and the base course layered [9].

This report has examined the typical field experiments on the geo-synthetic reinforcement of the flexible pavement, which has been carried out through the various researchers to improve the CBR of soil. The findings of this study may be used through the designers to evaluate the geo-synthetic reinforcement of the flexible pavements in their designs [10].The utilization of the Fiber Mesh and the Fiber Cast as a lime-stabilization option for the expansive soils has done in this study. As a performance metric, the California bearing ratio (CBR) is used. The probability analysis has revealed that the number and length of fibres has been significant factors in the CBR strength. It has also discovered that the differences in the intended CBR value has a significant impact on optimizing the length and quantity of the fibres [11].The author has demonstrated that the impact of the several geo-synthetic materials on the soft sub-grade in terms of the strength characteristics. The use of geo-synthetics over a sensitive subgrade (expansive soil) has proven to be one of the feasible and cost-effective solutions for strengthening road pavement and therefore enhancing the service life [12].

The author has focused on the influence of the geo-textile reinforcement on the California bearing ratio values when put at a preset location in an experimental pavement layer. Without the reinforcement, natural gravel soil has been chosen and tried. The CBR has been increased to include in an un-soaked circumstance. The use of geo-grid reinforcement in the road pavement layers could result in the increased strength and the environmental advantages [13].

The influence of the geo-textile used for the subgrade reinforcement has been investigated using experimental and numerical methods. The standard lab known as the California bearing ratio(CBR) test has been performed on the geo-textile-covered soil. It has also discovered that the woven geo-textile performed better than the non-woven geotextile. The ABACUS, which is known as a finite-element software, is also utilized to back analyze tentatively determined CBR values that are found to be in the acceptable agreement with the findings of the test [14].

The Clayey soil has been reinforced using geo-synthetics as a tensional material. The Thermally fortified nonwoven geotextiles (NW) and also the superior needle-punched nonwoven geotextiles (SNW) with diverse properties have been included in the samples (NW 8, 10, 21, 30 and SNW 14, 25, 62, 75). The bearing ratio of reinforced soils through the usage of needle-punched non-woven geotextiles rises, according to these experiments [15]. Table 2.4 shows Comparison of various geo-textiles with unreinforced soil.

Table 2.4 Comparison of various geo-textiles with unreinforced soil

Parameters	For 2.5mm CBR (%)	For 5mm CBR (%)
SNW 14	16	15.7
SNW 25	18.2	16.1
SNW 62	20	17
SNW 75	21	18
NW 8	19	18
NW 10	21.5	19.7
NW 21	27	25
NW 30	29	28
Unreinforced soil	19	18

The tests have been carried out on the unpaved test sections that has been reinforced with geotextile and geo-grid, with the potential use of a (DCP) and a (SCP) to analyze the well-being of the geotextile and geo-grid reinforcement for the CBR. The DCP results have might analyze the crucial changes in the strength of the unpaved test section as well as the penetration depth. The geotextile's higher penetration obstruction contributes to the test area's enhancement in terms of the demonstration [16].

As the report describes the results of a large-scale research center testing program to be used in an enormous direct shear device to reinforce the four distinct soils, which includes one sand and three clays with varying characteristics through three different geo-grids and one woven geotextiles. It is suggested that using interface borders of the soils at their 95 percent concentrated dry density and moisture content of 2% over their optimal values should be more common [17].

The performances of a geo-synthetic reinforced stiff clay foundation system, which has been enhanced under circular loads has investigated through various series of laboratory model experiments. In both designs, five separate series of tests have been carried out. As the three-dimensional geo-cell reinforcements and geo-grids reinforcements have been used. The geo-cell has been discovered to be the most beneficial soil reinforcement approach, which provides the highest increase in CBR [18].

On weathered mudstones geogrid-reinforced coarse-grained soil as the study offers results through the large-scale consolidated drained (CD) and consolidated undrained (CU) triaxial testing, as well as energy-dispersive X-ray (EDX), scanning electron microscopy (SEM), and other disintegration tests. The results of the tests has been revealed that geogrid-reinforced soil has better results for soil strength [19].

As using the triaxial experiments with and without the layers of geotextile and consolidated to three levels of limiting the pressures to 50, 100, and 200 kPa as this study has focused on the influence of limiting the stress on the mechanical behavior of the geotextile reinforced sand. The results of the tests has revealed that the geotextile integration contributes in improving the mechanical conduct of sand, which results in a significant increase in shear strength and the cohesion value [20].

The results for the small-scale tests applied on a geotextile reinforcement material in the different soils are represented significantly through usage of the gravimetric water content (GWC). The interface shear strength could be noticed as a decreased (by as much as half) at merely 2 percent of OMC (for example, OMC+2 percent) in comparison to the OMC -2% that is believed to be addressed in the as-assembled condition [21].

The benefits and impediments of utilizing geo-synthetic support yet additionally in researching the flow development and design methods with the end goal of figuring out, which is determined through the best practices when utilized in a comprehensive manner. As besides, this examination additionally recognized and evaluated the ideal state of the soil, execution measures, development detail, and design methods of the incline. The two contextual analyses have been assessed and a rundown of the accepted procedures, existing strategies and suggestions has also attached to this study. To give pliable obstruction and soundness, geosynthetic support or reinforcement has been utilized for fixing the repairing failed slopes, building new embankments, and augmenting existing embankments [22].

2.8 Local Researches

The Geosynthetic reinforcement especially geotextile is not commonly used in Pakistan. As there are not comprehensive or well renowned papers for the geotextile reinforcement at local level. This research is used to study the effect of geosynthetic as in the inclusion on strength characteristics of the subgrade soil.

In all these previous studies, there was little effort spent for the optimization of geosynthetic reinforcement. Maximum 2 or 3 non-woven geotextiles were used for each study. In the present study, the effect of inclusion of ten different tensile strength (10, 25, 35, 50, 65, 80, 100, 115, 123 and 140 kN/m) of non-woven geotextile for optimization of California bearing ratio (CBR) value of soil was investigated.

Chapter 3

3 Methodology

There have been four phases of the research as shown in figure 3.1. In first phase, the author compiled some initial data to start the research. Like from where the soil would be collected, the quantity of soil etc. Then in second phase, the author collected the soil sample and non-woven geotextiles from industry. In third phase, the lab tests were performed on the samples and in the last phase, there were results and conclusions.

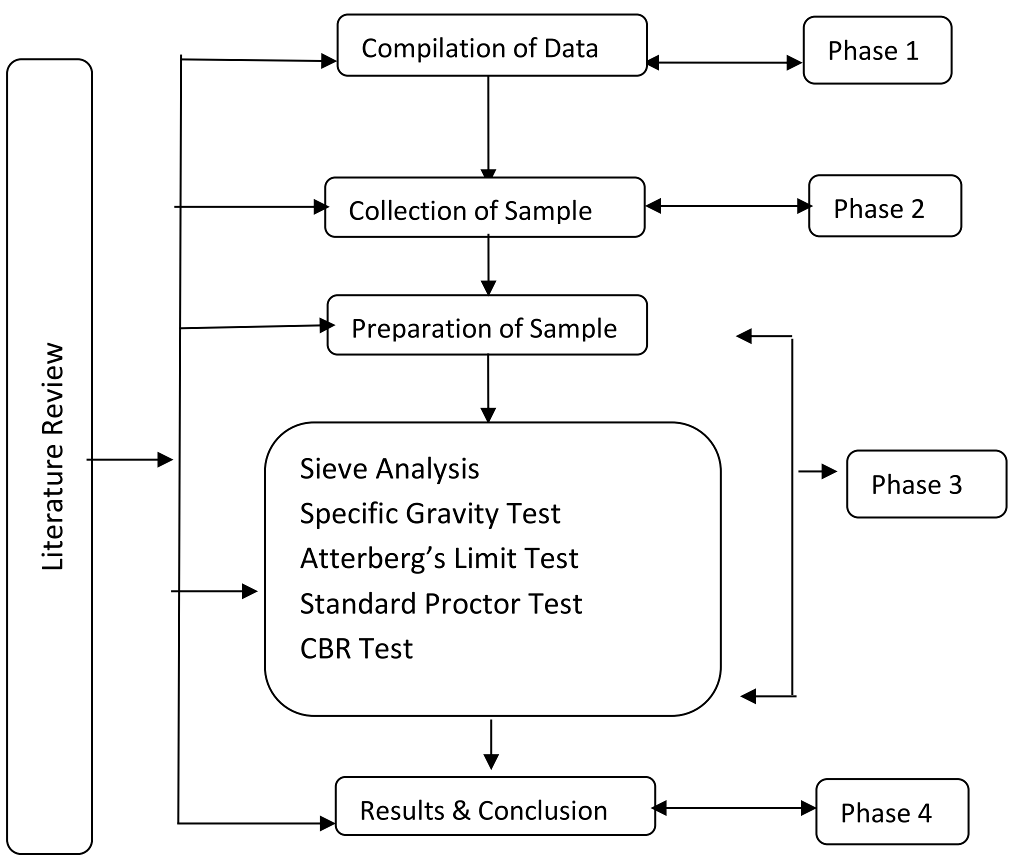


Figure 3.1 Flowchart for methodology

This diversified research covers the improvements of the CBR value of soil through the usage of the geosynthetic reinforcement. The geotextile (non-woven) is being used to enhance the strength characteristics of the subgrade soil. The soil used in the present research has been locally available soil, which has been obtained from the Top City Housing Society Islamabad, Pakistan. As the soil is silty clay. According to AASHTO, up to A4 or maximum A5 soil is used for the construction of the road. If we have to use A6 or A7, which is composed of silt and clay mostly, we have to improve the CBR value. So, we have used the Geosynthetic Reinforcement as all the laboratory tests has been performed as per American Standards of Testing Materials (ASTM).

3.1 Materials

The materials used for the research are soil, geosynthetic reinforcement (nonwoven) and water. The geotextile (non-woven) has been primarily used in this pertinent research. As it has been of different tensile strength values mainly (10, 15, 25, 35, 50,75,100,125,150,160 kN/m or (150, 350, 500, 700, 900, 1100, 1300, 1500, 1600 and 1800 GSM).

3.1.1 Soil Sample

The silty clay used in the research has been collected from the Top City Housing Society Islamabad, Pakistan. The sample has been collected from the depth of about the 6-8 feet to avoid organic matter and some other impurities.

3.1.2 Geosynthetic reinforcement

The geotextile (non-woven) has been primarily used in this pertinent research. As it has been of different tensile strength values mainly (10, 15, 25, 35, 50,75,100,125,150,160 kN/m or (150, 350, 500, 700, 900, 1100, 1300, 1500, 1600 and 1800 GSM). The geosynthetic layer as a support or reinforcement could be utilized viably to build up the unpaved road on the soft soil subgrade, causing the enhanced existence of the road and improve the value of CBR to make the research more viable and comprehensive. Non-woven geotextile of ten different tensile strengths (10, 25, 35, 50 , 65,80 , 100 , 115,123,140 kN/m) or (150, 350, 500, 700, 900, 1100, 1300, 1500, 1600 and 1800 GSM) has been used in this research. Figure 3.1 shows Woven vs Non-woven Geotextile.

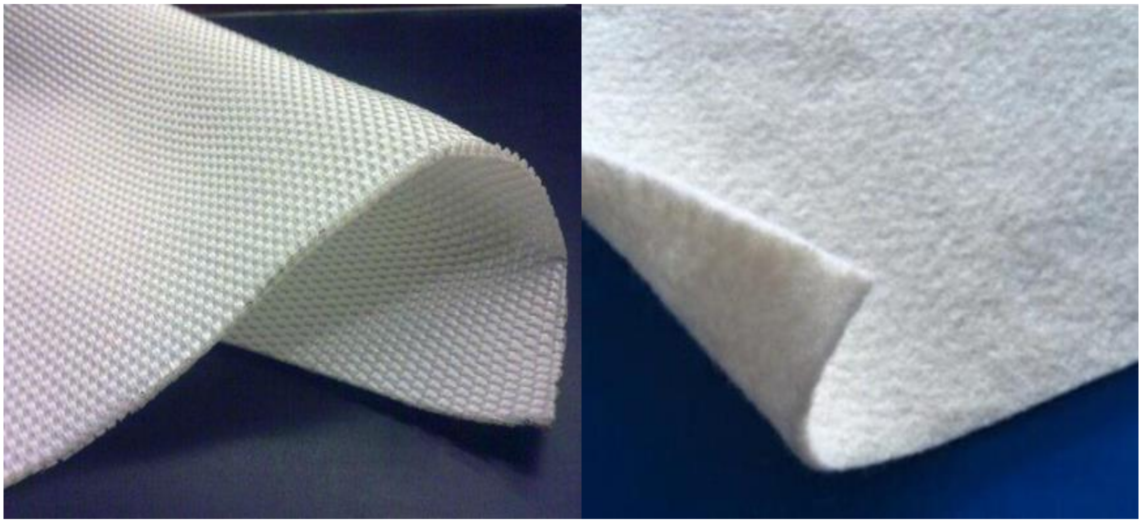
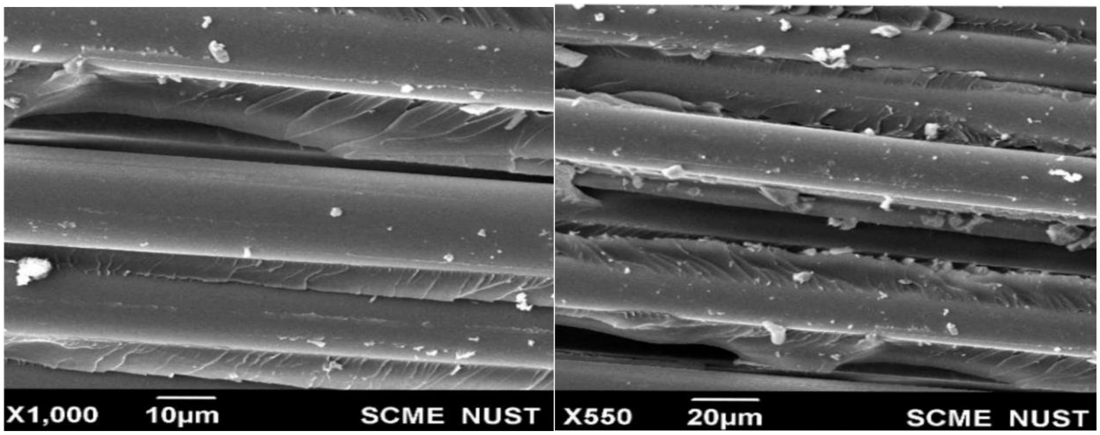
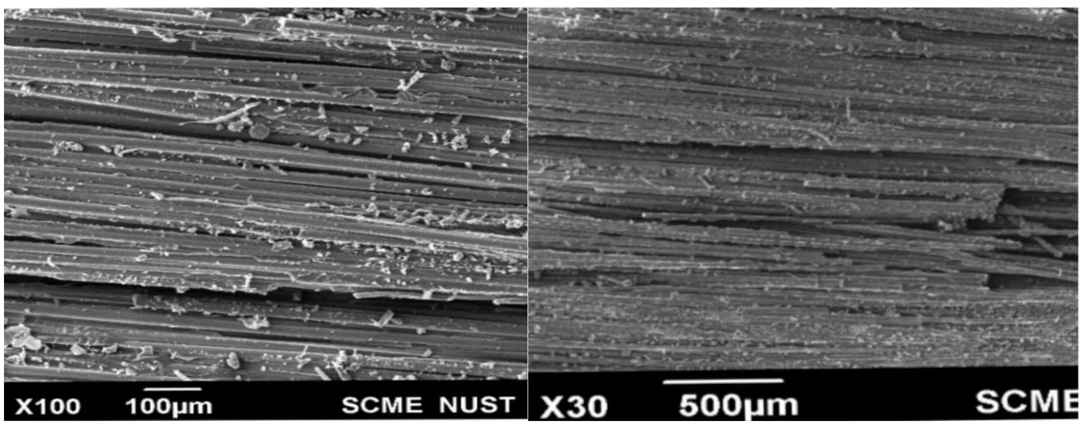


Figure 3.2 Different Geotextiles (a) woven geotextile and (b) non-woven geotextile

SEM (Scanning Electron Microscope) analysis that had been performed on the nonwoven geotextile as shown in figure 3.2. The fibres had some particles adhere to them and some clumps of material are wedged to the pores. Some pores extend through the fabric. The surface is smooth with spacing like pores. Also, NW that had been used is 100% polypropylene that is very good to bear the stress for construction and installation.



(a)1000 times magnified image (b)550 times magnified image



(c)100 times magnified image (d)30 times magnified image

Figure 3.3 SEM Analysis for magnification of non-woven geotextile;(a)1000 times magnified image, (b)550 times magnified image, (c)100 times magnified image and (d)30 times magnified image

3.2 Sieve Analysis Test

In this research, a sieve analysis has been done, the grain size analysis of soil sample was accomplished by performing sieve analysis using the set of standard sieves. The US No. 4,10, 16,30,40,50, 100 and 200 sieves were used in the analysis. Gravel content is the percent retained on US # 4 sieve, the materials passing through sieve US # 4 and retained on US # 200 sieve is sand content. The soils samples were classified using results of sieve analysis and Atterberg's limits by AASHTO Classification system as well as Unified Soil Classification System (USCS). Figure 3.2 shows Sieve Analysis Apparatus.

Figure 3.4 Sieve Analysis Apparatus

3.3 Hydrometer Analysis Test

Hydrometer analysis were performed on the soil sample by following the standard procedure given by ASTM D-4318. To determine the percentage of silt and clay contents, hydrometer analysis was performed on the soil sample passing through sieve # 200. Sodium hex metaphosphate used as a dispersing agent in hydrometer analysis.

3.4 Atterberg's Limit

Atterberg's limits tests has been performed on all three soils samples passing through US sieve # 40 as per their ASTM D-4318. Casagrande's apparatus is used to performed liquid limit test and plastic limit is performed by rolling the threads of soils samples on the smooth glass plate with the help of hand. AASHTO and USCS classification system classify the soils on the basis of Atterberg's limits. The plasticity of the soils is a significant parameter to know about their behavior in the field. Figure 3.4 shows Casagrande method for Atterberg's limits.

Figure 3.5 Casagrande method for Atterberg's limit

3.5 Standard Proctor Test

Standard proctor test was performed for soil as per their ASTM D-698. The volume of the mold was about 2124 cm^3. The weight and dropping height of the hammer was 5.5 lbs and 1ft, respectively. Compaction was done in three equal layers with 56 number of blows per layer. Tests was start form 7 percent moisture content and gradually varied the moisture content up to increase in the density. Tests was terminated after observing the decreasing trend for the density. Figure 3.5 shows mixing and compaction of soil for standard proctor test and 3.6 shows Standard Proctor Test Apparatus.

(a) Mixing of soil (b) compaction of soil

Figure 3.6 Mixing and compaction of soil for standard proctor test; (a) mixing and (b) compaction of soil

3.6 California Bearing Ratio Test

CBR tests were carried out in this research for soaked as well as unsoaked conditions for both virgin and reinforced soil. Non-woven geotextile has been used as reinforcement. CBR tests were carried out using loading machine, Penetration measuring device, mold, spacer disk, rammer etc. Mold has the inner diameter of 6 inch and height of 7 inch. Compaction was carried out in five equal layers with 65 blows, 30 blows and 10 blows per layer. Figure 3.7 and 3.8 shows Reinforced Soil sample with non-woven geotextile.

Figure 3.7 Reinforced Soil sample with non-woven geotextile

Figure 3.8 CBR Test performed on reinforced soil sample

Chapter 4

4 Results and discussions

All the results of the laboratory tests which are performed during the research are given in this chapter and discussed in detail. Furthermore, different graphs and bar charts of different tests are discussed.

4.1.1 Particle size distribution

Particle size distribution tests have been carried out on soil sample as per their ASTM standards. And according to the results, 92.8% of the soil is silty clay and 7.2% is sand. The results are shown in 4.1

Table 4.1 Sieve Analysis of soil

Sieve No.	Sieve Size (mm)	Weight Retained (gm)	Cumulative Weight Retained (gm)	% Retained (gm)	% Passing
4	4.75	0	0	0	100
10	2	0	0	0	100
16	1.18	0	0	0	100
30	0.600	0	0	0	100
40	0.425	0	0	0	100
50	0.30	0.3	0.3	0.06	99.94
100	0.15	5	5.3	1.08	98.92
200	0.075	30	35.3	7.2	92.8
Pan		451	486.3	99.2	0

4.1.2 Atterberg's Limit Test

Atterberg's limits tests were carried out on soils sample passing sieve # 40. For the accuracy of results, Atterberg's limits tests were performed triple times on soil sample. Tests were performed as par their ASTM standard. According to tests performed, average value of the liquid limit and plastic limit for soil came out to be 24% and 18% respectively. The plasticity index was 6%. The results are shown in table 4.2

Table 4.2 Atterberg's Limits

No. of Blows range	25-35	20-30	15-25	PL
No. of blows	34	24	16	
No. of can	11	17	57	53
Wt. of can (g) W_3	31.15	32.21	30.88	31.44
Wt. of can+wet soil (g) W_1	49.02	57.75	55.41	44.36
Wt. of can+dry soil (g) W_2	45.68	52.79	50.45	42.38
W_W	3.34	4.96	4.96	1.98
W_S	14.53	20.58	19.57	10.94
Moisture Content	22.98	24.10	25.34	18.00

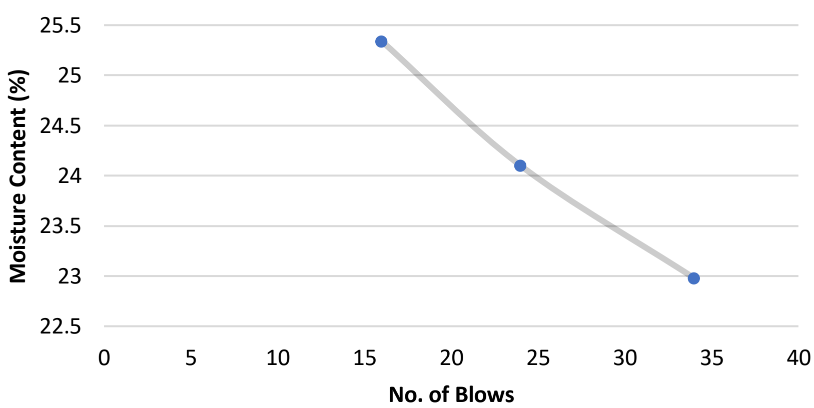


Figure 4.1 Liquid limit of the soil sample

4.1.3 Hydrometer Analysis Test

Hydrometer analysis and Sieve analysis tests have been carried out on soil sample as per their ASTM standards. Percentage of materials of soil has shown in table 4.3

Table 4.3 Percentage of materials of soil

Material	Percentage
Gravel	0
Sand	7.2
Silt	60
Clay	32.8

4.1.4 AASHTO/USCS Classification of Soils

According to AASHTO classification, the soil is classified in the group A-4. It is of the category of silty soils with the general rating for subgrade as fair to poor.

According to USCS soil classification, it is inorganic soil having PI in between 4 and 7. According to the A Line chart, it lies in the hatched area i.e., CL-ML. The soil is silty clay.

According to USDA soil texture triangular classification, the soil lies in the category of silty clay loam.

4.1.5 Standard Proctor Test

Standard proctor tests were also performed on soil sample. The maximum dry density and optimum moisture content came out to be **1.81 g/cm^3** and **17%** respectively. The results are shown in 4.4

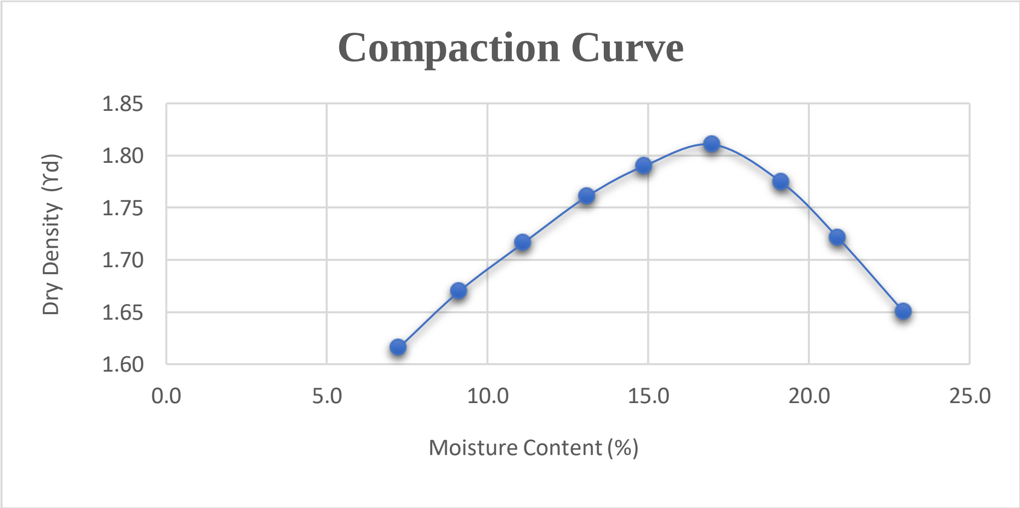


Figure 4.2 Compaction curve

Table 4.4 Physical and index properties of soil

Particulars	**Soil**
Color	Brown
Sand %	7.2
Silt %	60
Clay %	32.8
Liquid limit (LL)%	24
Plastic limit (PL)%	18
Plasticity Index (PI), %	6
USCS/AASHTO	CL-ML/A-4
Optimum moisture content (OMC), %	17
Maximum dry density (MDD), γd (g/cm^3)	1.81

4.1.6 Load-Penetration behavior

The Figure 4.3 and Figure 4.4 show the variations of load-penetration curves obtained from CBR tests for soaked as well as unsoaked soil conditions for reinforced and unreinforced soil. CBR value was calculated for 0.1-inch (0.00254 m) as well as for 0.2-inch (0.00508 m). For soaked 65 blows, the percentage increase in CBR was 100% and for unsoaked 65 blows, the percentage increase in CBR was 110%. All the mentioned CBR values are corresponding to 0.2-inch penetration.

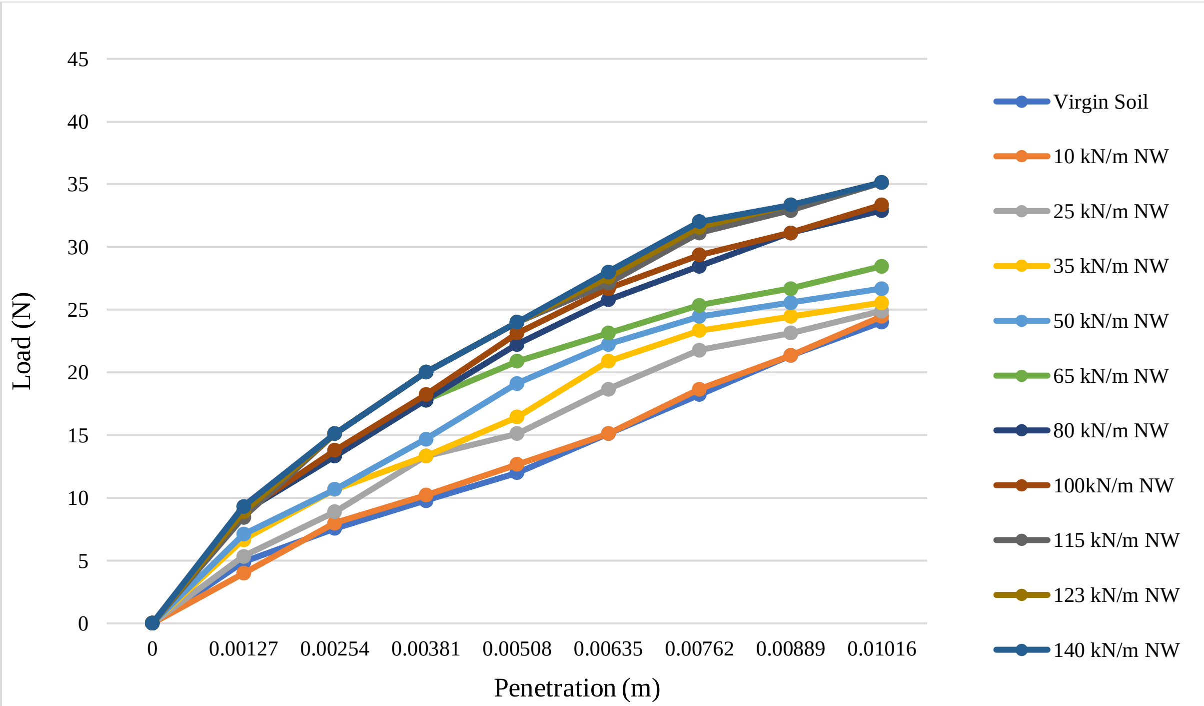


Figure 4.3 Soaked case with 65 blows per layer

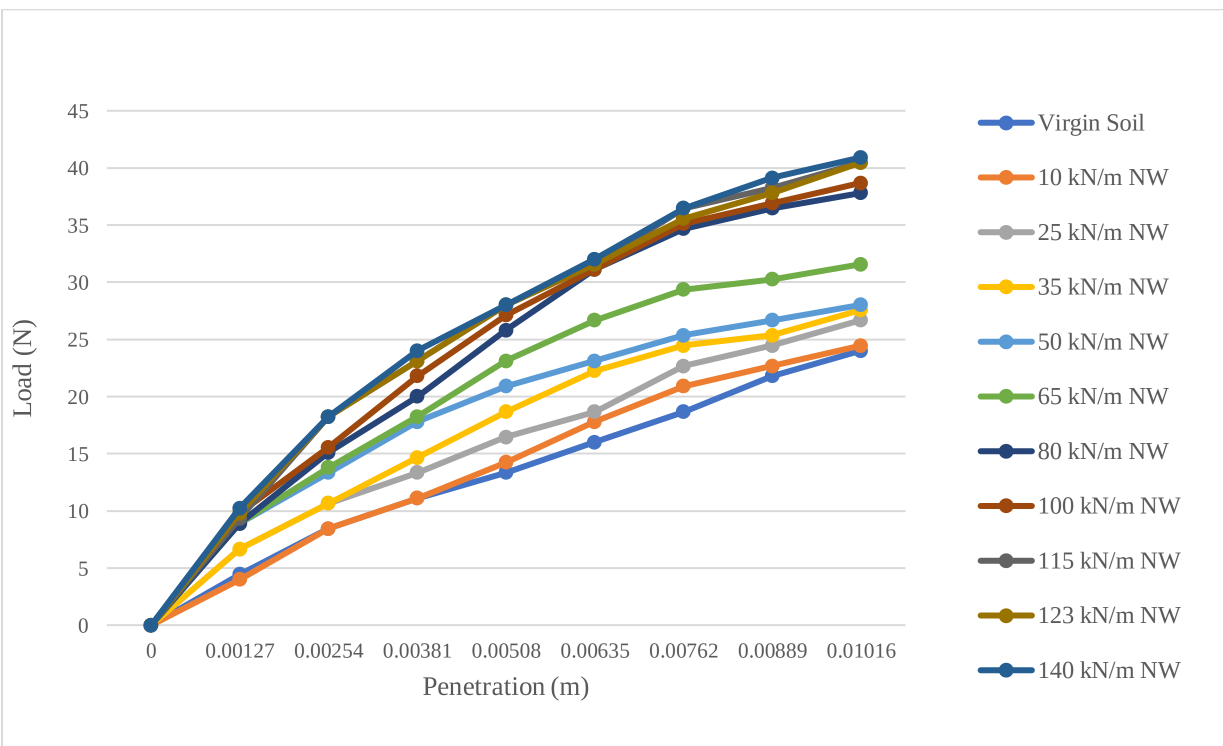


Figure 4.4 Unsoaked case with 65 blows per layer

The Figure 4.5 and Figure 4.6 show the variations of load-penetration curves obtained from CBR tests for soaked as well as unsoaked soil conditions for reinforced and unreinforced soil. CBR value was calculated for 0.1-inch (0.00254 m) as well as for 0.2-inch (0.00508 m). For soaked 30 blows, the percentage increase in CBR was 132.7% and for unsoaked 30 blows, the percentage increase in CBR was 121.21%.

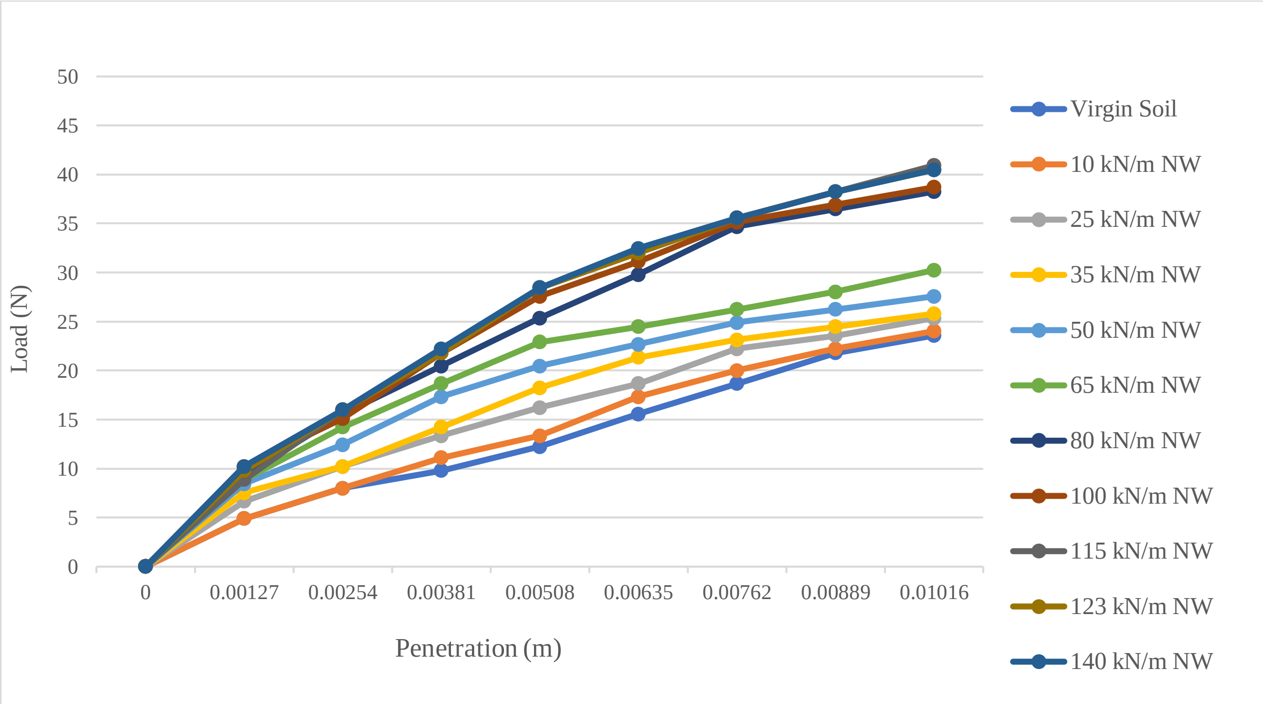


Figure 4.5 Soaked case with 30 blows per layer

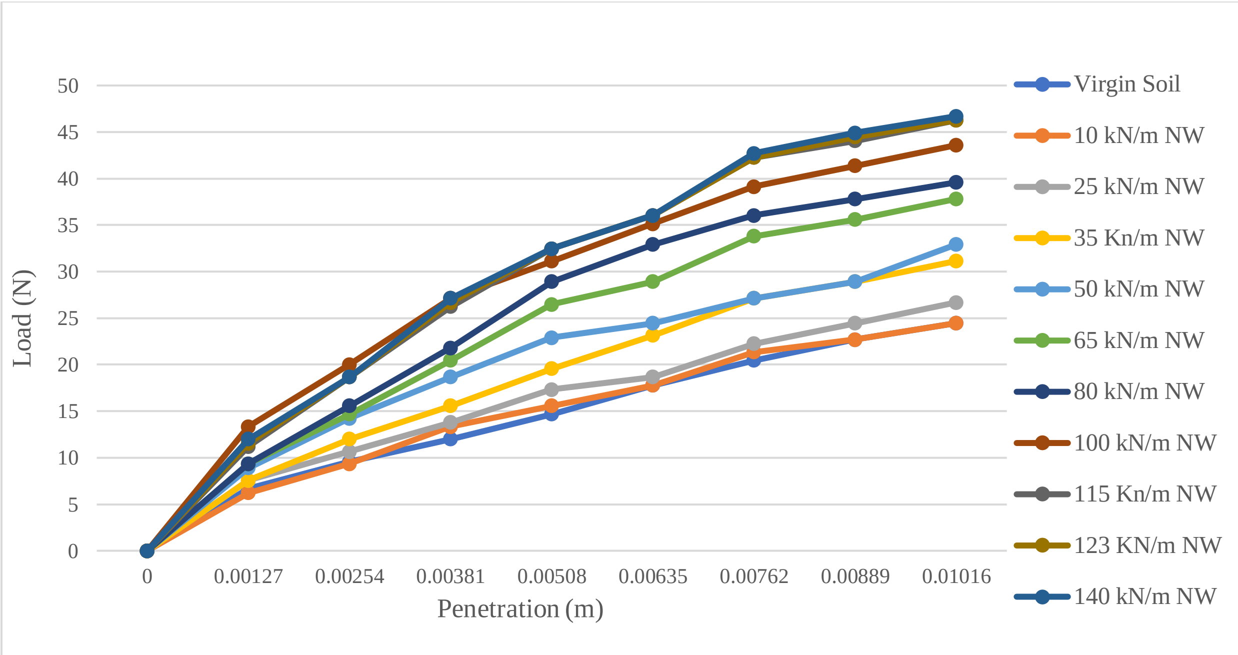


Figure 4.6 Unsoaked case with 30 blows per layer

The Figure 4.7 and Figure 4.8 show the variations of load-penetration curves obtained from CBR tests for soaked as well as unsoaked soil conditions for reinforced and unreinforced soil. CBR value was calculated for 0.1-inch (0.00254 m) as well as for 0.2-inch (0.00508 m). For soaked 10 blows, the percentage increase in CBR was 163.33% and for unsoaked 10 blows, the percentage increase in CBR was 152.73%.

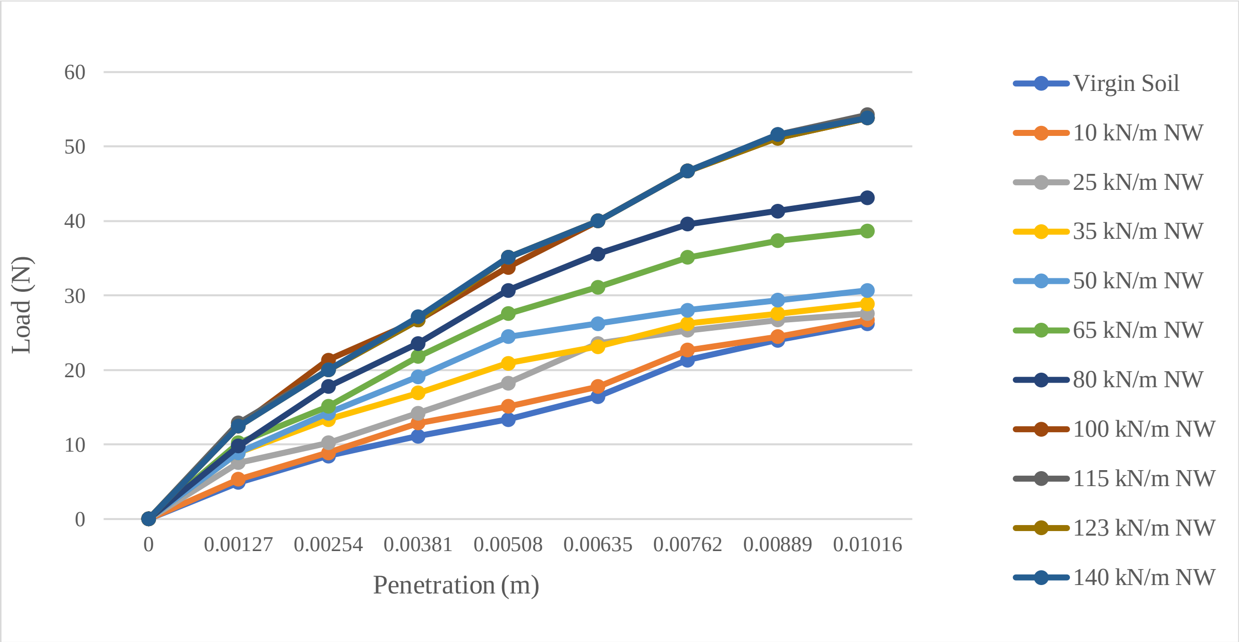


Figure 4.7 Soaked case with 10 blows per layer

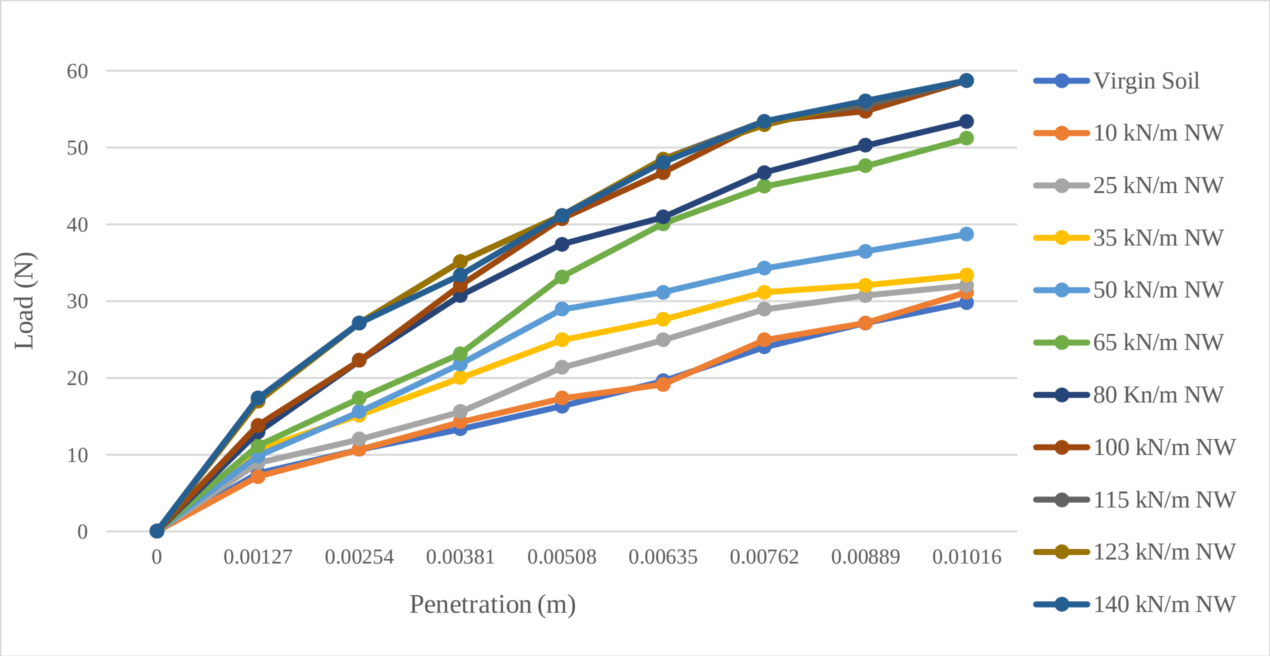


Figure 4.8 Unsoaked case with 10 blows per layer

4.1.7 CBR Results

It has been analyzed that when NW thickness was increased, the CBR value of soil was enhanced extensively, which assists in increasing its CBR value up to NW-1500 GSM. It may be the result of the analysis that the reinforcing elements assists in interacting with the soil particles through the surface friction and interlocking properties. As the function capability of the bond is its transferring properties to stress through the soil to its reinforcing elements by mobilizing the tensile strength of the reinforcing elements that causes an improvement in load carrying capacity of the reinforced soil. It has been concluded that adding of the nonwoven geotextile layer in soil improves the loading capacity and decreasing the value of the immediate settlement. The nonwoven geotextiles' design and selection is primarily based on the proficient engineering principles that assists to users and the long-term interests of the industry at the same time. As in the present time, the nonwoven geotextiles are the thick filter that provides exceptional performance at the minimum weight. The results of the laboratory tests that has been performed in this research are discussed in detail. In the Figure 4.9 and Figure 4.10, there is a comparison between soaked and unsoaked cases of soil for CBR values. For the soaked condition of soil, the percentage increase in the CBR value of the soil was 6.66% to 161.765% and for unsoaked condition, the percentage increase in the CBR value of the soil was 5.40% to 153.65%.

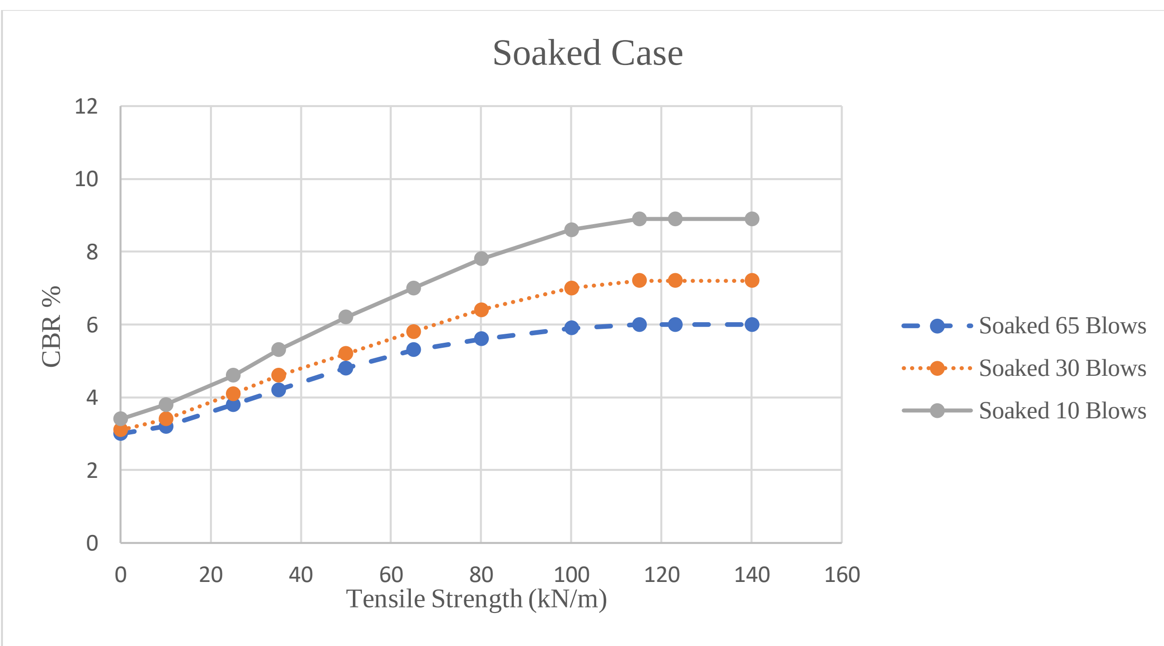


Figure 4.9 Comparison of soaked case

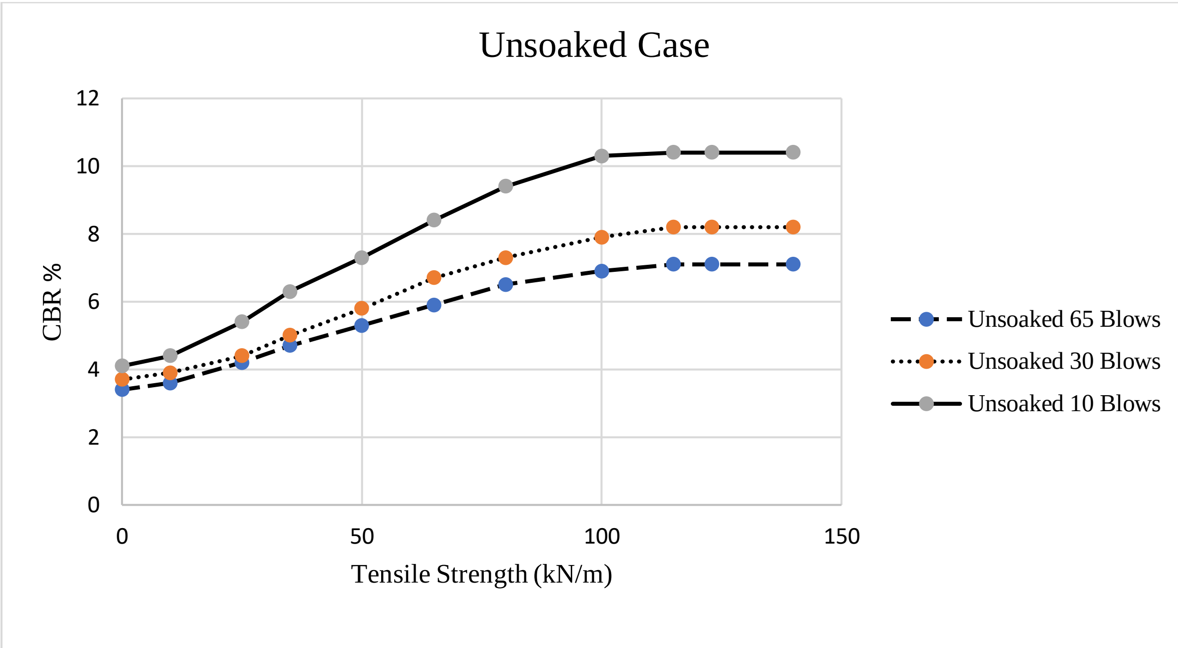


Figure 4.10 Comparison of unsoaked case

Chapter 5

5 Conclusions

The purpose of having this research is to study the effect of different geosynthetic materials (non-woven) on the value of CBR of soil. To achieve required purpose, soil was taken from Top City Housing Society Islamabad, Pakistan. Different laboratory tests have been conducted on the soil. By using Geosynthetic reinforcement, the CBR value of soil has been increased. Several conclusions are made based on results obtained from laboratory investigations. These conclusions are given below.

- Adding layer of non-woven geotextile improved the CBR value of soil more than that of the unreinforced soil.
- The performance of soils in soaking condition can be improved using geotextiles. The CBR value of soil for soaked conditions and unsoaked conditions has increased by adding the layers of geotextile. But the soaked parameter is more reliable as it is the worst condition in comparison of unsoaked soil.
- Non-woven geotextile has been added in the soil in the increasing order of Tensile strength. At about 115 kN/m of tensile strength of geotextile, the optimization has been achieved.
- There is not further increase in the value of CBR of soil after 115 kN/m. So, 1500 GSM or 115 kN/m tensile strength of needle-punched non-woven geotextile is the maximum value up to which the CBR value of soil has increased.
- For the soaked condition of soil, the percentage increase in the CBR value of the soil is 6.7% to 161.8%.
- For unsoaked condition, the percentage increase in the CBR value of the soil is 5.40% to 153.7%.
- NW geotextiles offer a cost-effective alternative solution for protection, filtration and separation applications and amount of immediate settlement for subgrade decreases by using geotextile reinforcement.

5.1 Recommendations for future work

- It is recommended to find out the optimization of woven geotextile
- It is also recommended to find out the optimization of geogrid
- It is recommended to find out the Optimization of geocomposite
- Comparison of woven, non-woven, geogrid and geocomposite should also be done
- Use different type of soils and reinforced with all of the above maintained reinforcements and compare the results.

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