USE OF GEOSYNTHETICS IN PAVEMENT CONSTRUCTION

Final Year Project UG-2014

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This is to certify that the thesis titled

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DECLARATION

It is hereby solemnly and sincerely declared that the work referred to this thesis project has not been used by any other university or institute of learning as part of another qualification or degree. The research carried out and dissertation prepared was consistent with normal supervisory practice and all the external sources of information used have been acknowledged.

ABSTRACT

Communication networks are extremely essential for the economic growth of a country and highways serve a vital role in connecting people across the country and generating economic activity. In Pakistan, conventional methods of highway and road construction are still in practice and thus, the design life of highways in Pakistan is around 10 to 15 years. Furthermore, road construction and repairing is expensive and requires a large investment of time and money.

Therefore, our final year project is primarily focused on studying, analyzing and comparing the effect of different geosynthetics on the properties of the pavement and proposing a geosynthetic that is both cost-effective and significantly increases the design life of the pavement.

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Chapter 1

Introduction

1.1 General

Transportation plays a very important role in the development of a nation by facilitating trade and commerce. A transportation system consists of the infrastructure that helps people in travelling from one place to another. Such infrastructure includes roads, rails, airports etc.

Like many developing countries of the world, road transportation is the preferred mode of communication for both passenger and freight traffic in Pakistan. Pakistan has a total of approximately 2,50,000 km of paved roads, out of which the National Highway Authority (NHA) manages only 3.5% i.e. 10,000 km. However, these 3.5% roads carry almost 85% of the total commercial traffic.

The typical cross-section of a flexible pavement consists of the subgrade, unbound subbase aggregate, unbound base aggregate, asphalt concrete layers and the overlay (Figure 1.1). The unbound subbase aggregate and unbound base aggregate serve as the foundation for the pavement and the asphalt concrete layers and overlay constitute the main structural element of the pavement.

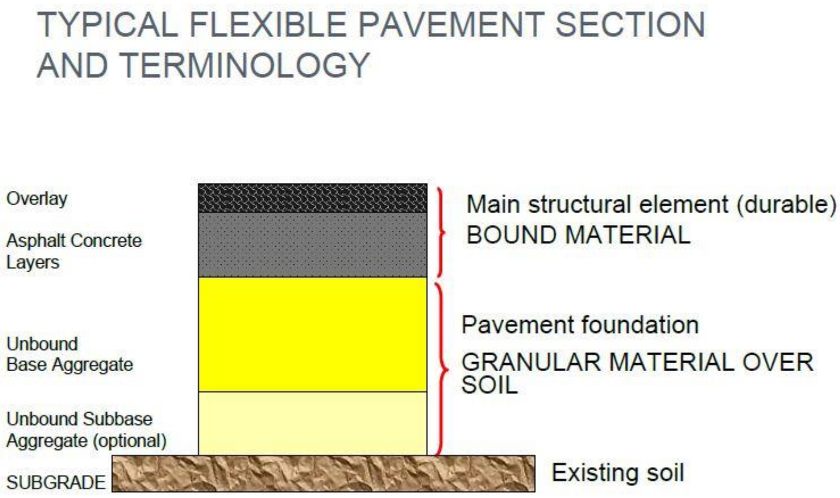

Figure 1.1 Typical Cross-Section of Flexible Pavement

When geosynthetics are placed between these layers, they can serve the following functions based on the placement:

- Separation (between the base course and subgrade)
- Filtration (preventing the washing out of materials while allowing water to flow through)
- Drainage (to prevent water logging)
- Reinforcement (to reduce differential settlement)

1.1.1 Geosynthetics

Geosynthetics are planar products manufactured from polymeric materials. They are used with soils and aggregate in a variety of geotechnical engineering applications.

There are several types of geosynthetics used nowadays, some of the them are:

- Geogrids
- Geotextiles
- Geocomposites
- Geonets
- Geomembranes
- Geosynthetic clay liners
- Geofoam
- Geocells

However, in pursuing our final year project we primarily dealt with geotextiles and geomembranes as they have a significant effect on the properties of the pavement.

- <u>Geotextile</u>

  A geotextile used at the top of the subgrade significantly reduces the subgrade deformation and its performance is better as a separator between subgrade and base as compared to geogrid. Furthermore, the use of geotextile reduces the pore water pressure and does allows the intermingling of finer base and subgrade particles. Frictional properties of a geotextile do not allow the lateral movement of aggregate particles in different layers of pavement.

Figure 1.2 Geotextile

- <u>Geomembrane</u>

Geomembranes are thin elastic materials whose basic function is to stop the flow of liquids between different layers in soil bed.

When geomembranes are used in a pavement it significantly reduces the changes in the moisture content of the soil. It also provides many other properties to the pavement that includes enhanced strength, lighter weight, transferability and decrease in cost.

Figure 1.3 Geomembrane

1.2 Problem Statement

The increase in population and development of new urban centers has led to an increase in the number of roadways required to connect people. Road construction and repairing is an expensive process and requires a large investment of time and money.

Furthermore, during the rehabilitation process, disruption of traffic is observed which results in congestion. Recently, Motorway (M2) was rehabilitated after being in service for sixteen years and the rehabilitation process took almost a year, causing a noticeable congestion on the M2.

Use of geosynthetics in pavement construction can result in reduced overall construction and maintenance costs and an increased design life of the pavement, thus resulting in a reduction in the time and money spent for the rehabilitation of the pavement.

Performance of geosynthetics is highly dependent on their positioning within the cross-section of the pavement. So, to achieve the aim of cost-effective and long-lasting pavements using geosynthetics, thorough study and analysis is required.

1.3 Work Procedure

To check the performance of different geosynthetics under different positioning within the cross-section of the pavement, the following steps were carried out:

- Selection and procurement of material
- Sample preparation
- Testing
- Compilation of results
- Conclusions and recommendations

During the sample preparation and testing phase of the project, the following tests were performed:

- Tests on subgrade soil
  - ❑ Modified Proctor Test

- Atterberg's Limit (Liquid Limit and Plastic Limit)
- Sieve Analysis
- Hydrometer Analysis

- California Bearing Ratio (CBR) Test
- Triaxial Test
- Permeability Test

1.4 Aims and Objectives

The focal aims and objectives of this research work are as follows;

- Comparison of the changes in pavement properties using different geosynthetics.
- Proposing geosynthetics that result in cost-effective and long-lasting pavements.
- Comparing our results with the results obtained through the software (Composite Geosynthetic – Base Course Model)

1.5 Utilization

This research can be used worldwide for increasing the design life and load carrying capacity of pavements. Improvement of the load carrying capacity of flexible pavements using conventional techniques is costly. Thus, geosynthetics can offer improved structural capacity along with reduced deformation in a cost efficient and eco-friendly manner.

1.6 Thesis Organization

This thesis is organized into five chapters. The background and purpose of the research are presented in the first chapter. The scope of the research program along with objectives is also included in the first chapter.

The second chapter includes a brief literature review on the use of geosynthetics in pavement design. The various tests performed to analyze the behavior of geosynthetics in the subgrade were studied. Finally, some research papers on the effect of geosynthetics on the design life of the pavement were explored.

The third chapter explains the methodology adopted to accomplish the objectives of the study. The details of the conventional tests and their protocols adopted in this research are also explained. It also includes the criteria adopted for the selection of materials.

The fourth chapter includes the results. The test results obtained are summarized in tables and explained with the help of figures. The results obtained using the software (Composite Geosynthetic – Base Course Model) are also included in this chapter.

The fifth and final chapter presents the summary and conclusion of the research. Recommendations for the implementation of this research in Pakistan are included in this chapter. Moreover, recommendations for further research in this field are also included.

Chapter 2

Literature Review

2.1 General

Several research papers were studied to understand the behavior of geosynthetics in pavements. These research papers helped us in the selection of the materials that were appropriate for our research. In order to recognize the various tests that were required to determine the effects of geosynthetics in the base-subgrade interface, we used the research paper by Jorge G. Zornberg. According to the research paper by Charles A. Adams, the CBR values increase upon the introduction of a geosynthetic in the soil.

2.2 Advances in the Use of Geosynthetics in Pavement Design

JORGE G. ZORNBERG of The University of Texas at Austin, USA.

Geosynthetics installed in pavements perform several functions such as separation, sealing, filtration, lateral drainage, and reinforcement. The enhancement in the design life of geosynthetic reinforced pavement is due to: increased bearing capacity, lateral restraint and tensioned membrane effect.

The geosynthetic also act as tensioned membrane. The reinforcement gives us an additional vertical reaction part to the applied cyclic load. Still substantial rutting depths are required to view this phenomenon. This reinforcement mechanism develops just in areas where the subgrade CBR value goes under 3.

The design procedures used for geosynthetic reinforced asphalt pavements are as follows:

- AASHTO Method (pavement in this case is considered to be a multi-layer system that has only one structural number that expresses the thickness of layers and their resistivity to repetitive loads)
- NCHRP Mechanistic-Empirical method (in order to improve reduce life-cycle costs, design reliability, characterize better the effects of seasonal moisture variability and drainage, and avoid untimely failure of pavements.) (Olidis and Hein 2004)

The working of geosynthetic-reinforced flexible pavements can be analyzed using laboratory as well as field tests. The laboratory tests are divided into two major categories: Confined and Unconfined tests.

2.2.1 Unconfined Tests

These tests include:

- Wide-width tensile test:

Unpaved road design with the tensile stiffness of 5% is recommended. Whereas for paved road design, tensile strain of 2% in geosynthetics is recommended for design. (Berg et al.,2000)

Bray and Merry (1999) deduced that strains differ across the sample from a plane strain, biaxial order near the corners, to a uniaxial order at the middle portion the specimen.

- Biaxial loading test:

This method primarily focuses on geogrids installed in pavements allowing characterization of the mutual strength of tensile ribs and connections in just one test.

- Junction efficiency test

Junction strength quantifies the influence of stability that may cause collapse of the reinforcement throughout the pavement construction and repetitive traffic loading.

- Torsional stiffness test:

It is used to measure the planar rotational rigidity of the geogrids.

2.2.2 Confined Tests

According to Han et al., Geosynthetics that are used in base strength enhancement are subjected to repetitive traffic loads. These conditions cannot be studied by using monotonic unconfined tests. Most importantly, geosynthetic and soil confinement are dependable on interaction between geosynthetics and soil particles in addition to the properties of soil macrostructure and properties of geosynthetics.

According to Elias et al., in unconfined tests of geosynthetics the approach used is conservative and the confinement sufficiently increases their mechanical properties.

Confined tests include:

- Cyclic plate load test:

  TBRs ranged from 1 to 70 and BCRs ranged from 20% to 50% from results of cyclic plate load tests in parts reinforced with G.

- Cyclic triaxial test

  Shear stresses are studied in this test that are developed due to repetitive traffic loads. The test show that permanent deformation is reduced in the pavement to a great extent whereas the resilient modus of soil remains same.

- Repetitive pullout test

  This test provides a useful mechanism to characterize the interface shear moduli in finite element simulations performed to define the M-E approach. However, pullout test results conducted on six geosynthetics indicated that relations amongst the predicted and measured values was extreme.

- Bending stiffness test

  The bending stiffness test was given by Sprague et al. in 2004 for a small-scale index test in order to predict the behavior of geosynthetics when installed in pavements. The test apparatus is a changed version of the multi-axial tension test for geomembranes. (ASTM D 5617)

- Modified pavement analyzer test

Proposed by Han et al. (2008) to evaluate the changes in the properties of base course layer, when reinforced with different types of geosynthetics.

- Pullout stiffness test

Developed by Gupta (2009) to analyze the soil and geosynthetic interaction in reinforced pavements.

Research performed using the PST has shown that monotonic pullout tests shows promising results during characterization of the soil-geosynthetic interaction subjected to low strain values.

2.2.3 Results

The purpose of this paper was to generalize information generated so far in North America to classify the properties of flexible pavements when they are reinforced using geosynthetics.

This research concludes that the mechanical properties of the geosynthetics used for pavement reinforcement applications are enhanced when they are placed in the soil. Overall, available experimental evidence shows that the lateral restraint mechanisms contributes to the enhanced performance of geosynthetic-reinforced pavements.

2.3 Advanced Geosynthetics in Flexible Pavement: A full scale test and numerical study

T.Imjai, M.Guadagnini, K.Pilakoutas

This paper provides information about the improvement of hot mix asphalt material, mix designs and methods of reinforcing road pavement layers to cater for pavement distresses. The paper also gives an insight about the methods that can be used to extend the useful life of the road and provide economical ways for repair and maintenance. Extensive tests were performed at full scale to evaluate the performance of geosynthetic reinforced materials in flexible pavements. Three test sections having reinforced pavements and one test section having unreinforced pavement were constructed. Different static loads of 20, 30 and 40 tons were applied by test truck and pavement deformation and vertical stresses were measured after intervals of 3, 6, 12, 24 and 36 months. The numerical model was prepared and it showed a good agreement with the field data.

The research paper concluded that geosynthetic pavements have better performance and strength and geogrid reinforcement at base-sub base interface provides better rutting resistance. This research will provide us a framework for collecting data in the field and then generate a numerical model. Finally, based on this numerical model, well-informed design recommendations for the use of geosynthetic reinforcement in flexible pavements can be made.

2.4 Effect of Triaxial Geogrid Reinforcement on CBR: Strength of Natural Gravel Soil for Road Pavements

Charles A. Adams, Ernest Apraku, Richter Opoku-Boahen

The use of geosynthetic reinforcement in road pavements is increasing day by day. In this research paper, we studied the effect of geosynthetic reinforcement on the California Bearing Ratio (CBR) values of an experimental payment layer of gravel soil.

First, the natural gravel soil was selected and its CBR value was determined. Then a layer of geogrid was placed above the third layer and the CBR values were checked in both soaked and un-soaked conditions. The increment in the CBR values is 12% and 31% for T×160 and T×170 geogrids, respectively in soaked conditions. The results also show an increase in the CBR values for un-soaked condition.

The material was natural gravel soil and was taken from a construction site near Kumasi. Different tests were performed on the material like compaction, particle size distribution, consistency limits.

The CBR test was performed according to the standards provided by American Society of Testing and Materials (ASTM D1883). All the CBR tests were performed in a modified proctor mould for both soaked and un-soaked conditions. The soil having optimum moisture content is placed in 5 layers within the CBR mould and each layer is compacted by 56 blows, produced by dropping a rammer with a weight of 44.5 N from a distance of 457 mm.

Three sets of CBR tests were performed that are; soil with no geogrid, soil reinforced with T×160 geogrid and soil reinforced with T×170 geogrid. For soaked CBR test, the mould was soaked in a drum of water having a surcharge placed on it for 4 days. The penetration resistance of the material was determined up to a limit of 7 mm of penetration due to equipment restrictions.

When the natural gravel sample test results were compared with MRH technical specifications, it was discovered that the material was not compatible with the requirements for subbase layer but for base coarse it satisfied the plastic limit. Due to the deficiency of fine particles there was an inadequate CBR.

It was observed that the penetration values of CBR increased by having geogrids in the soil sample. It was observed that that T×170 offered better resistance to penetration. Thus, it was concluded that geogrids improve performance and impart strength to the roads.

2.5 Performance of Geosynthetics – Reinforced Asphalt Pavements

Hoe I. Ling and Zheng Liu

Geosynthetics are used for tensile reinforcement of soil but in case of unpaved roads, they are used as a separator for the aggregates and the foundation soil. In this research paper, the performance of road pavements has been studied when they are subjected to monotonic, cyclic and dynamic loading.

A geogrid was installed at the bottom of the asphalt layer. Asphalt was prepared on site with aggregates having D50 = 3 mm and C_u = 13.3 mm. The asphalt content was taken as 3.5%. The specimens were cured for 6 months prior to testing. Ottawa Sand with D50 = 0.25 mm and C_u = 1.65 mm was used in subgrade soil.

Two types of geogrids (biaxial polypropylene geogrid and uniaxial polyester geogrid) were used having same strength to compare the performance of both in road pavements.

Although the performance of asphalt pavement was improved with the geogrids but there was a problem in the rehabilitation and repair of the pavements. However, with more research and dedication it was found that the presence of geosynthetics reinforcement would not pose much technical difficulty during repairs or make the project very much uneconomical.

The results from static and dynamic loading tests indicated that the geosynthetics cause the stiffness and strength to increase.

Chapter 3

Research Methodology

3.1 Introduction

This purpose of this chapter is to discuss the methodology adopted to achieve the objectives of our research study, which includes the procurement of materials, preparation of the samples and various tests performed on the prepared samples. The research was carried out under controlled conditions.

The primary focus of the research was to determine the effect of geosynthetics on the shear strength and CBR value of the subgrade. Therefore, the procedure adopted for the preparation of samples and the input parameters used for the testing of specimens are discussed in this chapter.

The following methodology was adopted for carrying out the research:

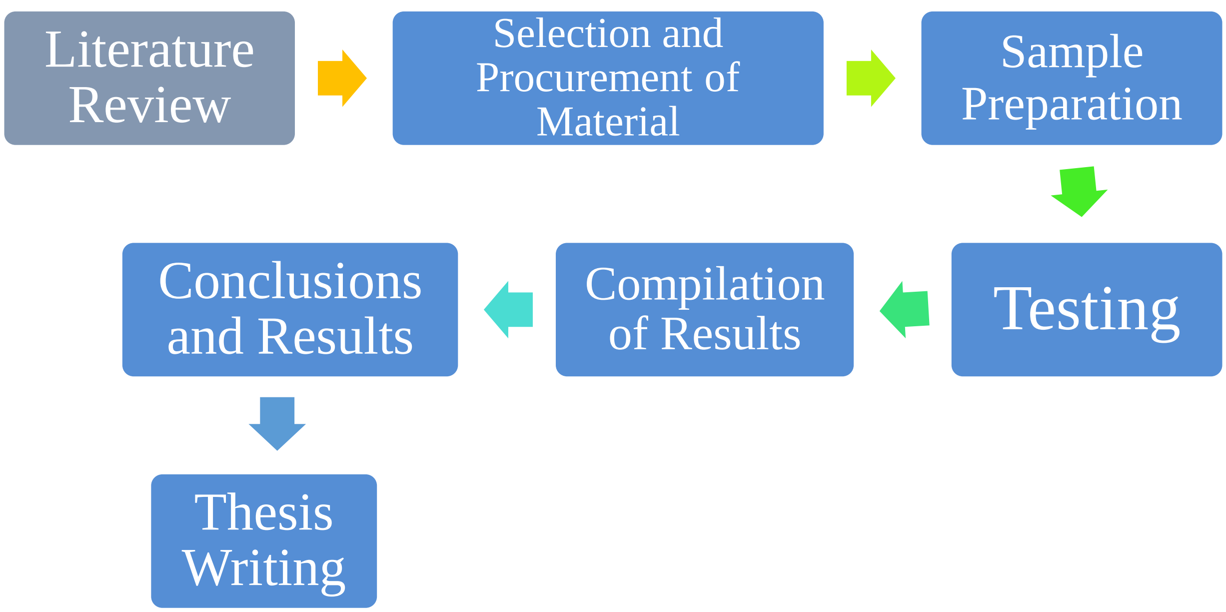

Figure 3.1 Research Methodology

3.2 General

Soil is the natural support on which the civil structures such as buildings, pavements. etc. are constructed. Soil is the loose mass of minerals available in excess over the crust of the earth that is generated mostly from the weathering of rocks.

The lower most part of the pavement is constructed with compacted soil and is known as subgrade. Road embankments are also constructed by excessive soil compaction. Studying the properties of soil is highly important in pavement engineering.

3.3 Procurement of Material

3.3.1 Soil

The soil was taken from the site of the under-going MetroBus Project near G-11 intersection in Islamabad. Both disturbed and undisturbed samples were obtained and brought to NIT lab.

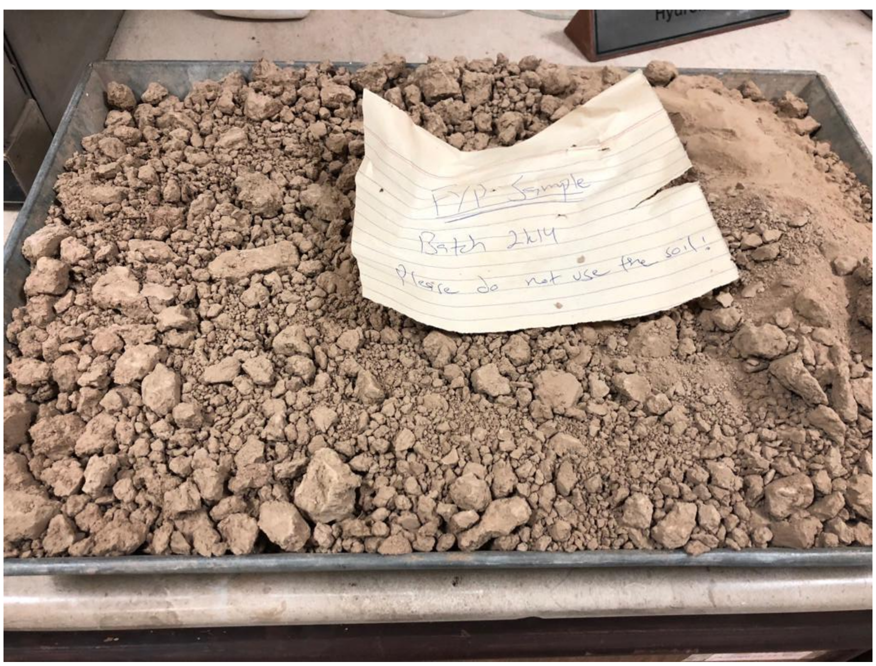

Figure 3.2 Soil Sample

3.3.2 Geosynthetics

We contacted multiple sources to get some information about the procurement of our required materials. We sent an email to City Scientific Center (Rawalpindi) who are known to be the importers of geosynthetics, they were not able to import the required geosynthetics. Afterwards, we asked some graduates of NICE who are employed at renowned organizations to provide some information regarding the procurement of geotextiles, geomembranes and geogrids. After great effort, we were able to procure our required materials from Geotech Lining in Lahore. They imported the geomembrane and geotextile from their suppliers in China.

We received 1 mm thick sheet of HDPE geomembrane and 250 g/m^2 sheet of non-woven geotextile from Geotech Lining.

3.4 Material Testing

Following tests were performed to determine the type of soil we were dealing with:

3.4.1 Sieve Analysis

Sieve analysis of soil is conducted to obtain the particle size distribution curve of soil. It is widely used in identification and classification of soil. It helps to determine the specification of soil in air fields, roads, earth dams and other soil embankment construction. Standard used to perform this test is AASHTO T88 and ASTM D422.

Sieve Number	Opening Size (mm)
4	4.750
6	3.350
8	2.360
12	1.680
16	1.180
20	0.850
30	0.600
40	0.425
50	0.300
60	0.250
80	0.180
100	0.150
140	0.106
200	0.075
270	0.053

Figure 3.3 Sieve Analysis

3.4.2 Hydrometer Analysis

Hydrometer analysis of soil is performed to determine grain size distribution of soil passing No. 200 sieve which is further used for classification of soil. The test is not applicable if less than 10% of the material passes through No.200 sieve. Standards used for the procedure are AASHTO T87-70 & T88-70 and ASTM 421-58 & D422-63. Sodium-Hexa-Meta-Phosphate or Sodium Silicate solution is added as a dispersing agent to the soil sample. After proper mixing of soil with dispersing agent in a mixer. The test is conducted in 1000 ml cylinder i.e. filled with water to the 1000ml mark.

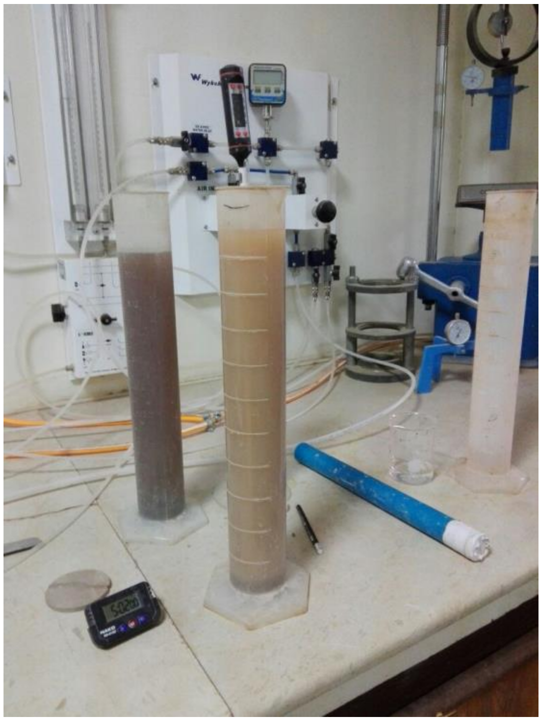

Figure 3.4 Hydrometer Analysis Apparatus

Hydrometer readings are taken at the following intervals of time: 1, 2, 3, 4, 8, 15, 30 minutes and 1, 2, 4 Hrs. along with the temperature readings. Hydrometer readings are taken at the top of the meniscus.

Where,

T is time in minutes

R is Hydrometer Reading with composite correction

L is effective depth of hydrometer in cm

D is diameter of soil particle

P is soil in suspension (%)

a is correction factor obtained from table

W is air dried weight of sample

K value is obtained from table

Hydrometer reading	L (cm)	Hydrometer reading	L (cm)
0	16.3	26	12.0
1	16.1	27	11.9
2	16.0	28	11.7
3	15.8	29	11.5
4	15.6	30	11.4
5	15.5	31	11.2
6	15.3	32	11.1
7	15.2	33	10.9
8	15.0	34	10.7
9	14.8	35	10.6
10	14.7	36	10.4
11	14.5	37	10.2
12	14.3	38	10.1
13	14.2	39	9.9
14	14.0	40	9.7
15	13.8	41	9.6
16	13.7	42	9.4
17	13.5	43	9.2
18	13.3	44	9.1
19	13.2	45	8.9
20	13.0	46	8.8
21	12.9	47	8.6
22	12.7	48	8.4
23	12.5	49	8.3
24	12.4	50	8.1
25	12.2	51	7.9

G_s	Temperature (°C)						
	17	18	19	20	21	22	23
2.50	0.0149	0.0147	0.0145	0.0143	0.0141	0.0140	0.0138
2.55	0.0146	0.0144	0.0143	0.0141	0.0139	0.0137	0.0136
2.60	0.0144	0.0142	0.1040	0.0139	0.0137	0.0135	0.0134
2.65	0.0142	0.0140	0.0138	0.0137	0.0135	0.0133	0.0132
2.70	0.0140	0. 0138	0.1036	0.0134	0.0133	0.0131	0.0130
2.75	0.0138	0.0136	0.0134	0.0133	0.0131	0.0129	0.0128
2.80	0.0136	0.0134	0.0132	0.0131	0.0129	0.0128	0.0126

G_s	a
2.50	1.04
2.55	1.02
2.60	1.01
2.65	1.00
2.70	0.99
2.75	0.98
2.80	0.97

Table 3.1. Correction Factors for Hydrometer Analysis

3.4.3 Atterberg Limits

The Atterberg limits of a soil are used to obtain general information about a soil and its strength, compressibility, permeability, shrinkage and swell properties of soil. To estimate consolidation settlement (where the limits are expressed in percentage, the compression index is used in determining the expected consolidation settlement in clay. These are also used for classification of soil and making construction specifications. Standards used are AASHTO T89-68 & T90-70 and ASTM D423-66 & D424-59. Casagrande apparatus is used to perform the test.

Figure 3.5 Atterberg Limits

3.4.4 Modified Compaction Test

Modified Compaction test or Modified Proctor test is used to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of soil. Compaction is done to remove air and to increase the density to obtain the moisture-density relationship for a given compactive effort on the soil. Standards used are AASHTO T99-70 & T180-70 and ASTM D698-70 & D1557-70. 2-3% of water is mixed in 7 kg of soil sample. Mixture is added to the standard proctor mould in 5 layers. Each layer is compacted with 25 distributed blows of a 4.54 kg rammer that falls from a height of 38 cm.

3.5 Characterization of Soil

Several parameters are used for the characterization of soil. Some of them are discussed below.

3.5.1 Resilient Modulus

The elastic modulus is an important parameter used in the analysis and design of a pavement structure. For soil and granular material, the equivalent term used is resilient modulus (M_R).

Figure shows a triaxial state of stress, to which a sample of soil, placed I a triaxial cell is subjected. To simulate the dynamic loading conditions as observed in the field due to traffic, the

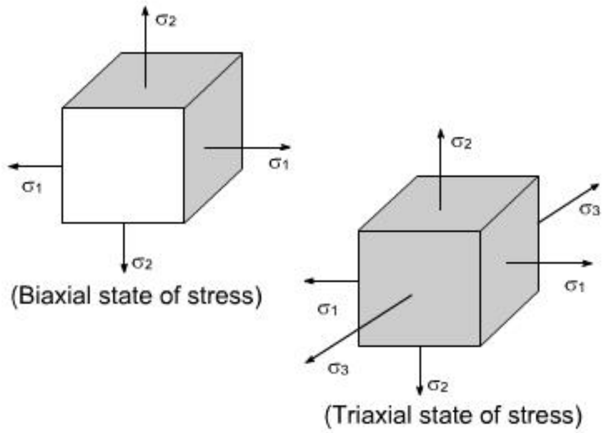

Figure 3.6 Triaxial State of Stress

stresses σ1 – σ3 (known as deviatoric stress or pressure) is made pulsating. This dynamic nature of triaxial testing is intended to match the loading and the unloading durations in the same way as they occur in the in-service road. Deformation of the sample occurs when the load is applied to it, and the recovery takes place when the load is removed.

During dynamic triaxial testing on soil or granular material, a fraction of the total strain is unrecoverable even when the load is removed this is known as permanent deformation.

The permanent deformation is prominent, when the sample is subjected to a large number of repetitions. On an in-service road as well, permanent deformation occurs due to repetitive traffic loading called rutting.

If the facilities for repeated triaxial test are not available, the M_R value of the subgrade soil may be estimated from its CBR value with the help of the following equations:

$M_R = 10CBR$ For CBR

$M_R = 17.6CBR^{0.64}$ For CBR

The M_R value obtained from these empirical formulae is in MPa unit.

3.5.2 Poisson's ratio

Poisson's ratio 'μ' is defined as the ratio of lateral strain ε_l to the axial strain ε_a, caused by a load parallel to the axis along which ε_a is measured. It is found for most of the pavement structures, the influence of μ value is normally small. This allows the use of typical constant values for analysis rather than direct testing. The μ values of clayey subgrade vary from 0.4 to 0.5 and a value of 0.5 is adopted for wet conditions. The μ values of saturated clays and sand can be taken as 0.5 to 0.35, respectively.

3.5.3 Permeability

Permeability of soil is the ease with which water can flow through it. It helps a designer to take into account the sub-surface drainage considerations of a pavement structure. The basic law of permeability, known as Darcy's law, is given by

$$Q = k \times i \times A$$

Where,

Q is the quantity of flow or discharge

k is the permeability of the media

i is the hydraulic gradient

A is the cross-sectional are perpendicular to the direction of flow

The coefficient of permeability is determined either in the laboratory by

- the constant head test
- the falling head test

In the field, pumping test is used for the determination of the coefficient of permeability. The factors affecting permeability of soil particles are particle size, shape, relative distribution (gradation), degree of saturation, degree of compaction, etc. For example, sand has a high coefficient of permeability whereas the permeability of clay is low. Permeability of soil can be increased by adding flocculants (e.g. lime, gypsum) and can be decreased by deflocculants (e.g. cement slurry).

3.6 Tests on samples

This section discusses the shear test, the CBR test, the plate load test, and the triaxial test for characterization of soil.

3.6.1 Shear test

Some of the shear strength tests are (i) direct shear test (ii) vane shear test, and (iii) triaxial shear test. In direct shear test the soil sample is put within a rectangular mould, sandwiched between two porous layers. The mould has some holes for drainage purpose. Normal pressure is applied to the mould and the upper half of the shear test box is moved gradually with the application of horizontal shear force till the sample fails. This failure load is measured for various values of normal loads.

The friction which is developed due to interlocking of particles, is contributed by larger soil particles. Thus, the angularity of particles and the degree of compaction affects the value of internal friction for a particular soil. For saturated clays, the angle of internal friction can be assumed to be zero. Clay particles have little friction; they contribute to shear strength in the form of cohesion which is the mutual attraction between the soil particles.

Direct shear test has the following demerits:

- Shear stress distribution is not uniform within the sample.
- The area of the sliding surface decreases as the test progresses.
- The horizontal plane of failure is an imposed one.

3.6.2 CBR Test

CBR test stand for California Bearing Ratio test. The CBR test procedure is very popular due to its simplicity and low cost for conducting test. The CBR test can also be performed for marginal aggregates. It is an ad hoc penetration test whose results are used to design pavements based on some experience-based curves plotted between CBR, thickness of the pavement, and the number of traffic repetitions.

For CBR test on the remolded sample, soil is compacted in the CBR mould (inner diameter 150mm) with optimum moisture content (determined from modified proctor test). This material should pass through the 20mm sieve. The larger size material, if present, is replaced by an equal amount of material passing through the 20mm sieve and retained by the 4.75 sieve. Compaction of the soil sample is doe either by static or by dynamic methods as follows:

- In the static method, a calculated quantity of soil mixed with requisite moisture is put into the mould in such a way that after the desired level of compaction it occupies exactly the volume up to the top level of the collar. After initial tamping with a steel rod, a filter paper is put on the soil sample ad the displacer disc is placed above it. Soil is compacted with a compression machine until the top of the displacer disc flushes with the top collar of the mould.
- In the dynamic method, soil mixed with required moisture content is compacted into the mould in three layers using the standard soil rammer. For the subgrade soil intended for pavement constructions, heavy compaction (as per modified proctor density) is used for heavily trafficked roads such as national highways, expressways, or major district roads. In other cases, standard compaction is adopted.

The mould is kept immersed in water for four days. While immersed, a weight, equivalent to the expected surcharge on subgrade by the pavement, is loaded on the sample. Swelling of the sample is measured by a dial gauge fixed over the sample. The mould, after four days of soaking is taken out and water is allowed to drain off. The sample, along with the surcharge, is then subjected to loading in the CBR equipment.

Figure 3.7 Soaked CBR Mould

In the CBR test, a plunger of diameter 50mm penetrates the mould of diameter 50mm, at the rate of 1.25mm/min where the soil sample is placed.

Figure 3.8 CBR Apparatus

The load values correspond to the penetration values of 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm are measured and plotted on graph. The curve obtained may be of two possible types:

- The smooth curve B in which the penetration increases as the pressure is increased and later the rate of increase of pressure gradually decreases. This case requires no further correction to the plot.
- The load does not increase or increases only slightly with the initial increase in penetration, though later, of course, the load starts increasing. This situation may arise when the loading is slightly inclined or the sample has surface irregularities. Some seating load is thus required after which the soil sample starts taking the load. The nature of the curve obtained is shown in curve A. In this case a correction needs to be applied before proceeding to calculate the CBR value. A tangent is drawn to the point on the curve where the change of direction of curvature takes place. The point where the tangent touches the x-axis is taken as the new origin and axes are shifted to that point.

The standard aggregates are the aggregates from California on which the CBR test was actually evolved and the values for the pressure sustained by them are 70 kg/cm2 and 105 kg/cm2 for 2.5 mm and 5.0 mm penetration respectively.

Generally, the 2.5 mm CBR value is found to be greater than the 5 mm CBR value. If it is not so, the test is repeated. If the repetition test also yields the 5 mm CBR value to be greater than the 2.5 mm CBR value, then the 5 mm CBR value is chosen as the CBR value of the sample.

3.6.3 Plate Load Test

The plate load test provides the value of the modulus of subgrade reaction of the subgrade soil and the bearing capacity of soil. It is also used for estimation of elastic modulus of subgrade.

The modulus of subgrade reaction k is defined as the pressure sustained per unit deformation of subgrade at the specified deformation or pressure level, with the specified plate size used in plate load test. Physically, it is similar to the spring constant of soil. We were unable to perform this test because of the unavailability of the required equipment in the NIT Lab.

3.6.4 Triaxial test

The triaxial test is conducted on a cylindrical specimen where the length of the sample is generally twice its diameter. A vertical pressure $\sigma1$ is applied from the top and a uniformly distributed pressure $\sigma3$ in the form of fluid pressure, is applied along the curved surface of the specimen. The term $\sigma1-\sigma3$ is the deviatoric pressure, and $\sigma3$ called the confining pressure. In the triaxial testing, various values correspond to $\sigma3$ values, for the failure of the sample due to shear, are noted, and accordingly the Mohr Rupture envelope is obtained. The failure envelope is then used to calculate the c and φ values of the sample. Depending on various drainage and consolidation conditions, different sets of results may be obtained from the triaxial test. The subgrade conditions in pavement generally correspond to the consolidated, undrained situation. In a dynamic triaxial test, the deviatoric stress, $\sigma1-\sigma3$, is made pulsating so as to simulate the traffic loading conditions. This test is used to determine the resilient modulus of soil or of the granular material sample. If the confining pressure is not applied, the test is called the Unconfined Compressive Strength (UCS) test. The UCS tests are generally used for the strength estimation of the cemented materials.

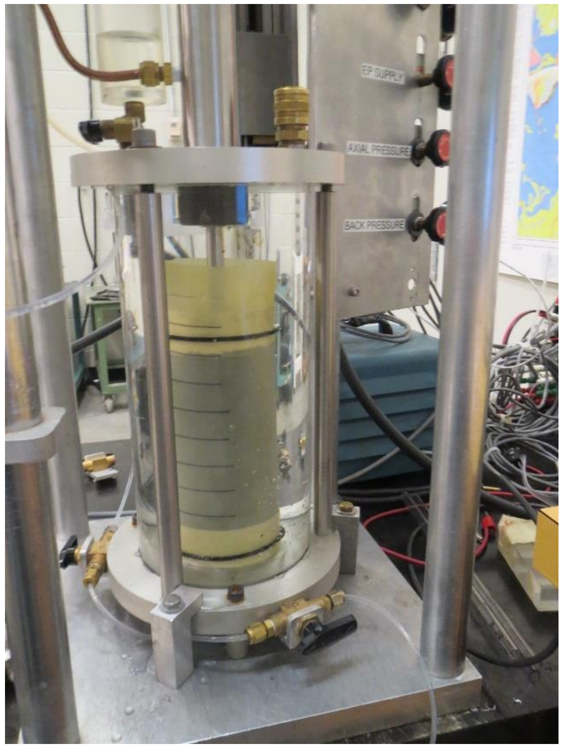

Figure 3.9 Triaxial Test Apparatus

3.7 Software

The software we used is Composite Geosynthetic – Base Course Model. This software was developed by National Cooperative Highway Research Program (NCHRP) in 2017 to quantify the influence of geosynthetics on pavement performance This software basically compares the strains in the base and HMA surfaces for reinforced and unreinforced pavements. The input parameters used in the software were selected according to the guidelines of AASHTO.

Material	**Resilient Modulus (MR)**	
MPa	**psi**	
HMA at 32°F (0 °C)	14,000	2,000,000
HMA at 70°F (21 °C)	3,500	500,000
HMA at 120°F (49 °C)	150	20,000

Table 3.2. Resilient Modulus of HMA

Material	Elastic Modulus	
	MPa	psi
Diamond	1,200,000	170,000,000
Steel	200,000	30,000,000
Aluminum	70,000	10,000,000
Wood	7,000-14,000	1,000,000-2,000,000
Crushed Stone	150-300	20,000-40,000
Silty Soils	35-150	5,000-20,000
Clay Soils	35-100	5,000-15,000
Rubber	7	1,000

Table 3.3. Elastic Modulus of Different Materials

Chapter 4

Results and Analysis

4.1 General

The main purpose of this research was to analyze the effect of different geosynthetics in the subgrade of the pavement. Furthermore, a comparison of the design life and price between a normal subgrade and a subgrade reinforced with geosynthetics was to be done.

Initially, various tests were performed to determine the type of soil that we were using to prepare our samples. After the characterization of the soil, three different tests were performed to determine the CBR value, permeability and shear strength of the soil.

4.2 Characterization of Material

Several tests were performed in the soil laboratory to determine the physical properties of the soil sample obtained from the MetroBus project site. A summary of the results of these tests is shown in table 4.1.

Test Description	**Specification Reference**		**Result**
Sieve Analysis	ASTM D 422		**Fines = 11.3%**
Hydrometer Analysis	ASTM D 421-58 & D 422-63		**Silty soil**
Atterberg Limits	L. L	ASTM D 423-66	**22.5%**
	P. L	ASTM D 424-59	**11%**
Modified Compaction Test	ASTM D 1557-70		**MDD = 1.99 g/cm^3** **OMC = 8.8%**

Table 4.1. Characterization of Material

Using these results and the soil classification tables provided by AASHTO, it was concluded that the soil we were dealing with was high-plasticity clay (CH).

4.3 CBR Test Results

After the classification of soil, CBR test was conducted. Both soaked and unsoaked CBR values were determined for the virgin sample, the sample reinforced with geomembrane and the sample reinforced with geotextile. It is to be noted that the geomembrane and geotextile sheets were placed after compacting two layers of soil in the mould. The results of these tests are tabulated below.

4.3.1 CBR Results for Virgin Sample

Penetration (mm)	Load (kN)	Stress (kN/sq in)
0.64	0.207	0.069
1.27	0.341	0.113667
1.91	0.49	0.163333
2.54	0.65	0.216667
3.18	0.849	0.283
3.82	1.075	0.358333
4.46	1.3	0.433333
5.08	1.502	0.500667
5.72	1.734	0.578
6.36	1.972	0.657333
7	2.223	0.741
7.62	2.474	0.824667

Table 4.2. Unsoaked CBR Test Results for Virgin Sample

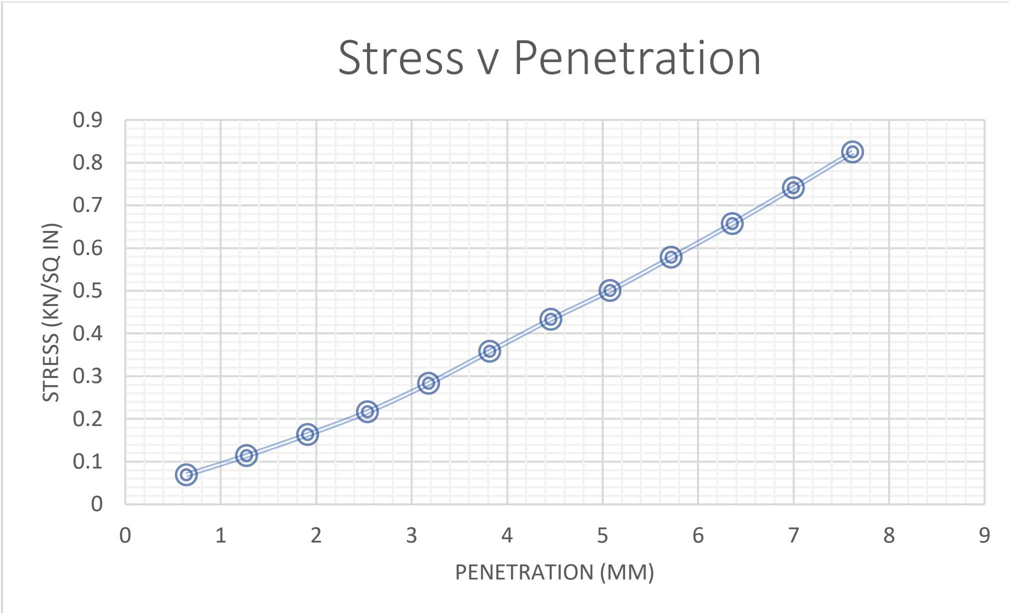

Figure 4.1 Stress vs. Penetration graph for Table 4.2

From the graph shown in Fig 4.1, the unsoaked CBR value of the virgin sample was calculated to be 7.5%.

Penetration (mm)	Load (kN)	Stress (kN/sq in)
0.64	0.1904	0.063467
1.27	0.313	0.104333
1.91	0.4508	0.150267
2.54	0.598	0.199333
3.18	0.781	0.260333
3.82	0.989	0.329667
4.46	1.196	0.398667
5.08	1.381	0.460333
5.72	1.595	0.531667
6.36	1.814	0.604667
7	2.045	0.681667
7.62	2.27	0.756667

Table 4.3. Soaked CBR Test Results for Virgin Sample

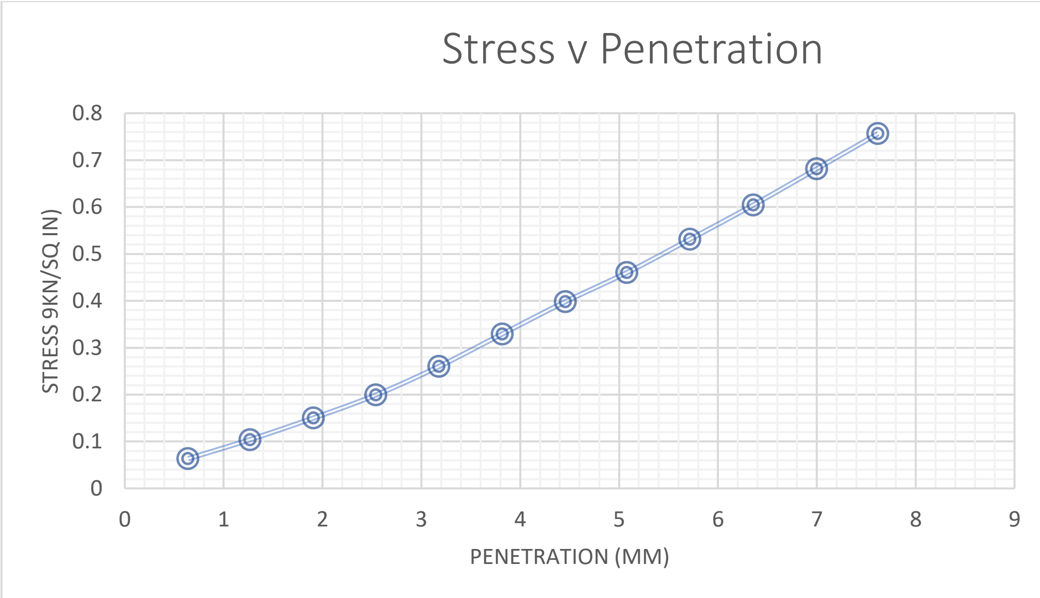

Figure 4.2 Stress vs. Penetration graph for Table 4.3

From the graph shown in Fig 4.2, the soaked CBR value of the virgin sample was calculated to be 6.89%.

4.3.2 CBR Results for Geomembrane Sample

Penetration (mm)	Load (kN)	Stress (kN/sq in)
0.64	0.215	0.071667
1.27	0.37	0.123333
1.91	0.555	0.185
2.54	0.732	0.244
3.18	0.94	0.313333
3.82	1.156	0.385333
4.46	1.391	0.463667
5.08	1.617	0.539
5.72	1.869	0.623
6.36	2.114	0.704667
7	2.369	0.789667
7.62	2.624	0.874667

Table 4.4. Unsoaked CBR Test Results for Geomembrane Sample

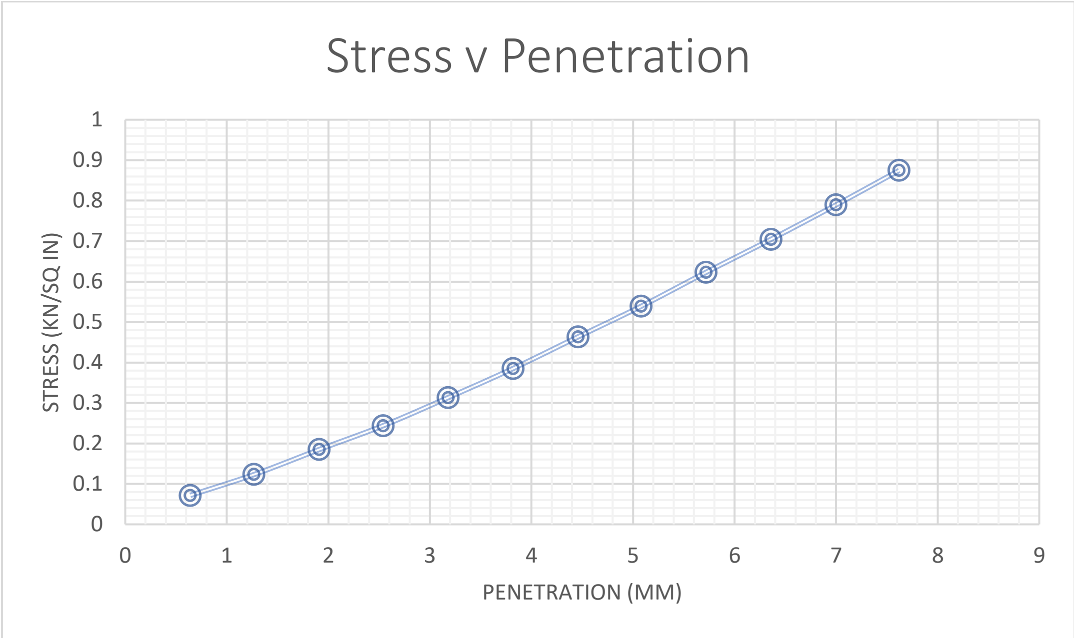

Figure 4.3 Stress vs. Penetration graph for Table 4.4

From the graph shown in Fig 4.3, the unsoaked CBR value of the geomembrane sample was calculated to be 8.07%.

Penetration (mm)	Load (kN)	Stress (kN/sq in)
0.64	0.191	0.063667
1.27	0.329	0.109667
1.91	0.493	0.164333
2.54	0.651	0.217
3.18	0.836	0.278667
3.82	1.02	0.34
4.46	1.237	0.412333
5.08	1.439	0.479667
5.72	1.663	0.554333
6.36	1.881	0.627
7	2.108	0.702667
7.62	2.335	0.778333

Table 4.5. Soaked CBR Test Results for Geomembrane Sample

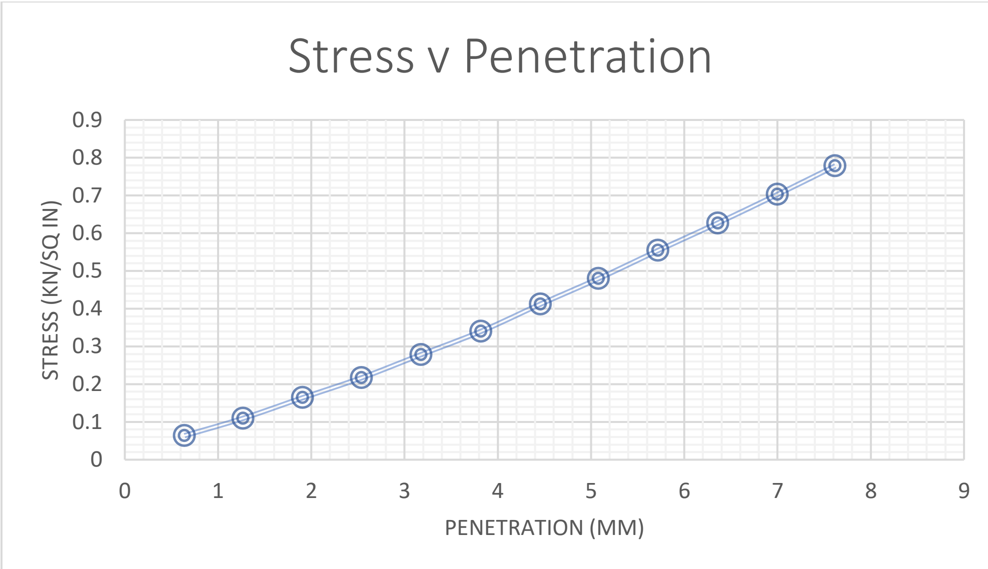

Figure 4.4 Stress vs. Penetration graph for Table 4.5

From the graph shown in Fig 4.4, the soaked CBR value of the geomembrane sample was calculated to be 7.19%.

4.3.3 CBR Results of Geotextile Sample

Penetration (mm)	Load (kN)	Stress (kN/sq in)
0.64	0.201025	0.067008
1.27	0.34595	0.115317
1.91	0.518925	0.172975
2.54	0.68442	0.22814
3.18	0.8789	0.292967
3.82	1.08086	0.360287
4.46	1.300585	0.433528
5.08	1.511895	0.503965
5.72	1.747515	0.582505
6.36	1.97659	0.658863
7	2.215015	0.738338
7.62	2.45344	0.817813

Table 4.6. Unsoaked CBR Test Results for Geotextile Sample

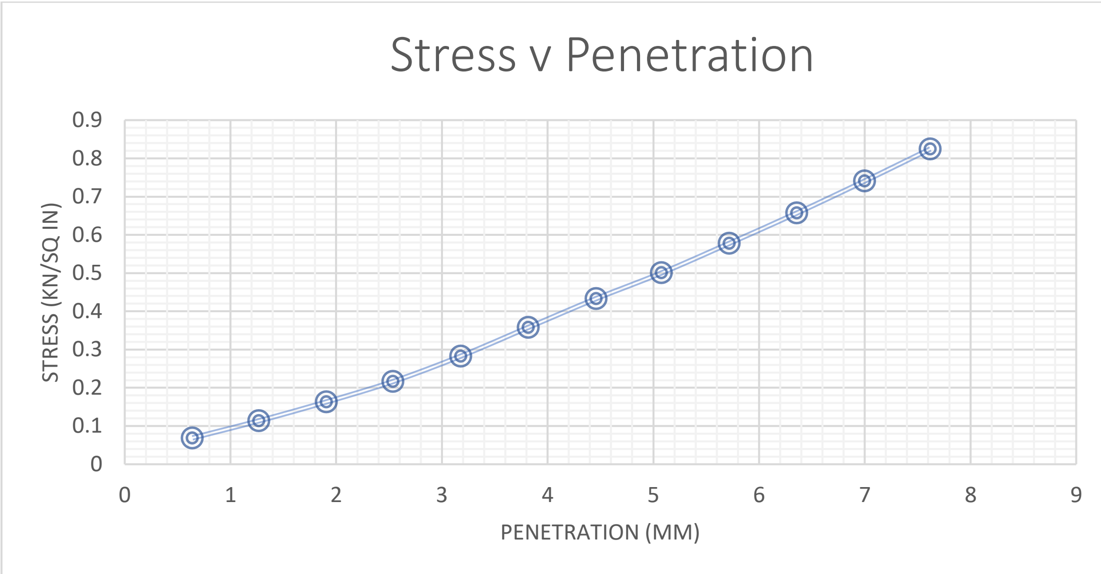

Figure 4.5 Stress vs. Penetration graph for Table 4.6

From the graph shown in Fig 4.5, the unsoaked CBR value of the geotextile sample was calculated to be 7.54%.

Penetration (mm)	Load (kN)	Stress (kN/sq in)
0.64	0.182784	0.060928
1.27	0.30048	0.10016
1.91	0.432768	0.144256
2.54	0.57408	0.19136
3.18	0.74976	0.24992
3.82	0.94944	0.31648
4.46	1.14816	0.38272
5.08	1.32576	0.44192
5.72	1.5312	0.5104
6.36	1.74144	0.58048
7	1.9632	0.6544
7.62	2.1792	0.7264

Table 4.7. Soaked CBR Test Results for Geotextile Sample

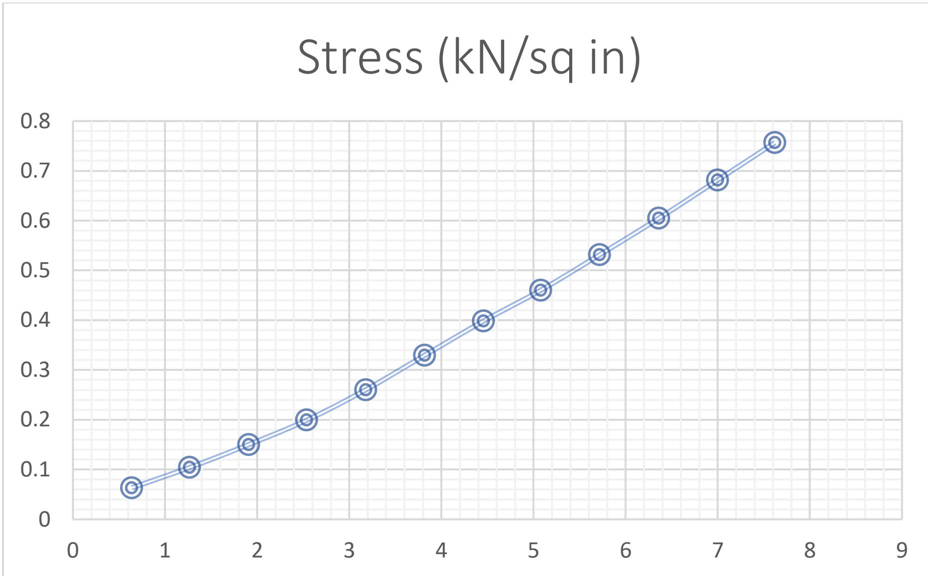

Figure 4.6 Stress vs. Penetration graph for Table 4.7

From the graph shown in Fig 4.6, the soaked CBR value of the geotextile sample was calculated to be 6.64%.

4.4 Triaxial Test Results

After performing the CBR tests, triaxial tests were conducted to determine the shear strength parameters of the soil. Two basic shear strength parameters (i.e. angle of friction ‘φ’ and coefficient of friction ‘c’) were determined using the triaxial test. These tests were performed in the soil laboratory of NUST Institute of Civil Engineering under controlled conditions. The results of these tests are discussed in the following lines.

4.4.1 Triaxial Results for Virgin Sample

After plotting the Mohr – Coulomb graph using the data obtained from the triaxial test for the virgin sample, the angle of friction ‘φ’ and coefficient of friction ‘c’ were calculated to be 2.4° and 11.75, respectively.

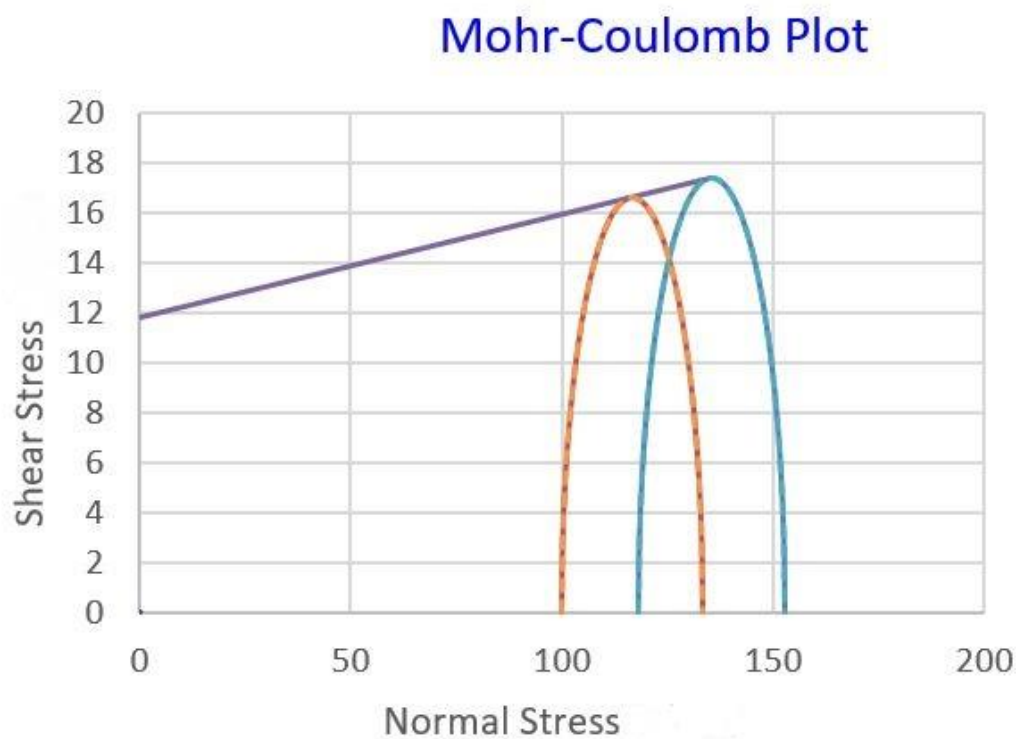

Figure 4.7 Mohr – Coulomb Plot for Virgin Sample

4.4.2 Triaxial Results for Geomembrane Sample

After plotting the Mohr – Coulomb graph using the data obtained from the triaxial test for the geomembrane sample, the angle of friction ‘φ’ and coefficient of friction ‘c’ were calculated to be 3.4° and 8.72, respectively.

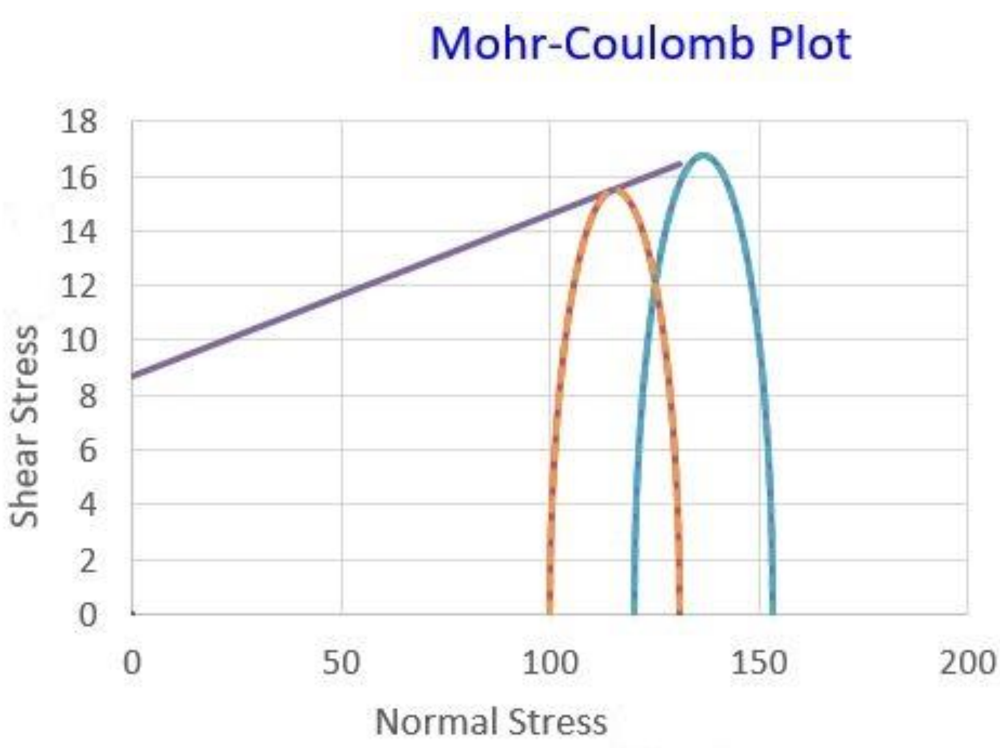

Figure 4.8 Mohr – Coulomb Plot for Geomembrane Sample

4.4.3 Triaxial Results for Geotextile Sample

After plotting the Mohr – Coulomb graph using the data obtained from the triaxial test for the geotextile sample, the angle of friction ‘φ’ and coefficient of friction ‘c’ were calculated to be 4.9° and 6.38, respectively.

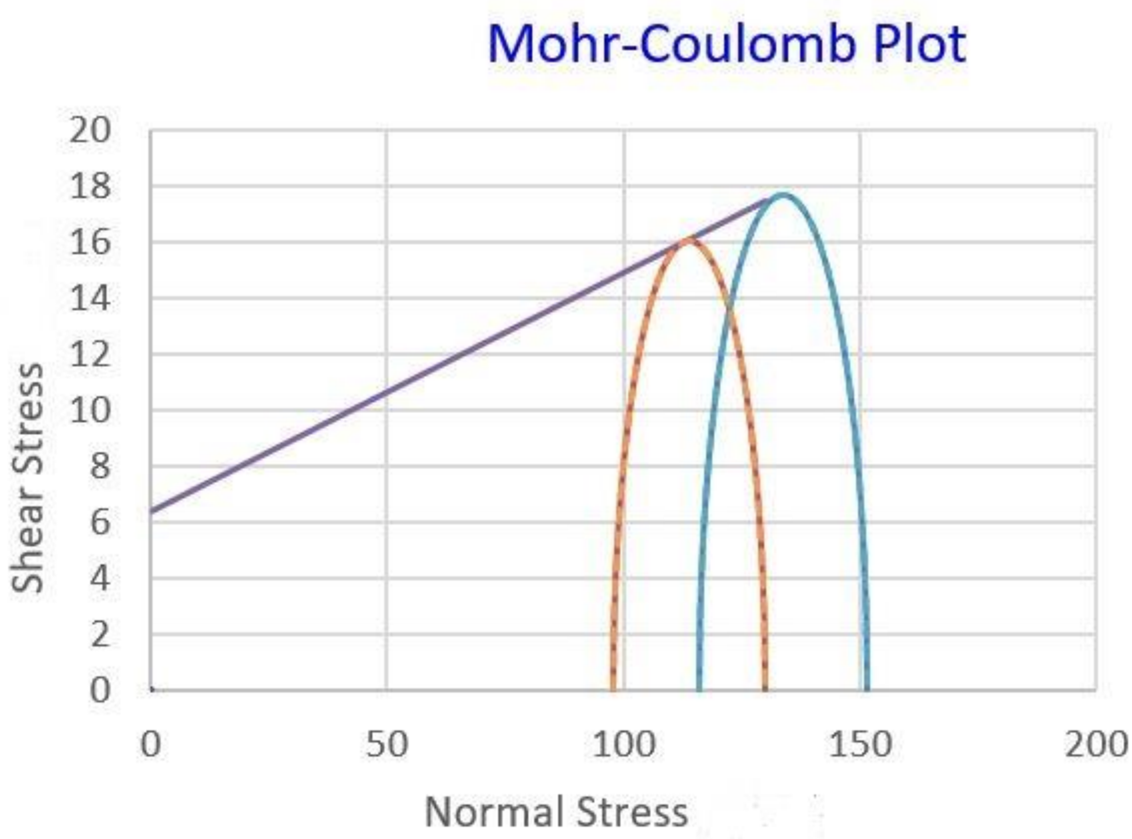

Figure 4.9 Mohr – Coulomb Plot for Geotextile Sample

4.5 Permeability Test Results

Lastly, to determine the co-efficient of permeability of the samples, we performed permeability test suing the falling head method. This test was performed in the soil laboratory of NUST Institute of Civil Engineering. Undisturbed soil samples from the site were obtained for performing this test.

The results of the permeability tests conducted on virgin sample, geomembrane sample and geotextile sample are tabulated below:

Sample	**Co-efficient of Permeability (at 20 °C)**
Virgin Sample	0.000519 cm/sec
Geomembrane Sample	≈ 0 cm/sec
Geotextile Sample	0.000413 cm/sec

Table 4.8. Co-efficient of Permeability of Various Samples

4.6 Software Results

We used Composite Geosynthetic – Base Course Model for comparing the strains in the base and HMA surfaces for reinforced and unreinforced pavements. This software was developed by National Cooperative Highway Research Program (NCHRP) at Texas A & M in 2017 to quantify the influence of geosynthetics on pavement performance. The input parameters used in the software were selected according to the guidelines of AASHTO.

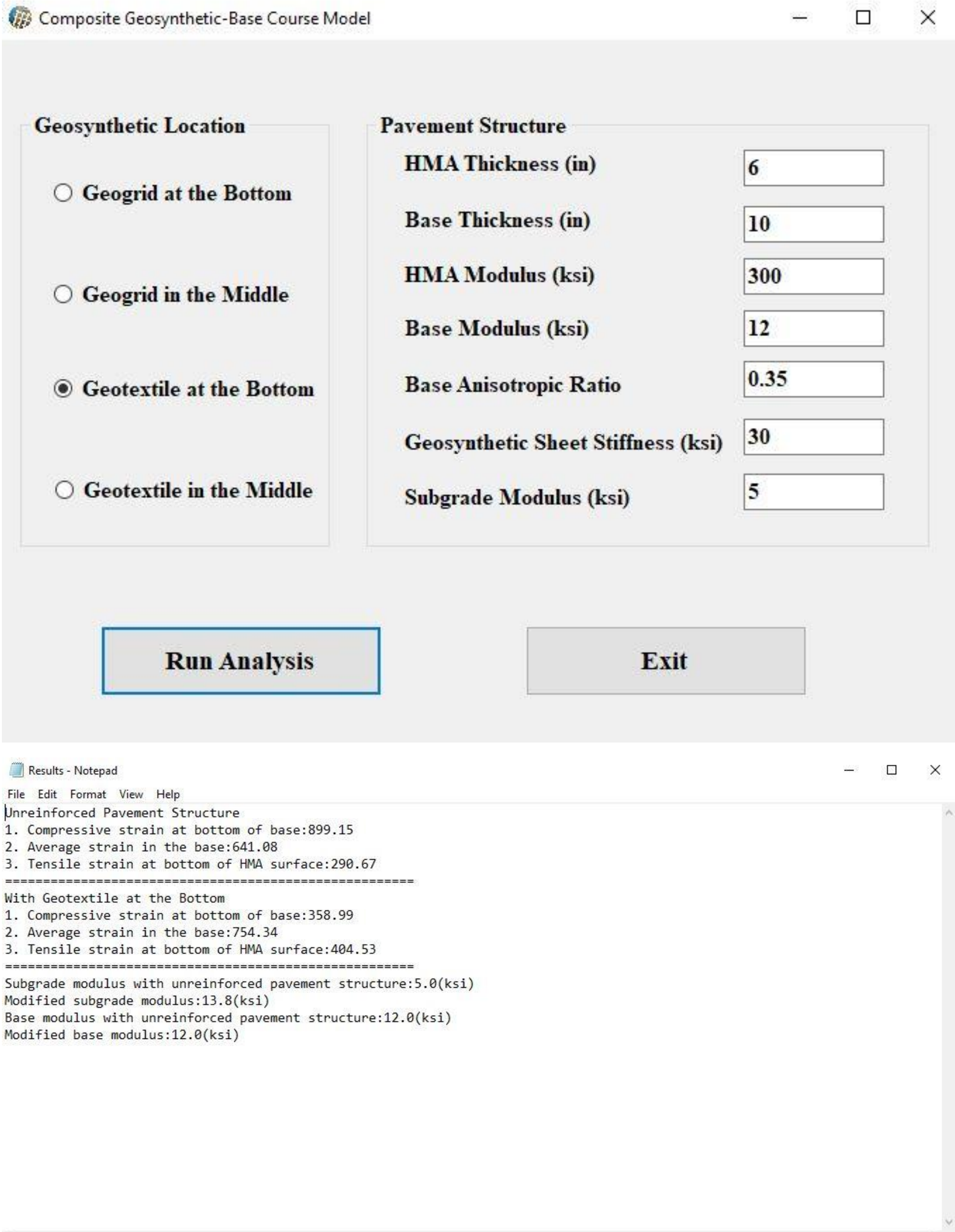

Figure 4.10 Input Parameters and Results of Software Analysis

4.7 Summary

In this chapter, a detailed analysis of the results of several tests performed for our research study were discussed. Furthermore, these results were represented either in form of tables or graphs. The standards and the procedures adopted while performing the tests were also discussed briefly.

Chapter 5

Conclusions and Recommendations

5.1 Summary

Our final year project was primarily aimed at studying, analyzing and comparing the effects of different geosynthetics on the properties of the subgrade and proposing a geosynthetic that is both cost-effective and significantly increases the design life of the pavement. The methodology discussed in Chapter 3 was employed to achieve the objectives of our research. This particular chapter discusses the conclusions drawn from our study.

5.2 Conclusions

The conclusions that were drawn from the test results and software analysis discussed in the previous sections are listed below:

- The use of geomembrane and geotextile in the subgrade results in a slight increase in the shear capacity and load bearing capacity of clayey soil.
- By using geomembranes, the CBR value increased by 7.6 % for unsoaked CBR test.
- There is very little increase in the CBR value of soil when geotextiles are used in the subgrade. The CBR value increased by just 1 % for unsoaked CBR test when geotextiles were used.
- A geomembrane sheet effectively resists the flow of water.
- The use of geotextiles results in a decrease in the permeability of the soil. The permeability of soil decreased by 20% when geotextiles were introduced.
- The cohesion decreased by 26 % and the angle of friction increased by 42 % when a sheet of geomembrane was introduced in the soil.
- Geotextiles also have some impact on the shearing properties of soil. The cohesion decreases by 58.29 % and the angle of friction increases by 62.38 %.

5.3 Discussion

After a careful and thorough analysis of the conclusions listed above, we can say that it is not economical to use geosynthetics in clayey soils as they will just add to the initial construction cost of the pavement without any significant increase in the shear strength and load bearing capacity of the subgrade. However, if geosynthetics are used in sandy soils, the results might be different from the ones obtained in this research study.

5.4 Limitations

There are a few limitations in the results of this research study, which are listed below:

- The main purpose of this research was to study the effect of geogrids in subgrade. However, we were unable to procure the required geogrids from local suppliers.
- Several other tests are required to fully understand the behavior of geosynthetics when they are introduced in a pavement. The testing apparatus needed to perform these tests was not available.
- Cyclic triaxial test gives a better understanding of the shear strength of the subgrade material as the subgrade experiences cyclic loads during its design life. Cyclic triaxial test could also not be performed due to the unavailability of equipment.

5.5 Recommendations

- Further research should be conducted to understand the effects of geosynthetics in different types of soils.
- Further research should be conducted to understand the effects of geosynthetics when they are placed between different layers of an asphalt pavement.
- The effects of tensar geogrids in the subgrade should be analyzed.

References

ZORNbERG, J. G. (2011). Advances in the use of geosynthetics in pavement design. Geosynthetics India, 11, 23-24.

Imjai, T., Guadagnini, M., & Pilakoutas, K. (2015). Advanced Geosynthetics in Flexible Pavement: A Full-Scale Test and Numerical Study.

Adams, C. A., Apraku, E., & Opoku-Boahen, R. (2015). Effect of triaxial geogrid reinforcement on CBR strength of natural gravel soil for road pavements. *Journal of Civil Engineering Research*, *5*(2), 45-51.

Ling, H. I., & Liu, Z. (2001). Performance of geosynthetic-reinforced asphalt pavements. *Journal of Geotechnical and Geoenvironmental Engineering*, *127*(2), 177-184.

Luo, R., Gu, F., Luo, X., Lytton, R. L., Hajj, E. Y., Siddharthan, R. V., ... & Pournoman, S. (2017). *Quantifying the Influence of Geosynthetics on Pavement Performance* (No. NCHRP Project 01-50).

Al-Qadi, I. L., Brandon, T. L., Valentine, R. J., Lacina, B. A., & Smith, T. E. (1994). Laboratory evaluation of geosynthetic-reinforced pavement sections. Transportation Research Record, (1439).

Mallick, R. B., & El-Korchi, T. (2017). *Pavement engineering: principles and practice*. CRC Press.

Ai-Qadi, I., & Appea, A. (2003). Eight-year field performance of secondary road incorporating geosynthetics at subgrade-base interface. *Transportation Research Record: Journal of the Transportation Research Board*, (1849), 212-220.

Al-Qadi, I. L. (2002, September). The proper use of geosynthetics in flexible pavements. In *GEOSYNTHETICS: STATE OF THE ART-RECENT DEVELOPMENTS. PROCEEDINGS OF THE SEVENTH INTERNATIONAL CONFERENCE ON GEOSYNTHETICS, 7-ICG, HELD 22-27 SEPTEMBER 2002, NICE, FRANCE.* (Vol. 3).

Koerner, R. M. (2012). *Designing with geosynthetics* (Vol. 1). Xlibris Corporation.

Han, J., & Gabr, M. A. (2002). Numerical analysis of geosynthetic-reinforced and pile-supported earth platforms over soft soil. *Journal of geotechnical and geoenvironmental engineering*, *128*(1), 44-53.

Hight, D. W., & Stevens, M. G. H. (1982). An analysis of the California Bearing Ratio test in saturated clays. *Geotechnique*, *32*(4), 315-322.

Bowles, J. E. (1970). *Engineering properties of soils and their measurement* (No. 187 pp).

Alan Bishop, W., & Henkel, D. J. (1957). *The measurement of soil properties in the triaxial test*. Edward Arnold (Publishers) Ltd; London.

Silver, M. L., Chan, C. K., Ladd, R. S., Lee, K. L., Tiedemann, D. A., Townsend, F. C., ... & Wilson, J. H. (1976). Cyclic triaxial strength of standard test sand. *Journal of Geotechnical and Geoenvironmental Engineering*, *102*(ASCE# 12145 Proceeding).

Daniel, D. E. (1983). Permeability test for unsaturated soil. *Geotechnical testing journal*, *6*(2), 81-86.

Gibson, R. E. (1970). An extension to the theory of the constant head in situ permeability test. *Géotechnique*, *20*(2), 193-197.

Nunn, M. (1997). Long-life flexible roads. In *Eighth International Conference on Asphalt PavementsFederal Highway Administration* (No. Volume I).

Furniss, M. J., Roelofs, T. D., & Yee, C. S. (1991). Road construction and maintenance. *American Fisheries Society Special Publication*, *19*, 297-323.

Zornberg, J. G., & Gupta, R. (2009, October). Reinforcement of pavements over expansive clay subgrades. In *Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering* (Vol. 1, pp. 765-768).