EXPERIMENTAL STUDIES ON PHYSICAL MODEL OF A ROAD EMBANKMENT REINFORCED WITH GEOSYNTHETICS AND VERIFYING THROUGH PLAXIS SOFTWARE VER 8.6

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I, Yogesh, Roll No. 2K20/GTE/20 of M.Tech. GEOTECHNICAL ENGINEERING, hereby declare that the project Dissertation titled **"EXPERIMENTAL STUDIES ON PHYSICAL MODEL OF A ROAD EMBANKMENT REINFORCED WITH GEOSYNTHETICS AND VERIFYING USING PLAXIS SOFTWARE VER 8.6"** which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of technology, is original and not copied from any source without proper citation. This work has not been used for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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ABSTRACT

It is a well known fact that soil is a weak material in tension. It is a material that can bear pressure and shear loads but is not stable in front of tensile loads. When it comes to road embankments,weak subgrades are a common problem in road construction. Whether it is a temporary access road or a permanent road built over a weak subgrade, a large deformation of the subgrade can lead to deterioration of the paved or unpaved surface. Due to less shear strength and high compressibility of soft soils, construction of soil embankment on these types of soils leads to problems such as big and non-uniform settlements. Reinforcing soil is one of the effective and trustable method for improvement and treatment of soil properties. Soils reinforcements are composite materials which include elements that can bear tensile loads. Soil reinforcements are used at different issues such as earth dams, slopes or retaining walls and even on stabilization of soil layers under shallow foundation or embankments of roads.

Usage of geosynthetics for increasing height of embankments and their stability has been increased significantly in recent years. Using geosynthetics cause decrease of tensile weaknesses and make the soil more stable by decreasing the settlement of it. Geosynthetics reinforcements can be divided into groups of geo-membranes,geo-textiles, geo-grids, geo-nets and geo-composites. They are used vastly because of economic reasons and easy application at reinforcing structures like embankments, dams and slope. Due to inceasing traffic at recent years, many of road embankments have been made on soft soils. As a consequence of this, engineers have been encountering different problems such as settlement and instability of slopes, so,we go for geotextiles as a trustable material for reinforcing and improving the soil properties. Geosynthetics reinforcement has special effect on increasing the safety factor of slopes.

A physical model is prepared in the laboratory which includes the similarity of model size and material used in test and test is performed to examine the failure mechanism occurred by the movement of vehicles on the road. Numerical Modelling has also been done to analyze the deformations and stability of the road slope using PLAXIS 2D software.

The study shows that geogrids are an effective tool to enhance the stability of the road embankment. They make the soil stronger in tension. They reduce the deformation of the slope. They restrain the movement of the slope in horizontal direction thus, enhancing the stability. It shows a comparison between the unreinforced and the reinforced slopes.

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List of Abbreviations/symbol

Symbol	Title
kN	Kilo Newton
mm	Millimeter
hr	Hour
Kg	Kilogram
Ø	Angle of internal friction
C	Cohesion
E	Modulus of elasticity
OMC	Optimum Moisture Content
MDD	Maximum Dry Density
G	Specific gravity
γ	Unit Weight
E	Void ratio
W	Water content
W	Weight of soil
W_s	Weight of solids
W_w	Weight of water
V	Volume of soil
γ_w	Unit weight of water
W_l	Liquid limit
W_P	Plastic limit
γ_d	Dry unit weight
γ_{sat}	Saturated unit weight
γ_b	Bulk unit weight

CHAPTER 1

INTRODUCTION

1.1.GENERAL

1.1.1 Road embankment

Roads have been playing the role of an interlinking network since many years. Roads and highways are one of the important part of today's social and economic development. At the earliest, roads were nothing but a trail formed by people moving on the same path repeatedly.Highway development begun from Roman roads, Tresaguet method of construction, Metcalf method of construction, telford method of construction and continued upto Macadam method of construction.

The embankment is made up of a set of compressed sheets or rises of suitable material that are stacked on top of one another until the subgrade surface level is attained. The apex of the embankment is the subgrade surface, which is where the sub-base is placed. An embankment can be built out of any suitable material. The aforementioned are the elements of embankment construction:

• Lift Thickness

• Material

• Compressed Level

The size and type of compaction equipment being used by contractor determines the thickness of the lift. For several types of compaction equipment, like pressurised crushers, vibration drums crushers, divided padded wheel, or smooth steel wheel rollers, the Standard Specifications state the greatest free lifts thickness and mechanical need.

The subgrade of a road is composed of soil. As it is known to us that soil is a weaker material in tension, so, we need to find a solution to this issue. The low tensile strength and the insufficient bearing capacity are two main reasons for the failure of pavements. This occurs due to extreme vehicular laods particularly. This failure can be seen in the form of permanent vertical deformation in the entire length of the road. This reduces the service life of highways.

In such circumstances, it becomes essential to boost the weak subgrade or enhance the stiffness of base course. To achive this motive, we can use geosynthetic as a base and sub-base strengthening material for flexible pavement structures. This use of geosynthetics has expanded a lot in the previous years.

1.1.2 Geosynthetics

All synthetic materials utilised in conjunction with soil, rock, or other civil and structural material are referred to as geosynthetics.These are "geopolymers" really. The geosynthetics products are almost polymeric. They are available in a variety of forms in the market, each with its own set of trade names/designations, and are mostly used in geotechnical, environmental, hydraulic, and transportation engineering fields.

1.1.2.1 Types of geosynthetics

a) Geotextiles

The geosynthetic is permeable and comes in the shape of flexible sheets made of polymeric textiles. The geotextiles available today are divided into three categories based on their manufacturing process:

- Woven geotextiles
- Non-woven geotextiles
- Knitted geotextiles
- Stitch-bonded geotextiles

Fig.1.1 Geotextiles(Source : Google images)

b) Geogrids

Geogrid is a mesh-like polymeric planar product made up of crossing components called rib that are connected at the junctions. Extrusion, bonding, or interlacing can be used to connect the ribs, as well as the resulting geogrids are known as extruded geogrid, bonded geogrid, and woven geogrid, respectively. The holes between both the transverse and longitudinal ribs, known as openings, are large enough to justify interlock with surrounding soil particles, which is a critical aspect of geogrids. Extended ellipses, located close with rounded edges, squares, and rectangles are the shapes of the apertur s. The openings range in size from around 2.5 to 15 cm. When compared to geotextile fibres, geogrid ribs are frequently fairly stiff. In the case of geogrids, junction strength is also significant since load is transferred through one kind of rib to the other through these junctions when they are installed in the soil. Extruded geogrids are classified according to the orientation of stretching during manufacturing . These are shown under :

- ❖ Uniaxial geogrids are formed by stretching standard punched polymer sheets longitudinally and hence have a substantially higher strength in tension along the longitudinal axis than those in the perpendicular direction.
- ❖ Biaxial geogrids are created by stretching conventional punched polymer sheets longitudinally and transversally, and hence have

identical strength in tension in both directions.

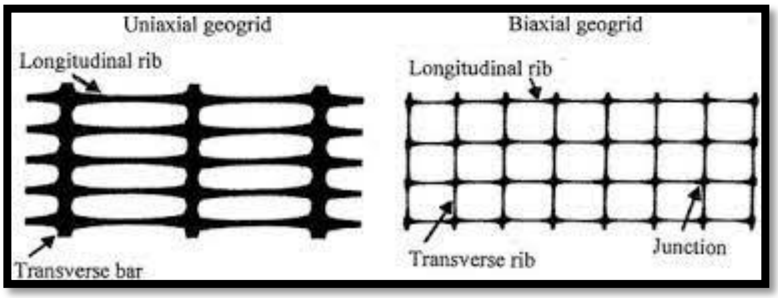

Fig. 1.2 Geogrids (Source : Google images)

c) Geonets

Geonets lool like geogrids and are extruded polymer meshes.They differ from geogrids not in terms of format or configuration, but rather in terms of functionality. Geonets have diamond-shaped perforations with a length of 12 mm and a width of 8 mm. The angles are between 70 and 110 degrees.

Fig. 1.3 Geonets (**Source : Google images)**

d) Geomembranes

A geomembrane is a persistent membrane-like barrier or liner made of low-permeability materials that controls fluid migration. Asphaltic, polymeric, or even a blend of both materials may be used. We call it a barrier when we can use it into the earth's bulk. The term liner is commonly applied to geomembranes that are utilised as such an interface or as a surface revetment.

Fig.1.4 Geomembrane(Source : Google Images)

e) Geocomposites

The word "geocomposites" refers to products made up of 2 or many geosynthetic reinforcement that, especially when combined, execute specified functions more efficiently than when used alone. Geotextile-geonet, geotextile-geogrid, geotextile-geomembrane, geonet-geomembrane, geotextile-geomembrane,etc. are some of the possible combinations.

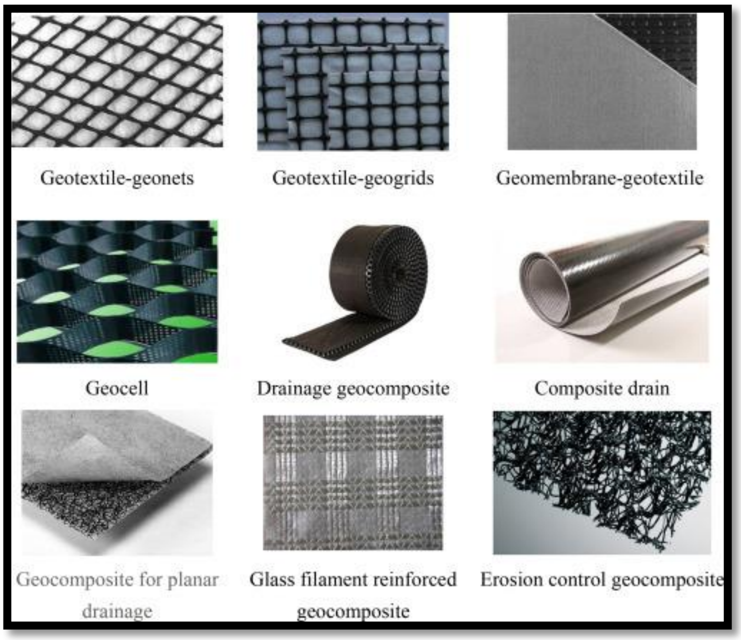

Fig.1.5 Geocomposites(Source : Google images)

1.1.2.2 Functions served by Geosynthetics in Highways

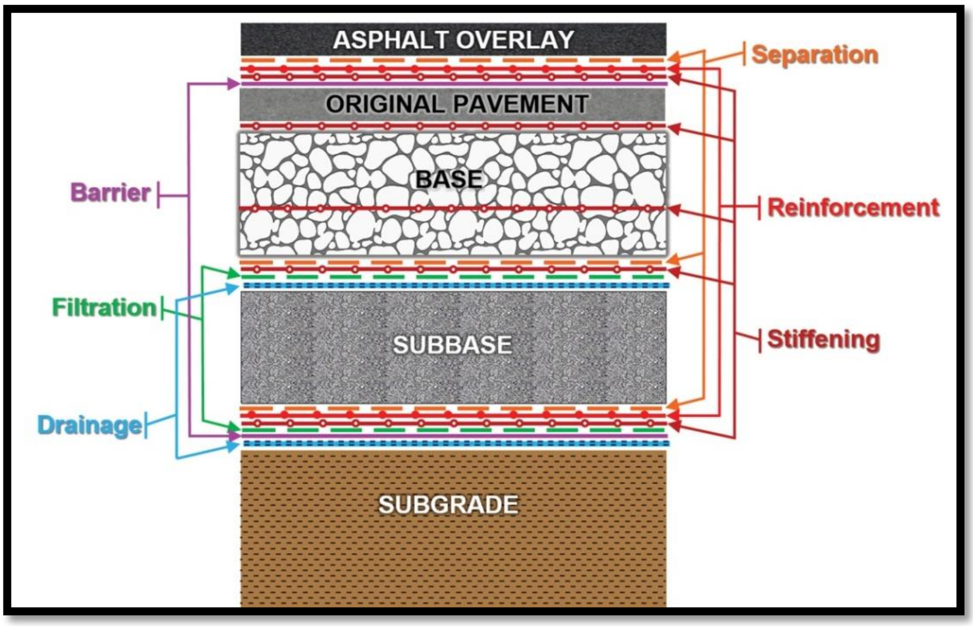

Fig. 1.6 Various functions of geosynthetics (Source : Google Images)

The geosynthetics serve the following functions in highways :

- **Separation:** When placed between two incompatible materials, the geosynthetic ensures the integrity and usefulness of both. It could also entail long-term stress reduction. Those employed to characterise the geosynthetic's survivability during installation are among the key design features to execute this role.
- **Filtration:** Liquid can flow over the geosynthetic's plane while fine particles are retained on the upstream side. The geosynthetic permeability (cross-plane permeability per unit width) and parameters of the geosynthetic porous distribution are important design properties for this function .
- **Reinforcement:** Tensile forces are generated by the geosynthetic in order to maintain or increase the soilgeosynthetic composite's stability. The geosynthetic tensile modulus is an essential design characteristic for performing this purpose.
- **Stiffening:** Tensile stresses are generated by the geosynthetic in order to control deflections in the soil-geosynthetic composition. The rigidity of the soil-geosynthetic combination is one of the most important design properties to achieve this function.
- **Drainage:** Well within plane of its structure, the geosynthetic permits liquid (or gas) flow. Geosynthetic transmissivity is a key design property for quantifying

this function.

1.2 Scope

As unreinfoced slopes of road embankments are subjected to large deformations,so, they are prone to tremendous risk to loss of life and property which in turn affect the social and economic development. This would hamper the process of development and urbanization. That’s why we go for geogrid reinforced road embankments because they not only impart the tensile strength and increase the laod carrying capacity of the road but are an economic alternative also.

This study will throw light on the improvements procured due to geogrid reinforcement of the physical model and numerical model of the road embankments.

1.3 Objective

- To design the physical model of an unreinforced road embankment in laboratory.
- To design the physical model of a geogrid-reinforced road embankment in laboratory.
- To use Plaxis 2D to create a numerical model of an unreinforced slope and compare the findings to those produced in the lab.
- To use Plaxis 2D to create a numerical model of a reinforced slope and compare the findings to those produced in the lab.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND

The research of highway embankments has taken place all around the globe.The road failures or we can say the slope failures are very dangerous. They not only cause economical losses but disturb the vehicular movement to a large extent also. So. They need to be monitored with a good solution.

A lot of work has been conducted on the performance of geosynthetic reinforced slopes all over the world to prove how efficient they are. The body of available material spans many years and is rapidly expanding. As a result, it is impossible to accurately characterise it in a single chapter. Instead, below is a summary of significant references, as well as relevant recommendations to earlier works that include in-depth evaluations of related literature.

Salahudeen et al. (2016) have done their research on the use of geosynthetics for the amelioration of ground on the basis of numerical analysis by making use of plaxis 2D. As geosynthetics possess quite well strength in tension and compression,so, they were used for strengthening the soft soils. Soft soils have less strength in shear and are subjected to large deformations. They studied the technique of reinforcement by geosynthetics on the basis of the results of the numerical modelling. The reinforced soil structures are very effective in terms of cost as these kind of reinforcements can be accessed very easily. That’s how it has come out to be one of the most creative and stimulating methods in civil engineering field. In comparison to reinforced concrete walls, rammed earth walls and slopes are cost-effective soil holding structures that can withstand extreme deformations.

An embankment with suitable fill properties was designed in the software. Geogrids were used for the reinforcement purpose. The elasto-plastic theory; Mohr-Coulomb model best represents soil, that is an anisotropic, non-homogeneous, three-phase material. The software simulates the geogrid, embankment soil, and the geogrid structure's interaction with the soil. The deformation at the node and the pressures at the stress points are the software's main outcomes from finite element calculations.

The outcomes of this simulation lead to the following conclusions:

- The reinforced embankment’s stability analysis gives more or less the acceptable results that can be simulated in reality.
- The slopes that are geosynthetically reinforced are conservative and gave better outcomes of deformations and shear strains than the unreinforced slopes.
- Installation of geogrid layers at the apt place in the slope would enhance the load carrying capacities of that kind of slopes. They are also good for soils with low strength.

Benmebarek et al. (2015) paid heed towards the construction method of the embankment of a road that intersects a part of nearly 11 km on sabkha soils in Algeria. Very grave problems were faced during the probing of soils of subsurface and the uppermost embankment layers’ construction because of uplifting water table avove the surface and the poor bearing capacity of the surface. It was found that by making use of basal geosynthetic layer, the slope performance was found to ameliorate. As soil's bearing capacity improved, the crafting of these layers became visible, allowing for the safe manufacturing of the very first layers while also improving compaction quality.

Numerical modelling was done using PLAXIS software. Geosynthetics has been used in almost every branch of geotechnical engineering these days. One of the most usual use of it lies in the designing of pavement where soft and low- strength soils are encountered. The advantages associated with the use of geosynthetic reinforcement are as follows :

- Reducing the differential and total deformations.
- Enhancing the bearing capacity of soft soil
- Stopping the pollution of base materials
- Decreasing the width of pavement
- Increasing the service life of footpath

The outputs of the numerical modelling and the inspection of sites suggests that :

- Flood of sabhka place decreased the CBR values to less than 1 %.
- Without the segregation of geotextiles, it was impossible to stop the mixing of the uppermost lift of aggregate and soft subgrade.
- The numerical simulations suggest an enhancement of nearly 85 % in bearing capacity of the strengthened slope and the undrained cohesion of subgrade upto 10 kN/$\mathbf{m^2}$.
- They also show that the enhancement in bearing capacity is more considerable for low subgrade undrained cohesion.

Wulandari et al. (2015) have done their research to find out the optimal value of the strength in tension of the geotextile as reinforcement in embankment of road. They also took into account the allowable safety factor and the settlement. The checking of stability of the slope was done using the PLAXIS software. Three ways of sequence modelling was done:

- Checking the embankment stability without any kind of reinforcement.
- By taking into consideration the stability of the model, the length of geotextile reinforcement was found.
- Checking the model stability along with different strength in tension of the reinforcement.

Actually, with the expansion of vehicular volume in Indonesia, a large no. of road embankments are being made on soft soils. This lead to very large deformations and slope instability. It was concluded in this work that with the enhancing of the geotextile reinforcement’s strength in tension, the safety factor also enhances.

Baig et al. (2019) have done their research on a to be constructed reinforced earth(RE) wall. It is to be constructed for an approach road on the Vishaka side by making use of the finite element software. Actually, the construction was done using the limit-equilibrium approach, but this analysis was done using the finite element method to determine the settling of this RE wall in relation to its stability.. Plaxis 2D was being used to estimate the global safety factor.This RE wall is a conjugated material of construction that consists of soil without cohesion plus reinforcement.

The soil was classified to be SW(well graded sand). The OMC and MDD were found to be 10.73% and 20.9 kN/$\mathbf{m^3}$. The cohesion strength was 9.1 kPa, and the angle of frictional resistance was 24.2 degrees. The strengthening has a significant impact on improving stability.An improvement of 1.2 to 1.5 was recorded in safety factor. For larger values of safety factors,larger tensile reinforcements are suggested.

Majedi et al.(2017) have done their work on the influence of geosynthetics' axial stiffness , the no. of layers and the angle of inclination of slope were checked on a clayey layer with the help of Plaxis software. Soft soils possess low strength in shear and high compressibility. Due to this, the designing of slopes on such soils results larger and uneven deformations. These days the reinforcement of soil to enhance stability and strength of soil is a trustworthy way. By making use of geosynthetics, the strength in tension of ths soil ameliorates and the deformations reduce thus improving stability.

The strengthening of soil in various situations like earthen dams, retaining walls, stabilizing layers of soil below shallow foundation or road slopes. It is a well known fact that soils have the capability of tolerating stress and shear forces but can't stand loads in tension.

The following conclusions were drawn :

- ❖ The usage of geogrids result in a decrement in the horizontal motion of slope and cause an increment in safety factor.
- ❖ The suitable location for placing geogrids lies between base soil and embankment.
- ❖ The enhancement in stiffness of geogrid causes a reduction in horizontal manoeuvres but this doesn't have any notable influence on the vertical manoeuvres in vertical direction.
- ❖ The reduction in slope inclination will reduce the longitudinal manoeuvres of slope.

2.2 CONCLUSION

Findings suggest that the usage of geosynthetics in road embankments, retaining walls, MSE walls,etc. will improve their life by strengthening them and improving their bearing capacity. This will lead to an increase in factor of safety. These reinforcements make soil capable of standing tensile loads. The service life of the slope would increase and the deformations over a stipulated time period would decrease. In addition to all these benefits, it is a cost-effective method. So, it's wise and good to go for geogrid reinforcement for the road emabankments.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explains the materials and procedures utilised in this study to guarantee that the study's goals are met.The slope designing was done completely in the laboratory in a tank. The slope dimensions are decided in correspondence with the tank dimensions and the material properties are determined and then material simulation is done by performing grain size distribution to meet the inherent soil property of parent material of slope. To identify the soil qualities needed for the analysis, the laboratory tests are performed.

3.2 RESEARCH WORK

As it has been mentioned above that the slope for the road embankment was designed in the soil mechanics laboratory in civil engineering department of DTU. A tank present in the laboratory was chosen for the purpose of physical modelling.

3.2.1 Description of slope

The dimensions of the tank are as follows :

Length = 106 cm = 1.06 m

Width = 93 cm = 0.93 m

Depth = 69.5 cm = 0.695 ≈ 0.7 m

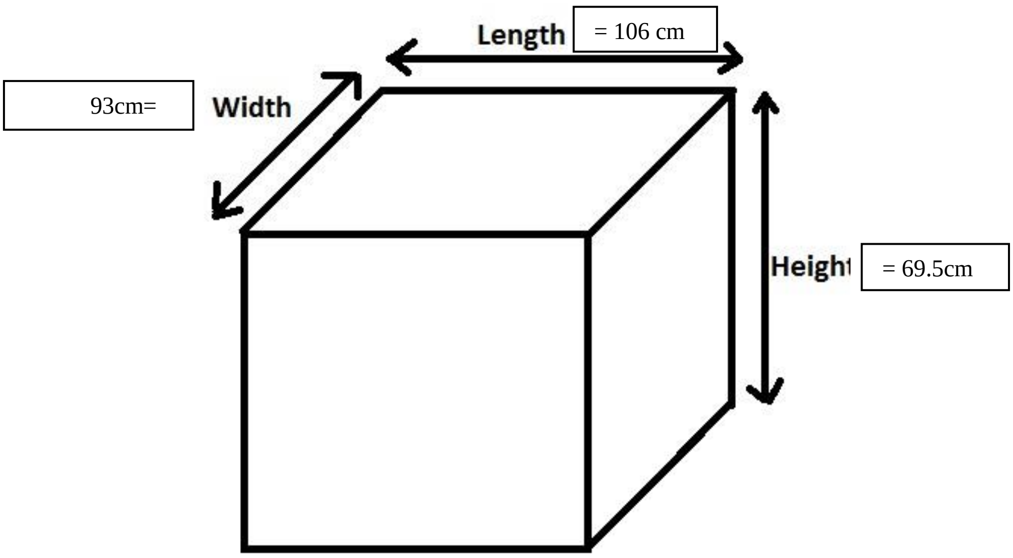

Fig.3.1 Schematic diagram of rectangular tank

The slope model was chosen keeping in mind the dimensions of tank so that loading can be applied suitably. The following were the dimensions of the slope model :

Base length = 106 cm

Base depth = 27.5 cm

Offset on both sides = 3 cm

Slope height = 25 cm

Slope = 1V:1.5 H

Top width = 25 cm

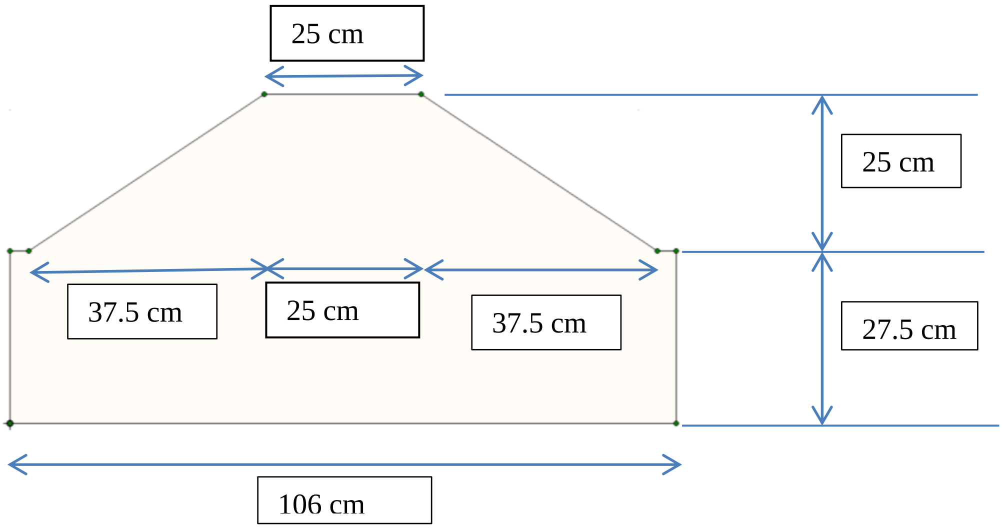

Fig. 3.2 Schematic diagram of slope

3.3 Materials and methods

In this study, a model was adopted to study the failure mechanism of slope.The soil taken out from the tank is checked for its various engineering properties such as its nature,type,water content,OMC,MDD,etc. Various experiments were performed on the soil sample to procure information about the soil.

3.3.1 Laboratory investigation

Laboratory investigation has been done to find the properties of soil.

3.3.1.1 Water content

It is found in laboratory by the help of moisture meter. It is a method for determining the water content of soil inside the lab that is both quick and accurate.It involves the placing of nearly 1gm of the soil sample in the tray of the machine. The moisture meter is then closed and started with slteadily increase in temperature. The temperature can reach upto a maximum value of 105°C. The moisture metre would display the value of the soil's water content when the sample had dried completely. For a surrounding air dried sample, this process could take 1-3 minutes, while a wet sample may take longer.

Fig. 3.3 Moisture meter

Fig. 3.4 Moisture meter showing water content

3.3.1.2 Soil Classification

A sieving test (or gradation test) is a method of determining a granular substance's particle size distribution by passing it through a series of sieves with increasingly lower mesh sizes and measuring the amount of material stopped by each sieve as a percentage of the total mass.

Sieving as per IS 2720 part 4 is used to determine gradation analysis in coarse sand. In a laboratory, this test is carried out on a sample by conducted on a specimen of aggregate. A nested row of sieves having wire mesh screen is used in a conventional sieve analysis. Particle size analysis determines the percentage of various particle sizes available in a dry sample. For coarse-grained soil, sieve analysis is usually performed.Sieve analysis is the true representative of particle size distribution as it is independent of the temperature. Sieve analysis is done for the particles having size greater than 0.075 mm that is for all soil fractions which are retained over 75 micron sieve.

According to IS 460:1962 sieves are designated terms of size of the openings are in mm. In the sieve analysis, different sieve arranged one over each other in the vertical plane with the sieves having maximum size of openings at the top and minimum size of opening at the bottom. A adequate amount (500 gm) of oven - dry soil sample is placed on the top most sieve, and sieving is done manually or in a sieve shaker for 10 minutes. 75 micron, 150 micron, 300 micron, 600 micron, 1.18 mm, 2.36 mm, and 4.75 mm sieves were utilised in my test, and they were organised as shown in the fig. 3.5.

Percentage finer = 100 – Percentage retained (3.1)

The outcome of the test is reported in percent finer and the related particle size on a log scale, and the test results will be detailed in the following chapter.

Fig. 3.5 IS sieves

3.3.1.3 Atterberg limits

The liquid limit, palstic limit, and shrinkage limit of a soil are the Atterberg limits. IS 2720 part 5 is used to determine the liquid and plastic limits.

a) Liquid limit

It's the water content below which soil has a proclivity to flow. The viscosity of soil switches from plastic to liquid near the liquid limit. At this limit, all soil has a shear strength of only 2.7KN/m^2.Compression index can be calculated by performing liquid limit test for analyzing settlement. When the soil's natural moisture content exceeds the liquid limit, it is soft; when the soil's natural moisture content falls below the liquid limit, it becomes brittle and hard. A liquid limit test can be used to determine the plasticity of soil.

Procedure-

- Collect approximately 120 gm. of air-dried soil that has passed through a 425 micron IS sieve.
- Make a homogeneous paste by addition of water with a consistency of 30 to 35 falls of cup to create a regular groove with a length of 12 mm.
- After placing a portion of this homogenous paste in the cup of the Manual Liquid Limit device, spread it out with small spatula strokes.
- Cut the homogenous soil paste to a maximum thickness of one centimetre.
- Using Casagrande's grooving tool, create a clean, precise groove of the right dimension.
- Raise and lower the cup at a pace of two rev/sec to establish flow contact between two portions of the soil for a distance of 12 mm.
- Count the blows until the groove is about 12 mm deep.
- To evaluate the moisture content of the soil, take a noteworthy soil specimen from the cup.
- Change the water content at least 3 times during the test, and the blows must range from 15 to 35.

Flow index , $I_f = \frac{w_1 - w_2}{\log_{10}(N_2/N_1)}$ **(3.2)**

Where, I_f = Flow Index

w_1 = Water content in percentages equivalent to N_1 blows

w_2 = Water content in percentage equivalent to N_2 blows

Fig. 3.6 Casagrande's apparatus

b) Plastic Limit

Plastic limit computation is just as demanding as liquid limit computation. The plastic limit is the water content at which a soil sample transforms from semi-solid to plastic. The plastic limit is sometimes defined as the moisture content at which soils start to crumble when rolled into a 3 mm diameter thread. The amount and kind of clay minerals in the soil determine the plastic limit. As a result, fine soils containing clay have a higher plastic limit.

Procedure –

- Take roughly 20 grams of soil that has been sieved at 425 microns.
- Mix the soil with filtered water in the dessicator to make it easier to shape with your fingertips.
- Allow 24 hours for the water to drain from the soil.
- Roll around 10 gm of this plastic soils clump between your fingers and a glass plate to make a thread with a consistent diameter all the way down. Rolling should be done at a rate of 80-90 strokes per minute.
- Continue rolling until you get a 3 mm diameter thread.
- Re-roll the consistent mass soil.
- Continue this process till the thread collapses at a diameter of 3

mm.

- Collect the bits of the crumpled thread in an airtight container to determine the moisture content.
- Take the average of the results after completing the test 3 times.
- The results will be discussed in chapter 6.

Fig. 3.7 Plastic limit test

3.3.1.4 Specific Gravity

It can be determined by using pycnometer method as per IS 2720 part 3.

Procedure-

- Mass of empty pycnometer is noted (M1).
- A sample of oven-dried soil is inserted in the pycnometer, and the mass of the pycnometer is recorded once more (M2).
- Empty volume of the pycnometer is filled with the water in multiple stages along with the subsequent removal of air either by use of vacuum or by continuous stirring of sample. Mass of pycnometer filled with water is again noted (M3).
- Pycnometer is completely emptied and again we fill it with water after its proper cleaning and is again weighted (M4).
- The results of test will be disused in next chapter.

$$\text{Specific Gravity, G} = \frac{\text{Mass of solids of given volume}}{\text{Mass of water of same volume}}$$

$$G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)} \quad (3.3)$$

Fig. 3.8 Pycnometer

3.3.1.5 Unit weight

To investigate the compactive qualities of soils, a variety of tests can be utilized.

Because compaction is so important in most earthwork projects, standard processes have been created. In most cases, this entails compacting earth into a molds at varied moisture levels.It is generally of two types:

1. Standard Proctor Compaction Test
2. Modified Proctor Compaction Test

In my experiment, I employed the conventional proctor test to determine the unit weight of my test soil specimen, which was compressed into a mould in three equal layers, each getting 25 blows of a standard weight hammer. The apparatus is depicted in the diagram below. This test provides 595 kJ/m^3 of energy (compactive effort).

The mold's volume is 1000 cm^3,mass of mold is 4.17 kg and 2.5 kg is the hammer mass. Hammer drop = 300 mm.

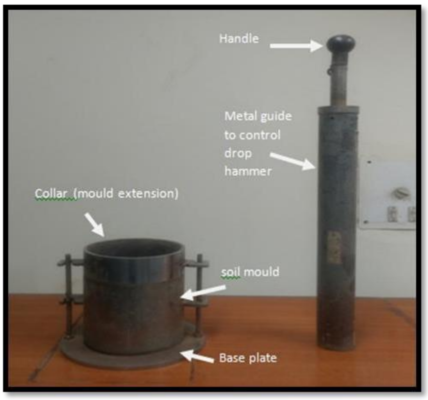

Fig. 3.9 Standard Proctor test

$$\text{Bulk Unit Weight}(\gamma_b) = \frac{W}{V} = \frac{W_s+W_w}{V} \quad \textbf{(3.4)}$$

$$\text{Dry Unit Weight}(\gamma_d) = \frac{\gamma_b}{1+w} = \frac{G\,\gamma_w}{1+e} \quad \textbf{(3.5)}$$

$$\text{Saturated Unit Weight}(\gamma_{sat}) = \frac{(G+e)\gamma_w}{1+e} \quad \textbf{(3.6)}$$

Where:

W= soil's weight; W_s = solids' weight;

W_w = water's weight; V = soil's full volume ;

γ_w= water's unit weight; w = water content, e = void ratio

3.3. 1.6 Direct Shear Test

The Direct Shear Test is a process used to assess the shear resistance of soil materials in an experimental setting. When a material is sheared, its shear resistance is characterized by a high resistance it can withstand. The Direct Shear Test is one of the most frequent and straightforward methods for determining the strength of a soil, and it may be done on both undisturbed and remoulded samples.

The Mohr-Coulomb (M-C) Failure Criterion is used in soil mechanics to determine shear strength. According to the M-C Criterion, shear strength is determined by three factors:

1.Effective stress in its natural state (σ_n)

2. The material's friction angle (∅)

3.The material's cohesiveness (c)

The qualitative relationship between those elements is represented as follows:

$$\tau = c + \sigma_n \tan \emptyset \qquad (3.7)$$

Fig. 3.10 Direct shear test machine

CHAPTER 4

PHYSICAL MODELLING

4.1 GENERAL

The physical model gives an overview of the procedures adopted in field to construct an embankment. This gives good insight of the field work. It is very much relatable to the field condition. The physical modelling if done gives more good insight of the model. It is a more efficient and commonly utilised method for investigating the road embankment's settling and failure mechanisms.

Physical model is one of the good,effective and common way of testing a road embankment similar to the prototype. By using this framework model slot the deformation parameters can be determined. It is possible to see the sliding properties and mechanism, and some mechanical parameters can be obtained. It gives values of the the various mechanical parameters that can be related to the prototype by adopting a suitable scale. Based on earlier research, this study uses a physical model test with almost the same engineering basis.

The physical modelling is done in two ways. Firstly,the simple slope without any kind of reinforcement was designed and failure load and deformations were determined. Secondly, the slope with reinforcement with geogrid was designed. It is designed in two ways. Firstly, it was reinforced with a single layer at half the slope depth. The same failure load and settlements were found for this slope as well. After that, third slope was designed with geogrid reinforcemnet at two positions. These were placed at a spacing of one-third the slope height .

Fig. 4.1 Preparation of unreinforced embankment

Fig. 4.2 Prepared embankment

Fig.4.3 Laying of geogrid layer

Fig. 4.4 Slope with a single layer of reinforcement

Fig. 4.5 Slope with two layers of reinforcement

4.2 EXPERIMENTAL SET-UP

As explained in previous section of experimental set-up, the experimental platform includes a cuboidal tank and a loading system. So frame-type model tank and the loading are explained below. Results of test performed are shown in next chapter. To measure the vertical and horizontal deformation, we used dial gauges as shown in the figure below.

Fig.4.6 Loading machine along with the dial gauges

4.2.1 Rectangular Tank

The rectangular tank used for performing physical modelling is present in the laboratory. It is 106 cm long, 93 cm wide and 70 cm deep. It is made up of iron and has a thickness of 1cm. The slope for the road embankment is designed by taking into consideration the dimensions of the tank.

Fig. 4.7 Rectangular tank used for physical modelling

4.2.2 Loading Machine

A hydraulic jack is used to model the vehicular laod acting on the road surface. As the vehicular load acts as a point load and is a type of instantaneous loading,so, we apply the load at the middle of model road surface. This is done from the symmetry point of view. The machine is based on the Pascal’s law which states that

Load applied = load lifted.

The fluid used is oil. A rod is used to generate fluid pressure which in turn lifts the plunger of the hydraulic jack. This is how this assembly is used to apply the laod on the road surface. The load at failure can be read from the proving reading provided.

The horizontal and vertical settlements are measured using the dial gauges attached on the base plate as shown in fig. 4.6.

Fig. 4.8 Loading machine

4.2.3 Geogrid

The geosynthetics used for the reinforcement purpose is geogrid. It is laid down in two layers. Each one is layered at a height interval of 8 cm of the embankment height.

The properties of the geogrid are as follows :

Table 4.1 : Properties of geogrid[18]

Properties	**Value**
Polymer type	Polypropylene
Structure	Biaxial geogrid
Stiffness	550 kN/m
Aperture size	30 mm

Fig. 4.9 Biaxial geogrid

CHAPTER 5

NUMERICAL MODELLING

5.1 GENERAL

The numerical modelling of the road embankment slope is done using PLAXIS 2D software. This software was used to design the subgrade settlement in this study, and it is based on the finite element method. Plaxis 2D is indeed a finite element technique used in the domain of geotechnical engineering to analyze reliability and deformation in two dimensions. For the calculation of non-linear, time-dependent, and asymmetric behaviour of soils and rocks, it employs advanced soil constitutive models. The geogrids, the elevated soil, as well as the interactions between both the geogrid framework and the soil are all modelled in Plaxis 2D.The input parameters of the soil are fed into the material sets and then the boundary conditions,loading, construction stages all are defined in a predesigned geometry of the slope model. Plaxis 2D will then generate mesh diagram for the slope model along with availing the options of global and local mesh refinements. On the basis of its simulation techniques, Plaxis will perform iterations and calculations and will show the final results in pictorial and numerical form.

The graphs can also be generated. The factor of safety can also be calculated. We get deformed mesh, the horizontal and vertical displacement, total stress,pore water pressure, effective stress,etc. In addition to this, the stress and deformations in contour, mean shadings,arrows form can also be presented.

5.2 NUMERICAL MODELLING OF UNREINFORCED SLOPE

For modelling the unreinforced slope, the road embankment is drawn with suitable coordinates in the PLAXIS software. The soil properties are added to the material sets tab. After applying the soil to the region, load is applied. To simulate the same failure load as obtained in the laboratory,we use a plate to exert the load. The point loading is applied on it.

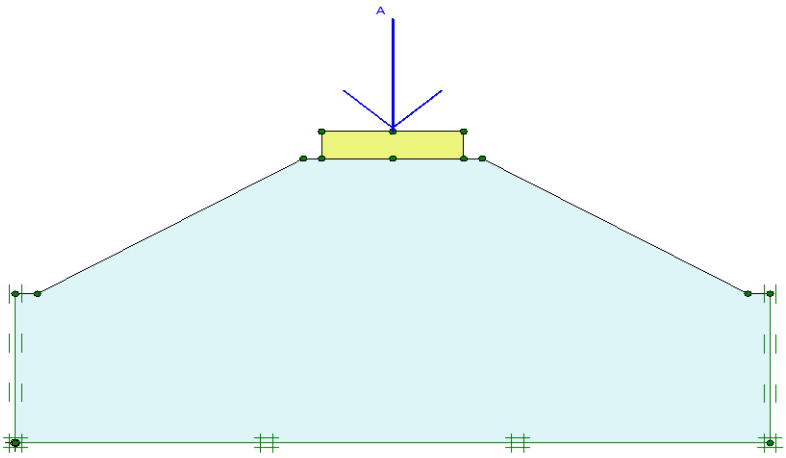

Fig. 5.1 Unreinforced slope modelled numerically

Table 5.1 : Characteristics of embankment fill

Design Parameters	Magnitude
Unsaturated unit weight	18.01 kN/m^3
Saturated unit weight	19.93 kN/m^3
Permeability (horizontal and vertical)	1.000 m/day
Young's modulus	30000 kN/m^2
Poisson's ratio	0.3
Cohesive strength	20.67 kN/m^2
Angle of frictional resistance	14.015°
Angle of dialation	0°

Iron plate was used in the laboratory to exert load on the embankment. It is represented in the software using a plate. It's material model is linear elastic and non-porous is the material type.

Table 5.2 : Characteristics of iron plate

Design parameters	Magnitude
Unit weight	78.73 kN/m^3
Young's modulus	210 Gpa
Poisson's ratio	0.26

The vertical and horizontal deformations are determined by applying the laod value of 5 kN.The deformed mesh for 5 kN loading has been shown below :

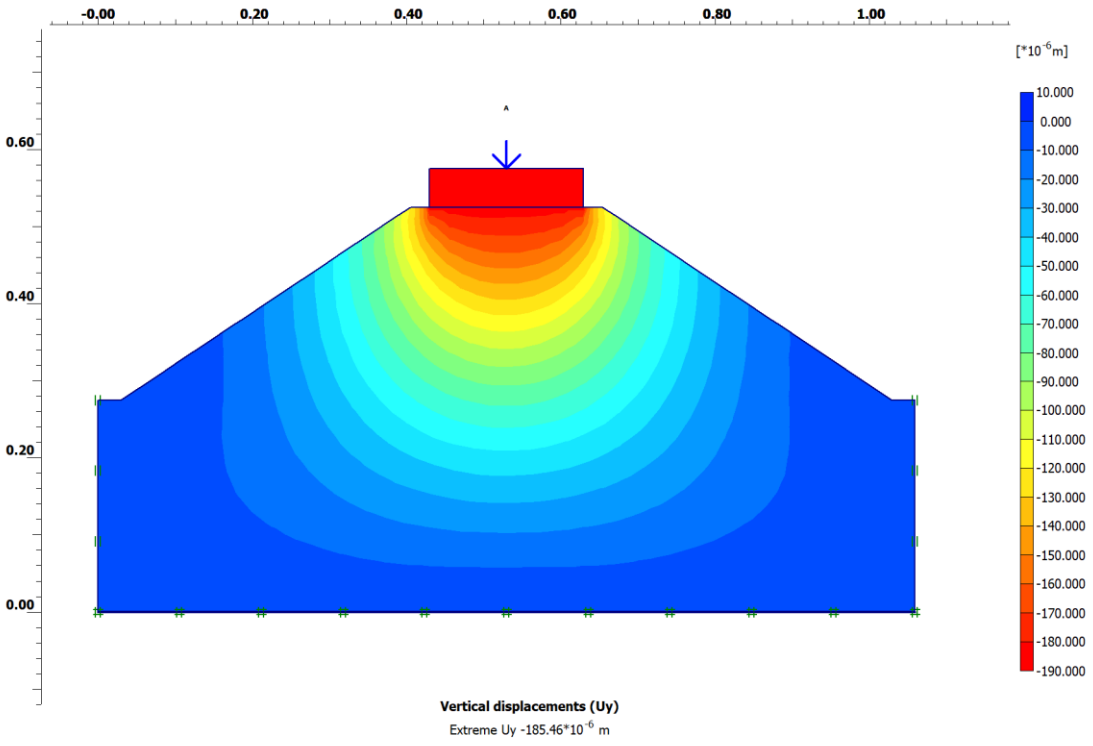

Fig. 5.2 Vertical deformation obtained under failure load

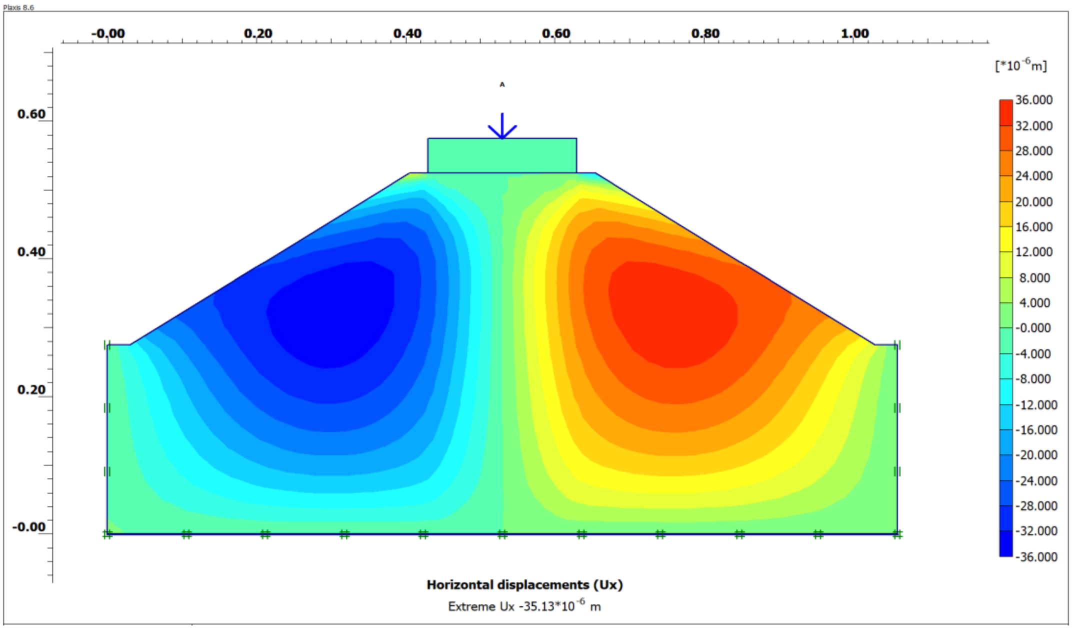

Fig. 5.3 Horizontal deformation obtained under failure load

The results for other loadings are tabulated in the next chapter.

5.3 NUMERICAL MODELLING OF SLOPE REINFORCED WITH SINGLE GEOGRID LAYER

The same model is made again but this time it is reinforced with a geogrid at half of its height; at 12.5 cm from top.

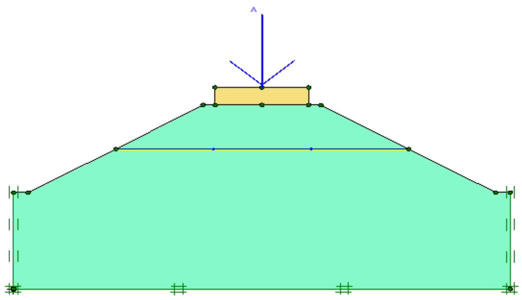

Fig. 5.4 Slope model reinforced with single geogrid layer

The deformed mesh for 9 kN loading has been shown below and the rest value are given in next chapter.

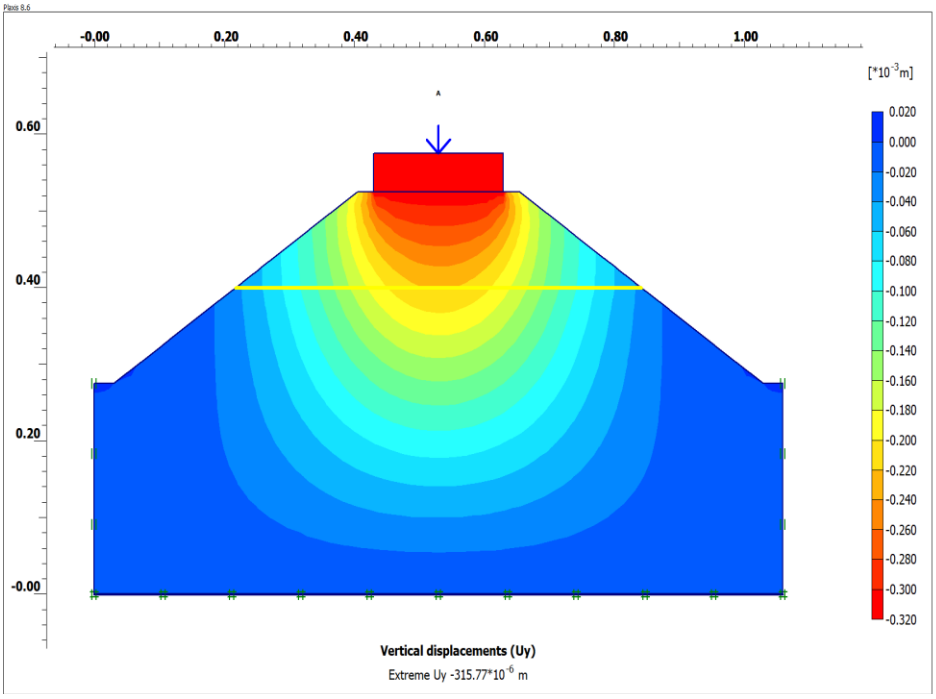

Fig. 5.5 Vertical deformation obtained for slope with a single layer of reinforcement

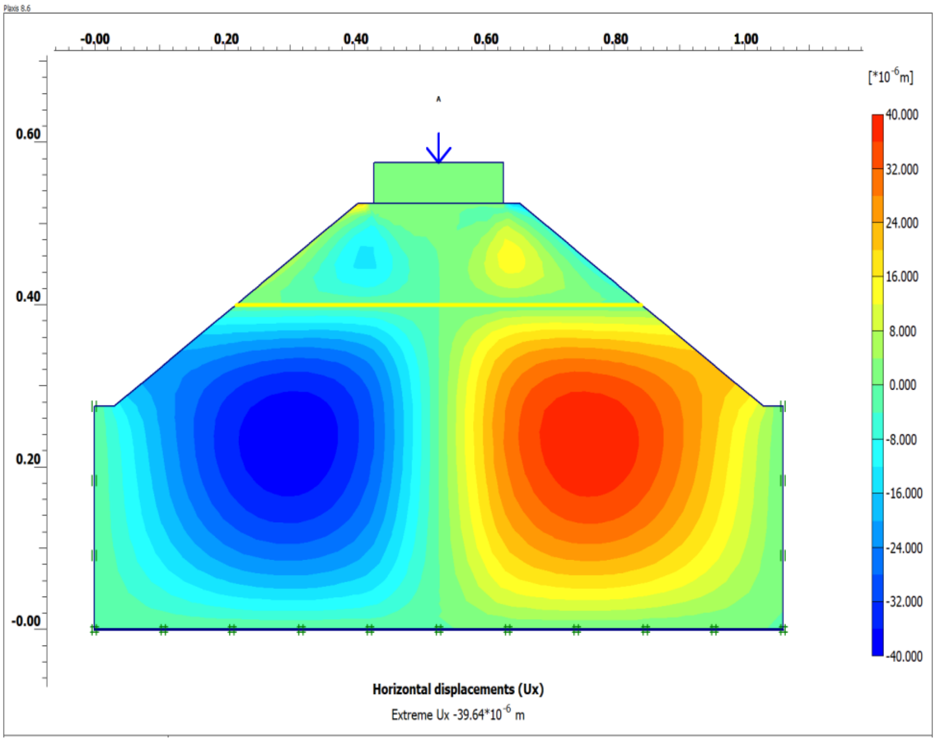

Fig. 5.6 Horizontal deformation obtained for slope with a single layer of reinforcement

5.4 NUMERICAL MODELLING OF SLOPE REINFORCED WITH TWO GEOGRID LAYERS

The model is designed again with same fill properties but geogrid layer is applied at two positions. These are spacing of one-third from top which means a vertical spacing of 8.3 cm is provided for each geogrid layer.

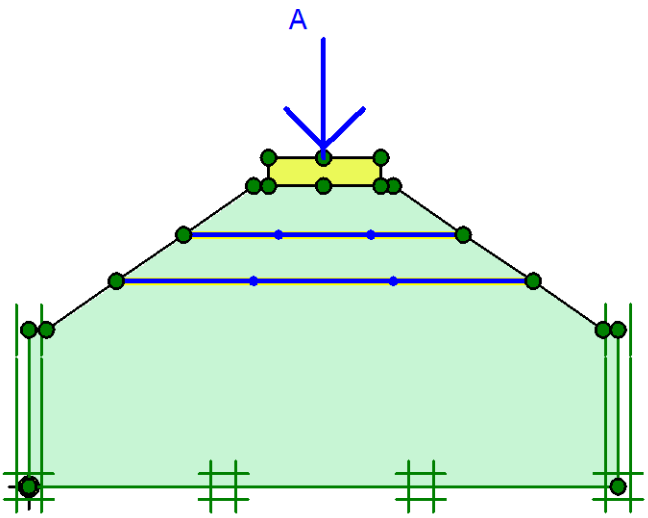

Fig. 5.7 Slope model reinforced with two geogrid layers

The deformed mesh for a loading of 15 kN is shown below and rest of the results are shown in next chapter.

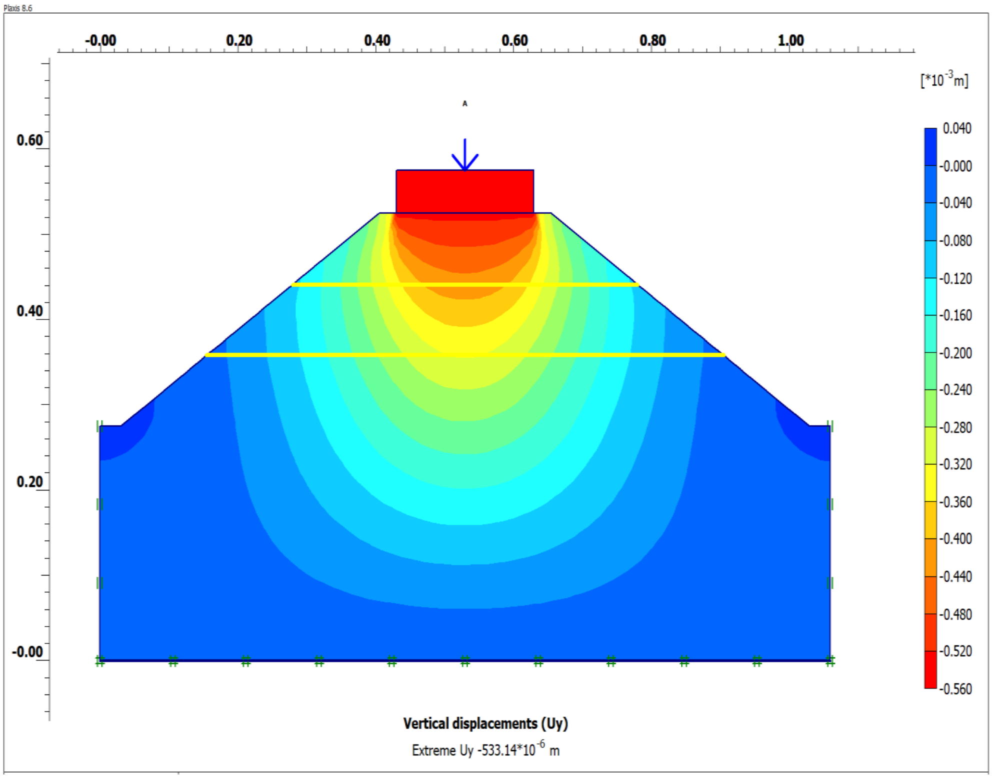

Fig. 5.8 Vertical deformation obtained for double layer reinforced slope

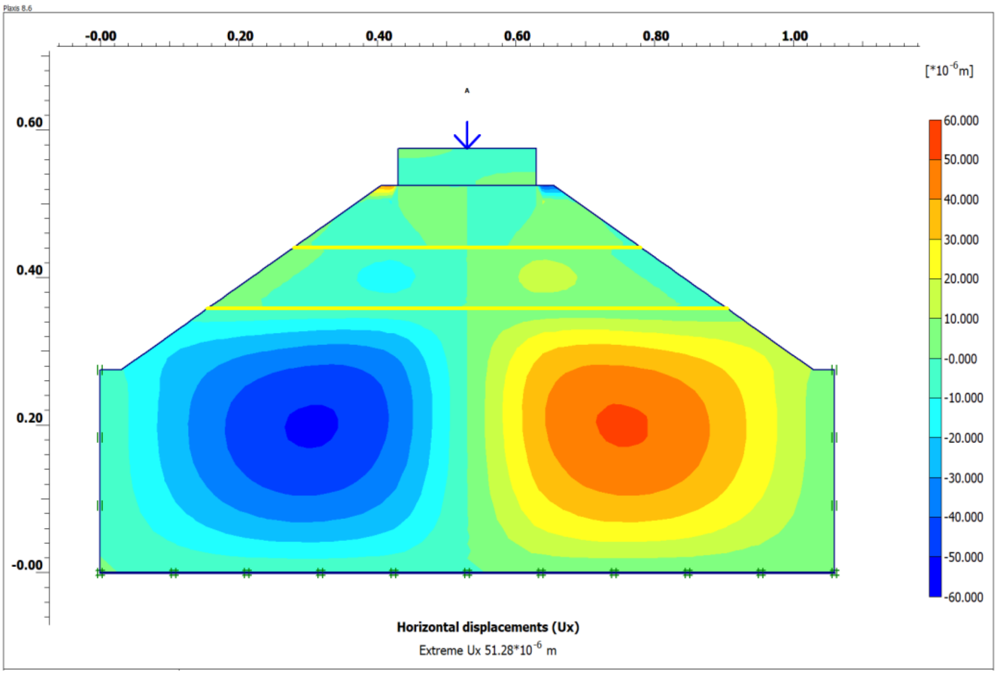

Fig. 5.9 Horizontal deformation obtained for double layer reinforced slope

CHAPTER 6

RESULTS AND DISCUSSION

6.1 LABORATORY RESULTS

A laboratory examination was conducted to determine the characteristics of soil for the purpose of analyzing the stability of a road embankment and determining soil material similarity. Distinct tests are used to obtain different physical and technical qualities of the soil.Results of the tests are discussed in this section.

a) SIEVE ANALYSIS

The following are the findings of the sieve analysis::

Table 6.1 : Observations of sieve analysis

Size of sieve in ‘mm’	Weight of soil retained in ‘gm’	Percent weight Retained	Cumulative perecent retained	Percent finer than
4.75	314	31.4	31.4	68.6
2.36	118	11.8	43.2	56.8
1.18	110	11	54.2	45.8
0.6	108	10.8	65	35
0.3	144	14.4	79.4	20.6
0.15	52	5.2	84.6	15.4
0.075	20	2	86.6	13.4
Less than 0.075	134	13.4	100	0

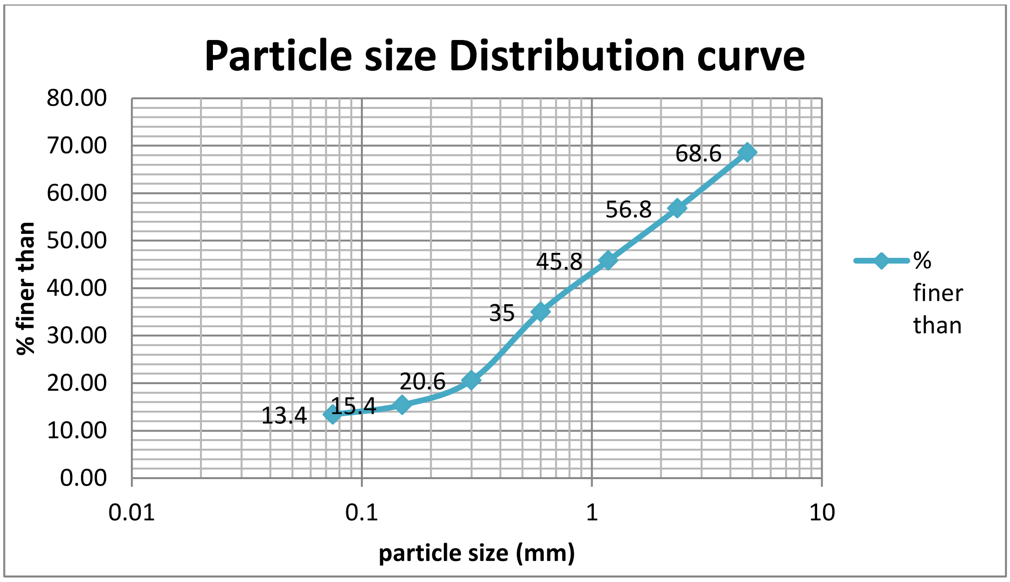

Fig.6.1 Grain size distribution curve

The findings of the sieve analysis reveal that more than 50 % of soil fraction is retained above 75 µ sieve. This means that the soil is coarse grained. Total coarse fraction is 86.6 %. As more than 43.8 %(0.5 of 86.6%) is passing through 4.75 mm sieve size, so , the soil is classified as sand with % fineness 13.4%(> 12%).

Now, we need to check the liquid limit and plastic limit of the soil to find whether it is silty or clayey sand.

b) ATTERBERG LIMITS

The outcomes of liquid limit and plastic limit test are listed below :

Table 6.2 : Observations of liquid limit test

No. of blows(N)	Water content(%)
16	39.38
20	31.71
27	21.4
32	15.56

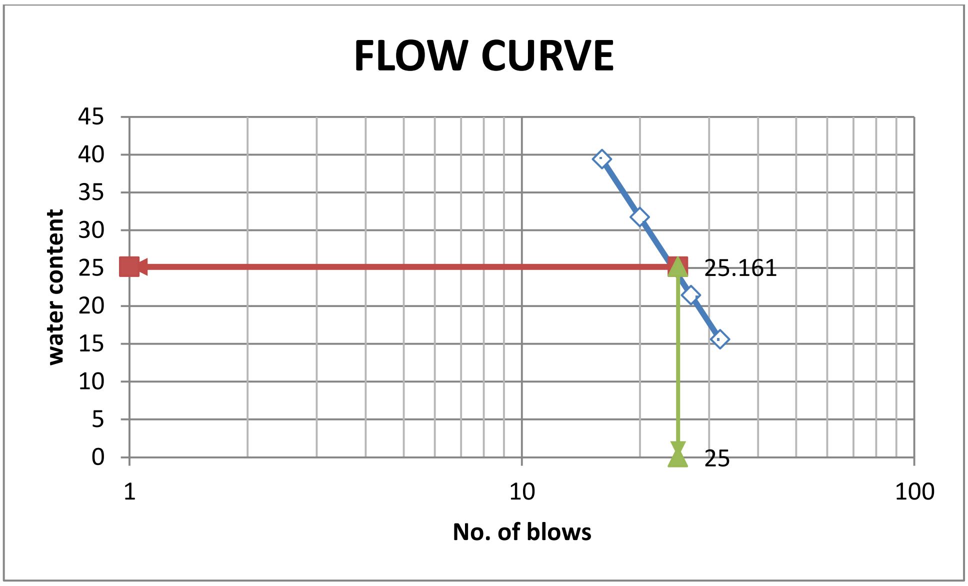

Fig.6.2 Flow curve

The liquid limit of the soil is 25.161% at 25 no. of blows.

Table 6.3 : Observations of plastic limit test

Observation no.	Plastic limit(%)
1	19.81
2	16.91
3	15.18
4	11.81

The average value of plastic limit is 15.93%.

$I_P = w_L - w_P$ **(4.1)**

$I_P = 25.161 - 15.93 = 9.231$ %

Equation of A-Line is $I_P = 0.73(w_L - 20)$ **(4.2)**

$I_P = 0.73 \times (25.161 - 20)$

$I_P = 3.768$ %

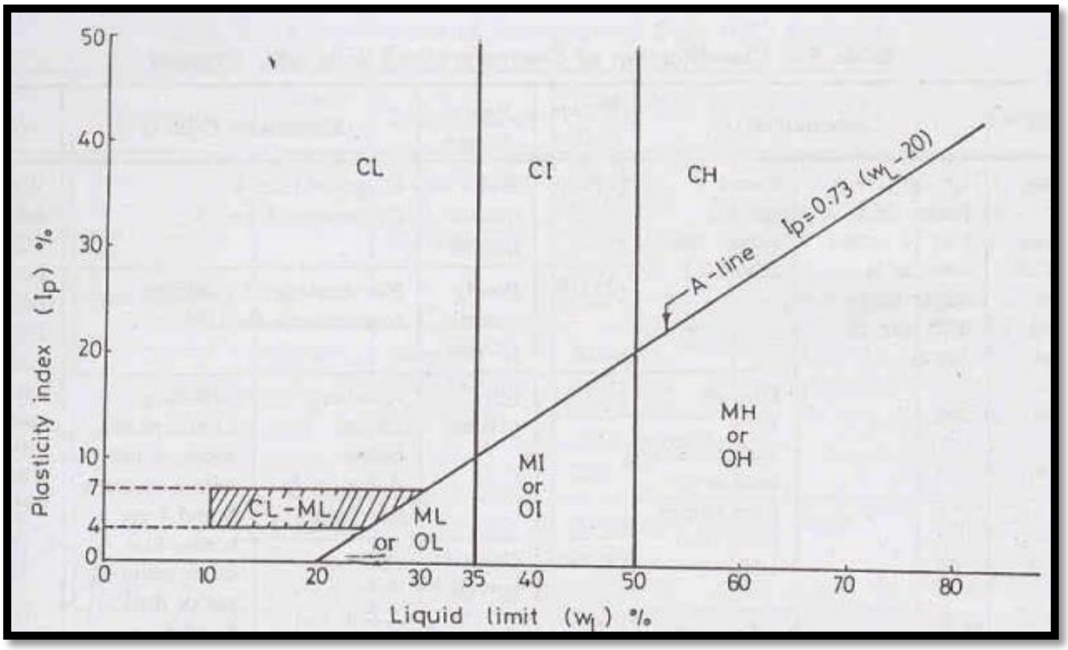

Fig. 6.3 Plasticity Chart

As the obtained value of plasticity index lies above A- line and w_L < 35%, so, the soil has clay as fine material with low compressibility(CL). In addition to this, I_P > 7% ; clay > silt. So, the soil is classified as clayey sand(SC).

c) SPECIFIC GRAVITY

The observed values of the Pycnometer test are as follows :

Mass of empty pycnometer(M_1) = 700 gm

Mass of pycnometer and soil (M_2) = 1190 gm

Mass of pycnometer filled with soil and water (M_3) = 1783 gm

Mass of pycnometer filled with water fully(M_4) = 1480 gm

$$\text{Specific Gravity, G} = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

$$G = \frac{(1190 - 700)}{(1190 - 700) - (1783 - 1480)}$$

$$G = 2.62$$

d) STANDARD PROCTOR TEST

Table 6.4 : Observations for Standard Proctor test

Moisture content (%)	Mass of mould and soil(gm)	Mass of soil (gm)	Bulk density (g/cm^3)	Dry density (g/cm^3)	Dry unit weight (kN/m^3)
2.23	5688	1518	1.518	1.485	14.57
4.85	5828	1658	1.658	1.581	15.51
6.21	5880	1710	1.71	1.61	15.79
10.21	6006	1836	1.836	1.666	16.38
13.7	6020	1850	1.85	1.627	15.96
16.07	6000	1830	1.83	1.577	15.47
19.23	5920	1750	1.75	1.471	14.43

The graph below depicts the relationship between moisture content and dry density:

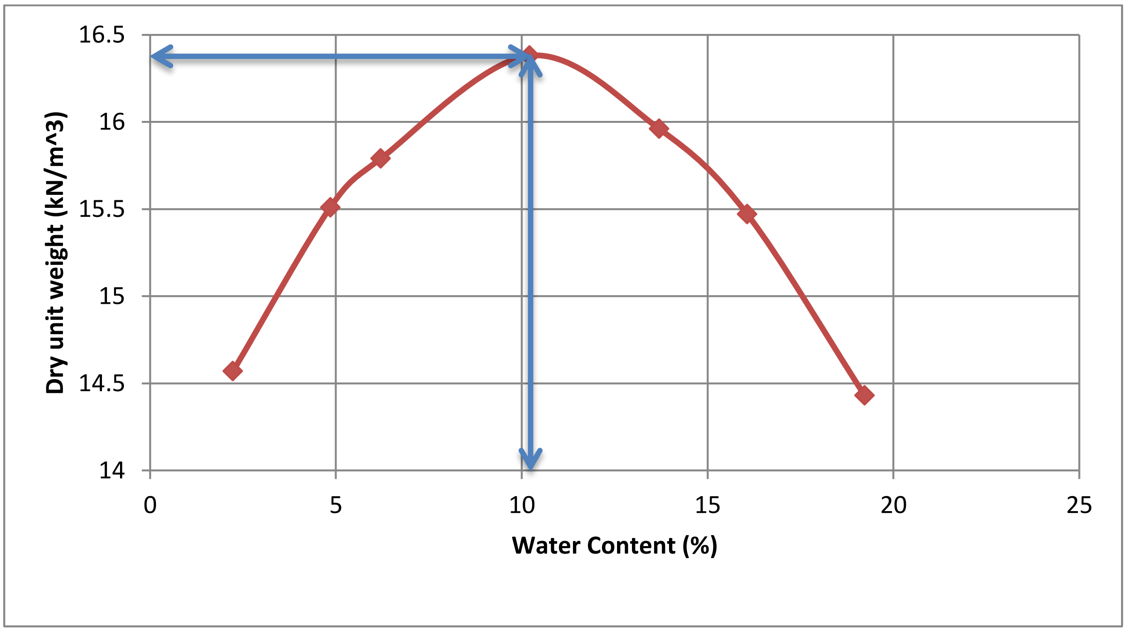

Fig. 6.4 Compaction curve for Standard Proctor test

From the curve, we get OMC(optimum moisture content) as 10.21% &

MDD(maximum dry density) as1.67 g/cc = 16.38 kN/m^3.

Bulk density = 1.836 g/cc = 18.01 kN/m^3

Using the relation, $\gamma_d = \frac{G\,\gamma_w}{1+e}$, we get

Void ratio, e = 0.57

Now, $\gamma_{sat} = \frac{(G+e)\gamma_w}{1+e} = \frac{(2.62+0.57)*9.81}{1+0.57}$

$\gamma_{sat} = 19.93 \text{ kN/m}^3$

e) DIRECT SHEAR TEST

The test was performed at three values of normal stresses. These were 0.5 kg/cm^2 ,1.0 kg/cm^2 and 1.5 kg/cm^2. The maximum value of shear stresses obtained in these three cases was noted down. A graph comparing normal and shear stress was plotted to find values of cohesion and friction angle.

Table 6.5 : Observations for direct shear test

Maximum normal stress (kg/ cm^2)	Maximum shear stress (kg/cm^2)
0.5	0.3358
1.0	0.4606
1.5	0.5854

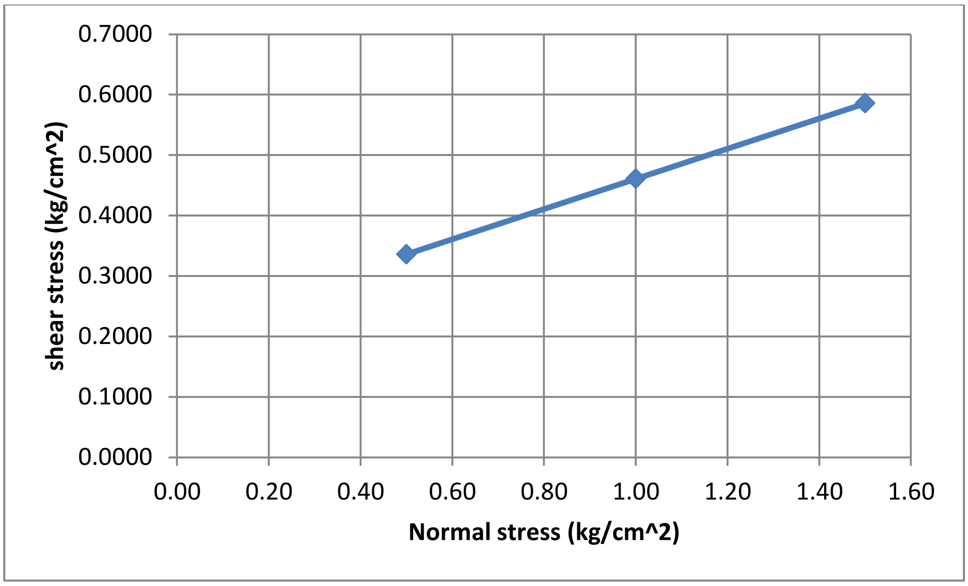

Fig. 6.5 Failure envelope

The friction angle and cohesion were determined to be 0.211 $\mathrm{kg/cm^2}$ and 14.0147°, respectively. These values were obtained from the intercept and slope of the curve above respectively.

6.2 PHYSICAL MODELLING RESULTS

The failure load and the deformations obtained for the unreinforced and reinforced slopes are reported under.

a) Unreinforced slope

Failure load = 5 kN

Vertical deformation at failure = 0.82 mm

Horizontal deformation at failure = 7.55 mm

The plate over which load is applied through hydraulic jack has an area of 20cm × 20 cm.

Area at a depth of 25 cm = $(20 + 2 * 37.5)^2$ = 95 $\mathrm{cm^2}$ = 95 × 10^{-4} $\mathrm{m^2}$

Vertical Stress at a depth of 25 cm

$$\sigma = \frac{5}{95 \times 10^{-4}} = 526.32 \text{ kN/m}^2$$

Fig. 6.6 Proving ring showing failure load for unreinforced slope

Fig. 6.7 Slope failure

b) Reinforced slope with single geogrid layer

Failure load = 9 kN

Vertical deformation at failure = 0.5025 mm

Horizontal deformation at failure = 6.4 mm

Vertical Stress at a depth of 25 cm

$$\sigma = \frac{9}{95 \times 10^{-4}} = 947.37 \text{ kN/m}^2$$

Fig. 6.8 Proving ring showing failure load for single layer reinforced slope

c) Reinforced slope with double geogrid layer

Failure load = 15 kN

Vertical deformation at failure = 0.5705 mm

Horizontal deformation at failure = 11.98 mm

Vertical Stress at a depth of 25 cm

$$\sigma = \frac{15}{95 \times 10^{-4}} = 1578.95 \text{ kN/m}^2$$

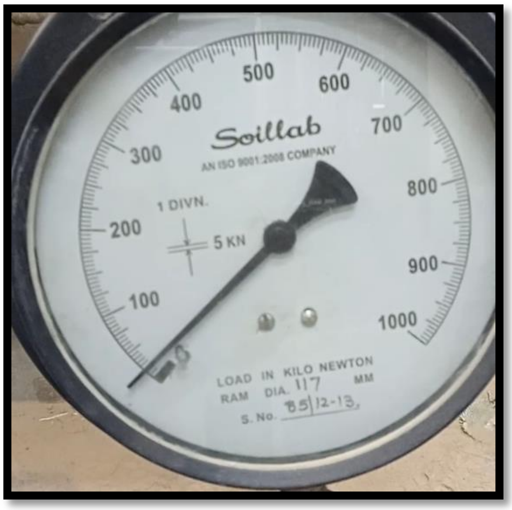

Fig. 6.9 Proving ring showing failure load for double layer reinforced slope

Table 6.6: Percent increase in failure laod from unreinforced to single layer reinforced slope

Case	Failure load(kN)	% increase in failure load
Unreinforced slope	5	-
Single layer reinforced slope	9	$\frac{9-5}{5} \times 100 = 80\%$

Table 6.7: Percent increase in failure laod from unreinforced to double layer reinforced slope

Case	Failure load (kN)	% increase in failure load
Unreinforced slope	5	-
Double layer reinforced slope	15	$\frac{15-5}{5} \times 100 = 200\%$

Table 6.8: Percent increase in failure laod from single layer reinforced slope to double layer reinforced slope

Case	Failure load (kN)	% increase in failure load
Single layer reinforced slope	9	-
Double layer reinforced slope	15	$\frac{15-9}{9} \times 100 = 66.67\%$

6.3 NUMERICAL MODELLING RESULTS

a) Unreinforced slope

Failure load = 5 kN

Vertical deformation at failure = 0.185 mm

Horizontal deformation at failure = 0.035 mm

b) Reinforced slope with single geogrid layer

Failure load = 9 kN

Vertical deformation at failure = 0.316 mm

Horizontal deformation at failure = 0.04 mm

c) Reinforced slope with double geogrid layer

Failure load = 15 kN

Vertical deformation at failure = 0.533 mm

Horizontal deformation at failure = 0.051 mm

6.4 DISCUSSION

- Increase in failure load from unreinforced to slope reinforced with single layer of geogrid in percentage is 80 %. The reason behind it is that the geogrid takes up the tensile stresses.
- Increase in failure load from unreinforced to double-layer reinforced slope in percentage is 200 %. This is due to the fact that the two layers of reinforcements are taking the tensile stresses now. More the no. of layers, more will be the increase in the failure load.
- From a single layer bolstered slope to a double layer reinforced slope, the failure load increases by a percentage value of 66.67%. This is because the geogrid reinforcement has the primary goal of resisting tensile loads or preventing unacceptable deformations in geotechnical constructions. The reinforcement acts as a tension member which is attached to the soil/fill materials by friction, adhesion, interlocking, or confinement, and so

enhances stability of the total soil mass.

- The vertical stress at the same depth of 25 cm is 526.32 kN/m^2 in case of unreinforced model. It has a magnitude of 947.37 kN/m^2 for single layer reinforced slope. The value for double layer reinforced slope is 1578.95 kN/m^2. The reason behind this is that the geogrid membrane effect increases the load-bearing capability of the underlying soil beneath the laden area.
- The stress in case of single layer reinforced slope is 1.8 times the stress in case of unreinforced slope.The stress in case of double layer reinforced slope is 3 times the stress in case of unreinforced slope.For the case of single layer to double layer reinforcement, the pressure ameliorates by 1.67 times.

CHAPTER 7

CONCLUSION

7.1 CONCLUSIONS

- It can be concluded from the results that the road embankment reinforced with two layers of geogrid will be the most effective one in terms of decrement in load.
- It would be the most stable one in bearing large loads. As a result, the load bearing capability of a two-layer reinforced slope is the greatest. So , the load carrying capacity improves as the number of geogrid layers increases.
- The deformation values obtained in both horizontal and vertical direction show a decreasing trend in either case. So , the geogrid will resist the deformations and deformations vary inversely with the no. of geogrids.
- The results obtained from the physical modelling show more percent changes than the results of the numerical modelling. The reason for this may be that gradual loading is applied in the laboratory and sudden loading is applied in the software.

7.2 FUTURE SCOPE OF THE PROJECT

- In future initiatives, the influence of geogrid reinforcements on the soil's bearing capacity can be investigated.
- Depending on the soil suitability, the test can also be conducted on other kinds of soil used as a road subgrade.
- The effect of vertical spacing of the different geogrid layers can also be checked in the upcoming projects.

REFERENCE

[1] Baig A. A., Tiwary A.K.(2019). "Behavior & stability analysis of geogrid reinforced earthwall: a case study in Vizianagaram (A.P.). "International Journal of Civil Engineering and Technology (IJCIET) ,Volume 10,pp. 830–843

[2] Benmebarek S., Berrabah F., Benmebarek N., Belounar L. (2015). "Effect of Geosynthetic on the Performance of Road Embankment over Sabkha Soils in Algeria: Case Study." Springer ,Int. J. of Geosynth. and Ground Eng. 1:35.

[3] IS 2720 (Part 3/Sec 1):1980 " Determination of specific gravity"

[4] IS 2720 (Part 4):1985 " Grain size analysis"

[5] IS 2720 (Part 5):1985 " Determination of liquid limit and plastic limit"

[6] IS 2720(Part 7):1980 "Determination of water content-dry density relation using light compaction."

[7] IS 2720(Part13): 1986 " Direct shear test"

[8] Jha A.K.,Madhira M.(2017). "Analysis of Effect of Reinforcement on Stability of Slopes with Marginal Soil." Indian Geotechnical Conference GeoNEst , IIT Guwahati, India

[9] Kolli I.,Balunaini U.(2017). "Geosynthetic Reinforced Earth Dams - A Study of Case Histories." Indian Geotechnical Conference GeoNEst, IIT Guwahati, India

[10] Madhumathi R.K., Amala Raju A.A., (2016). "Study on improvement in bearing capacity of soil using geogrid reinforcement." International Journal of Civil Engineering and Technology (IJCIET) Volume 7, Issue 6,pp. 172–178

[11] Majedi P.,Ghalehjough B.K., Akbulut S., Celik S.(2017). “Effect of Reinforcement on stability and Settlement of Embankment: A Finite Element analysis of Different Kinds of Reinforcing and Construction Conditions.” European Journal of Advances in Engineering and Technology, 4(10),pp. 759-764

[12] PLAXIS 2D tutorial manual V8

[13] Raouf El Abd E. Moamen.(2020). “Stability of geogrid reinforced embankment on soft clay.” Journal of Engineering Sciences Assiut University Faculty of Engineering Vol. 48, No. 5,pp. 830-844

[14] Rui Z.,Ming-xu L., Tian L.,Jian-long Z.,Chao G.(2020). “Stability analysis method of geogrid reinforced expansive soil slopes and its engineering application.” Springer, J. Cent. South Univ. 27: 1965−1980

[15] Safadoust J., Amiri S.N., Esmaeily A.(2013). “Numerical Analysis of Reinforced Embankment Over Soft Foundation.” Journal of Engineering Science and Technology Review 6 (3),pp. 153- 159

[16]Salahudeen, A. B. and Sadeeq, J. A.(2016). “ Numerical modelling of soil reinforcement using geogrids.” Proceedings of the Fourth International Conference on Engineering and Technology Research, Volume 4,ISBN: 978-2902-58-6

[17] Shukla S.K., Sivakugan N.,Das B.M.(2009). “Fundamental concepts of soil reinforcement — an overview.” International Journal of Geotechnical Engineering,pp. 329-342

[18] Singh M., Trivedi A., Shukla S.K.(2022). “Evaluation of geosynthetic reinforcement in unpaved road using moving wheel load test.” Geotextiles and Geomembranes, Volume 50, Issue 4, pp. 581-589.

[19] Touahmia M., Rouili A., Boukendakdji M., Achour B.(2018).
“Experimental and Numerical Analysis of Geogrid-Reinforced Soil Systems.” Arabian Journal for Science and Engineering, ISSN 2193-567

[20] Wulandari P.V., Tjandra D.(2015). " Analysis of geotextile reinforced road embankment using PLAXIS 2D." The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5). Procedia Engineering 125,pp. 358 – 362.

[21] Zornberg J.G.(2017). " Functions and applications of geosynthetics in roadways." Transportation Geotechnics and Geoecology.Procedia Engineering 189,pp. 298 – 306.