INVESTIGATING THE IMPACT OF VETIVER GRASS COMPOSITE WITH RICE HUSK ASH ON SOIL SHEAR STRENGTH: A BIOENGINEERING WAY OF SLOPE STABILIZATION

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Submitted by:

SHIVAM

(2K21/GTE/18)

Under the Supervision of

PROF. AMIT KUMAR SHRIVASTAVA

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

MAY 2023

DELHI TECHNOLOGICAL UNIVERSITY

(**Formerly Delhi College of Engineering)**

Bawana Road, Delhi -110042

CANDIDATE'S DECLARATION

I, Shivam, M. Tech Geotechnical Engineering, Roll No. 2K21/GTE/18, hereby declare that the Dissertation titled "Investigating the Impact of Vetiver Grass Composite with Rice Husk Ash on Soil Shear Strength: A Bioengineering Way of Slope Stabilization" that I submitted to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of Master of Technology is original and has not been copied from any source. This work has never been used to confer a degree, diploma associateship, fellowship, or any other equivalent title or honor.

Place: Delhi **SHIVAM**

Date: 31 May 2023 **2K21/GTE/18**

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the project Dissertation titled "**Investigating the Impact of Vetiver Grass Composite with Rice Husk Ash on Soil Shear Strength: A Bioengineering Way of Slope Stabilization**" submitted by Shivam, roll no. 2K21/GTE/18 (Civil Engineering), Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of a Master of Technology degree, is a record of the project work completed by the student under my supervision. To the best of my knowledge, thematter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Place: Delhi

Date: 21 May 2023

Prof. A K SHRIVASTAVA

SUPERVISOR

Department of Civil Engineering

Delhi Technological University

Delhi-110042

ABSTRACT

The plant's property of arresting the soil by roots reinforcement technique reinforces the slopes and increases stability. Using vegetation in bioengineering offers a viable slope protection solution. As a result of soil problems in environmental applications and effective solid waste disposal, research has been done to examine the feasibility of employing solid wastes to enhance soil engineering behavior. In this paper, the mechanical effect of vegetation and solid waste on slope stability is calculated by studying the effect of vetiver grass composite with rice hush ash on the stability of the soil. Laboratory tests were performed for soil, vetiver, and RHA (rice husk ash) composite. At different RHA content of 5%, 10%, 15% & 20% mixed in the soil on which vetiver grass was planted. According to the test findings, soil+vetiver+10%RHA gives the highest strength among different compositions. Soil+vetiver+10%RHA increased shear strength overall, decreasing cohesiveness from 15.37 to 13.10 KPa and increasing the soil friction angle from 33.22° to 40.96°. Based on the results obtained from the direct shear test, the factor of safety (FOS) was determined with and without a composite of vetiver and 10%RHA content by using PLAXIS 2D at different slope angles(A) of 30.96^{0}, 36.87^{0}, and 45^{0}. A maximum percentage increase in FOS was observed at 18.78% for soil+vetiver+10%RHA with respect to bare soil at a slope of 45°. This study offers a scientific explanation for the impact of plant and RHA cover on the stability of the slope.

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2K21/GTE/18

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Slope failures and associated impacts happen often worldwide. During the rainy season, landslides are a common occurrence that causes damage to property, animals, and people while obstructing local transportation infrastructure. An established method for the reliable, effective, and practical study of landslide mechanisms is modeling (Paswan and Shrivastava 2022). Although these occurrences are unpredictable, their impact can be reduced by applying engineering techniques to ensure the slope's stability before construction (Paswan and Shrivastava, 2021). There are several methods for dealing with slope instability and which one is chosen is influenced by objectives, hazards, and financial resources. The traditional slope stabilization method involves extracting and replenishing old soil with suitable soil materials, adding retaining walls, putting in soil nails, using geosynthetics, and other methods (Chok et al., 2015). However, the primary flaws with these methods are they all require heavy expenses and highly skilled labor. Regarding economics and environmental aspects, using vegetation can be beneficial compared to various conventional methods (Maffra and Sutili, 2020).

Soil bioengineering, which stabilizes mountain slopes and reduces its effects on ecosystems, is being employed more and more frequently around the world, however, the effectiveness of this technique needs to be adequately evaluated by post-intervention environmental monitoring. A composite soil-root system is created by the interaction of the grassroots with the soil. Higher tensile strength roots are placed in the soil using this composite technique. Root systems multiply the soil's shear strength by building a link and by facilitating adhesion between the soil mass and roots (Fan and Lai, 2014). A promising grass that grows well in a variety of situations and reduces erosion is vetiver grass (Islam et al.,2020). Additionally, the presence of vetiver root enhances slope stability and avoids topsoil erosion. Rain that falls straight on bare soil has the potential to remove more soil than droplets that are diverted by plants. Vetiver has proved its root strength to arrest slope failures and increase the shear strength of the soil (Badhon et al., 2021; Jared and Noorasyikin, 2021; Mondal and Patel, 2020; Mu’azu et al. 2018).

On the other hand, as a means of increasing solid waste disposal in the world one fact should be considered If the waste has useful features, the amount that is disposed of in landfills can be decreased so that it can be used for many geotechnical applications. India is a large producer of rice, and the milled husk is generally utilized as a fuel in the boilers that process the rice, either directly combusting it or gasifying it to produce electricity. The annual production of rice husk ash (RHA) is about 20 million tonnes (Hajare, 2012). In countries like India where there is a sustainable production capacity of rice, using RHA can be taken as a cost-effective solution. The RHA's silica content is influenced by the burning temperature. For the manufacturing of pozzolana cement, the burning of rice husk to produce amorphous silica is ideal. Many studies use RHA to decrease permeability with an increase in RHA content in the soil. The physical characteristics of RHA were conserved under SEM, and this was ascribed to the soil's increased permeability after RHA treatment. RHA can enhance the shear strength of soil, as evidenced by the fact that the shear strength coefficient increases considerably as RHA increases (Pode 2016; Rahman et al. 2014; Sarkar et al., 2012). Additionally, shear strength should be the subject of qualitative and quantitative investigation, particularly for the composite made of vetiver grass and RHA. So, the composite of vetiver grass and RHA is the subject of laboratory testing in this work, and based on the results numerical modeling is done to know the stability of the slope using PLAXIS 2D.

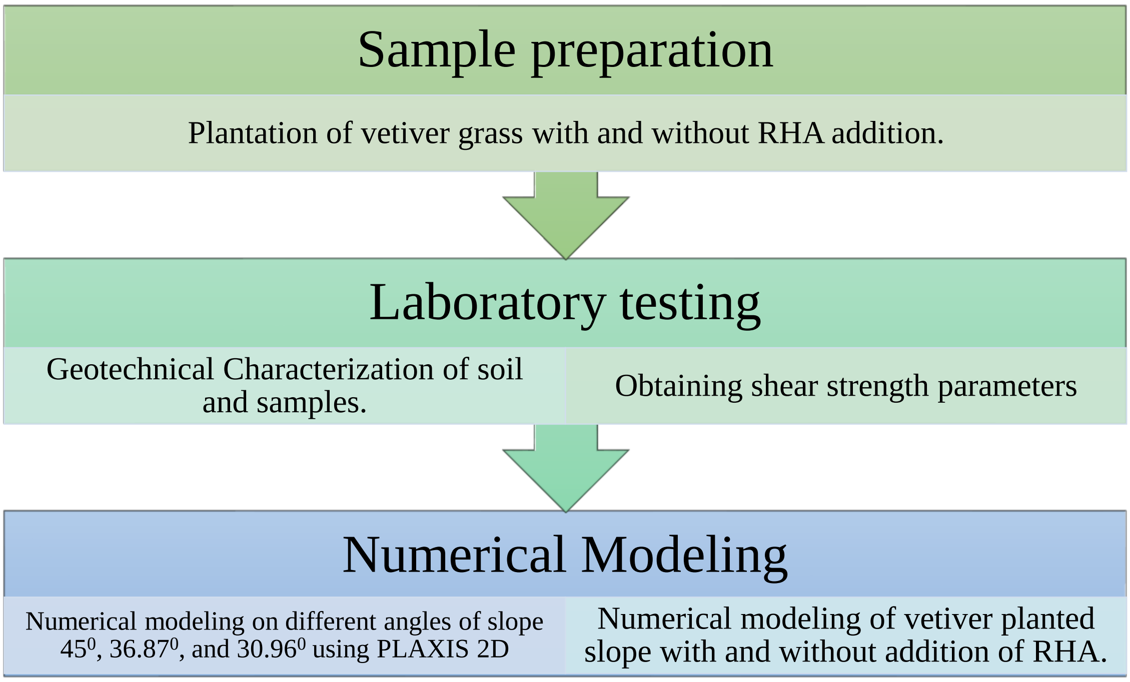


Fig. 1.1 Representation of Steps involved in the research work

1.2 AIM OF RESEARCH

- To compare the shear parameter of a) soil, b) soil+vetiver, and c) soil+vetiver+RHA (composite).
- To study the effect of RHA on the shear strength of the soil.
- To compare the growth of root and shoot of vetiver grass and composite of RHA and vetiver grass.
- Validation of the obtained data through numerical modeling using PLAXIS 2D.

1.3 STRUCTURE OF THE THESIS

The structure of the thesis basically contains the components of the thesis in chronological order. Chapter 2 contains the literature review and the research gap in those literature reviews. Chapter 3 goes through the sample preparation and the laboratory testing involved in the study. Chapter 4 gives the input of the numerical model done on the bases of the result of the laboratory tests. Chapter 5 gives the results and discussion of the laboratory test and the numerical modeling output. Chapter 6 involves the conclusion and future scope of the research of this thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE WORK

Table 2.1 shows the literature work during the research in tabular form. Table 2.1 includes the Author's name, Description of work, Technique or method used in the paper, Type of plant or percentage of RHA included and the result obtained in the research paper.

Table 2.1. Literature work

Author's Name	Description	Technique used/Method adopted	Type of Plant/ Percentage of RHA	Results obtained
Badhon et al. (2021)	This study aims to assess the enhanced soil shear strength characteristics and to assess the stability of vegetated slopes.	Laboratory testing and numerical modeling using PLAXIS 2D	Vetiver grass (Chrysopogon zizanioides)	At different types of soil, 50% is the maximum increase in shear strength. PLAXIS results show a 20.6% increase in FOS of the sandy slope.
Islam et al. (2020)	This study uses PLAXIS 2D software to mathematically examine the stability of hill slopes and the efficacy of vetiver for protecting slopes.	Numerical modeling using PLAXIS 2D	Vetiver grass (Vetiveria zizanioides)	The result shows a 2-15% increase in FOS for sandy slope. Whereas for clay there is an insignificant increase in FOS.

D’souza et al. (2016)	In this work, in situ direct shear experiments were carried out on a soil plot at various depths.	Direct shear test	Vetiver roots	At a depth of 0.15m the shear strength increased by 139% whereas at a depth of 0.75m, the shear strength increased by 47%.
Rahardjo et al. (2014)	This study demonstrates how orange jasmine and vetiver grass can reduce the amount of rain infiltration.	Tensiometers, installed at different depths	Orange Jasmine and Vetiver grass	Test results show a significant change in minimizing the loss of matrix suction.
Tsige et al. (2019)	Incorporating the impact of plant roots into slope stability calculations along a road corridor is demonstrated in this research.	Tensile strength testing, triaxial compression tests, and Numerical modeling using PLAXIS 2D	Eucalyptus globules (tree), Salix subserrata (shrub), Chrysopogon zizanioides, and Pennisetum macrourum (grasses)	There is an increase in FOS by 22-34% due to the root reinforcement of plants and trees.

Jared et al. (2021)	The purpose of this study is to identify the root characteristics of the Vetiver Grass as well as the physical and mechanical qualities of the soil containing Vetiver Grassroots.	Root morphology and direct shear tests with and without root	Vetiver grass	According to the findings, soil with roots has a higher shear strength than soil without roots.
Dhital et al. (2012)	This paper provides a quick summary of how soil bioengineering is used on slopes and stream banks.	Brush layering, palisades, live check dams, fascines, and vegetative stone pitching	Tree roots	Soil bioengineering techniques are affordable, employing locally accessible materials and inexpensive labor. Nevertheless, scientific implementation, record-keeping, and work assessment are vital.
Badhon et al. (2021)	This study examined the relationship between the tensile strength of roots per unit soil area and the increased shear strength of rooted soil.	Morphological characteristics and tensile test	Vetiver grass roots	The mobilization tensile strength of roots and the extra shear strength of rooted soil were shown to be roughly inversely correlated.

Mondal et al. (2020)	The extent to which riparian buffers are built through riverbank alteration, planted and maintained, and the effectiveness of the grass in limiting erosion through a brief case study from West Bengal.	Ecogeomorphological survey	All Bioengineering applications	Vetiver grass is a highly popular technique in soil erosion control and riverbank irrigation mitigation.
Rao et al. (2016)	This study calculates the mechanical impact of plants on slope stability.	1. Equivalent cohesion approach and root. 2. Root as a pile approach Using PLAXIS 3D	Vetiver grassland	FOS increased from 1.36 to 1.43 compared with bare soil.
Tamgoua et al. (2016)	This study creates a 3D numerical simulation model to evaluate how the stability of hillslopes is affected by the structure of forest stands and 3D root systems.	3D finite element method implemented in SIMULIA software	Forest land	The highest overall stability increase is provided by block morphology with tap-like edges. Additionally, the stand parameters with the greatest impact on the slope's safety factor are the inter-tree distances in the slope direction.

Chok et al. (2015)	This research uses finite element methods to examine how root reinforcement affects slope stability.	A finite element code called slope64 described by Griffiths and Lane	Root reinforcement	The findings of the finite element calculations show that when the influence of root reinforcement is factored into account, the factor of safety of a slope improves.
Ali et al. (2018)	This research pairs a slope stability framework with the mechanical and hydrological impacts of plants.	Mathematical analysis	Tree	Results show there is an increase in FOS when trees are at the toe of the slope by 8%.
Rathan et al. (2016)	In this research, an effort is undertaken to investigate the viability of using solid wastes to enhance the engineering behavior of challenging soils.	Study index and engineering properties of soil mixed with RHA	RHA (Rice husk ash)	Results show that the cohesion value decreases from 60 to $20Kn/m^2$ and the internal friction angle increased from 17.5^0 to 39^0
Verma et al. (2020)	This study aims to strengthen the colluvial soil that was weak in the Kotropi landslide in Himachal Pradesh.	By varying the amounts of additives, different samples of soil are created, and direct shear tests are then performed.	RHA and micro silica powder	Maximum strength is found to be achieved by using 4% of micro silica powder and 15% of rice husk ash.

Sarkar et al. (2012)	The impacts of rice husk ash (RHA) on the geotechnical parameters of stabilized soil, including strength, workability, compaction, and compressibility characteristics, are discussed in this research.	Various laboratory tests, such as compaction, Atterberg limits, free swell index, unconfined compressive strength, direct shear, and consolidation tests, as well as original soil samples were conducted for different RHA content percentages.	RHA	The result of the study shows that by including 10% RHA content, the unconfined compressive strength and shear strength of soil may be improved.
Karakurt et al. (2023)	Effect of adding rice husk ash on Soils' consolidation properties.	Laboratory tests	RHA	The consolidation properties of low plasticity clayey soils are somewhat influenced by rice husk ash.
Karakurt et al. (2023)	Using rice hush ash, a laboratory investigation on the liquid limitations of soils was enhanced.	Laboratory tests	RHA	In this work, the consistency limitations of soils are enhanced using rice husk ash, an organic pozzolanic waste product.

Choobbasti et al. (2018)	This work investigates the link between the physical and mechanical characteristics of the soil and the addition of rice husk ash	Laboratory tests	RHA and Lime	One of the primary findings of this article is an increase in CBR quantity caused by an increase in RHA.

2.2 RESEARCH GAP

- RHA mixed as an additive for vetiver is not studied in the past and can give prominent results for stability of the slope.
- Infiltration of rainfall effect on grass is not yet answered clearly by any existing studies.
- There is insufficient information available in research papers that shown the growth effect of RHA on the vetiver grass.
- Strength is dependent on the root density of the plant. It can be different in the same plant species and this problem is not addressed in previous studies.

CHAPTER 3

SAMPLE PREPARATION AND LABORATORY TESTS

3.1 MATERIAL USED

3.1.1 Specification of soil

Blackish brown silty clayey sand was used in this study, collected from a Nursery at Delhi Technological University, Delhi, India. The collected soil was soft and mixed with some moisture. IS classification system is used for the classification of the soil. The soil is classified as SM-SC silty clayey sand with some organic content due to its past uses.

3.1.2 Specification of vetiver grass

Vetiver grass was collected from Delhi (28.7041° N, 77.1025° E). The scientific name "Chrysopogon-zizanioides" is locally known as "Khas, Khas-Khus" in the native language.

3.1.3 Specification of rice husk ash

RHA was produced in Kurukshetra by burning rice husks that had been collected from a nearby mill. The generated RHA includes around 60-70% silica, a crucial component for enhancing the quality of the soil. Before use, Rice hush ash is Sun-dried to remove its moisture content. The constituents and compositions of RHA are listed in Table 3.1(Rathan et al., 2016).

Table 3.1 Constituents and Composition of rice husk ash (Rathan et al., 2016)**.**

CONSTITUENTS	COMPOSITION
SiO_2	67.3%
Al_2O_3	4.9%
MgO	1.81%
Fe_2O_3	0.95%
CaO	1.36%
Loss	17.78%

3.2 PREPARATION OF SAMPLE

PVC (Polyvinyl Chloride) pipes with a diameter of 4 inches and a length of 1 foot each were used to plant vetiver grass. Three of the pipes contained bare soil, three of the pipes contained soil that had been planted with vetiver, and the other three pipes contained soil that had 5% RHA mixed in similarly 10%, 15%, and 20% RHA mixed and planted vetiver as shown in Figure 3(a). The sand was inserted into the pipes in three layers, and each layer was tamped using a 30 cm long, nearly 2 kg heavy steel tamping rod with 25 blows each to get the appropriate density per layer. Undisturbed rooted soil specimens of 60mm*60mm size were retrieved 75 days after they were planted from the pipes. Samples were collected 10 cm below the top surface of a pipe. Samples were cut 10cm below the top layer to avoid disturbance in the sample as shown in Figure 3(b).

(a)

(b)

Fig. 3.1 (a) Vetiver Grass planted in PVC pipes; (b) Vetiver Grass planted soil having RHA in PVC pipes.

3.3 LABORATORY TESTING AND EXPERIMENTAL STUDIES

3.3.1 Grain Size Distribution

Wet sieving 300 g of oven-dried soil sample at 105°C - 110 °C to determine the grain size according to IS. The process was then conducted for dry sieve analysis according to IS:2720 (Part 4)-1985. 4.75 mm to 75-micron sieves were used for the analysis of grain size. Figure 3.2 shows the sieve analysis output according to IS: 2720 (Part 4).

Fig. 3.2 Sieve analysis according to IS code.

3.3.2 Bulk Density and Moisture Content

Bulk density was determined by the Core Cutter method as recommended by IS:2720 (Part 29)- 1975. The samples of every set of PVC were taken for the determination of bulk density. The internal diameter and height of the core cutter were 10 cm and 13 cm respectively. After the determination of bulk density, every set of samples was taken in the container to determine the moisture content of the respective samples. Moisture content was determined as per IS:2720 (Part 2)-1973.

3.3.3 Specific Gravity

The specific gravity of the sample of soil taken from a nursery inside Delhi Technological University has been determined using Pycnometer. IS:2720 (Part 3, Section 1)-1980 has been used to calculate the specific gravity of the soil samples for all the samples. The specific is calculated by using the equation below:

$$\text{Specific Gravity (G)} = (W_2-W_1)/((W_2-W_1) -(W_3-W_4)) \quad [3.1]$$

Where W_1 = Weight of empty pycnometer

W_2 = Weight of pycnometer + oven dry soil

W_3 = Weight of pycnometer + oven dry soil + water

W_4 = Weight of pycnometer + water

All the weights in the above equation are in grams (g).

3.3.4 Liquid Limit and Plastic Limit

For the determination of Liquid Limit (LL), the Casagrande cup method was used. The soil paste is placed in the Casagrande cup and a groove is made in the center of it in accordance with IS: 2720 (Part 5). The maximum moisture content that, after 25 blows, would be required to close a groove's bottom by 0.5 inches is known as the limit in a liquid limit device. To close the groove after 25 blows with the required 12.5 mm (0.5 in.), it is difficult to change the soil's moisture content. As a result, the same soil was used in at least three tests, each of which was run at a different moisture level with N blows ranging from 15 to 35.

The Plastic Limit (PL), also known as the Lower Plastic Limit, is the water content at which soil changes from a plastic to a semisolid state. The plastic limit test was performed manually, in accordance with IS:2720 (Part 5), by repeatedly rolling an ellipsoidal-sized soil mass over a non-porous surface. The plastic limit, according to Casagrande, is the water content at which a thread of soil simply crumbles when it is carefully rolled out to a diameter of 3 mm (1/8"). After repeatedly molding the sample with varying amounts of water, the test was carried out.

3.3.5 Direct shear test

The soil sample is cut from the PVC pipes, then through a sampler of the direct shear box, samples were taken out 10cm below from the top of PVC in the undisturbed form as shown in Figure 3.3, and Figure 3.4 (b). The Layout of the planted PVC and from where the pipe cuts are shown in Figure 3.4(a). A direct shear test was performed on the sample with a desired normal load. Normal stress acting on the sample was 50KPa, 100KPa, and 150KPa, and the corresponding shear load was noted.

Fig. 3.3 Direct shear sample of rooted soil cut 10cm from the top

(a) (b)

Fig. 3.4 (a) Layout of planted PVC; and (b) Sample of the direct shear test.

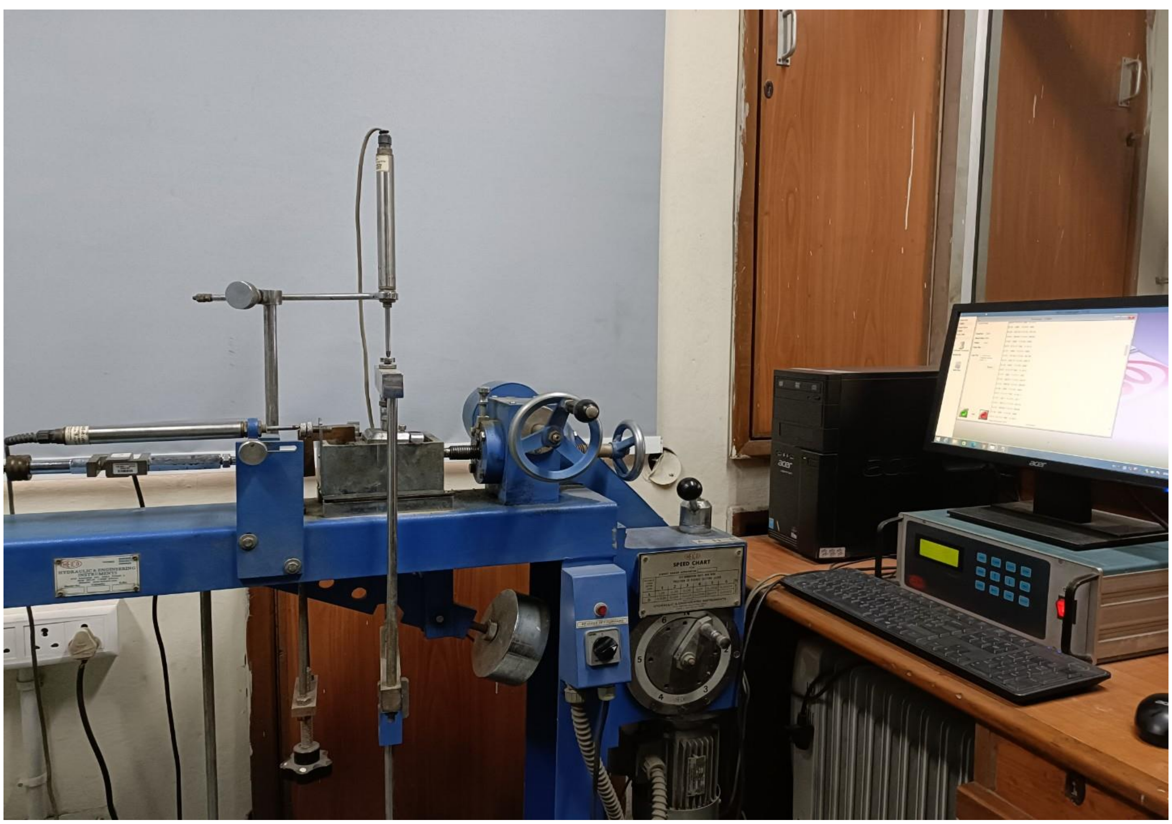


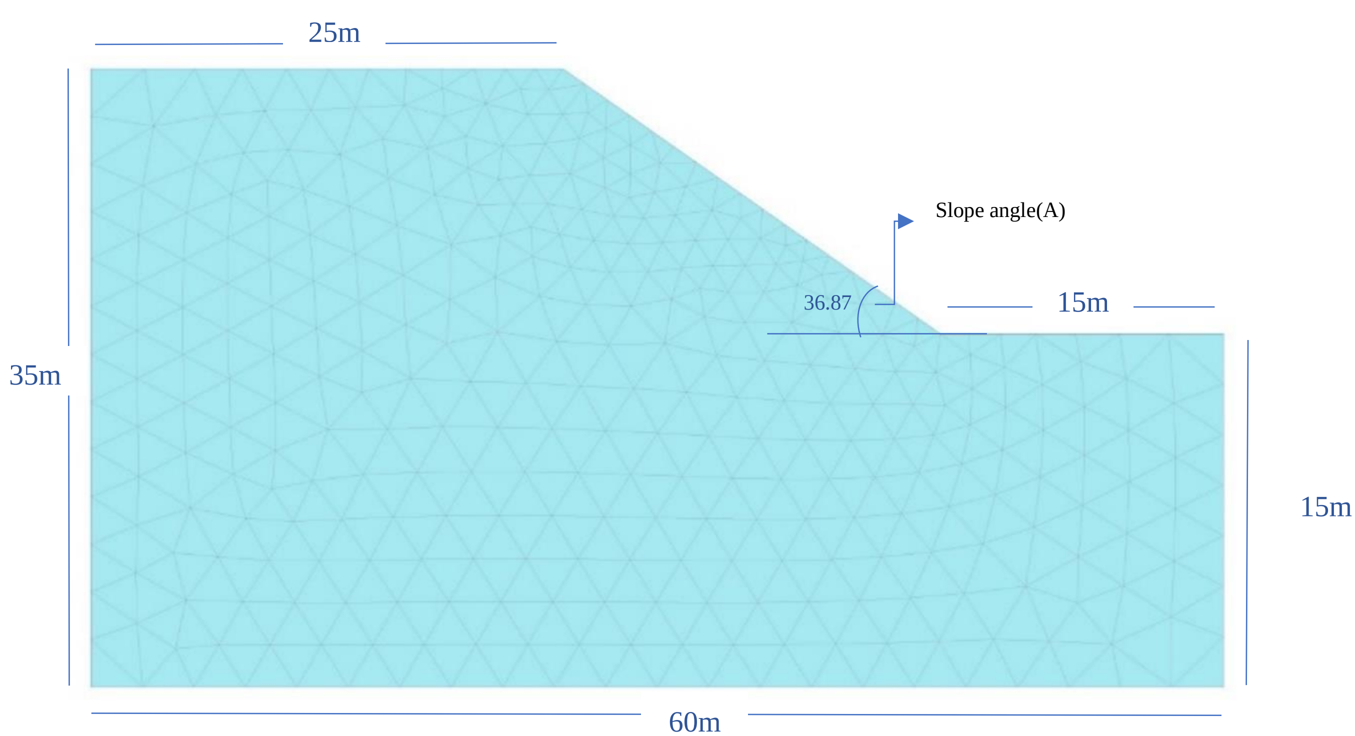
Fig. 3.5 Direct shear apparatus with computer analog.

The vertical displacement was measured with a dial gauge. As per IS code in order to apply the shear force, the consolidation process was first finished. When a vertical displacement dial gauge reads twice in a row for the same soil samples, then they were deemed to be consolidated, and the sample was put under shear strain using a 1.25 mm/min of steady strain rate. After that Horizontal displacement and shear load were measured with respect to normal stress. The direct shear test was performed on direct shear apparatus with computer analog as shown in Figure 3.5.

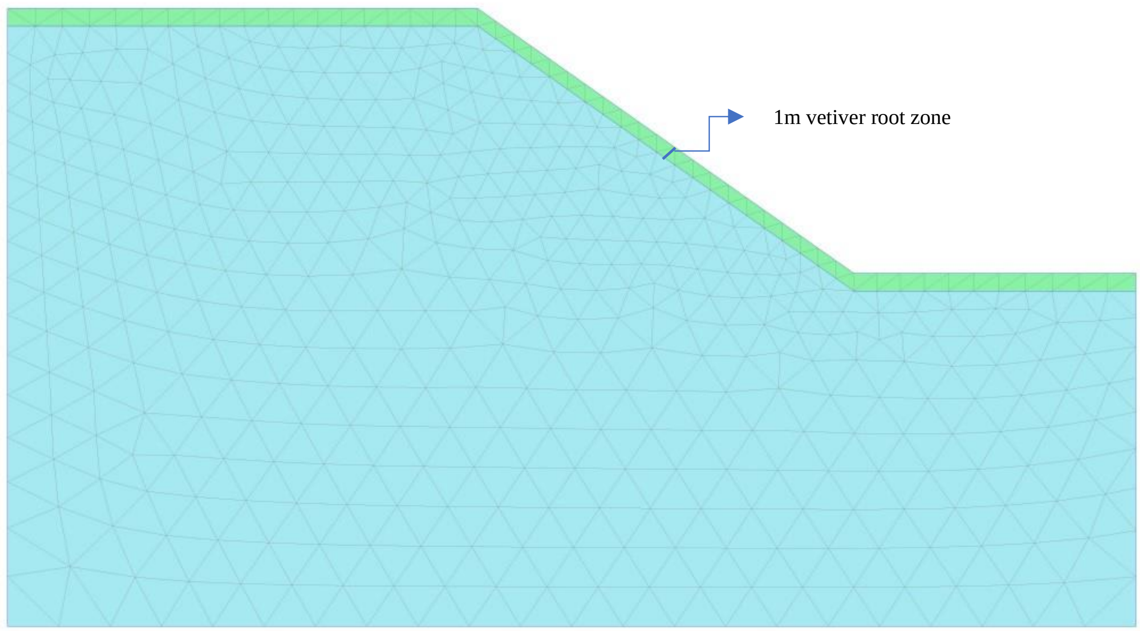
CHAPTER 4

NUMERICAL MODELING

A numerical study is done to assess the stability using the laboratory test results performed on undisturbed bare, rooted, and composite samples of RHA. PLAXIS 2D was used for FEM models at different slope angles for bare soil, soil+vetiver, and soil+vetiver+10%RHA. For the analysis, the root zone for vetiver was taken 1m as research studies show that vetiver can grow up to 1m in the span of 3 months. For rice husk ash the composite depth of root+10%RHA zone is also taken 1m with an assumption that RHA mixed in soil up to 1m as shown in Fig. 3. The study was conducted for different slope angles of 45˚, 36.87˚, and 30.96˚. Young's modulus is given by (Voottipruex et al. 2008) for soil+vetiver which gives the relation between young's modulus and the diameter of the root and for soil+vetiver +10%RHA by (Rojas et al. 2023). The Poisson ratio was taken as 0.3 in all cases.



(a)



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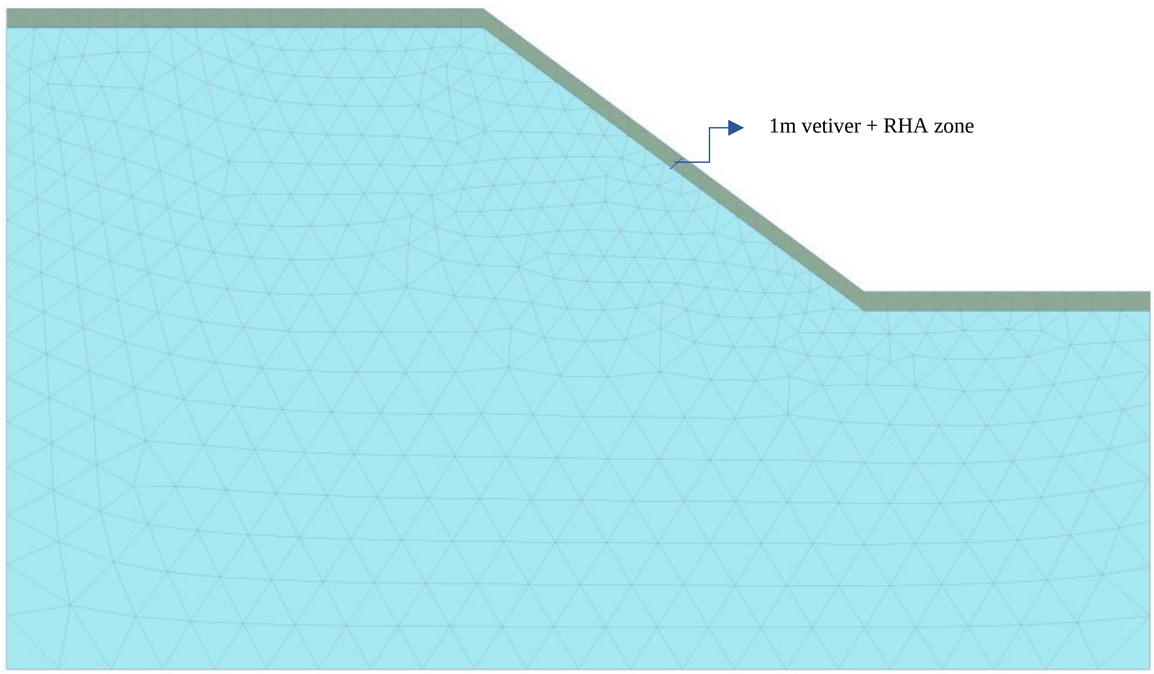


(c)

Fig. 4 Finite element mesh at 36.87° for (a) Bare soil, (b) Soil+vetiver, and (c) Soil+vetiver+10%RHA

The model used in the study for the 36.87° slope is given above in Figure 4. Similarly, the 45^0, and 30.76^0 slopes were also studied in this research work. Dimensions of the slope are as shown in the figure 4 (a). Their results are given in results and discussion in Chapter 5.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 LABORATORY TESTING

To understand the characteristics of soil, several laboratory experiments were carried out which include natural moisture content, natural unit weight, liquid and plastic limit, specific gravity, and shear parameters using the direct shear test. Given below are the results of these tests in Table 5.1.

5.1.1 Results for Particle Size Distribution

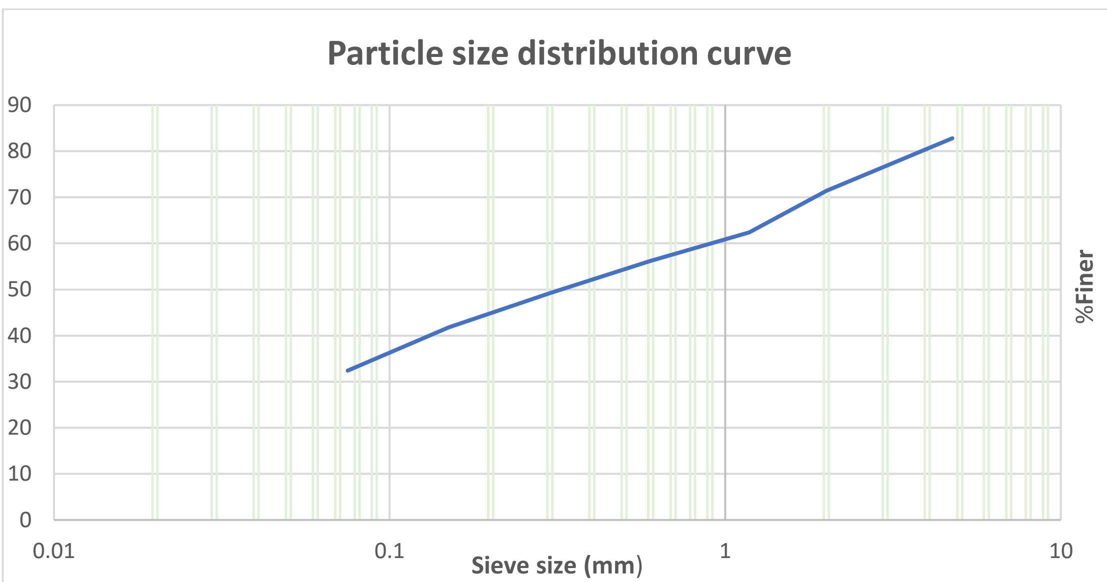


Fig. 5.1 Particle size distribution curve for the natural soil.

5.1.2 Results of testing of index properties of natural soil

Results of soil classification, natural water content, Unit weight, specific gravity, liquid limit, and plastic limit are shown in Table 5.1 below.

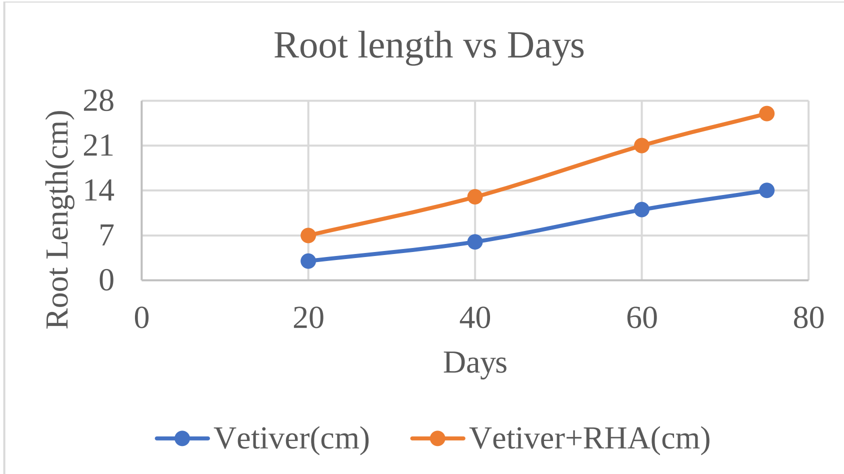
Table 5.1 Properties of natural soil.

Properties	Soil
IS classification	SM-SC
Natural water content	17.67%
Unit weight	15.5 KN/m^3
Specific gravity	2.56
Liquid limit	20.03986%
Plastic limit	15.94%

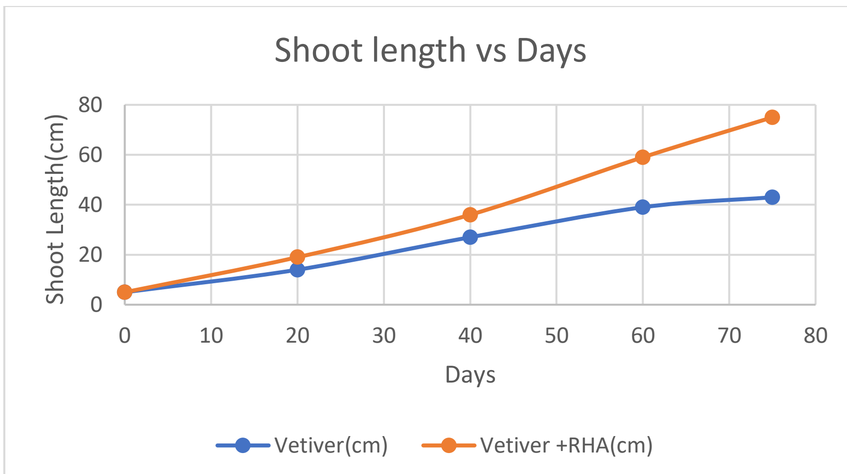
IS classification system is used for the classification of the soil. The soil is classified as SM-SC silty clayey sand with some organic content due to its past uses.

5.1.3 Root and Shoot Growth

For the comparison of the effect of RHA in vetiver grass, the root and shoot length of grasses was measured at regular interval basis of 20, 40, 60, and 75 days for both with and without RHA plants, and the rest of the plants remained undisturbed. Based on that data a comparison chart given below gives a sight of the effect on the growth of vetiver with and without RHA. Figure 5.2 shows the comparison of root and shoot length at specific intervals of time. The graph in Figure 5.2 a) and b) shows that there is near twice the difference in the growth of both root and shoot of vetiver with and without RHA. This shows that adding RHA into the soil highly promotes the growth of vetiver both in root and shoot cases respectively. Several papers show that the RHA can be added to soil to make it lighter, which results in a reduction in the dry density of soil. Additionally, by including 10% RHA content, the soil's unconfined compressive strength is found to be increasing and shear strength also tends to increase(Sarkar et al. 2012).



(a)



(b)

Fig. 5.2. a) Change in root length w.r.t days; b) Change in shoot length w.r.t days.

5.1.4 Results of direct shear test

Direct shear results are plotted on the graph as shown in Figure 5.3. In that graph, normal stress vs shear stress was plotted for different conditions of soil (Bare soil, soil+vetiver, soil+vetiver+5%RHA, 10%RHA, 15%RHA, and 20%RHA).

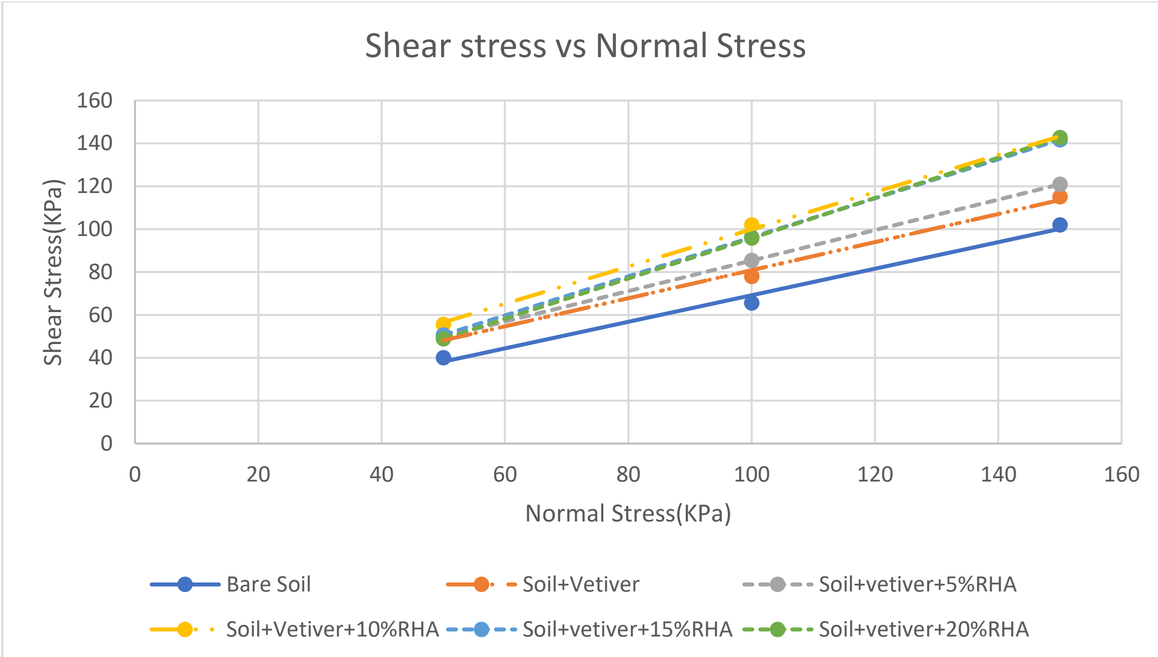
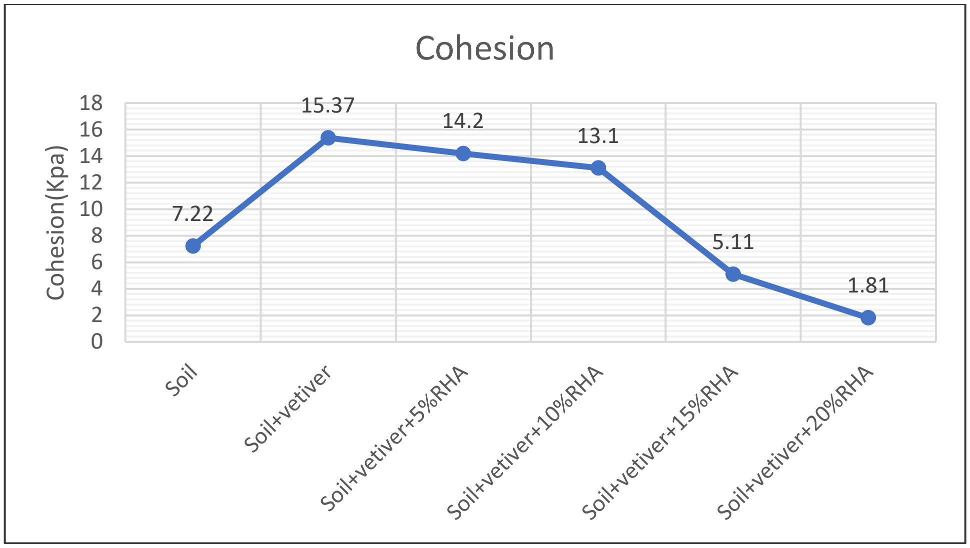


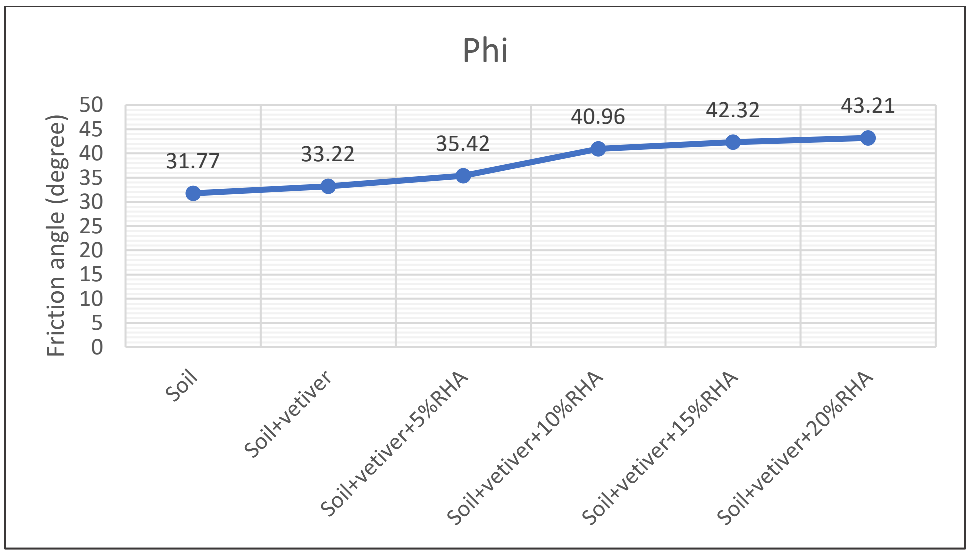
Fig. 5.3 Direct shear test results at different conditions of soil

Table 5.2. Cohesion and angle of friction values for different compositions.

Parameter	Bare soil	Soil+ vetiver	Soil+vetiver+5 %RHA	Soil+vetiver+10 %RHA	Soil+vetiver+15 %RHA	Soil+vetiver+20 %RHA
Cohesion (KPa)	7.22	15.37	14.2	13.1	5.11	1.81
ϕ (°)	31.77	33.22	35.42	40.96	42.32	43.21



(a)



(b)

Fig. 5.4 (a) Cohesion values of different compositions of soil and RHA; (b) Friction angle values of different compositions of soil and RHA.

The cohesion and friction angle values for the different compositions are calculated from direct shear tests are as shown in Table 5.2. The cohesion and friction angle trend for 5%RHA, 10%RHA, 15%RHA, and 20%RHA is similar in various research articles (Pushpakumara and Mendis, 2022; Sarkar et al. 2012). Direct shear test results show that among the different compositions of RHA, the soil having 10% RHA and on which vetiver grass was planted shows the maximum shear strength as compared to other compositions. *Hence, for further numerical modeling analysis, soil+vetiver+10%RHA composite is used*.

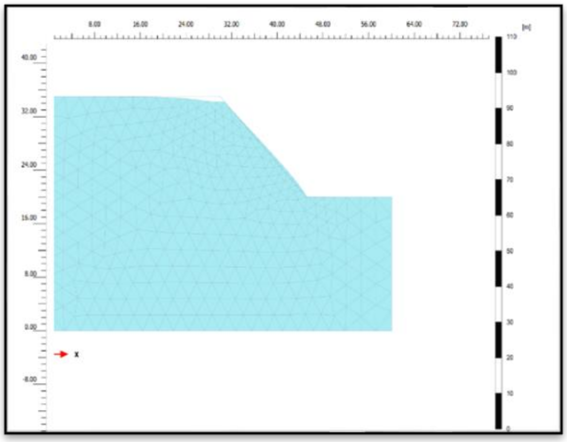
5.2 NUMERICAL MODELING OUTPUTS

Table 5.3. Parameters used in FEM analysis.

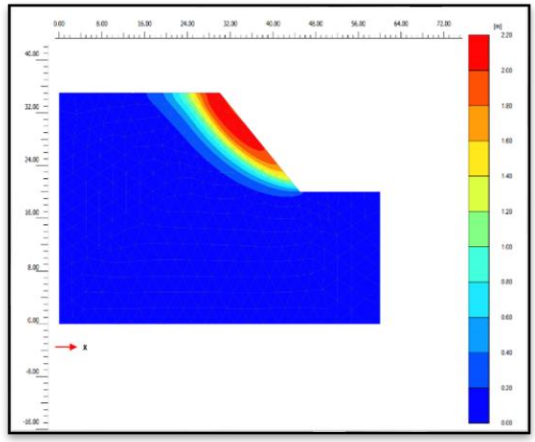
Composition	Cohesion (KPa)	ϕ (°)	Young's modulus (Kn/m^2)	Poisson ratio	Unit weight	Moisture content (%)
Bare soil	7.22	31.77	25000	0.3	15.5	17.67
Soil+vetiver	15.37	33.22	30000	0.3	16	17.6
Soil+vetiver+10%RHA	13.1	40.96	28000	0.3	14	16.2

Parameters taken for the numerical modeling in the FEM analysis are shown in Table 5.3. Numerical modeling output results are shown in Fig. 5.5 to 5.7. From the results observed from PLAXIS 2D analysis, change in FOS at slope angles 30.96°, 36.87°, and 45° for Bare soil, soil+vetiver, soil+vetiver+10%RHA presented in Fig. 5.8.

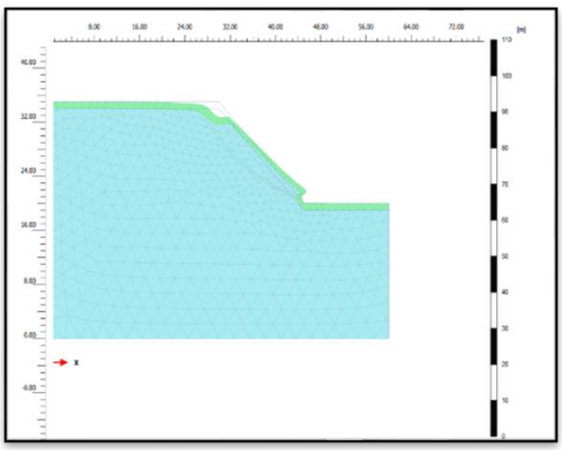
SLOPE ANGLE 45^0



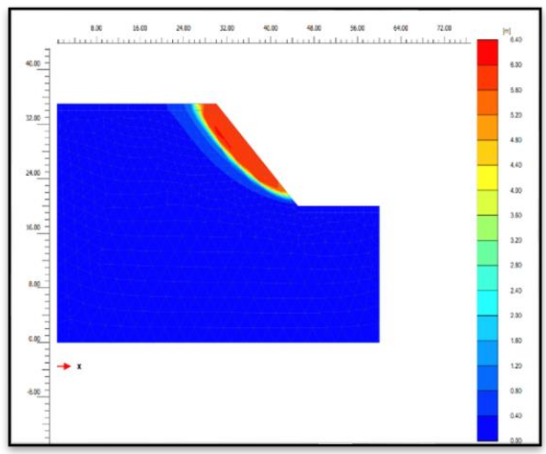
(a)



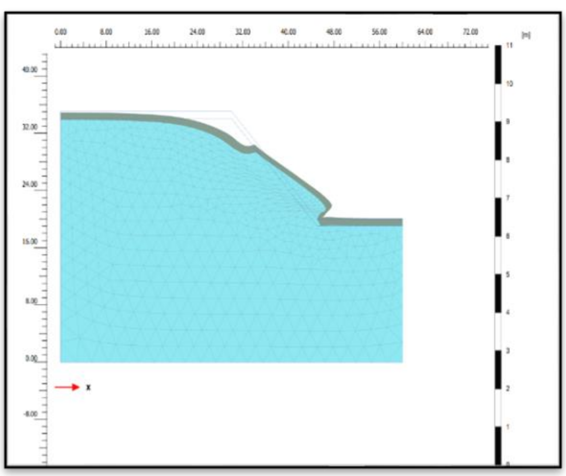
(b)



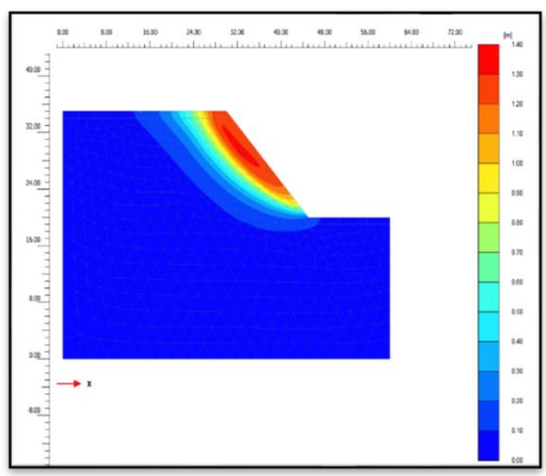
(c)



(d)



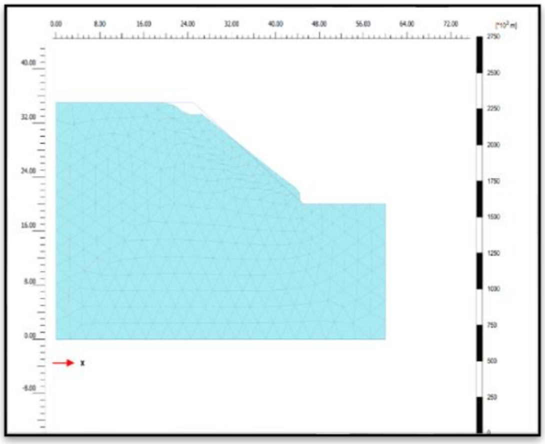
(e)

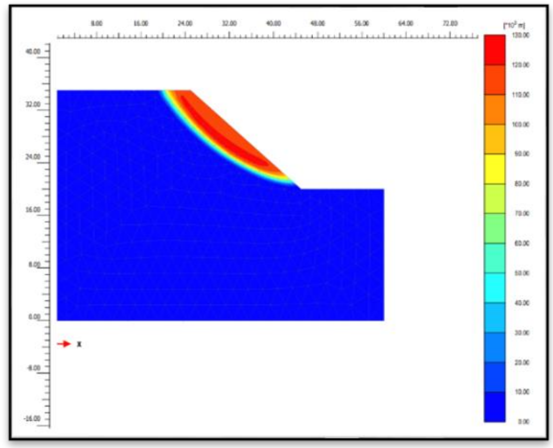


(f)

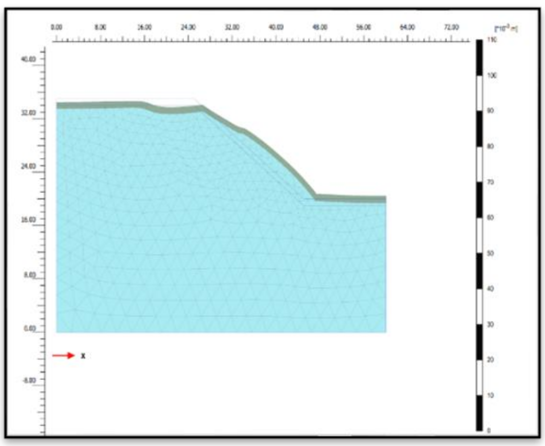
Fig. 5.5 (a), (c), (e) shows the deformed mesh for slope of 45^0 for bare soil, soil+vetiver, and soil+vetiver+10%RHA respectively; (b), (d), (f) shows the total displacement in factor of safety mode for slope of 45^0 for bare soil, soil+vetiver, and soil+vetiver+10%RHA respectively.

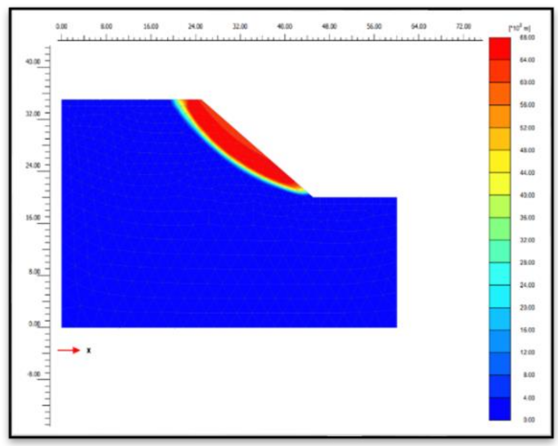
<u>SLOPE ANGLE 36.87^0</u>



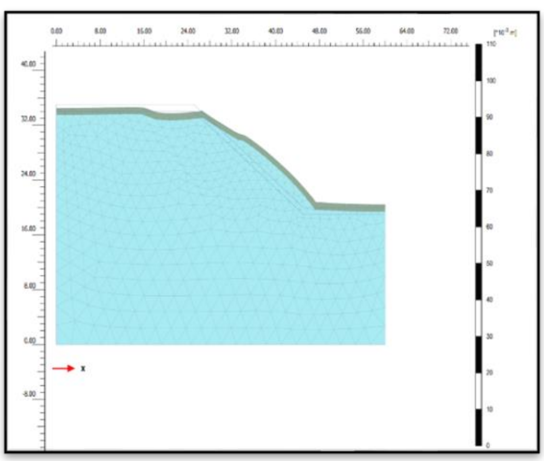


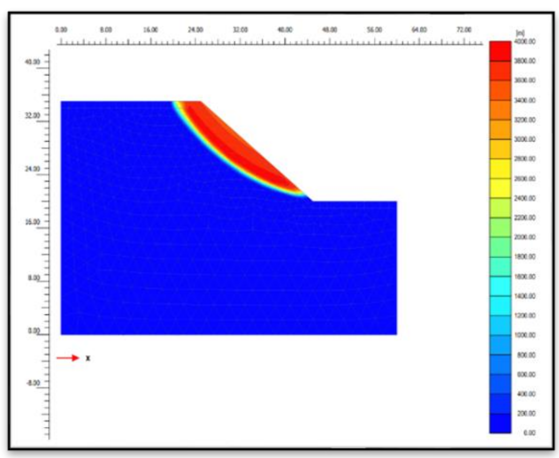
(a) (b)





(c) (d)

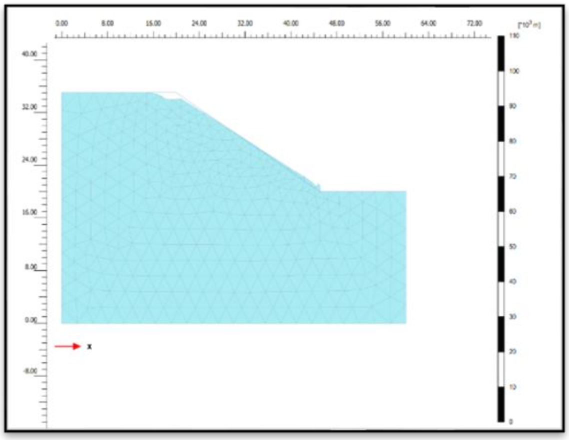


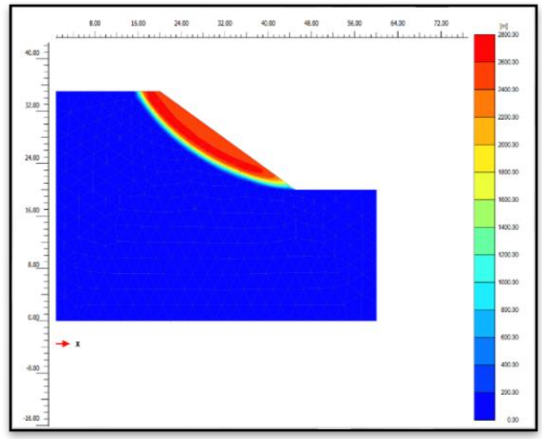


(e) (f)

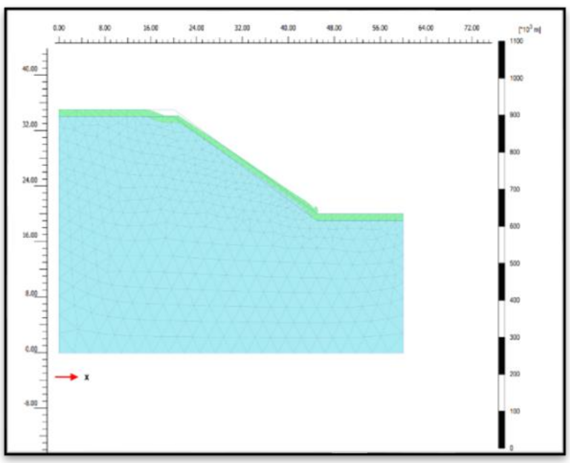
Fig. 5.6 (a), (c), (e) shows the deformed mesh for slope of 36.87^0 for bare soil, soil+vetiver, and soil+vetiver+10%RHA respectively; (b), (d), (f) shows the total displacement in factor of safety mode for slope of 36.87^0 for bare soil, soil+vetiver, and soil+vetiver+10%RHA respectively.

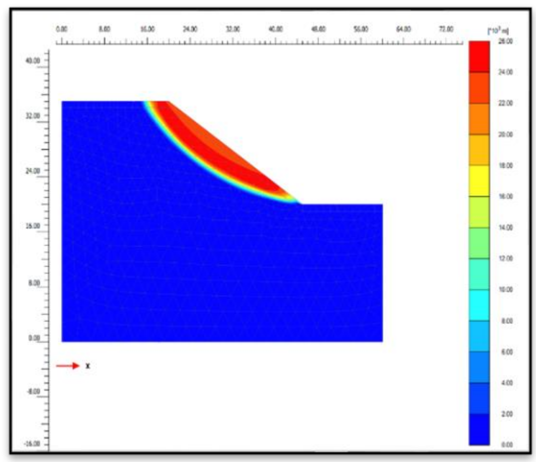
SLOPE ANGLE 30.96^0



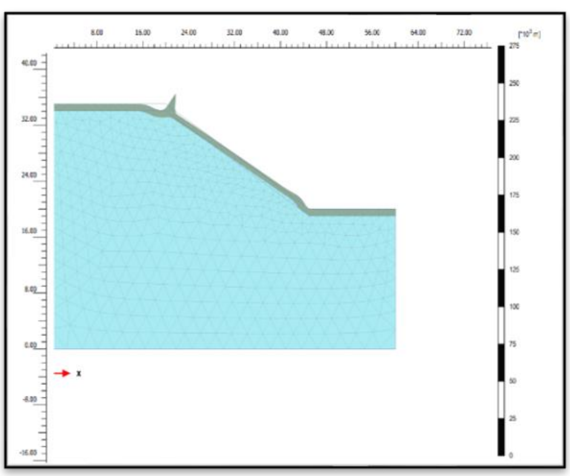


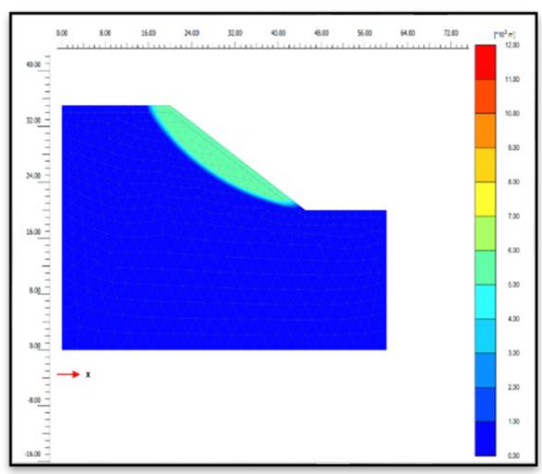
(a) (b)





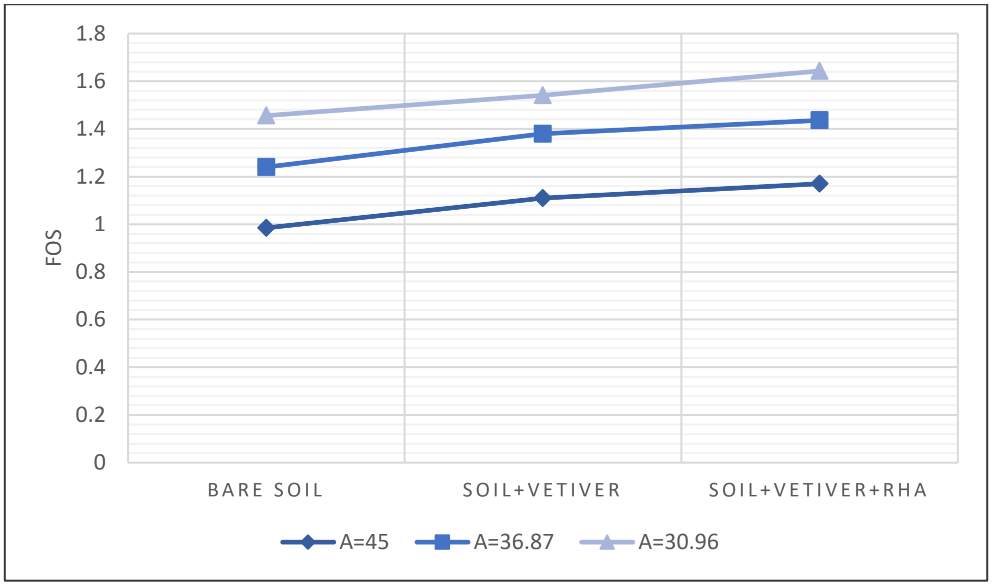
(c) (d)



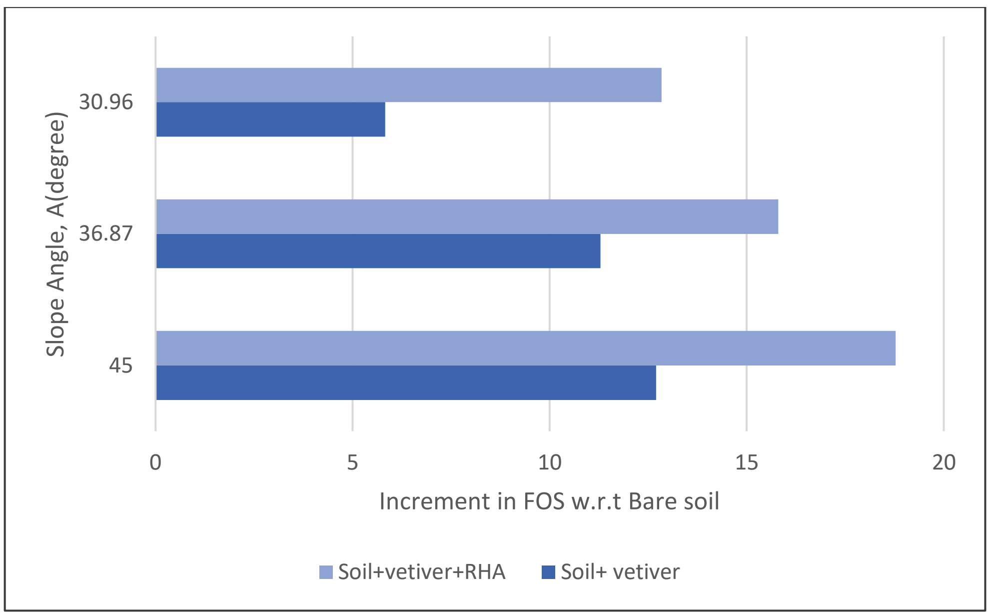


(e) (f)

Fig. 5.7 (a), (c), (e) shows the deformed mesh for slope of 30.96^0 for bare soil, soil+vetiver, and soil+vetiver+10%RHA respectively; (b), (d), (f) shows the total displacement in factor of safety mode for slope of 30.96^0 for bare soil, soil+vetiver, and soil+vetiver+10%RHA respectively.



(a)



(b)

Fig. 5.8 (a) FOS for different compositions at different slope angles; (b) Increment in FOS for soil+vetiver and soil+vetiver+10%RHA with respect to bare soil at different slope angles.

5.3 DISCUSSION

There is near twice the difference between the vetiver with and without RHA. This shows that adding RHA into the soil highly promotes the growth of vetiver both in root and shoot cases respectively. Hence, the promotion of the growth of roots with respect to time can be beneficial for the study.

Direct shear test results show that among the different compositions of RHA, the soil having 10% RHA and on which vetiver grass was planted shows the maximum shear strength as compared to other compositions. This shows that using 10% RHA can be beneficial for slope stability.

The model's input variables are given in Table 5.3. The increase in FOS is 5.83%, 11.29%, and 12.7% for soil+vetiver as compared to bare soil at 30.96°, 36.87°, and 45° respectively. 12.84%, 15.8%, and 18.78% increase in FOS for soil+vetiver+10%RHA as compared to bare soil at 30.96°, 36.87°, and 45° respectively. Hence clearly the highest increase in the percentage of FOS is observed for the case of soil+vetiver+10%RHA at 45° slope angle by up to 18.78% as shown in Figure 5.8(b).

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

Changing the composition of soil by adding RHA which is a solid waste into the soil can increase the strength of the soil and if the vetivers are also planted on that then not only the growth of plants will increase but also the soil strength will increase by a significant margin. The overall stability of a slope can be increased; however, this method may not be enough as a primary method for slope protection but it can be used as a secondary method for the stability of the slope. This study's findings allow for the following conclusion to be made.

- At different RHA content of 5%, 10%, 15% &20% mixed in the soil. According to the test findings, soil+vetiver+10%RHA gives the highest strength among different compositions. Soil+vetiver+10%RHA increased shear strength overall, decreasing cohesiveness from 15.37 to 13.10 KPa which is 14.76% decrease in cohesion and increasing the soil friction angle from 33.22° to 40.96° which is 23.29% increase in friction angle.
- Adding RHA for plantation increases strength and promotes vetiver growth as the growth of vetiver with rice hush is nearly twice as compared to without RHA both for root and shoot length as at 75 days the growth of roots of vetiver only was 14cm as compared to vetiver+RHA which is having root growth of 26cm at 75 day.
- As seen in the results of numerical analysis adding vetiver and RHA both into the soil gives the highest FOS as the FOS increased by 18.78% as compared to bare soil whereas planting only vetiver into the soil increases the FOS by a maximum of 12.7% which is for slope angle 45°.

6.2 FUTURE SCOPE

- Composite of vetiver roots and RHA can increase the shear strength of the soil. This can behave differently in case of rainfall when seepage occurs. Hence, Analyses are required for the rainfall case also.
- Soil is classified as Silty clayey sand having some percentage of organic clay, and hence, these results can be different for more cohesive soil like clay.
- Using vetiver to preserve shallow slopes is a practical, environmentally friendly, and effective solution. However, this approach alone might not be sufficient for deep-seated slope failures. Further research is required to see whether vetiver grass with rice husk ash may be used in conjunction with other techniques which are primary and conventional methods for slope stability to prevent both shallow and deep slope failures.
- Numerical modeling of the natural slope is required for the proper analysis.

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