Comparative soil shear strength analysis with and without native vegetation

Sadaf Qasim[1], Halima Bano[2*], Arjumend Masood[1], Sharafat Ali[3], Ayesha Akram[1], Furqan Khan[4], Reena Majid Memon[4], Faryal Sikander[4]

[1]Department of Civil Engineering, NED University of Engineering & Technology, Karachi, Pakistan

[2]Department of Civil Engineering, Dawood University of Engineering & Technology, Karachi, Pakistan

[3]College of Civil Engineering and Architecture, Henan University of Technology, Henan, China

[4]Department of Architecture & Planning, Dawood University of Engineering & Technology, Karachi, Pakistan

*Corresponding Author: Halima Bano

Abstract: *It has been observed that a significant number of slopes collapse either during or immediately after it rains. Even though it has been stated that the conditions that lead to these failures are caused by a rapid rise in pore-water pressure due to rainwater seeping into the soil, the important factors that lead to slope failures have not been explained well enough. This is because rainwater seeping into the soil causes a rapid rise in pore-water pressure. Several laboratory tests were carried out on modeled sandy slopes with the purpose of determining how the process of slope failure that is brought on by precipitation actually begins. Small-scale models of slopes failed the tests for one of two reasons: either water seeped up from the side or rain was forced to fall on top of the slope. Aside from measuring the pore-water pressure, changes in the volume of water in the soil as well as the movement of the ground itself were also measured. The studies showed that when the soil moisture level around the base of the slope reached virtually complete saturation, even when other regions of the sliding mass were still just half wet, the slope was more likely to fail. Additionally, the pattern of failure was recorded, and the results were compared with the outcomes of failure with and without the presence of vegetation cover, in addition to the shear strength parameters.*

Keywords: *Slope Stability, Strength, Vegetation, Direct Shear Test*

I. INTRODUCTION

Since the beginning of construction, people have understood that soil needs to have its engineering features improved in order to make better use of them [1]. The capability of the soil to resist sliding along internal surfaces inside a mass is one of the engineering features that is both one of the most significant and one of the most challenging. The stability of slopes is important in the design of excavations such as open pits, quarries, and foundations, as well as in natural slopes forming cliffs, valley sides, and reservoirs. Since the movement of the slope can have serious consequences, the soil needs to be stabilized to meet the requirements of engineering [2]. Altering the qualities of the soil through a variety of techniques to improve the soil's quality from an engineering perspective is what we mean when we talk about stabilizing the soil. The capacity of soil-covered slopes to tolerate and experience movement is what is meant by the term "slope stability." The relationship between shear stress and shear strength is the primary determinant of stability [3]. Climate-related occurrences have the potential to be the precipitating factors of a slope failure, which can then make the slope unstable and cause mass movements. Static and dynamic stability of slopes of earth and rock-fill dams, slopes of different forms of embankments, excavated slopes, and natural slopes in soil and soft rock are all included in the study of slope stability, which is a field that spans a wide range of topics [4].

II. LITERATURE REVIEW

Slope refers to any surface that is sloped at a particular angle. The steepness is proportional to the surface's incline. Natural slopes, which occur in nature and are generated by natural causes, are distinguished from manufactured slopes, which are constructed for embankments on highways, rivers, and even dams [5]. However, landslides or slope instability can occur when these slopes break, causing rock debris or soil mass to fall down the slope [6]. When shear pressures along a plane exceed the available shearing resistance, the rock or soil mass in that plane will slide downward. The aftermath of a landslide includes the loss of lives, the destruction of property and the built environment, and the need to identify mitigations to mitigate and prevent such occurrences in the future. Soil shear strength is determined by geotechnical analysis by comparing the shear stress created along the anticipated rupture surface [7]. Natural disasters like earthquakes and excessive rainfall, as well as human activities like bad construction methods on slope areas, have always posed a threat to slope stability [8]. In order to mitigate the damage caused by landslides and develop secure solutions for building on elevated lands, geologists and geotechnical engineers have studied and researched slope stabilization methods, mitigations, soil and rock mechanisms, and soil excavation [9]. Kenya joins the ranks of other countries throughout the world that have been impacted by slope instability, such as Nepal, Brazil, and the Philippines. The highlands are the worst hit because of their naturally steep slopes. There are a lot of people living in these places, and farming is their main source of income. Vegetation is regarded as one of the best strategies for minimizing slope instability, yet this has led to deforestation to make room for settlement [10]. The Kenya Meteorological Department reports that landslides account for 7% of the country's geophysical hazards.

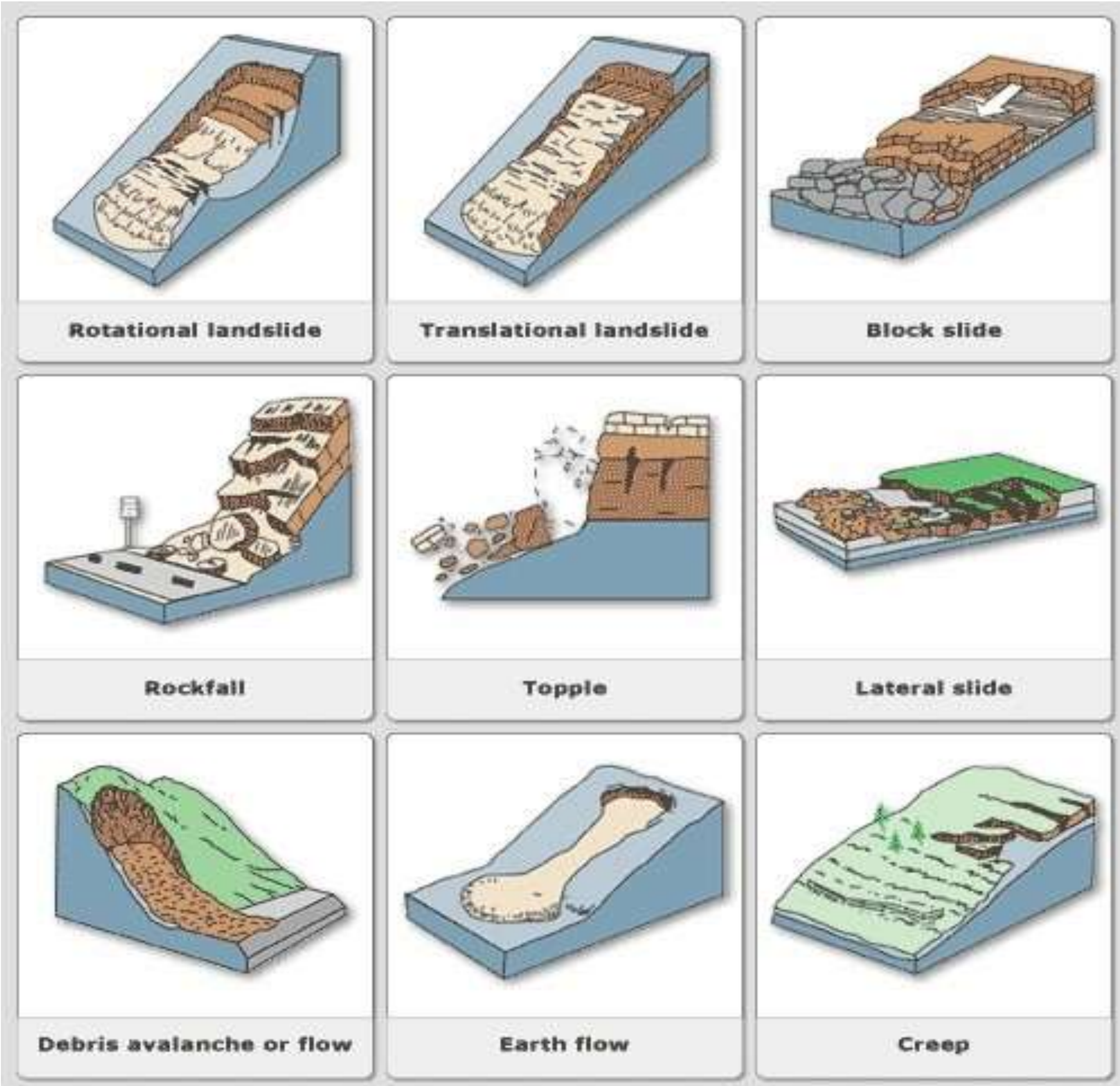


Figure 2. 1: Types of Failures (Source: U.S. Geological Survey)

Types of landslides

The movement or material involved in a landslide determines its classification. Slides, drops, and overturns are all examples. Sloughing and mudslides, because of the translational nature of slopes, typically form in locations where the neighboring stratum is at a shallow depth below the slope's surface, and their failure surfaces are typically flat and nearly perpendicular to the slope's orientation [11]. Lateral push from water filling some joints can cause a block to slide down intersecting joints or travel down a steeply inclined joint or bedding plane [12]. Shearing can occur through joints and other discontinuities in the rock mass in weaker soils. The shearing usually moves in a path parallel to the curve of the shear surface. The cross-section of a slide in soft homogenous soils can look like the arc of a circle, but in a stratified deposit, the slide takes on the shape of a flat sole [13]. Multi-form slides are common on retrogressive slopes. Slide activity may be amplified locally to mudslides in areas with high water contents caused by infiltration of surface water or concentration of overland flow. Although they are very mobile, their base and side shear surfaces prevent them from being mistaken for flows [12].

Figure2. 2: Example of Landslide and Rockslide

Extremely steep slopes are characterized by a precipitous drop in material, rock, or soil. Because of the outward force exerted by gravity, shear surfaces may form on some objects [12]. The emergence of enlarging fissures and the elimination of the base support of individual blocks or masses precede falls, which are confined to surface zones in soil or rock. Causes of rockslides include frost breaking, chemical degradation, temperature fluctuations, root wedging, and water pressure [14].

Figure2. 3: Example of rock fall

Flows

Unlike a slide, which includes relatively minor internal deformation, a flow is a mass movement. Movements on a large number of discrete shear surfaces or a high-water content in the mass in motion that causes the bulk to operate like a fluid are indicative of this type of motion [12]. Velocities in the displacing mass are distributed as they would be in a viscous liquid. Water content, mobility, and the development of movement are all factors that might cause slides to transform into flows [15].

Figure2. 4: Example of mudflows

III. CAUSES OF LANDSLIDES

Slope failures are typically brought on by the following:

The pull of gravity, pressure caused by water seepage, surface erosion on slopes caused by water movement, and Slope-side flooding happen when water levels drop quickly [16]. A lack of sufficient shear strength mobilization to meet the shear stresses created on any impending failure plane by the loading on the slope is the major cause of slope instability owing to probable shearing [17]. Soil is pushed and pulled from higher to lower elevations because of the aforementioned factors. The most crucial of these forces is the gravitational pull in the direction of most likely travel. Although the importance of water flow or seepage to stability issues is widely acknowledged, these impacts are not always clearly characterized. Seepage inside a soil mass results-seepage forces, which have far more influence than is generally believed. Slopes can become more resistant to mass movement due to erosion on the surface, which can be caused by the removal of a particular weight of soil. However, instability is reduced when erosion causes undercutting at the toe, which can either increase the slope's height or shorten the incipient failure surface [18]. The soil's buoyancy decreases, and its weight increases when the groundwater or a free water surface near the slope is lowered, as happens, for example, when the water surface in a reservoir is suddenly drawn down. When the mass is increased, shear stresses also rise [19].

IV. SHEAR STRENGTH

In soil, shear is the propensity for one mass to slide with regard to another, and it can happen in any plane. However, the plane of rupture, a potential failure plane, is the only plane of interest. The capacity of soil to withstand shear failure between soil layers above and below a probable failure plane is known as its shear strength. In their own unique ways, all soils can increase their shear strength [20]. The resistance in granular soils like sands and gravels is called intergranular friction because of the physical locking together of soil particles. Since this is a form of frictional resistance, its size depends on the specifications of the interlocking of particles and the contact pressure operating normally to the plane of shear. The shear strength of cohesive soils is built up by the cohesion, or the atomic force of attraction between the particles [21]. The resistance in soil with a variety of grain sizes is proportional to the sum of the contributions of friction from the granular fraction and cohesion from the cohesive fraction [20]. It is generally believed that cohesion and internal friction contribute to soils' shear strength.

Using Coulomb's principle of friction, the shear strength of soil can be expressed as:

$$\tau_f = c + \sigma_n \tan \Phi$$

Where
σ_n is the effective normal stress on the failure plane
c is the cohesion
Φ is the angle of internal friction
τ_f is the shear stress on the failure plane

In saturated soil, the total normal stress at a point is the sum of the effective stress and the pore water pressure, i.e.

$$\sigma = \sigma' + u$$

The effective stress, σ', is carried by the soil solids. So

$$\tau_f = c' + \sigma' \tan \Phi'$$ [7]

The shear strength parameters c and Φ of soils either in the undisturbed or remolded states may be determined by any of the following methods discussed below:

V. LABORATORY METHODS

Direct or box shear test

Although the direct shear test is easy to carry out, it does have some limitations. It's possible that the results can't be trusted. This is because the soil is not given the option to fail along its weakest plane—the plane of a split in the shear box—during the test. Furthermore, the shear stress distribution over the specimen's shear surface is irregular. Despite its drawbacks, the direct shear test is the quickest and cheapest way to determine whether sandy soil is dry or wet [7].

Triaxial compression test

One of the most trustworthy procedures for assessing shear strength characteristics is the Triaxial shear test. It has found widespread application in both academic study and practical testing. The following factors contribute to the test's credibility: It complements the direct shear test by revealing the soil's stress-strain behavior. In comparison to the direct shear test, which concentrates stress along the plane of failure, this one creates more homogeneous stress conditions. The loading path can be adjusted more freely [7].

Field method

Vane shear test [21] or by any other indirect methods.

Effect of rainwater and excess pore pressure

Water can move from high-energy to low-energy areas of a soil's structure, thanks to the soil's porous, interconnected structure. In soil mechanics, understanding how water moves through porous material is crucial. It's needed for doing stability evaluations of earth dams and earth retaining structures that are subject to seepage forces, determining the amount of subterranean seepage under different hydraulic circumstances, and researching issues concerning the pumping of water for underground construction [7]. The chemical and hydrothermal transformation and solution of water can affect the strength of soil-forming materials. As pore water pressure rises, shear strength inevitably decreases. Saturation causes a decrease in cohesiveness due to capillary forces. Cracks and shale loosen up [15].

VI. FFECT OF VEGETATION ON SLOPE STABILIZATION

Slope stabilization with vegetation is crucial [23]. The species and root type of the plant, as well as the age of the tree, affect how well it works. Slope-stabilizing systems are included, and they all play a part. The amount of precipitation available for penetration is less since the leaves not only intercept but also absorb and produce evaporation of the precipitation. Plants' roots and stems make the soil more porous and rougher, improving its infiltration capacity [24], [25]. Reduced pore water pressure is a direct result of root extraction and transpirational loss of soil moisture. The shear strength of soil is enhanced by the anchoring effect of roots. Roots tether surface soil particles, making them less likely to wash away during erosion [26]. The lengthy fibrous binders they provide within a weak soil mass, their ability to anchor a weak soil mass to fissures in bedrock, and their ability to bridge zones of weakness to more stable soil, all contribute to their effectiveness in stabilizing slopes. As the depth of the soil increases, the effect of bedrock anchoring decreases and the other two factors become more important. Plant roots' reinforcing action when mixed with soil is analogous to soil's cohesiveness [27], [28]. Forests are preferable to other types of vegetation during periods of severe rainfall because of their high interception rate, which lessens the amount of precipitation that reaches the ground [29]. By creating networks of preferential drainage channels in the soil and substrate, they also boost secondary permeability.

However, soils excel in compression and struggle under tension. When soil and roots work together, they create a composite material in which the roots act as fibers with high tensile strength and adhesion that are embedded in a matrix of soil mass with lower tensile strength. Consequently, the tensile of the roots is what gives the soil-root composite its total strength [30]. In terms of soil stabilization and anchoring, vegetation with deep roots is preferred over that with shallow roots. The taproot is an excellent example of a system of roots like this. Growing roots past the anticipated failure plane enhance shear strength. A root pullout test and root tensile strength are performed to demonstrate the effectiveness of roots in soil reinforcing. A tensile force is applied to the root tip in a root pull-out test. There are several potential causes of root failure, including excessive stress in the main root, gradual tension failure in the branch roots, or root slippage. How the root's shape and tensile strength compare to the shear strength of the soil determines the dominant failure mechanism [31]. To measure the tensile strength of a root, we clip it and pull it until it breaks.

Root morphology and structure

The study of how roots are built is called root morphology [32]. Since plants' root systems vary, certain kinds of vegetation are better suited than others for stabilizing slopes and preventing soil erosion. When deciding which roots are best for stabilization and soil erosion management, characteristics including distribution, length, orientation, and diameter are taken into account.

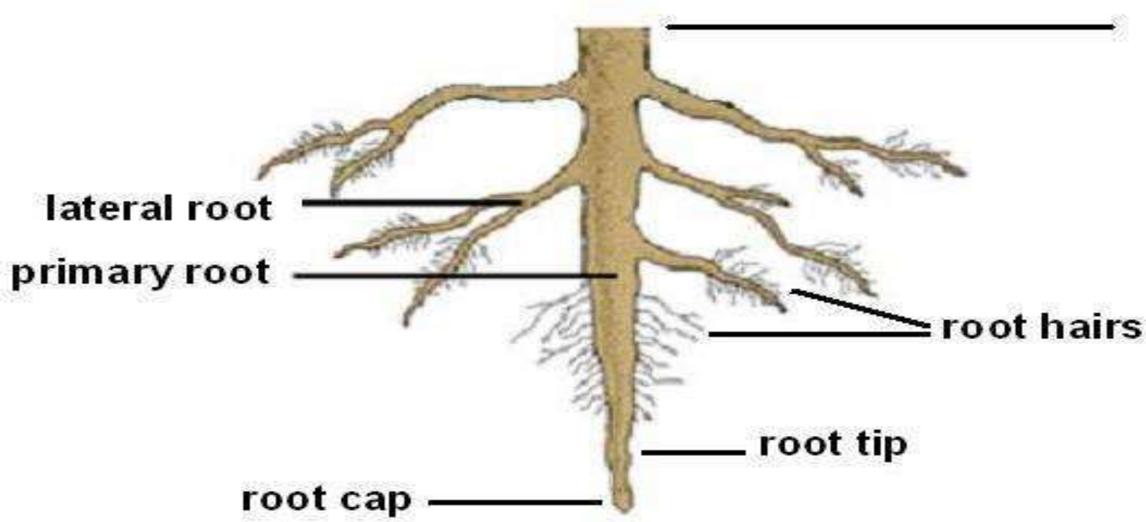


Figure2. 5: Root morphology

The final root structure is affected by several elements, such as soil type, tree species, age, health, environmental pressures, planting density, and silvicultural management. Trees and other woody plants, in particular, can reduce the likelihood of shallow landslides by altering soil moisture through evapotranspiration and reinforcing the soil with their roots.

Typical Origins of Root

Because there are so many distinct kinds of roots, each one has its own set of distinguishing features and adaptations. Types include:

Fibrous roots

They are densely distributed on the soil's surface and have numerous fine hair-like roots. Since the system is efficient in absorbing water and minerals, it is useful for preventing soil erosion.

Figure2. 6: Fibrous roots

Taproot system

This system is rooted vertically and has many secondary horizontal roots. The root spreads out and grows deep into the ground, anchoring the plant and making the ground more stable.

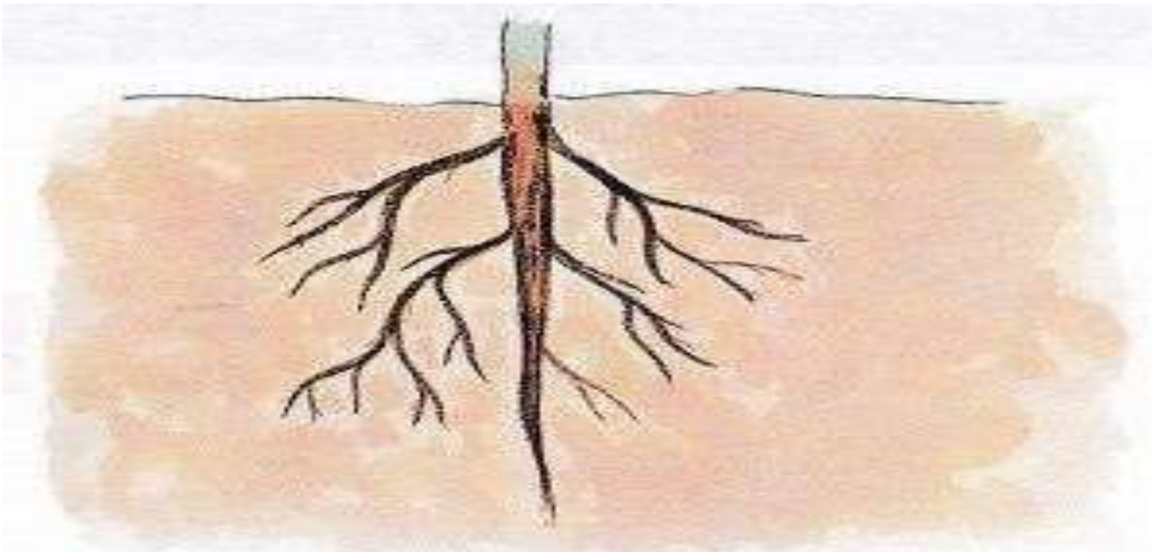


Figure2. 7: Taproot system

Adventitious root system

Stem roots, branch roots, leaf roots, and woody root systems all originate from other parts of the plant. Grass and other monocots with shallow roots typically have them.

Figure2. 8: Adventitious root system

Contractile Roots

These are the roots that shorten and drive the stem, corm, or bulb even further into the ground. Roots spread out and grow deep into the ground to secure the plant's position. The top begins to shrink, and the stem is yanked down to further bury itself. This is due to the vascular tissue buckles but retains its function as a result of the shape changes caused by the radial and axial growth of cortical cells. The surface of these items is wrinkled.

Figure2. 9: Contractile Roots

Aerial Roots

The ivy Hedera is a good example of a plant that produces adventitious roots above the earth, and these roots adhere to the surface of objects like trees and walls to provide support for the climbing stem.

Figure2. 10: Aerial Roots

Root as Reinforcement

The effectiveness of root reinforcing is conditional on several factors, including root morphology, root tensile strength, soil-root cohesive strength, and root spread [33]. Wind loadings and self-loadings are common stresses on trees in mountainous areas. The mechanical stimulus exerted by a plant's own weight as it ascends a sloping surface is known as "self-loading." The tree's roots help it anchor itself by conducting the loading pressures felt by the stem back into the soil [34]. Bending stress (within roots and stem), tension (within roots), compression (within and between roots and soil), shearing forces (between roots and soil and within soil), gravity (which acts in the direction of the probable motion), and the force of seeping water are just some of the forces that trees and soil must resist to remain stable. These pressures generate shear stresses throughout the soil mass, and unless the shearing resistance on all potential failure surfaces is greater than the shear stress, movement will occur [30]. Evaporation and transpiration from plants remove soil moisture, which in turn can raise soil suction or decrease pore water pressure and, in turn, boost shear strength due to hydrological impacts. Evaporation by plants not only strengthens soil by decreasing its moisture content but also lightens its mass, making it easier for plants to grow [35]. Larger trees are the only ones likely to have an effect on slope stability due to the amount of vegetation. The typical loading on a tree between 30 and 50 meters tall is between 100 and 150 kilonewtons per square meter. Planting the larger trees near the base of the slope where rotational failure is possible can raise the factor of safety by 10%. However, the safety factor may be reduced by 10% if the tree is located at the peak of the slope [36]. Soil shear strength and root anchoring can be improved by allowing roots to extend beyond the possible failure plane and even beyond the bedrock. A larger resistance to root pullout is provided by the soil's cohesiveness, which is generated by the tensile tension of the roots [37]. Root failure manifests itself differently depending on root length and root branching structure [38]. When the root's supporting forces exceed its resisting forces, it slips out of the soil mass and fails in tension. Once the roots are pulled out, there is no more adhesion between the soil and the roots, and the earth's strength is not increased [39]. Some shatter with increasingly applied force in stages corresponding to the progressive breaking of roots of higher diameters, while others reach their greatest peak resistance and then sustain a high resistance that steadily diminishes when the branches of the roots fail after significant strain [40].

VII. METHODOLOGY

The study's goals are to enhance slope stability via vegetation cover on the surface of the slope, to review applications of vegetation as slope stabilization, to observe the failure pattern of the slope due to the seepage, and to investigate the change in shear strength parameters of the soil before and after failure. The subsequent sections will elaborate on this method of analysis.

VIII. MATERIALS

The following resources have been employed in the pursuit of our aims:

Sand

Sand is a granular material made up of tiny fragments of rock and minerals that have been broken down naturally.

Clay

Clay is a fine-grained soil that is stiff and sticky when wet and is used to build bricks, pottery, and ceramics when dried and baked.

Water

Water is a colourless, odourless, clear liquid that makes up most of the Earth's oceans, rivers, lakes, and rain.

Figure 3. 1: Material

Soil Properties

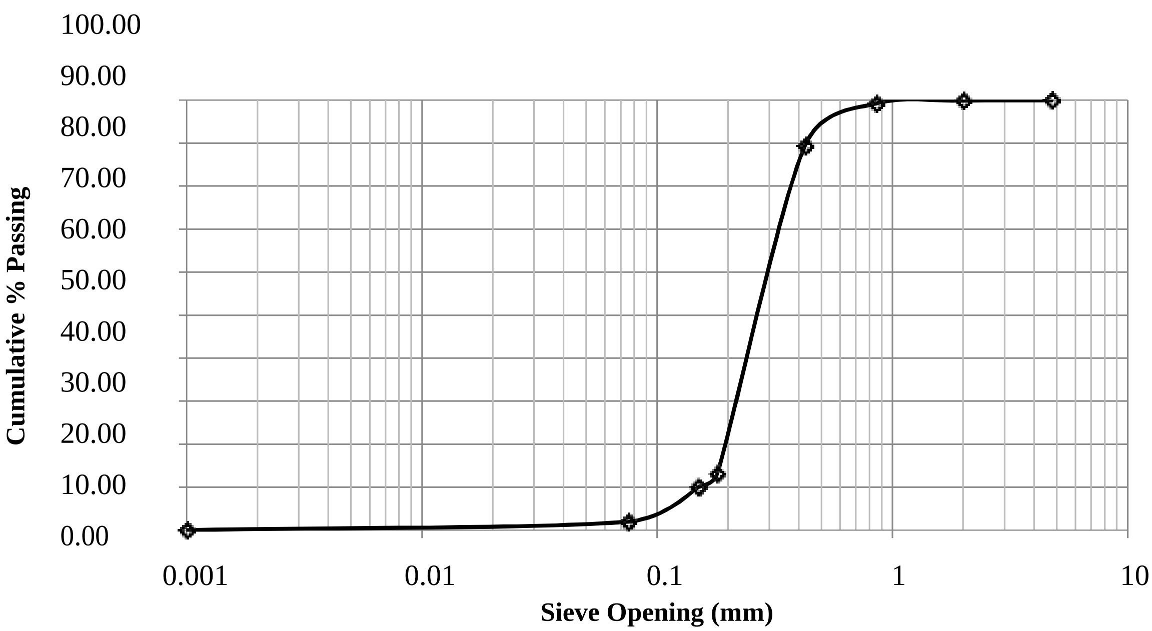
Prior to conducting our experiment, we measured the soil's index qualities. Since the goal of the experiment is to determine the soil's shear strength, measuring that parameter is essential.
The sample is initially prepared by mixing the appropriate amounts of sand and clay.

Grain Size Distribution of Soil

The dirt was classified using sieve analysis after it was mixed. The following are examples of data collected from sieve analysis, which were used to determine the grain size distribution of the soil by plotting the opening size of the sieve against the cumulative percentage of passing dirt:

Table 3. 1: Sieve Analysis Result of the sample

Sieve No.	Sieve Opening (mm)	Mass Retained (g)	% Retained	Cumulative % retained	Cumulative % Passing
4	4.75	0	0.00	0.00	100.00
10	2	0.57	0.11	0.11	99.89
20	0.85	3.41	0.68	0.80	99.20
40	0.425	48.91	9.79	10.59	89.41
80	0.18	381.12	76.32	86.91	13.09
100	0.150	15.33	3.07	89.98	10.02
200	0.075	40.24	8.06	98.04	1.96
Pan	0.001	9.78	1.96	100.00	0.00



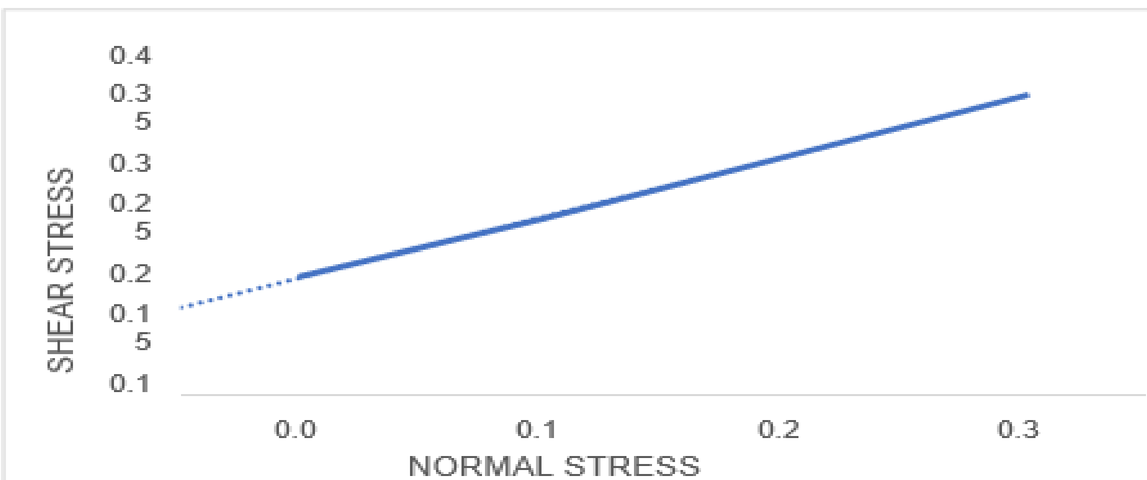
Graph 3. 1: Grain size distribution of soil used in the study

IX. SHEAR STRENGTH PARAMETER OF SOIL

After determining the soil's particle size distribution, a direct shear test was conducted to measure the material's cohesion (c) and angle of internal friction Φ. Using the results of this test, we calculated the normal and shear loads and used this information to create a graph showing the relationship between normal stress and shear stress, from which we were able to derive the cohesion and angle of internal friction. Here are the values:

Table 3. 2: Results of Direct Shear Test

Normal load	Normal stress	no. of division	Shear force	Shear stress
2	0.08	24	3.6	0.144
4	0.16	35	5.25	0.21
6	0.24	47	7.05	0.282
8	0.32	59	8.85	0.354



Graph 3. 2 Graph Representing Shear Strength Parameters

X. EXPERIMENTAL SETUP

The experimental box is divided into two sections: the first, 1 ft. in length and 2 ft. in height, is used to retain water and allows seepage to the soil through a perforated wall. The length of the adjacent compartment, which houses the soil slope, is 3.5 feet.

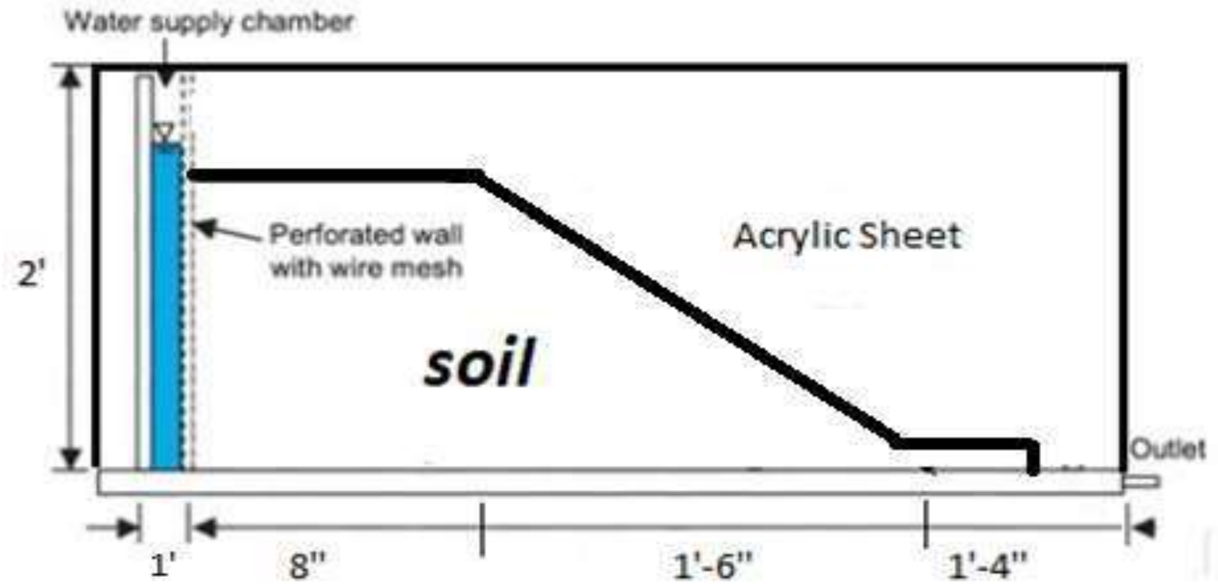


Figure 3. 2: Proposed dimensions of the experimental box

Figure 3. 3 Actual dimensions of the experimental box with water

XI. TESTING PROCEDURE

The first step in preparing a soil sample is to combine the appropriate amounts of sand and clay. After the experimental box has been created with the necessary dimensions, the sample can be placed inside. Filling the water chamber and maintaining a consistent head after the slope has been formed allows water to soak into the soil. The soil becomes increasingly saturated as water percolates through it, increasing pore water pressure and increasing the slope's propensity to collapse. Failure pattern and failure time were detected after slope failure. Soil shear strength parameters were measured both before and after failure in order to make a direct comparison. The same procedure was repeated, this time with vegetation covering the soil.

XII. VEGETATION COVER

The slope was maintained in the same way as before, but this time we planted Bermuda grass (Cynodon Dactylon) on it to see if it would help prevent the slope from completely collapsing and to compare the results to those obtained without vegetation. After the grass was grown, we tended to it for a month to encourage its roots to go deep into the soil and create a dense surface. A month later, we repeated the experiment using the same method. Soil shear strength is measured again in an effort to establish a baseline for comparison with future experiments.

Figure 3. 4 Slope with Vegetation Cover

XIII. ANALYSIS AND RESULTS

The presentation of the results in this chapter is broken down into four sections. The first stage involves determining the soil's shear strength parameter prior to and during failure in the absence of vegetation cover. In the second section, we look at the soil's shear strength both before and after failure due to plant cover. Time to slope failure is compared between slopes with and without vegetation cover in the third section. The final section of the result details the failure mode observed during both tests (without and with vegetation cover).

XIV. SHEAR STRENGTH PARAMETER WITHOUT VEGETATION COVER

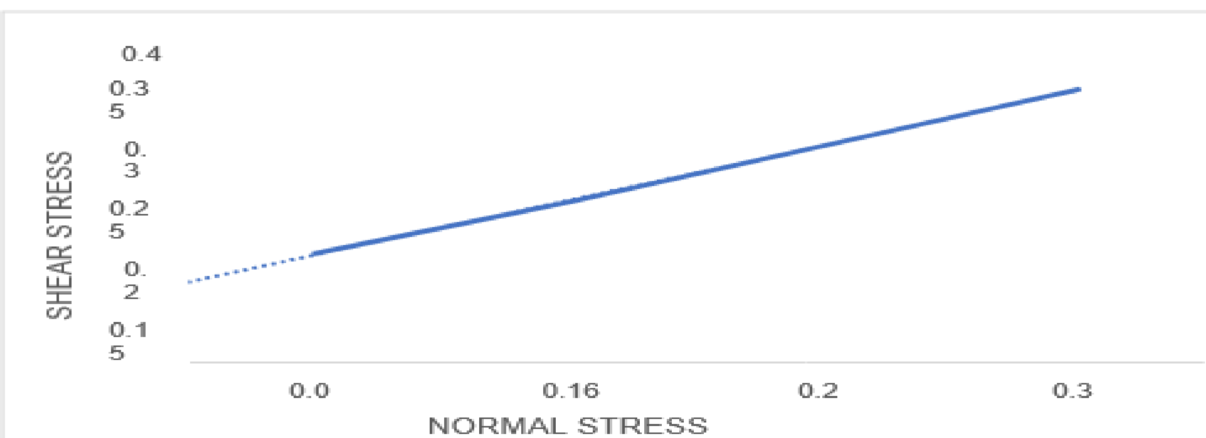
At first, a direct shear test was performed to determine the soil's shear strength parameters, and the observed data was as follows:

Before Failure

Figure 4. 1: Slope before Failure

Table 4. 1: Results of Direct Shear Test

Normal load	Normal stress	no. of division	Shear force	Shear stress
2	0.08	24	3.6	0.144
4	0.16	35	5.25	0.21
6	0.24	47	7.05	0.282
8	0.32	59	8.85	0.354



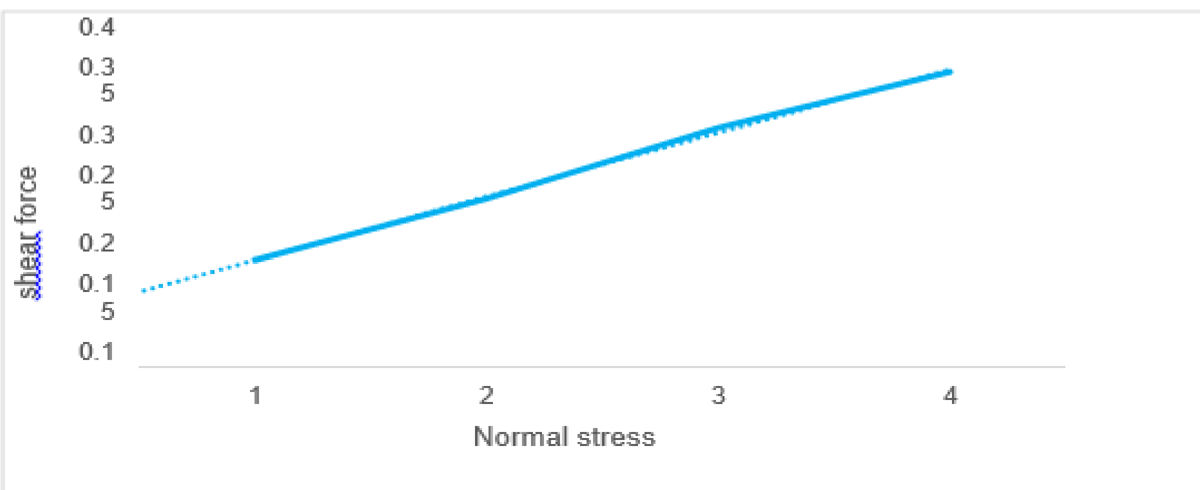
Graph 4. 1: Results of the Direct Shear Test

After Failure

Figure 4. 2: Slope after failure

Table 4. 2: Results of Direct Shear Test

Normal load	Normal stress	no. of division	Shear force	Shear stress
2	0.08	21	3.15	0.126
4	0.16	33	4.95	0.198
6	0.24	47	7.05	0.282
8	0.32	58	8.7	0.348



Graph 4. 2: Results of the Direct Shear Test

XV. SHEAR STRENGTH PARAMETER WITH VEGETATION COVER

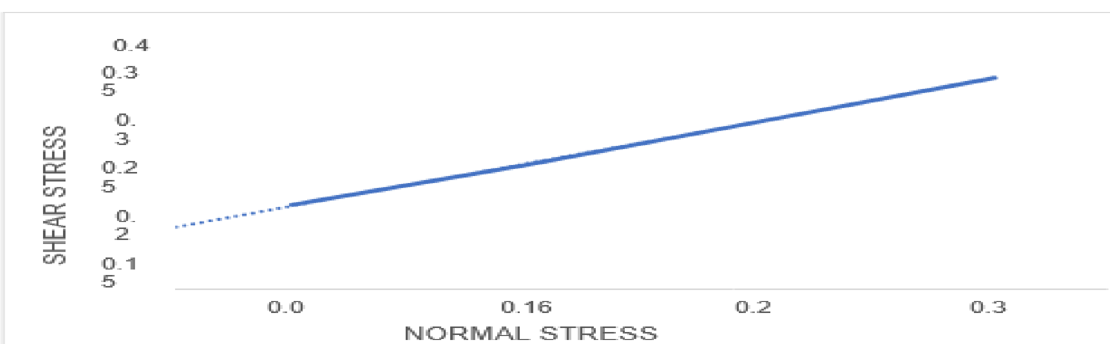
Soil shear strength was measured again after grasses had been grown on the managed slope, following the same protocol as before. Before and after failure, the soil's shear strength parameter looks like this:

Before Failure

Figure 4. 3: Slope before failure with vegetation cover

Table 4. 3: Results of the Direct Shear Test

Normal load	Normal stress	no. of division	Shear force	Shear stress
2	0.08	24	3.6	0.144
4	0.16	35	5.25	0.21
6	0.24	47	7.05	0.282
8	0.32	59	8.85	0.354



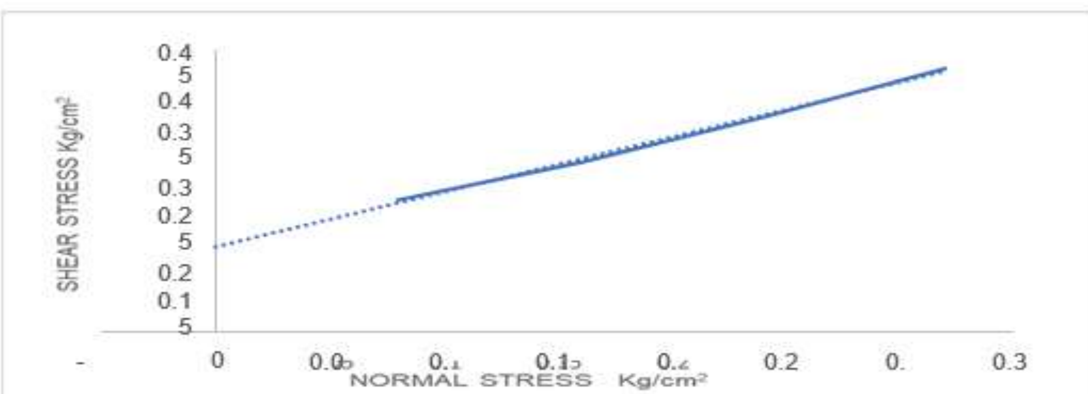
Graph 4. 3: Results of the Direct Shear Test

After Failure

Figure 4. 4: Slope after failure with vegetation cover

Table 4. 4: Results of the Direct Shear Test

Normal load	Normal stress	no. of division	Shear force	Shear stress
2	0.08	35	5.25	0.21
4	0.16	45	6.75	0.27
6	0.24	57	8.55	0.342
8	0.32	70	10.5	0.42



Graph 4. 4: Results of the Direct Shear Test

XVI. TIME TAKEN BY THE SLOPE TO FAIL

Slope failure time is the amount of time it takes for water to soak through and cause the slope to collapse. The following are the times required by the slope during the experiment (without and with vegetation cover, respectively):

Without Vegetation Cover

The time taken by the slope to fail without vegetation cover was measured as 55 minutes.

With Vegetation Cover

The time taken by the slope to fail with vegetation cover was measured as 143 minutes.

XVII. TYPE OF FAILURE OBSERVED

It was a translational failure that manifested itself in both experiments.

XVIII. CHANGE IN THE SHEAR STRENGTH PARAMETER OF THE SOIL AFTER FAILURE WITH AND WITHOUT VEGETATION COVER

Without Vegetation Cover

Cohesiveness decreased after the failure of the slope without vegetation cover, as shown by the graph, likely due to the washing away of clay particles by the water flow, which allowed the sand particles to become more numerous and dominant.

With Vegetation Cover

It was found through graph analysis that the value of cohesiveness decreases after the failure of a slope devoid of vegetation cover. This is due to the washing away of clay particles by the water flow, which allows the sand particles to become more dominant.

XIX. CONCLUSION

Vegetation cover has become an undeniable factor in soil and slope stabilization. Its importance is only now being fully appreciated, and the tests are being carried out as detailed in earlier chapters.

Slope failure due to translational failure was seen after 55 minutes of testing on a slope devoid of vegetation cover. The angle of internal friction of the sample increases due to the dominancy of the sand particles, and tests conducted before and after the failure show that the cohesiveness of the soil reduces after the collapse of a slope without vegetative cover. Tests repeated on a slope that had been covered in vegetation showed a marked improvement in the slope's resistance to seepage and collapse. The new slope failure time is far longer than prior tests, coming in at 143 minutes. Failure analysis of the samples reveals that the angle of internal friction decreases as a result of the removal of some sand particles with the flow of water, while the value of cohesiveness of the soil increases because of the removal of some sand particles with vegetation cover.

The more vegetation there is covering a slope, the more stable it will be against failure since deeper roots mean more stability. It takes a significantly longer amount of time for the slope to fail when vegetation is present, which is evidence that vegetation cover provides a large amount of resistance against failure. This is because vegetation slows the slope's erosion by reducing water seepage through the soil and by binding the soil with its roots.

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