ASSESSING THE USE OF MARBLE DUST AS A FILLER IN ASPHALT CONCRETE FOR DURABLE FLEXIBLE PAVEMENTS

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A FINAL YEAR RESEARCH AND DESIGN PROJECT REPORT SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

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ABSTRACT

Bududa District in the eastern part of Uganda faces serious risks from landslides to infrastructure and human populations. This study looked into how horizontal drainage systems can be applied to reduce the risk of landslides in Shikuruwe Village, Naposhi parish. The objectives of this study include; determining the characteristics of the site, conducting a hydrological survey of the area and designing a horizontal sub drainage system.

The soil properties that were determined include the soil density, cohesion, angle of friction, shear stress and effective stress, liquid limit, soil structure. The methodology was applied according to British Standards, and the tests done included the atterberg limit tests, particle size distribution test, specific gravity and the falling head permeability test, triaxial test under unconsolidated undrained conditions and the direct shear box test under consolidated drained conditions. Spatial analysis, hydrological data, geological mapping, and field observations will also be used. Monitoring groundwater levels, conducting field surveys, and sampling soil were used to gather geological and hydrological data. Hydrological modeling and Geographical Information System were also used to develop a horizontal sub drainage system.

The design of the horizontal system involved the use of software like GEOSTUDIO for slope analysis and slip surfaces, MODEFLOW for designing optimal drain configuration.. The design included considerations like drain spacing, drain length and drain configurations. The aim of the study was design optimal drainage configuration to reduce the risk of landslides happening.

DECLARATION

I, AHABWE MARTHA, declare that this report titled, “Horizontal sub drainage system approach towards landslide risk mitigation. A case study of Shikuruwe Village, Naposhi Parish, Bududa District” is my own original work and all sources used in its preparation are fully acknowledged and referenced in the report. I declare that the research was conducted in an ethical manner in accordance, and has not been submitted to any other institution for any qualification or award.

Signature……………………………………

Date……………………………………………………

AHABWE MARTHA

APPROVAL

This is to certify that this research design and design project by AHABWE MARTHA has been dine under my supervision and has been approved for submission to the university.

Signature: …………………………..

Date: …………………………………..

DR. ENG. OLENG MORRIS

ACADEMIC SUPERVISOR

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LIST OF ABBREVIATIONS AND ACRONYMS

ASTM	American Society for testing and materials
HDPE	High density Polyethylene
PVC	Polyvinyl Chloride
BS	British Standards
UU	Undrained unconsolidated
CD	Consolidated drained
LDPE	Low Density Polyethylene
GPS	Global Positioning system
GIS	Geographic Information System
ISO	International Organization for Standardization
USCS	Unified Soil Classification System
DEM	Digital Elevation Model

CHAPTER ONE: INTRODUCTION

1.0 BACKGROUND

Climate change is a global concern as it disrupts rainfall patterns, leading to prolonged droughts or intense rainfall events, which can cause severe environmental disasters such as floods and landslides. In 2024 for example, notable incidents were noted, including large amounts of precipitation ever recorded in 75 years causing flash floods in Dubai in April; and the July heavy rains brought by monsoons leading series consecutive landslides and that killed 135 persons in Nepal (Resource and Report, 2024). Climate change projections on the African continent suggest a significant increase in temperature and rainfall trends for both short term (2030-2059) and long term (2070-2099) scenarios in the central region (Almazroui, 2020). A recent localized study of the Lake Kyoga basin in Uganda, of which Mount Elgon is located in the northern cattle corridor, revealed rising temperatures and precipitation from 2010 to 2020 (Obubu et al, 2021). This shift in weather patterns corresponds with notable increase in recorded landslide events in the area.

Bududa district in eastern Uganda has been identified as one the region most prone to rainfall induced landslides. The district is located in the region of Mount Elgon, which is an extinct volcanic shield with a maximum elevation of 4321 meters above sea level, and is characterized by intense precipitation and weathering on its steep cliffs that naturally triggers landslide events. The area is densely populated with settlements spreading across crests, hillslopes, and valleys due to the fertile soils for the culture of banana and coffee (Oleng, Ozdemir and Pilakoutas, 2024). Climate change has played a particular role in the increase of landslide events in the district as it has led to intense rainfall events. Some of the major landslides recorded in the last decade such as the Nametsi and Bukalasi in 2010, and the Buwalukani in 2012, and 2018 among others, happened in the same time interval (2010 – 2019) where climate projections of Lake Kyoga basin, of which Mount Elgon is located in the northern cattle corridor, were highlighting rising temperatures and precipitations (Obubu *et al.*, 2021).

1.1 PROBLEM STATEMENT

Landslides are a major concern in Bududa district. For instance, a multi-hazard statistical analysis conducted over more than eight decades shows that landslide hazard are responsible for 95 percent of deaths (2275), 60 percent of serious house destruction and damage (352), and they have directly and indirectly affected 94 percent of the population (315434). On this regard, the 2010 Uganda National Policy Preparedness and Management act highlights some key policy actions such as prohibition of settlement and resettlement of all the people living in risky lands, promotion of afforestation and, appropriate land use among others (Directorate of Relief, 2010). Despite the presence of the mentioned guidelines coupled with numerous studies providing the most up to date landslide susceptibility maps, part of the population is observed to be reluctant to leave the fertile lands on which they depend for living (Namuenge *et al.*, 2024).

Shikuruwe village in Naposhi parish, Bushika Sub County located in the western part of the district, has recorded several landslides in the region due to a high deformation magnitude, which is majorly caused by land use (terracing and cultivation on steep slopes), slope concavity, and a high infiltration rate, where the seeping water stagnates as it reaches the clay layer in the soil profile, thus leading to instability. A study on ground displacement in the district mentioned that mitigation measures could be applied on slopes with medium displacement rate to promote their stability. This is because a relatively stable ground is left behind when the unstable layer is washed away during a landslide, and it takes time for the remaining soil to experience instability again (Makabayi, Musinguzi and Otukei, 2021a). This study aimed to design a horizontal sub surface drainage system, and to assess its suitability in the reduction of the fluctuation of water in the soil profile due to seepage through drainage.

1.2 OBJECTIVES

1.2.1 Main objective

To assess the suitability of sub horizontal sub drainage system approach in the mitigation of landslide risk in Shikuruwe village.

1.2.2 Specific objectives

1. To characterize the site.
2. To conduct a hydrological survey.
3. To design the sub horizontal drainage system.

1.3 RESEARCH QUESTIONS

1. What are the properties of the soil and how do they affect groundwater flow in the area?
2. What are the watershed characteristics, the rainfall intensity, the movement of groundwater as well as flow rates of water?
3. What is the best horizontal sub-drainage system design configuration (material, pipe diameter, spacing, and depth) to minimize waterlogging?

1.4 SCOPE OF STUDY

1.4.1 GEOGRAPHICAL SCOPE

BUDUDA district western UGANDA lies at the foot of the South-Western slopes of the Mount Elgon Volcano, between latitude 2°49'N and 2°55'N, longitude 34°15'E and 34°34'E (Poesen and Deckers, 2009). The soil was sampled from Shikuruwe village which is located in Naposhi parish, Bushika sub-county in Bududa district with coordinates (x=649187 and y=117488).

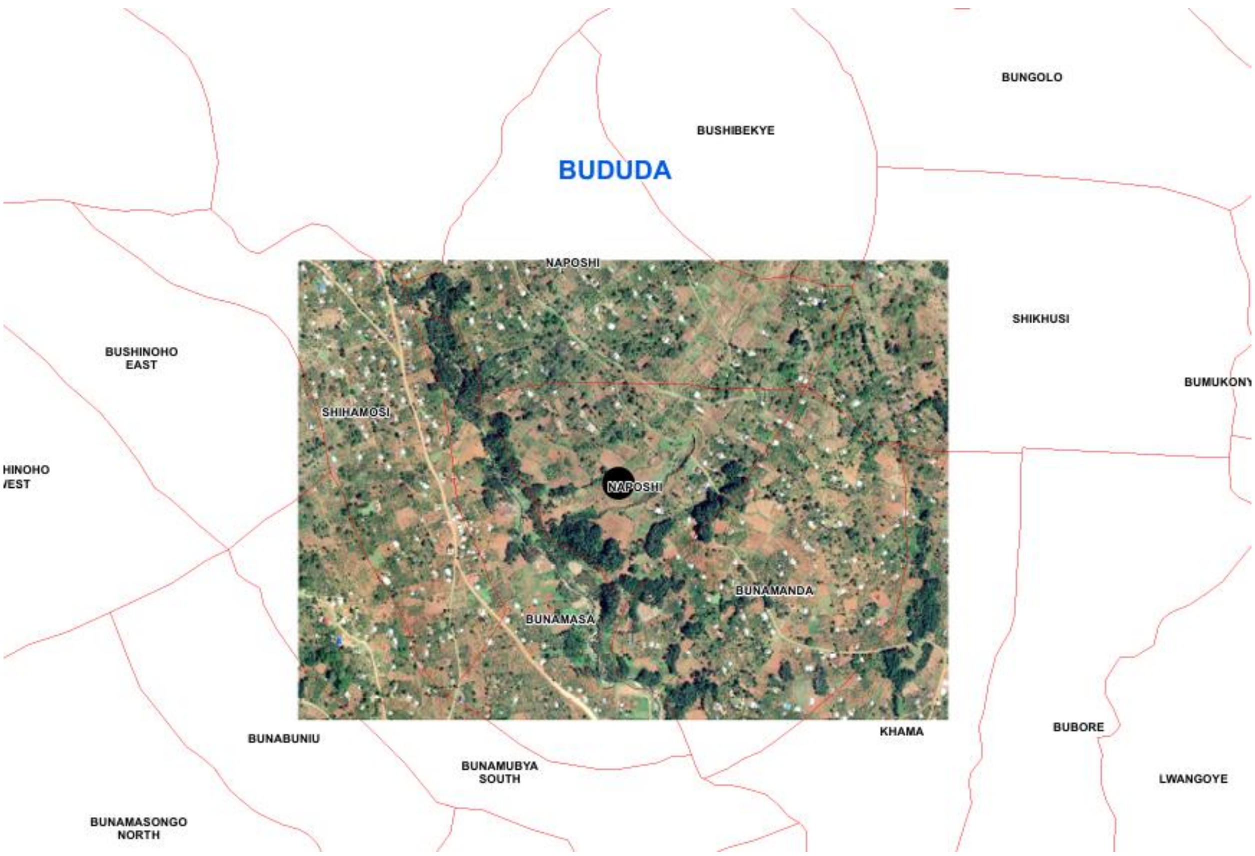

Figure 1: A map of Bududa district showing Naposhi parish.

1.4.2 CONTENT SCOPE

The scope of this research was aimed at determining the suitability of sub horizontal drainage system for landslide risk mitigation.

1.4.3 TIME SCOPE

This research was carried out from August 2024 to March 2025.

1.5 JUSTIFICATION

Landslides are a recurring natural hazard in Bududa district, eastern Uganda, causing significant loss of life, displacement, and economic devastation. Over the years this hazard has caused infrastructure damage including roads bridges, and buildings, disrupting economic activity according to a 2019 World Bank report. The most recent landslide in BUDUDA occurred on December 3, 2019 and was triggered by heavy rainfall. As a result, 53 fatalities were reported, and approximately 50 houses were destroyed. This region is susceptible to rainfall induced landslide given that the structure of the soil enhances water retention in the soil profile. For instance, with a high clay content of about 30%, Bududa soils exhibit a low drainage rate, field capacity, saturation and bulk density that cause stagnation as seepage water come in contact with the clay layer (Makabayi, Musinguzi and Otukei, 2021b).

A study on the sub-humid highlands of *DEBRE MAWI* watershed in Ethiopia showed the effectiveness of a low-cost sub surface drainage systems in enhancing gully bank stability. The drainage system was observed to reduce the groundwater level by 25% and promote considerable slope stability (Zegeye et al, 2021).

CHAPTER TWO: LITERATURE REVIEW

2.0 INTRODUCTION

2.1 LANDSLIDE HISTORY IN BUDUDA DISTRICT

Landslides are a widespread issue around the world. In the highlands of East Africa, for example, they are primarily caused by weathering processes, various tectonic activities related to the East African Rift Valley, and the wet climates typical of tropical mountainous areas. The favorable conditions in these mountains, for instance the climate and fertile soils, have attracted populations for the culture of crops like Arabica coffee, bananas, and potatoes. Consequently, recent decades have seen a demographic boom in mountainous areas, leading to an intensive agriculture and poor land management (Namuenge et al, 2024). This has increased pressure on the naturally fragile slopes, resulting in a higher frequency of landslide events.

Landslide causes have been categorized into two main types: co-seismic and rainfall-induced, along with human activities. The combination of co-seismic and rainfall-induced landslides is more prevalent in the western part of the East African Rift Valley, particularly in the eastern part of the Democratic Republic of Congo and the western regions of Rwanda and Uganda (specifically in the Kasese and Kisoro districts), while the rainfall induced landslides is more prevailing as moving away from the rift (Oleng, Ozdemir and Pilakoutas, 2024).

In Uganda, landslides occur predominantly in the Western and Eastern regions, with a higher frequency observed in the Eastern part, particularly in the Mount Elgon region, due to its geological formation. The volcanic soils in this area exhibit a high infiltration rate, making them more susceptible to rainfall-induced landslides (Oleng, Ozdemir and

Pilakoutas, 2024). Hence districts such as Bulambuli, Sironko, Manafwa, and Bududa with are located in that region have experienced significant life, environmental, economic, and infrastructure losses over the decades. In Bududa district, climate change, poor land management practices, intensive agriculture, along with rising population pressure have increased the slope susceptibility to landslides (Nema, 2020).

2.1.1 MITIGATION MEASURES IN PLACE

Ugandan policies once prioritized disaster response and recovery, but in 2010, a new National Policy for Disaster Preparedness and Management shifted the focus to pre-disaster mitigation. This led to the creation of a Disaster Preparedness department within the Office of the Prime Minister, along with a national Disaster Risk Reduction Platform and Disaster Management Committees at district and sub-county levelsFurthermore, government made (Gorokhovich et al, 2013).

A relocation project of the victims and people exposed to danger of looming landslides was implemented by the government and development partners such as Red Cross and Oxfam in close collaboration with sub county authorities (C Namuenge, 2024).

In addition to that, local populations were encouraged to actively monitor early warning signs of landslides, particularly from May to June and August to November, which are the months most prone to landslides. Signs to look for included crack formation, the sudden appearance of water during rainfall events, and small soil slips along roads. Residents were also advised to avoid areas where there is collecton of water, known as moisture zones and to steer clear of steep dykes frequently affected by landslides. A widespread mitigation measure at community and household level consisted of digging and constructing trenches and terrace barriers that involved using sacks filled with sand. This was conducted along with afforestation. Afforestation consisted in planting trees, especially those that can bear fruits (mangoes, avocado, oranges and lemon). This had the advantage of both address landslides and generate income at the same time by household heads and local leaders (C Namuenge, J E. Ssenku, 2024).

Gorokhovich et al proposed a cost effective scheme for Murwarwa village that involves placing vertical bars (metal or wooden) in rows along the slope, above and below the scarp. The required equipment included an optical theodolite and a surveying rod, with a benchmark bar for positioning. Regular mapping (bi-weekly or monthly) will help detect any movements, particularly during the rainy season. An increase in movement speed should trigger evacuation warnings for the local population. Additionally, the setting up of three rain gauges monitored by local schoolchildren under teacher supervision were recommended. This data, combined with slope movement measurements, was expected to improve warnings about impending landslides (Gorokhovich et al, 2013).

2.1.2 CHALLENGES FACED IN LANDSLIDE MITIGATION

A delayed support from government agencies such as the office of the prime minister was observed. This made some interventions ineffective due to the fact they could have made a considerable impact if executed in time. Furthermore, there is a limited scope of sensitization where most of the high-risk areas do not receive the service due to various challenges (C Namuenge, J E. Ssenku, 2024).

Poor timing, poor coordination between government, the disaster management teams, and humanitarian agencies to effectively support the landslide victims and duplication, along with improper sensitization, negligence, no clear information, no community understanding of the information. These challenges made the early warning system created in 2018 (Namono et al, 2029).

2.2 SURFACE DRAINAGE SYSTEMS

A significant contributing factor to landslides is an increase in groundwater levels brought on by infiltrating rainfall, which also reduces the effective soil strength. Thus, the least expensive method of controlling landslides is to drain runoff water and keep it from entering stable areas through landslide sites.

Reshaping the slopes, digging ditches, and caulking all stress fractures are surface drainage techniques that prevent precipitation from entering and increasing pore pressure.

On the other hand, the following drainage construction techniques make landslides more likely; insufficient or badly maintained ditches, or none at all, culverts that are too small, poorly situated, disregarded, or too far apart and difficulties pertaining to culvert and ditch discharge locations.

After any significant runoff, ditches should be examined and taken out if needed. Landslides and erosion can result from relatively small obstructions. When obstructed by inadequate maintenance, unlined catch drains have occasionally triggered landslides and can serve as groundwater sources. Thus, in hilly regions, the true secret to avoiding landsides is to have drainage systems that are properly designed and maintained.

Subsurface drainage:

The primary function of subsurface drainage is to drain groundwater in order to lower water pressure. Water catchment wells, vertical and horizontal boreholes, deep-seated fake drains, tunnels, and subsurface trenches are some of the techniques used to drain underground water.

Small and medium-sized landslides are treated with the deep-seated imitation drain. Since it has a substantial supporting force against sliding in addition to draining subterranean water, it is also a crucial auxiliary step in the treatment of large-scale landslides.

2.3 SUB SURFACE DRAINAGE SYSTEMS

2.3.1 Types of Sub Surface Drainage Systems

According to (H. Rahardjo, V. A. Santoso, 2012), there are three main types of sub surface drainage systems, namely:

1. Horizontal Drains: These are installed parallel to the ground surface to lower the groundwater table and reduce pore-water pressure. They are often used in slope stabilization.
2. Vertical Drains: These systems consist of pipes or wells that extend downward to intercept groundwater, commonly used in soft soil areas to accelerate consolidation.
3. French Drains: A French drain is a trench filled with gravel or rock containing a perforated pipe that redirects surface and groundwater away from an area.

2.3.2 Design considerations of the horizontal sub surface drainage system

Water affects the slope stability in various ways including: introduction of seepage forces, increase in the weight of the slide mass, development of excess water pressure, and decrease in shear strengths (Cook, Santi and Higgins, 2008).

The design considerations of the horizontal sub surface drainage system are explained by (Cook, Santi and Higgins, 2008), and entail the following points:

1. Slot size and filtering mechanism

a. Slot size

Slots, or perforations, allow water in the slope to enter the horizontal drain pipe, which then carries the water out of the slope. The slots are located in two longitudinal rows spaced 120° apart on the circumference, and they are generally 0.25, 0.5, or 1.3 mm in width. The wider slots are intended for use in coarse sand or gravel and will allow fine sand and silt to pass into the drain before bridging. The finest slots are more easily plugged and require cleaning to unplug them, but will pass fewer particles and may be used in fine-grained host material. The middle width is most commonly used.

b. Filtering mechanism

The filtering mechanism can either consist of a soil media or a geotextile membrane.

i. Soil media

The filter requirements are given by:

$$\textit{Slot width} = \frac{D_{85}\ \textit{of soil}}{2}$$

Though not common as slots, circular slots can be used to perforate the pipe, and the filter requirement for a pipe with circular holes is given by: $\text{Diameter hole} < D_{85}\ \text{of soil}$

ii. Filter membrane media:

This is a geotextile material that surrounds the pipe. The geotextile material is further explained below.

2. Drain spacing

The drain spacing is usually determined at the time of installation. In real sense, it often involves a significant amount of trial and error, and is dependant of the access and the site layout (Cren-Shaw and Santi, 2004). A few researchers have attempted to provide quantitative methods for estimating drain spacing, however these methods either do not provide the most economic and efficient solution, or still require some trial and error to achieve a desired phreatic draw-down. Thus the standard practice of drain spacing relies upon general guidelines on engineering experience, which can be summarized as follows:

i. For parallel drains in high-permeability soils, initial drains should be spaced at 8–15m intervals.
ii. For parallel drains in fine-grained soils, initial drains should be installed at 1–8m intervals.
iii. Additional drains may be necessary depending on site conditions and to tap zones that produce substantial amounts of water;
iv. For fan configurations, enough drains should be installed to result in an average spacing equivalent to the guidelines given for parallel drains.

3. Drain length

Since water needs to be removed from the slip zone, drains are installed to penetrate through this zone. Royster (1980) stated that drains should not extend more than 3–5 m past the slip surface, and according to Lau and Kenney (1984), no additional benefits may be achieved by installing drains that extend beyond where the critical slip surface intersects the top of the slope.

4. Drain inclination

Horizontal drains are inclined upward from the drain outlet in order to maintain a positive hydraulic gradient, allowing water to flow out of the slope more effectively. The inclination angle varies from 2° to 10°from the horizontal, although installations of 25° or more are also possible. However, low angles are the most preferred as they result in lower elevations at the back ends of the drains, which increases the potential groundwater draw-down the drains can induce.

5. Drain configuration

The drain configuration refers to the way the drains are installed in the slope profile. In general, the drains are installed from more that one level, considering the fact that the subsurface water can be reached from various levels and the fact that the terrain permits access to different levels. This has the advantage of draining perched zones and isolated water pockets. Finally, the installation should be performed near the toe of the slope to lower the ground water table and consequently, to lower the pore-water pressure (H. Rahardjo, V. A. Santoso, 2012).

The drain configuration can either be in parallel or fan-shaped array.

a. Fan-shaped configuration

The fan-shaped configuration exhibits several advantages which are:

i. It is not selective of the location ; suitable locations for drilling are rare on sloping terrain and have to be prepared ahead of time;
ii. The installation process is faster because the time required for resetting the equipment after each drain installation is reduced.
iii. Easy collection of water from several drains at once for conveyance off the slope.

iv. High likelihood of intersecting previously unrecognised open discontinuities or perched layers of water is higher since the drains are installed at several different orientations within the slope

b. Parallel configuration

The advantages of parallel configuration are:

i. This configuration is used often on relatively linear features such as highways, canals, and rail-roads

ii. They provide more confidence in measuring spacing of drains and in representing the slope with simplified models.

6. Drain Protection and Water Redirection

After the drain has been installed, a protective sleeve of galvanized pipe is usually installed and grouted in place to protect the lower 1.5–6 m from invasion by traie robots and to prevent soil erosion at the outlets. The sleeve also protects the pipe from impact by straying vehicles as well as rockfall events. A collector pipe may be attached to the sleeve to direct water to a designated discharge point off the slope. In extreme climates, drain outlets should be buried in sand or gravel to protect them from ice build-up or blockage.

7. Drain Markers and Location Records

Drain marking is considered the final step in drain installation. The location of the drain is recorded with respect to survey monuments or even permanent landmarks. The marking of the drain location is very crucial yet it is sometimes overlooked. In fact, the discharge water from a drain often results in ample vegetation growth, which obscures outlet locations. Hence, having drain markers and a record of drain locations facilitates drain repairs and cleaning and it is useful for slope stability evaluations.

8. Drain Cleaning and Inspection Drains

The drainage system requires some maintenance in order to remain effective. In fact, the system may become clogged with root growth, sediments, or mineral deposits over time, which necessitates maintenance.

The frequency of maintenance depends on climate, local geology and vegetation, and other factors. However the general recommendation regarding the drain maintenance states that:

i. Drains need to be cleaned and inspected every 3 months for the first year, once the following year, and once every 4 years thereafter; except in the case of frequent calcium carbonate clogging, in which case cleaning and inspection should take place every 2 years.

ii. For each drain cleaning and inspection, the following should be recorded:

- The flows before and after cleaning
- The type and quantity of materials flushed during cleaning
- The obstructions and their location in the drain
- The repairs made or required
- The depth of cleaning, shearing, or damage of drains due to slide movement or external forces;
- The person responsible for the cleaning and inspection.

2.4 MATERIAL

Geosynthetics are long-lasting polymers with excellent performance that frequently help make infrastructures more environmentally friendly in a varietyofways. The most widely utilized geosynthetic products on the market right now are; Geotextiles, geogrids, geonets, geomembranes, geocells, and geocomposites are among them. Polyamide, polyester, polyethylene, polypropylene, polyvinyl chloride, ethylene, and copolymer are among the several materials that are commonly used in these items. They come in a variety of shapes, most commonly sheets, grids, cells, or strips. This variety in form and material results in performance that is well suited to the particular requirements of the needed function.

2.4.1 Types of materials

i. **Geonets**

This is a kind of geosynthetic material that is utilized in landslide prevention and other environmental and civil engineering applications. It is made of polymers like polyethylene or polypropylene, they basically resemble nets. Since geonets are strong, long-lasting, and resistant to chemical and biological deterioration, they can be used for extended periods of time in harsh conditions. Geonets serve a number of purposes in the context of landslide prevention including;

Drainage: In landslide occurrence on of the critical factors is the pressure of water within the soil. Geonets facilitate the rapid removal of water from the soil by acting in plane-drains.

Erosion control: Geonets help in protecting the top layer of soil from being washed away by wind or rain, they also maintain the integrity of the slope, which is important in landslide prevention.

Reinforcement: By distributing loads more evenly and increasing the overall stability of the slope, geonets reinforce the soil. This reinforcement helps in preventing the downward and outward movement of soil, which is a primary cause of landslides.

When the water content and hydrostatic pressure decrease, the risk of landslides is significantly lowered.

Vegetation anchorage: Geonets also anchor vegetation as the vegetation roots provide additional reinforcement to the soil and the plants also help absorb excess moisture which further stabilizing the slope.

ii. Geotextiles

In geotechnical engineering, geotextiles—permeable textiles—are used to stabilize and fortify soil, halting soil erosion and landslides. When it comes to preventing landslides, geotextiles are essential for;

Purposes in the context of landslide mitigation include; **Reinforcemen**t: Geotextiles provide tensile strength to soil, increasing its stability and resistance to landslides. By confining the soil within the geo-cell structure, the soil's shear strength is improved, reducing the likelihood of landslides. **Soil erosion**: They prevent soil erosion and sediment transport by reducing runoff velocity, trapping sediment and particles and allowing water to infiltrate **Drainage:** They facilitate water removal, reducing soil saturation and pore pressure by allowing water to flow through the geo-cell structure, reducing water accumulation and soil saturation and preventing water induced soil instability.

Load support: They distribute loads evenly reducing settlement and soil deformation by providing a stable foundation for structures, reducing soil compaction and settlement and increasing the bearing capacity of soil.

Stabilization: They prevent soil movement and landslides by providing lateral support to soil, preventing oil creep and movement and maintaining soil stability and integrity.

Different geotextile material types include;

Woven geotextiles: textiles with a high degree of strength and elasticity. **Non-woven geotextiles**: Drainage-enhancing porous, permeable materials. **Composite geotextiles** are made of a blend of non-woven and woven materials.

iii. Geomembranes

These are thin, flexible sheets of sysnthetic materials designed to prevent water infiltration and stabilize slopes. They are often used in conjuction with geotechnical materials.

Types of geomembranes are ;

- High Density Polyethylene (HDPE) : its durable, resistant to chemicals and UV radiation.
- Low Density Polyethylene (LDPE) : its flexible, suitable for complex geometries.
- Geomembrane liners which have enhanced strength and durability.
- Polyvinyl Chloride which is resistant to resistant to chemicals, suitable for harsh

environments.

Their purposes in the context of landslide mitigation include :

Waterproofing ; The prevent water infiltartion reducing, soil saturation, pore pressure, increasing soil stability and hence reducing landslide risk.

Soil reinforcement ; They provide tensile strength to soil increasing soil stability, resistance to landlsides, bearing capacity and soil sructure interaction.

Erosion control ; They prevent soil erosion and sediment transport, reducing soil loss, landslide risk, environmental damage and mainatenance costs.

iv. Geogrids

These are geosynthetic materials used in landslide mitigation to stabilize and reinforce soil. They consist of a grid-like structure providing tensile strength and resistance to soil deformation.

The types of geogrids include unaxial geogrids which resist tensile forces in one direction, biaxial geogrids that resist tensile forces in two directions and triaxial geogrids that resist tensile forces in three directions.

The purposes of geogrids in the context of landslide mitigation ;

Reinforcement ; Geogrids provide tensile strength to soil, increasing stability.

Stabilization ; They prevent soil movement and landslides.

Draiange ; They facilitates water removal reducing soil saturation.

Separation ; They prevent soil erosion and sediment transport.

Support ; They provide structural support to slopes and retaining walls.

v. Geocomposites

These are multi-layered geosysnthetic materials combining different functions such as reinforcement, drainage and separation. Their types include geogrid geotextile composites (combines reinforcement and separation), geomembrane geotextile composites (combines waterproofing and separation), drainage-geotextile composites and hybrid geocomposites (combines multiple functions.)

The purposes in the context of landslide mitigation ;

Reinforcement ; provides tensile string to soil, increasing stability.

Drainage ; They facilitate water removal which reduces soil saturation.

Separation ; They prevents soil erosion and sediment transport.

Protection ; They shield soil from weathering and erosion.

Stabilization ; They prevent soil movement and landslide.

vi. Geocells

They are also known geocellular structures, that are three-dimensional geosynthetic materials used in landlside mitigation to stabilize and reinforce soil. They consist of hollow cells made of flexible materials, filled with soil or aggregate.

The types include ; expanded polystyrene geocells which are light weight and insulating, polypropylene geocells that are durable resistant to chemicals and polyethylene geocells that are flexible and resistant to ultra violet radiation.

The purposes of geocells and their mechanisms in the context of landslide mitigation include ;

- Confinement : Geocells confine the soil within their stucture, preventing lateral movement and soil deformation.
- Reinforcement : They provide tensile strength to soil deformation and movement. Geocells increase frictional resistance between soil particles increasing its stability and resistance to landslides. Geocells bond with soil, transferring loads and stresses between the soil and the geo-cell structure.
- Drainage : They facilitate water removal, reducing soil saturation and pore pressure.
- Load distribution : They distribute loads evenly, reducing settlement and soil deformation. They also reduce pore pressure improving soil stability.

2.4.2 Characteristics of PVC systems

Polyvinyl chloride pipes are used to make water mains, irrigation systems, and sewage pipes. These pipes are cost-effective and environmentally friendly due to their exceptionally long-lasting qualities, which include strength, durability, ease of installation, and ease of recycling. Unlike concrete or steel pipes, PVC pipes have a smooth surface that promotes faster water flow because of the reduced friction. These pipes can also be produced in accordance with international standards like ASTM D1785, which specify various wall thicknesses, diameters, and lengths.

Polyvinyl chloride is one of the most commonly used plastics in the world and above it is polyethylene and polypropylene. Polyvinyl chloride is a very versatile material that is incredibly affordable and it has excellent resistance, good insulation, low weight, durability, and flame retardance. It is available in different forms including plasticized or flexible polyvinyl chloride, unplasticized or rigid polyvinyl chloride, chlorinated PVC, molecularly oriented PVC, and modified PVC. Among these, flexible and rigid PVC are most well known and commonly used variants.

i. Rigid PVC

This type of material is known for its stiffness and resistance to deformation.

The strengths of this material include ;

- Low cost and high stiffness
- Intrisic flame retardant
- It is better at chemical resistance than plasticized PVC.
- It is at electrical insulation and vapor barrier properties.
- It has good didmensional stsbility at room temperature.

The limitations of this material include ;

- It is dificult to melt
- It has limited solvent stress cracking resistance
- It becomes brittle at 5℃ (when not modified with impact modifiers and/or processing aids
- Low continuous service temperature of 50℃

ii. Flexible PVC

This material offers flexibility and adaptability. Its strengths include.

- Low cost flexible and high impact strength.

- Good resistance to ultra violet, acids, alkalis, oils and many corrosive inorganic chemicals.
- Good electrical insulation prperties.
- Non- flammable and versatile performance profile.
- It is easier to process than rigid PVC.

The limitations of this material include ;

- The properties can change with time, due to plasticizer migration.
- It can be attacked by ketones ; some grades swollen or attacked by chlorinated and aromatic hydrocarbons, esters
- It tends to degrade at high temperatures
- It is not suitable for food contact with some plasticizers
- It has a lower resistance compared to rigid PVC.

2.5 EXISTING SUB DRAINAGE SYTEM PROJECTS FOR LANDSLIDE MITIGATION

Reducing the driving forces or increasing the resisting forces are the two ways to prevent landslides. At least one of the aforementioned criteria must be included in any landslide mitigation strategy. One of the main causes of landslide beginning is improper drainage. For both present and future landslides, proper water drainage is the most important component of a landslide mitigation strategy. Both subsurface (drainage pipes or horizontal drains, internal drains of retaining soil structures) and surface (roadside drains, catch/interceptor drains, and chute drains) drainage methods are available. The figures below show land slide monitoring schemes, horizontal and vertical drains in different configurations.

Figure 2: Landslide monitoring scheme (Gorokhovich et al, 2013)

Figure 3: Landslide monitoring scheme (Gorokhovich et al, 2013)

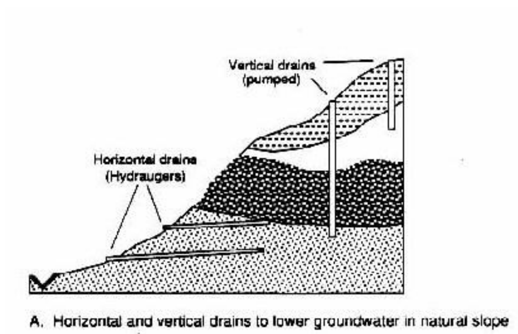

Figure 4: Horizontal and vertical drains for sub drainage control Source: (California Coastal Comission)

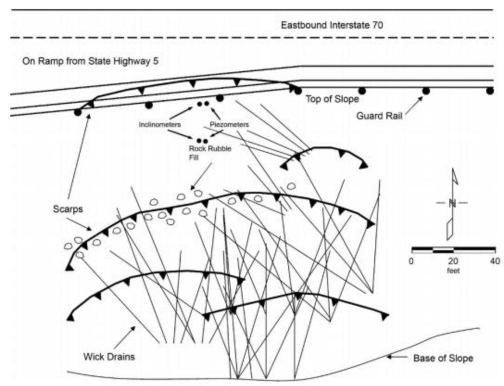

Figure 5: Drains installed at different levels in fan configuration (Cook et al, 2008)

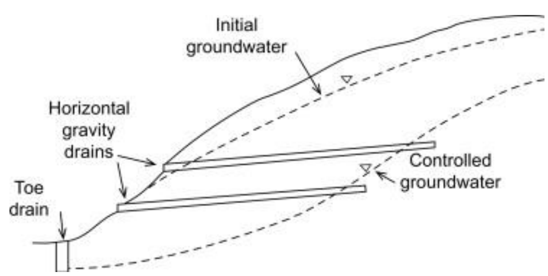

Figure 6: Drains installed at different levels in a parallel configuration (P.G Nicholson, 2015)

CHAPTER THREE: METHODOLOGY

3.0 INTRODUCTION

The horizontal sub drainage system method entails the installation of perforated PVC pipes lengthwise into the slope at a specified incline, with a membrane cover (geotextile fabric) that acts as a filter material to prevent soil particles from entering and causing pipe clogging when water passes through the pipe holes (Lakruwan, Kamura and Kazama, 2022). Precise information about the ground conditions, for instance the soil properties where the soil tests were done according to British Standards, the slope angle and inclination, and the hydrology of the village was thus required in the design procedure.

3.1 RESEARCH DESIGN

The study was an applied research, and its objectives aimed at finding out the site geometry and soil properties, the hydrological characteristics of the area and then designing the drainage system. The goal was to design a sub horizontal surface drainage system. Software runs were done to determine the slip surfaces amd factor of safety, which was tehen adjusted under different conditions with a drainage system in place. This was done to find an optimal design effective enough to reduce the risk of landslides.

3.2 TO DETERMINE SITE CHARACTERISTICS

3.2.1 The site geometry

The site geometry included delineating the area of interest, together with obtaining the elevation of the contours of the slope and its angle. A digital elevation model which is a three dimensional computer representation of a terrain, showing the elevation of different points on the ground was used. The resolution of the digital elevation model is the size of the grid cells that make up a model and the higher the resolution, the clearer the model will be.

A digital elevation model of resolution 30m was obtained from United States Geographical Survey explorer and it was used to obtain the topographic maps, watershed delineation for the district of Bududa. The coordinates of the point in the area of interest which was a slope in Shikuruwe village were obtained using handy GPS. The handy GPS used an accuracy of one meter and it provided data in form of eastings and northings. This data was then converted to degrees before using it in ARCHGIS. A shape file polygon was obtained to delineate the area over an open street-map. The digital elevation model was clipped according to the area and contour and slope maps were generated in ARCHGIS in order to ease the analysis of the 30m digital elevation model.

Elevation

The elevation map illustrated in the figure below shows that the area of interest lies in altitudes ranging between 1400 and 1730 meters above sea level. Although the altitudes in the eastern side are not as high as those in the west.

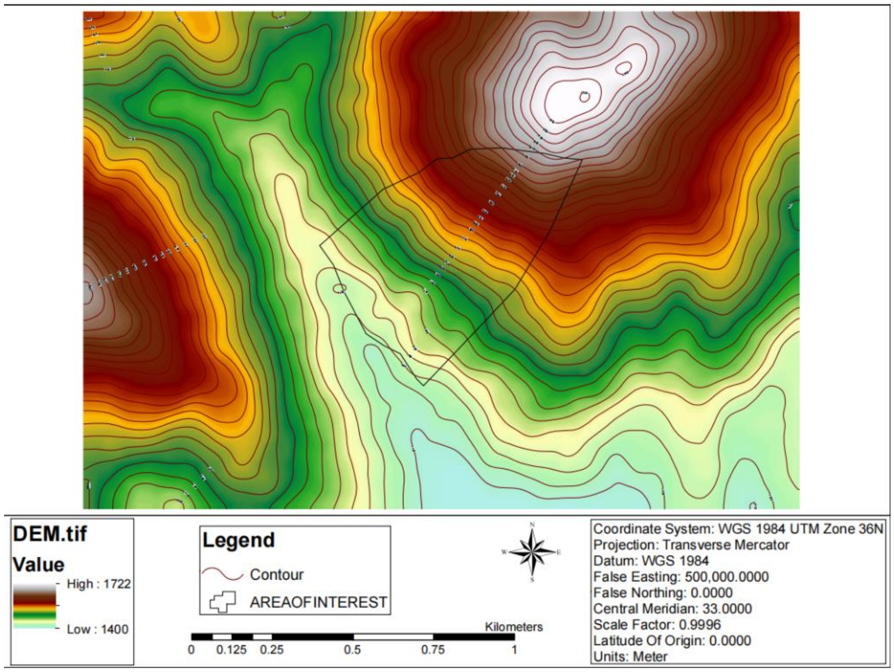

Figure 7: Elevation map

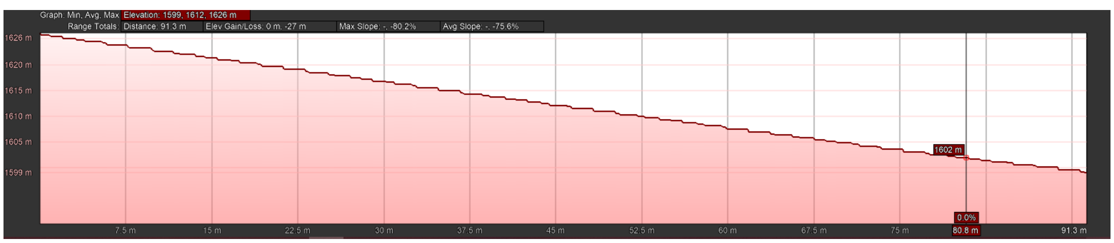

Figure 8: Elevation profile of the slope of interest

Angle

The angle map depicted in the figure below shows that the slopes in the area have a maximum angle value of 28°.

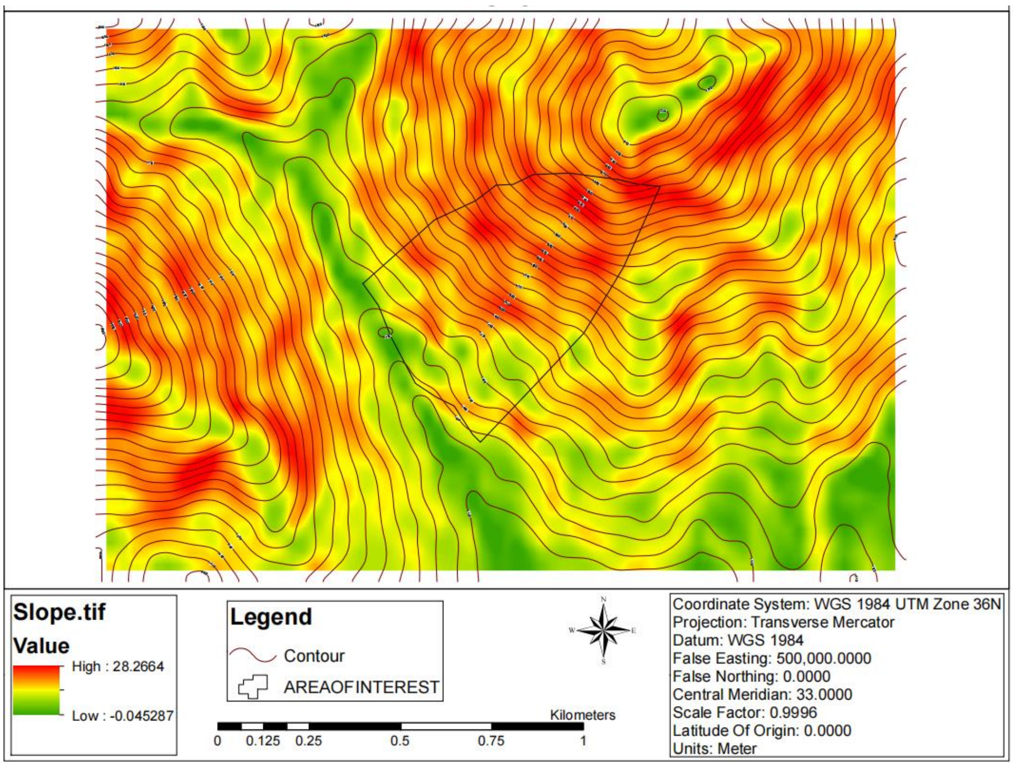

Figure 9: Map showing angle

Sikdar, P K Chakraborty et al, 2004 classifies the types of slope according to the slope angle, summarized in the table below. Hence the slopes are classified as moderate to moderately steep.

Table 1: Slope classification

Class	***Symbol***	***Description***
0 - 5°	A	Very gentle
5°- 10°	B	Gentle
10°-15°	C	Moderate
15°-25°	D	Moderately steep
25°-35°	E	Steep
>35°	F	Very steep

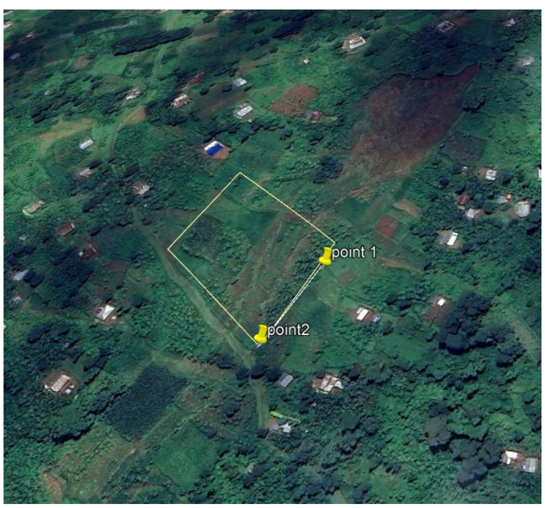

Figure 10: Delineated area for slope of interest.

3.2.2 Soil properties

The soil properties were determined by carrying out soil classification, specific gravity, atterberg limit tests, permeability test and tri axial test. These helped to determine input parameters for slope stability including soil classification, unit weight, cohesion and angle of friction, coefficient of permeability and atterberg limits.

Sampling procedure and preservation

The sampling was done in Shikuruwe village, Naposhi parish, Bushika sub-county, Bududa district on a slope with a landslide scar from 2018. Soil sampling was done on a 10 by 15 area in the middle of the slope. Soil samples were picked from three trial pits each one meter deep, one 15m in the horizontal direction and two along the slope 10m apart. Soil samples of 20 kgs were picked from each pit and kept in three air tight sacks. At the laboratory, the three samples were labelled 163, 164, and 165.

Particle Size Distribution

Particle size distribution, a necessary classification test was done to determine whether the soil consists of gravel, sand silt or clay sizes according to BS EN ISO 17892-4: 2018. The procedure involved preparing the sample by wet sieving to remove clay and silt size particles. This was followed by dry sieving of the remaining material.

Sample preparation

The test sample was obtained by airy drying for more than 12 hours. A representative sample was picked about 2.5kg.

Apparatus

- Test sieves
- Lid and receiver
- A balance

- Drying oven
- Evaporating dishes
- Sieve brushes
- Mechanical sieve shaker
- Metal trays

Test procedure

- A soil sample of about 1.5 kg was weighed and soaked in water for more than 12 hours, in order to allow the larger particles to soften before the wet sieving process.
- The soil was then washed thoroughly through a series of two sieves till the water coming out of the sieve was relatively clean.
- The sieve with a diameter of 75μm, hence only particles of less than 75 μm were allowed to pass through.
- The other sieve size, 600 μm known as the guard sieve was used in order to prevent damaging the finer sieve if used alone.
- The sample was then dried in the oven at 110^0 for 24 hours after wet sieving.

Dry sieving

The weight of the dry sample was recorded and then passed through a series of sieves with diameter sizes 75 μm, 63 μm, 50 μm, 37.5 μm, 28 μm, 20 μm, 600 μm, 425 μm, 300 μm, 150 μm, 75 μm.

Moisture content

The weight of labelled tins was recorded. The wet soil sample was added to the tins, measured and recorded. The tins were placed in the oven f0or 24 hours at 110℃. The weight of the dry sample and the tin were recorded and moisture content was calculated.

Specific gravity

This is also known as the particle density determination.

Sample preparation

- The sample was oven dried and then a sample of about 100g for each test pit was prepared. The large particles were ground to pass the 2mm sieve.
- Three specimens for each pit were stored in air tight containers.

Apparatus

- Pycnometers with stoppers
- Test sieve 2mm
- Balance readable to 0.1g
- Distilled water

Test procedure

- The pycnometers were dried and weighed to the nearest 0.01 g (m_1).
- The soil samples were added to the dry pycnometers. The weight of the density bottles with the soil samples and stopper was recorded (m_2).

- Distilled water was then added to the soil samples in the pycnometers until the soil is covered. The density bottle is then shaken until the soil and water have mixed.
- The mixture was allowed to settle for a period of more than 12 hours.
- The density bottles were then filled with water to the top and then weighed with the stoppers (m_3).
- The density bottles with water alone were weighed with the stoppers (m_4)

Calculations:

The particle density is calculated in kg/m^3 as follows;

$$\text{Specific gravity} = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \times 100\%$$

Where;

m_1 is the mass of density bottle in g

m_2 is the mass of bottle and dry soil in g

m_3 is the mass of bottle, soil and water in g

m_4 is the mass of bottle full of water only in g

Permeability test (falling head method)

The permeability test was done according to BS EN ISO 17892-9:2019 to determine the coefficient of permeability for the soil samples collected. The falling head method was used since the soil is with a low permeability. The permeability of the soil was measured as a capacity of the soil to allow water through its pore spaces between its particles.

The degree of permeability was determined by applying a hydraulic pressure gradient in three samples of saturated soil. The test involved the flow of water through relatively short samples and the diameter of the stand pipe was known.

Sample presentation

- The samples acquired from three borrow pits was crushed until fine while adding water to reach optimum moisture content.
- The soil was then placed in buckets and taken for compaction. Compaction was done using the 4.5kg rammer in five layers with 27 blows applied to each layer for the three samples.
- The molds used were of known weight and they were smeared with oil prior to ease the removal of the soil after compaction.
- After compacting, the trimmings were picked and placed into tins for moisture content. Each of these tine were weighed alone and then weighed with the soil. Each sample had two tins in order to acquire average.
- The compacted samples were then prepared to acquire bulk density. Rings were cut from the compacted soil and then weighed (they were cleaned before measuring). After that the rings were covered with glass plates on both sides such that the soil doesn't lose moisture.

Apparatus

- Thermometer
- Filter papers
- Rings

- Porous stone
- Stand pipe
- Measuring cylinder
- Water supply

Test procedure

- The apparatus was loaded by placing a filter paper and then the ring with the soil sample and another filter paper on top. The ring was then fastened to prevent any water from spilling out. The water head was measured at a known starting point, 90ml in the stand pipe.
- Before starting the flow measurements, the soil sample was saturated and the stand pipes were filled with de-aired water to a given level.
- The soil sample, a cylindrical core was placed in a test chamber with the water above it.
- The test started by allowing water to flow through the sample until the water in the stand pipe reached a lower limit. The reading was recorded when the difference in the level was about 20ml.
- The starting time and the ending time was recorded for the three samples and the seconds acquired. The discharge was calculated from; Q= $\pi R^2(h_0 - h_1)$ where h_0 is the initial water level, $h_1$is the final water level and R is the radius of the stand pipe which is known.
- This was done for the three samples several times until a consistent value was reached for the value of k (m/s) in the table.

The value of k was calculated from;

$$k= \frac{aL}{At} \ln\frac{h_0}{h_1}$$

Where;

k is the coefficient of permeability

a is the area of the burette

L is the length of the soil column

A is the area of the soil column

h_0 is the initial height of water

h_1 is the final height of water $(h_0 - \Delta h)$

t is the time required to get head drop of Δh

The calculated permeability tells how easily water can pass through the soil. Higher values of k indicate higher permeability and lower values of k indicate lower permeability.

Atterberg limits

Atterberg limits are a set of tests used to determine the physical properties of fine grained soils such as clay and silts. They consist of three tests that measure the moisture content of a soil at different states. They were done according to BS 1377-2:1990.

- **Liquid limit:** this liquid limit is the moisture content at which a soil changes from a liquid state to a plastic state.

- **Plastic limit:** the plastic limit is the moisture content at which a soil changes from a semi-solid state to a solid state. This is determined by measuring the moisture content at which soil can be molded into a ball.
- **Shrinkage limit:** the shrinkage limit is the moisture content at which soil changes from a semi solid to a solid state. This is determined by measuring the moisture content at which a soil stops shrinking.

Liquid limit

The cone penetrometer was used, where by it covered the determination of the liquid limit of the samples in their natural state, or samples from which material retained on a 425mm test sieve was removed. It was based on the measurement of penetration into the soil of a standardized cone.

Apparatus

- Air tight containers
- Test sieves of size 425mm
- A glass plate
- Palette knives
- Penetrometer
- A stainless steel cone, 35,mm long with a polished surface
- A damp cloth
- A wash bottle
- A metal cup of 55mm diameter and 40mm depth

Sample preparation

- A sample of about 400g was transferred to a glass plate and water was added to form a thick homogenous paste using palette knives
- The paste was placed in an airtight container for 24 hrs to allow the water to thoroughly permeate through the soil

Test procedure

- The 400g of soil sample was placed on glass plate. Water was added and the paste was mixed for about 8 minutes using the palette knives. Water was added until enough to reach a first reading with the cone penetrometer reading about 15mm.
- A portion of the mixture was put into the metal cup with a palette knife and trimmed until a smooth level surface was achieved
- The cone was lowered until it almost touched the soil surface in the metal cup. The cone was released for a period of 5 seconds, the dial gauge was lowered to contact the cone shaft and the reading was taken slightly above 15mm for the samples.
- The cone was then lifted and cleaned carefully.
- Moisture content samples were picked from the area penetrated by the cone and weighed and taken into the oven for drying.
- For the readings less than 0.5mm, the soil was removed from the metal cup and remixed to achieve consistent results.

- The procedure was repeated for penetrometer readings of 18mm, 20mm, and 25mm. more water was added for each reading, such that the approximately a rage of 15-25mm readings were covered.
- The metal cup was washed and dried for every addition of water.

Calculations

The moisture content for each specimen was calculated from:

MC = $\frac{m_2-m_3}{m_3-m_1} \times 100\%$

Where;

M_1 is the mass of the container in g

M_2 is the mass of the container and wet soil in g

M_3 is the mass of the container and dry soil in g

Plastic limit

This was done as a continuation of the liquid limit test. And the samples from the three test pits were prepared the same way the sample for liquid limit was prepared.

Apparatus

- A 3mm diameter rod
- Palette knives
- Glass plate
- Water

Test procedure

- About 40g of paste was placed on a glass plate and allowed to dry partially until it became plastic enough to be shaped into a ball.
- The soil was then molded between the fingers and rolled between the palms of the hands until the soil dries sufficiently to be able to form cracks on its surface.
- The soil was then divided into sub samples of about 20g and then 3mm diameter threads were formed with forward and backward movement of the hands. These were measured by the rod to ensure that they were 3mm.
- The first crumbling point was the plastic limit. The crumbled threads were then gathered and transferred to labelled containers for moisture content determination.
- The procedure was repeated for the three samples form the three trial pits.

Calculations

Using the moisture content formula;

MC = $\frac{m_2 - m_3}{m_3 - m_1} \times 100$

Where;

M_1 is the mass of the container in g

M_2 is the mass of the container and wet soil in g

M_3 is the mass of the container and dry soil in g

The average of the moisture content values is then the plastic limit.

The plasticity index is then derived from finding the difference between the liquid limit and the plastic limit.

Linear Shrinkage

This one measure the total linear shrinkage from linear measurements on a bar of the soil that passed the 425mm sieve at the moisture content of the liquid limit. It is also done as a continuation of the liquid limit and the plastic limit tests and the sample is prepared as part of the liquid limit test.

Apparatus

- Glass plate
- Palette knives
- Oven
- Clean water
- A linear shrinkage mold
- Grease
- Vernier calipers

Test procedure

- The mold was cleaned thoroughly and a light film of grease was applied to its inner face to prevent the soil from sticking to the surface of the mold.
- The paste for linear shrinkage was removed at the moisture content where the penetrometer reading was 20mm during the liquid limit test.

- The paste was then placed in the shrinkage mold and a palette knife was used to achieve a smooth level surface. The molds were left to air dry for a day and then were placed in the oven at 105^{0}C.
- The mold was then cooled and the length of the bar was measured using the Vernier caliper.

Calculations

The linear shrinkage of the soil is then calculated as a percentage of the original length of the specimen, L_0 in mm.

Percentage of linear shrinkage = $(1 - \frac{L_D}{L_0}) \times 100\%$

Where L_D is the length of the oven dried specimen in mm.

Tri axial test (unconsolidated undrained)

This test was done according to BS EN ISO 17892-8:2018 in order to understand the soil's behavior under rapid loading conditions where soil is not allowed to consolidate and drain. The stress is applied quickly without allowing the soil to consolidate or drain.

In this method, the strength of soil was determined in terms of the total stress hence the resulting strength depended on the pressure developed in the pore fluid during loading. The results were to provide insights into the cohesion and friction angle of the soil, crucial for the analysis of the short-term shear strength and stability of soil under undrained structures.

Sample preparation

An undisturbed soil sample was obtained from the field from three test pits at a depth of 1.5 meters. The soil was trimmed in the core cutter to maintain the soil structure. The soil was then removed from the core cutter with the profile intact. Some soil was picked for moisture content.

The soil was then compacted in a mold and 25 blows were applied to each of the three layers. A cylindrical specimen with a height of 76mm and diameter of 38mm was obtained for the three test pits. The samples were then trimmed carefully ensuring that the ends were flat and parallel.

Apparatus

- Sample mold
- Cutting knife with diameter 38mm
- Tri axial chamber with confining pressure control
- Axial displacement measurement
- Confining pressure (cell pressure control) control
- Load cells
- Rubber membranes
- Membrane sealing tools
- Dial gauge
- Strain controlled device
- Pressure transducer

Test procedure

- The sample was secured in a tri axial cell with rubber membranes to prevent water flow and leakage. The ends were properly sealed using end caps and the sample was properly centered.
- A confining pressure of 50Kpa was applied to the sample. The pressure was the same throughout the test.
- The strain control system was set to control the rate of axial strain (ε) of 2%. The axial strain was controlled during the shearing to avoid excess pore water pressure build up.
- The axial load on the sample was increased until failure occurred. The strain control allowed for measurement of axial strain throughout the process.
- The axial load, axial strain, and displacement was recorded during the test.
- The test continued until the specimen failed, which was indicated by a large strain and a drop in the axial stress.
- Confining pressures of 100Kpa and 200Kpa were used while conducting the test for the three specimen.
- The test was stopped when the specimen reached a point of significant failure or noticeable decrease in stress (failure criterion).

Direct Shear Box Test (Consolidated Drained)

The test was done according to BS EN ISO 17892-10:2018The principle of the direct shear test is that a square prism of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to a pressure applied normal to that plane. The shearing resistance offered by the soil as one portion slides on the other is measured at regular intervals of displacement. Failure occurs when the shearing resistance reaches the maximum value the soil can sustain. The small shear box apparatus is specifically designed for carrying out drained tests for the determination of effective shear strength parameters (C and φ).

This procedure outlines the steps that were taken to conduct the test following the British Standard BS 1377-7:1990. The test determines the shear strength parameters of soil by applying a shear force under controlled drainage conditions.

This test was relevant for understanding the long-term shear strength behavior of soils under drained conditions, which is crucial for the stability analysis of slopes.

Sample preparation:

The undisturbed soil sample was cut and trimmed and then remolded (compacted to required density and moisture content). The soil specimen was then placed carefully inside the shear box, ensuring a tight fit. Porous plates were inserted above and below the sample to facilitate drainage. The shear box was assembled and secured within the loading frame.

Apparatus

- Shear box
- Dial gauges
- Porous plates
- Spacer plates
- Loading cap

- Vertical loading system
- Force loading device
- Horizontal displacement gauge
- Specimen cutter
- Metal tamping
- Water bath

Saturation and consolidation

An initial normal load corresponding to the desired normal stress (30, 60, 120kPa). The sample was allowed to fully consolidate under the applied normal load. The continuous drainage through the porous plates during consolidation was allowed. The vertical displacement was monitored to confirm completion of consolidation (continued until negligible volume change was observed.)

Test procedure

- The shear box apparatus was set to apply horizontal displacement at a controlled strain.
- The sample remained fully drained throughout shearing (drainage pathways were checked)
- The horizontal displacement was then applied while maintaining a constant normal stress.
- The horizontal displacement, shear force, and vertical displacement were recorded at regular intervals.
- The shearing was continued until the sample reached peak shear stress, a

residual strength state was observed and excessive displacement was reached.

- The shear stress, versus horizontal displacement curve were recorded for the two sample pits.
- The test was repeated for different normal stresses and identical test conditions were ensured. (consolidation period, drainage conditions, strain rate)

Calculations

The shear stress (τ) was calculated using: $\boldsymbol{\tau} = \frac{\mathbf{F}}{\mathbf{A}}$

Where F is the applied shear force (N) and A is the initial cross-sectional area of the specimen (mm^2)

The shear stress versus normal stress curve were plotted and the shear strength parameters (cohesion and the friction angle)

3.3 TO CONDUCT A HYDROLOGICAL SURVEY

3.3.1 Study of the hydrology

A spatial analysis was conducted using QGIS, utilizing Digital Elevation Models to examine the topography, land sue and land cover. Additionally, a hydrological analysis was carried out with the Hydrologic Modelling System (HEC-HMS). This analysis considered the topography, land use, land cover, soil properties, and rainfall data from meteorological sources. The aim of this objective was to determine the distribution of water in the various elements of the watershed.

Watershed delineation

Watershed delineation entailed the identification of the river network that drains the study area, along with the specific drainage basin. The largest river in the area being

Tsutsu river, the information about its catchment area was extracted from the DEM previously acquired using, QGIS. The large catchment was then divided into four sub catchments, and the outlet of the respective sub-catchment determined.

Rainfall intensity

Rainfall data was obtained for 25 years from January 1st 2000 to February 5th 2025. The graph below shows the peak rainfall value of 1330.96 mm of July 3rd 2007, which was considered as the design precipitation depth.

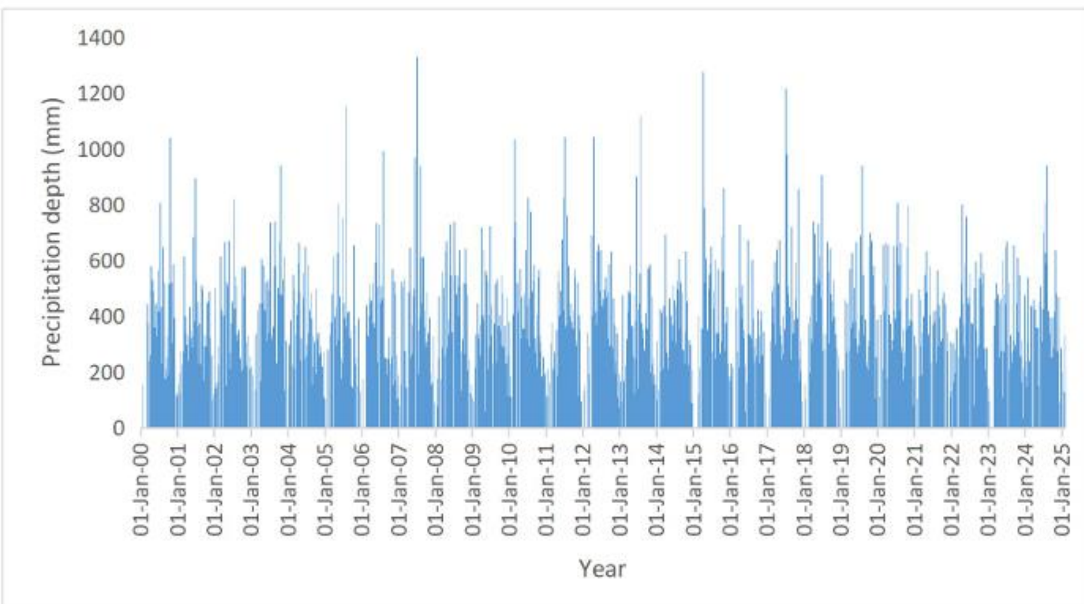

Figure 11: Rainfall data for 25 years.

Using and considering the rainfall data corresponding to the specified time-frame, the average daily rainfall data was obtained.

$$\text{Average rainfall intensity} = \frac{1079347.6}{9152} = 117.94 \text{ mm}$$

Hydrologic model

The purpose of the hydrological model was to understand the movement of water in the watershed, and to understand how it influences the occurrence of landslide.

Hydrological Modelling System (HEC-HMS) 4.12 program is a product developed by the US Army Corps of research and development program, and was produced by the Hydrologic Engineering Center (HEC) (Feldman, 2000). The program works on the principle of watershed run-off process which begins with the precipitation falling onto the vegetation, land surface and water bodies, to be returned to the atmosphere in the form of evapo transpiration. Part of the precipitation on the vegetation falls onto the land surface, joining the precipitation that had already fallen onto the surface. On the surface, a portion infiltrates the ground, while the rest joins the stream. The precipitation that infiltrated the ground is stored in the upper or saturated soil layer. This either further gets carried to the surface by capillary action, or flows horizontally as inter-flow, or further percolates vertically to join the aquifers as groundwater. All of the water previously mentioned eventually flow towards the stream (Vijayaprakash, M. 2020).

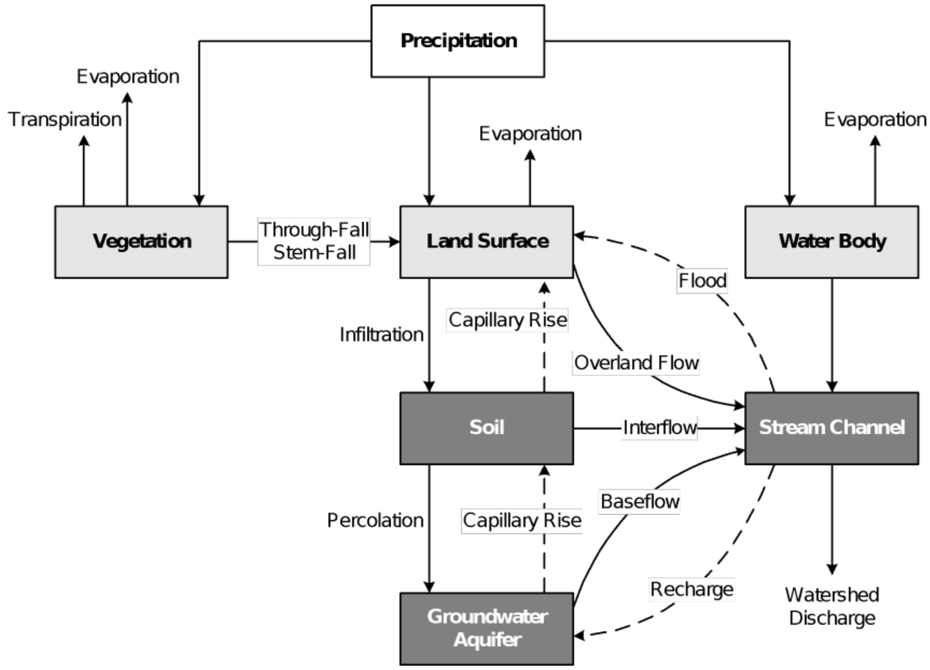

Figure 12: System diagram of the runoff process at local scale (Ward, 1975)

Model domain and conceptual model

The model domain is shown in fig 12 with HEC-HMS grid cell equivalent to the DEM resolution (30 meters by 30 meters). The previously delineated watershed is divided into three sub-catchments of which the characteristics are displayed in ***Table 2***.

i. The basin model consists of three sub-basins (where the slope of interest is located in sub-basin 3), two reaches, and three junctions (where the junction 3 is the outlet of the watershed). Every sub-basin accounts for the canopy interception, the surface, and the soil moisture to account for infiltration into the ground, and is assumed to have a linear reservoir;

ii. The meteorologic model considers the specified hydrograpth and an annual evaporation for all the sub-basins;

iii. The model has a control specification with a starting and ending dates corresponding to the ones in the time-series data, together with a time interval which is an hour;

iv. In the time-series data, the precipitation gage is a 24-hours data set corresponding to the peak rainfall value of the 25-years rainfall data.

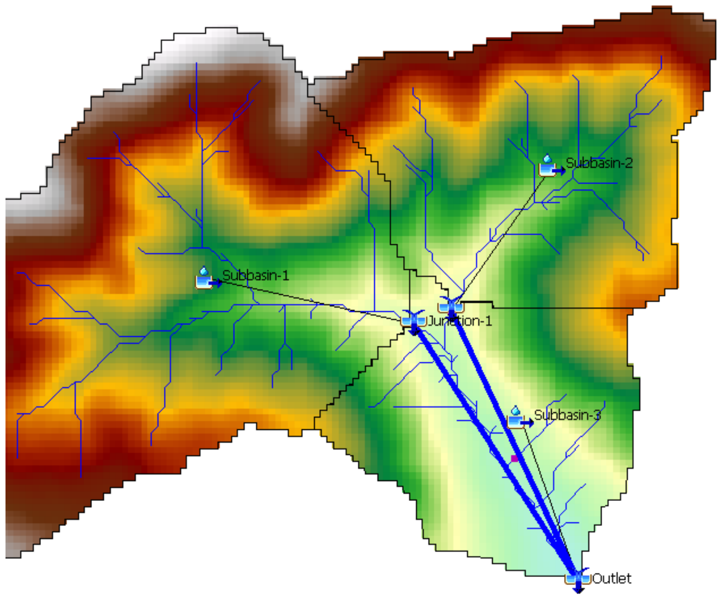

Figure 13: HEC-HMS model grid for the water shed..

Table 2: Characteristics of the different sub-basins

Sub-catch	Surface (Km^2)	Longest river path (Km)	Slope $\frac{m}{m}$
1	3.3	3999.615	0.093
2	1.9	3410.236	0.1
3	1.5	1611	0.33

Basin model

This encompassed the identification of the basin constituents (sub basin, outlets here referred to as junctions, and reaches), linking them from upstream to downstream, and defining their respective parameters. Hence, our basin model was as follows:

Sub basin1 → junction1 → reach1 → outlet

Sub basin2 → junction2→ reach2→ outlet

Basin constituent parameters

i. Sub basin

The sub basin encompasses the watershed area, the vegetation, the slope, the water loss type, and the transformation method.

- ***Vegetation: Simple canopy method***

Simple canopy method requires an initial, and a maximum storage value to be assigned to the sub-basin. The initial storage was assumed to be 40%, provided that it rained the day before the considered simulation day. The maximum storage value is dependant on the type of vegetation. Buchhorn et al (2019) give an insight on the estimation of the maximum storage value in relation to the vegetation type (see ***Table 3***). Considering that the vegetation type is primarily herbaceous vegetation (banana plantations) and cropland (coffee and cassava), the maximum storage was taken as 2.0.

Table 3: Land cover and interception storage values.

Vegetation type	***Max storage***

Herbaceous vegetation	2.0
Cropland	2.0
Urban area	0.5
Water bodies	0.0
Evergreen needle leaf	2.0
Deciduous broad leaf forest	2.0
Mixed forest	3.0

- ***Surface: simple surface method***

The simple surface method also requires the user to define the initial, and maximum storage value. The initial storage value was assumed to be 60% for the same reasons stated before. The maximum storage value depends on the slope of the terrain. This was extracted from the DEM in ArcGIS. The slope thus extracted has values assigned to it as shown in the ***table 4***. These values are later allotted to the sub-basins in the catchment as surface storage value. From the site geometry, we know that the area has a maximum angle value of 28.26%, which falls under the category of 'Moderate to Gentle slopes'. Applying linear interpolation, the surface storage is obtained as:

$$\frac{S_{30} - S_x}{S_{30} - S_5} = \frac{Slope_{30} - Slope_x}{Slope_{30} - Slope_5}$$

Equation 11. Linear interpolation for maximum surface storage

$$\frac{12.70 - S_x}{12.70 - 6.35} = \frac{30 - 28.26}{30 - 5}$$

$$12.70 - S_x = 0.44196$$

$$\mathbf{S_x\ (mm) = 12.258}$$

Table 4: Shape and surface storage values

Category	***Type of surface Slope (%)***	***Surface Storage (mm)***
Paved Impervious	NA	3.18-6.35
Flat, Furrowed	0-5	50.8
Moderate to Gentle Slopes	5-30	6.35-12.70
Steep, Smooth Slopes	>30	1.02

- ***Loss: SMA method***

Provided our interest in the effects of rain on the soil, the selected loss method was the Soil Moisture Accounting (SMA). This method requires several parameters to calculate the loss from three layers (soil, GW1,and GW2).

Initial storage condition

Based on the rule, the soil layer was assigned 50%, groundwater layer 1 as 20 % and groundwater layer 2 as 30% (Vijayaprakash, M. 2020).

Infiltration rate

The infiltration rate only pertains only to the top soil, which consists of a clay layer. The maximum infiltration rate was the average of the infiltration rate values obtained from the falling head permeability test for the three trial pits. Furthermore, the imperviousness was assumed to be 0% provided that this is mainly an agricultural land.

The equation below shows how maximum infiltration rate is calculated.

$$\mathbf{Max\ IR\ (mm/hr)} = \frac{\mathbf{IR_1 + IR_2 + IR_3}}{\mathbf{3}}$$

Where

$$\boldsymbol{IR\ (mm/hr)} = \sum n\ i = 1\ \frac{IR_i}{n}$$

$$\boldsymbol{IR_i} = \frac{h_1 - h_2}{\Delta t} * \frac{10mm}{\frac{1}{3600}h}$$

$\boldsymbol{h_1}$ **and** $\boldsymbol{h_2}$ **:** height of water in the tube in cm

$\Delta\boldsymbol{t}$**:** change in time in seconds

Hence,

$$\boldsymbol{Max\ IR\ (mm/hr)} = \frac{\mathbf{9.39 + 367.1 + 444.67}}{\mathbf{3}} = \mathbf{273.68}$$

Soil storage condition

This includes the calculation of soil storage, tension storage and soil percolation.

i. The soil maximum storage was obtained from equation below: the equation shows how the maximum soil storage is calculated from soil depth and porosity.

$$\boldsymbol{Max\ soil\ storage\ (mm) = \ soil\ depth\ *\ porosity}\ (\%)$$

Where; n is porosity

$\boldsymbol{Porosity\ (n)} = \ 1 - \frac{\rho_{bulk}}{2.7} * 100$

$= 1 - \frac{1.933*9.81}{2.7} * 100 = \ 28.40\%$

Hence,

$$\boldsymbol{Max\ soil\ storage\ (mm) = \ 1000\ *\ \frac{28.40}{100} = \ 284}$$

ii. The tension storage was obtained from the equation below:

$$\boldsymbol{Tension\ (mm) = \ soil\ depth\ *\ field\ capacity}\ (\%)$$

Tension storage

The field capacity of clay soils varies between 0.38% and 0.42%. Taking

FC= 0.4%,

$$\boldsymbol{Tension\ (mm) = \ 1000\ *\ \frac{0.4}{100} = \ 40}$$

iii. Finally the percolation in the soil layer was taken to be 40% of the infiltration rate, and 10% for GW1 and GW2 respectively (Vijayaprakash, M. 2020). Hence,

$$\boldsymbol{Soil\ percolation\ (mm/hr)\ = 273.68 * \frac{40}{100} = \ 109.472}$$

$$\boldsymbol{GW1/GW2\ percolation\ (mm/hr)\ = 273.68 * \frac{10}{100} = \ 27.368}$$

- ***Transformation: Unit Clark transform method***

The time of concentration (Tc) and storage coefficients (R) are the essential parameters for this method. Tc represents the time required to travel from the farthest point of the watershed to the outlet, while R represents the amount of water stored within the watershed during runoff (Timothy Melching, Charles S Kocher et al. 2000).

These were calculated based on the longest flow length (L), the slope (S), area of the sub basin (A), which were all estimated from the basin DEM using QGIS, and summarized in table 5 below:

Table 5: Key parameters for Unit Clark transformation method

Sub-basin	***Longest flow length (Km)***	***Slope ($\frac{m}{Km}$)***	***Area (Km^2)***
1	3.99	92.6	3.3
2	3.4	100	1.9
3	1.6	33.33	1.5

The time of concentration (Tc) and storage coefficients (R) were obtained from equation 18 below:

$$T_c = 1.54 * L^{0.875} * S^{-0.181}$$

$$R = 16.4 * L^{0.342} * S^{-0.790}$$

Time of concentration and Storage coefficient

where

L is the longest flow length in kilometers

S is the main-channel slope determined from elevations at points that represent 10 and 85 percent of the distance along in meters per kilometer. Table 6 summarizes the different values of Tc (time of concentration) and R (storage coefficient) for the different sub basins.

Table 6: Values for time of concentration and storage coefficient

Sub basin	***Tc (hr)***	***R (hr)***
1	2.28	0.74
2	1.95	0.66
3	1.23	1.21

Similarly, the values assigned for base flow calculations were based on assumptions which were later calibrated.

Junction

The junctions are the sub basin outlets determined when delineating the watershed in QGIS. They should be linked to the other basin components (the downstream element immediately following it is specified).

Reach

Reaches are related to the rivers of the system. The flow routing selected was the Muskingum model, for which the main parameters are K (hr) and X. A number of sub reaches was also determined, which is dependent on K and the running time-frame.

a. **Meteorological component**

The distribution of precipitation over the basin was performed using specified hydrograpth method, and the evapo-transpiration method taken as 'annual evapo-transpiration, where the rate was taken as 4mm/day.

b. **Time series**

The time series component contains the precipitation gages. A precipitation gage consists of a time series gage where the data source, unit, and time interval are specified, a time window to specify the start day and start hour, as well as the end date and end hour. Finally it has a table allowing to enter the rainfall data corresponding to the time window specifications, and graph to visualize the plotted graph for the entered data.

Daily rainfall was acquired for 25 years (Jan 1^{rst} 2000- Feb 5th 2025), and plotted to determine the peak rainfall. The peak daily rainfall has a value of 1330.96mm, and was considered as the design time frame in the context of risk aversion.

c. **Control**

The principle is to control the simulation run. This is done by specifying time to start and stop the simulation along with the time interval is specified under this model component. The start date/time and the end date/time is specified in the time window. This runs both for event and continuous simulation.

Our model was set to run for 24 hours (03 Jul. 2007 00:00-03 Jul. 2007 23:00), with a time interval of an hour.

Water losses

The model was design to account for losses in the watershed to occur from the soil infiltration, the canopy interception, and the surface run-off.

Considering 1330.96 mm of precipitation, the total water loss in all the sub basins was 510.47mm, or 38% of the total precipitation.

The infiltration water accounts for about 40% of the total loss, hence 204.188mm. This value can be expressed in cubic meters when knowing the surface area on which it is falling. Considering the sub basin 3 which had a surface area of 1.5Km^2 area, the precipitation volume was obtained from equation below by multiplying the depth and the area.

$$\boldsymbol{Q(m^3) = prec\ depth\ (m) * area\ (m^2)}$$

Precipitation volume was;

$$\mathrm{Q} = \frac{204.188}{1000} * 1.5 * 10^6 = \mathbf{306,280m^3}$$

This is the loss that occurred in 24 hours of rainfall. Hence to determine the loss per second is given by:

$$Q(m^3s^{-1}) = \frac{306,280}{24 * 3600} = \mathbf{3.545 m^3 s^{-1}}$$

Considering the area delineated for the slope of interest which is 8,234m^2, the corresponding loss per second is given by

$$Q(m^3s^{-1}) = \frac{3.545 * 8234}{1.5 * 10^6} = \mathbf{0.0195 m^3 s^{-1}}$$

3.4 To design the horizontal sub drainage system

The key parameter is the hydraulic gradient and the factor of safety of the slope which will help in the design of the sub drainage system. The factor of safety represents the ratio of the soil's shear strength to the shear stress imposed by the drainage system. The hydraulic gradient on a slope represents the rate of change in hydraulic head that is the water level over a given distance along the slope. The factors that influence the hydraulic gradient include; the slope angle and orientation, the soil properties, water table depth and fluctuation, rainfall intensity and infiltration and geological features.

There are several methods for calculating the hydraulic gradient of a slope but for this area, Darcy's law will be used to calculate the hydraulic gradient.

Darcy's law: Q = **-K*A***$\frac{dh}{dl}$

Hydraulic gradient = $\frac{\Delta h}{\Delta l}$

Design equation for the drainage system **Q** = $\frac{K \times A \times i}{n \times L}$

Where: **Q** is the flow rate in cubic meters per second

K is the hydraulic conductivity in meters per

second

i is the hydraulic gradient (dimensionless)

n is the porosity

L is the drain spacing in meters

There are several empirical methods for determining the factor of safety based on the failure mechanism. For Bududa landslides, previous studies have characterized the mechanism as small, shallow and translational (Makabayi, Musinguzi and Otukei, 2021b). Hence the simplified Bishop method will be used to compute the factor of safety which is expressed as:

$$FOS = \frac{C^1}{\gamma H} \times \frac{1}{\sin\beta} + \left[\frac{\tan\varphi^1}{\tan\beta} \times \left(1 - \frac{\mu}{\gamma H}\right)\right]$$

Where:

- *FOS*: Factor of Safety;β
- *c'*: effective cohesion in KPa;
- γ : unit weight of soil in KN/m^3;
- *H*: slope height in meters (m);
- *Β*: slope angle in degrees (°)
- φ': effective angle of friction in degrees (°); -
- u: pore water pressure.

$$FOS = \left(\frac{37.03}{18.97*239} \times \frac{1}{\sin 15.5}\right) + \left[\frac{\tan 14.07}{\tan 15.5} \times \left(1- \frac{239*9.81}{18.97*239}\right)\right] = 0.459$$

This value suggests a very unstable slope as it is below the required safety value. Table 7 summarizes the factor of safety ranges and implication according to Cahyaningsih, Catur Asteriani, 2019:

Table 7: Factor of safety ranges.

Factor of safety value	***Landslide intensity***
FOS less than 1.07	Landslide occurred regular/ frequent (unstable slope)
1.07< FOS< 1.25	Landslide case (critical slope)
FOS over 1.25	Rare landslide (relatively stable slope)

Design considerations included;

- Drain spacing: by increasing the spacing, hydraulic gradient will reduce and factor of safety will increase.
- Drain depth: by increasing the depth, hydraulic gradient reduces and the factor of safety increases.
- Drain diameter: increasing the diameter reduces the hydraulic gradient and increases the factor of safety.
- Filter material: the filter material to be selected should be suitable to maintain the hydraulic gradient and prevent clogging.

The design of the horizontal sub drainage system was then performed with the help of ***Geostudio*** software, which helped analyze the slope more intensively. The drain diameter, inclination angle, and spacing among other considerations were determined and designed using MODEFLOW software. Considering the different inputs, the hydraulic gradient and factor of safety trend were studied under various conditions (undrained unconsolidated and consolidated drained) to determine the optimal drainage system configuration.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 INTRODUCTION

This chapter shows the results obtained from the different tests carried out. This was done to achieve the specific objectives stated in chapter one.

4.1 SITE CHARACTERIZATION (SOIL CLASSIFICATION)

4.1.1 SIEVE ANALYSIS

This was conducted using the wet and dry sieve methods according to BS 1377: Part 2:1990. The results indicate that the natural sample can be classified as a fine grained soil, since more than 73% of the soil passed through the 0.075 mm sieve.

Prefix

The amount of particles that were retained on the 75μm sieve were less than 50% for the three samples hence the soil is fine grained. Fine grained particles can be described as either inorganic clay or silt/organic clay. The average plastic index was 19.09 which was above the A line and greater than 7. The soil was classified as an inorganic clay hence the prefix C.

C= Inorganic clay if P is above the A line and P > 7; According to the Unified Soil Classification System (USCS).

Suffix

Here the average liquid limit was 48.07, which was relatively high hence the use of the suffix H. On the other hand the extended Casagrande's system, the liquid limit values between 35% and 50% have the suffix I for plasticity that is intermediate. The soil was therefore classified as CH which is consistent with studies that have shown that the soil in the region is CH.

4.1.2 ATTERBERG LIMITS TEST

These tests show the behavior of soils in relation to the water content. The values obtained for the three soil samples collected where the shrinkage limit was obtained are shown below.

$$\boldsymbol{SL = 46.4 * (\frac{LL + 45.5}{PI + 46.4}) - 43.5}$$

Where: LL is the liquid limit and PI is the plastic index

The dimensions of the mold for linear shrinkage test were, L= 140.2mm and D= 12.5mm. The initial volume of the soil was obtained as half the volume of the cylinder as shown in equation below:

$$\boldsymbol{V_{initial} = \frac{1}{2}\Pi * R^2 * L}$$

$\boldsymbol{V_{initial}} = (\frac{1}{8} * \Pi * 12.5^2 * 140.2)$ = **$\underline{34410.257\text{mm}^3}$**

i. The volume of soil at shrinkage limit (22.79%) was obtained from

$$V_{SL} = 0.5\pi(12.5)^2(140.2)[1 - 0.228] = \mathbf{26564.72\ mm^3}$$

Considering the linear relationship between the water content and the volume of soil, the volume at plastic limit and liquid limit was obtained as follows:

ii. The volume at plastic limit (s+w)

$$\text{V}_{\text{PL}} = \frac{[100\% + (28.98 - 22.79)\%] \text{ x } 26564.72}{100\%} = \mathbf{28185.17mm^3}$$

iii. The volume at liquid limit (s+w)

$$V_{LL} = \frac{[100\% + (48.07 - 22.79)\%] \text{ x } 26564.72}{100\%} = \mathbf{33285.60mm^3}$$

This enabled plotting the graph seen in the figure below.

$$\boldsymbol{V_{initial}} = \frac{\mathbf{1}}{\mathbf{2}}\Pi * \frac{\boldsymbol{D^2}}{\mathbf{4}} * \boldsymbol{L}$$

$\boldsymbol{V_{initial}} = (\frac{1}{8} * \Pi * 12.5^2 * 140.2 * 10^{-3})\ cm^3 =$ <u>**$8.60cm^3$**</u>

The initial volume does not vary until the shrinkage limit. Hence the volume of soil at shrinkage limit is also taken as $8.60cm^3$. This helped determine the volume of soil at plastic limit and liquid limit, which are 10.93 and $18.13cm^3$ respectively. The graph was obtained from these calculations.

A graph of total volume against water content

The graph shows how the volume of the soil changes over a range of moisture contents.

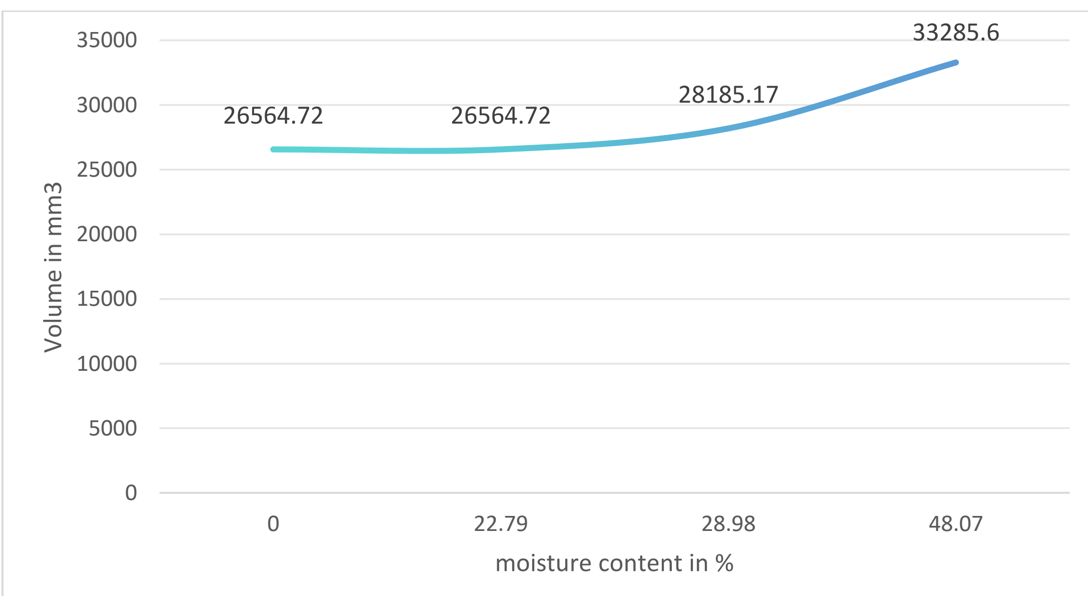

Figure 14: Atterberg limit graph

The liquid limit which is 48.07% indicates that the soil has a high water holding capacity and is likely highly plastic. The plastic limit which is relatively high, (28.98) indicates that the soil will exhibit plastic behavior over a wide range of moisture contents. The shrinkage limit, (22.79) is relatively low indicates that soil will shrink significantly as it dries causing cracking.

4.1.3 PERMEABILITY TEST (FALLING HEAD METHOD)

The permeability test results had an average coefficient of permeability value of 1.038×10^{-7} m/s, whereas the average infiltration rate was 27.3cm/hour which is rapid according to Poesen and Deckers, 2009.

The infiltration was observed to decrease as the time went on for the test, which mean that the soil tends to accumulate water in its profile as it reaches saturation. This is consistent with the behavior of clay soils which tend to have a low permeability and a high capacity to hold water in their profile.

The low average coefficient of permeability and the infiltration rate show that the sol has a limited ability to transmit water through its profile. This can lead to a high pore water pressure which reduces the shear strength of the soil hence a high risk of landslide occurrence. The results of the permeability test confirm that the clayey soil has a high potential for landslide occurrence, due to its low permeability and high water holding capacity.

A graph of infiltration rate against time

The graph below shows the infiltration rate through the soil over a period of 24 hours.

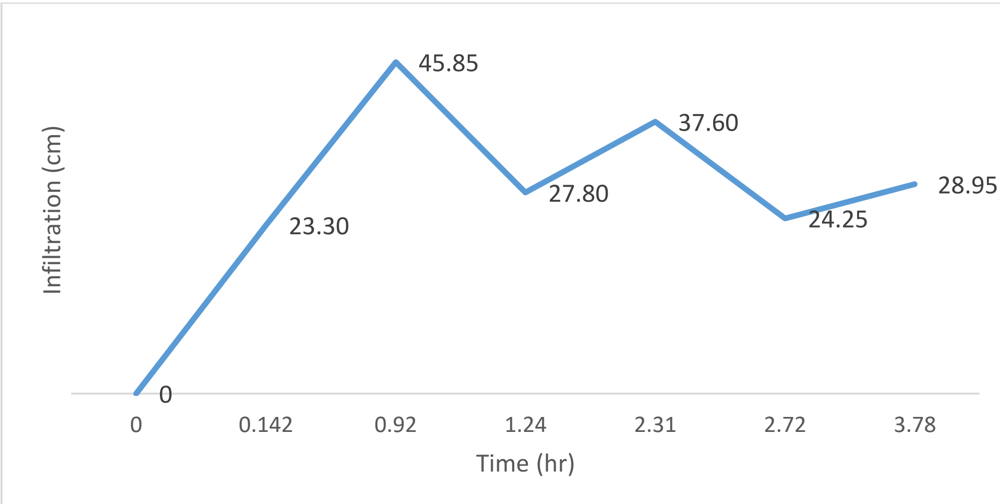

Figure 15: Infiltration rate graph

4.1.4 SPECIFIC GRAVITY

The first and third samples have an identical specific gravity value which is 2.61, which is within the typical range for clays and similar cohesive soils (2.60-2.75). The value of 2.61 is consistent with standard values for cohesive soils like clay, indicating that these two samples are likely dense and mineralogically stable. This specific gravity suggests typical mineral content with relatively low organic matter.

The first and third samples are consistent with typical values for clays, indicating a relatively dense soil composition with mineral content common in cohesive materials. The second sample being lower suggests the presence of more fine-grained particles such as silts or soil may be slightly more organic reducing its specific gravity.

Sample two had a slightly lower specific gravity, 2.51 as compared to the other two. The lower value might indicate that this sample has a higher proportion of less dense particles such a silt or organic material or it could have a higher porosity compared to the other samples

The difference in specific gravity likely affects the soil's behavior, including its shear strength, compaction, and moisture content properties.

4.1.5 TRIAXIAL TEST (UNCONSOLIDATED UNDRAINED CONDITIONS)

The soil samples underwent barreling which is a kind of distortion where the specimen became wider in the middle and narrower at the ends resembling the shape of a barrel. This was however minimized by applying confining pressures that were not too high or too low to prevent excessive distortion.

The cohesion values are within the typical range for cohesive soils like clay. The variation between the samples can be attributed to a difference in local conditions such as slight variations in soil composition or moisture content between the test pits. The cohesion values are therefore consistent with what we might expect for a clayey material. These values (32.4, 35.0, and 43.7) are within typical ranges for clays (10 Kpa-100 Kpa) according to BS 1377 Part 7.

The friction angles are on the lower side which is typical for cohesive soils like clays where the internal friction angle tends to be smaller compared to granular materials like sands. For cohesive soils, friction angles in the range of 10° to 20° are common. Therefore, the values (ranging from 12.2° to 16.5°) are consistent with the expectation for clays under undrained conditions.

Effective stress is the stress that contributes to the shear strength in the soil. Since the test was undrained, these values of effective stress reflect the initial effective stress (taking pore pressure into account). The differences in effective stress are minimal, and these values indicate that effective stress is fairly consistent across the three test pits.

The moisture content in the first sample likely explains the higher cohesion, but it suggests that the sample may behave more like a liquid under stress. This is because a high moisture content can make it easier for the soil particles to slide past one another. The angle of friction typically decreases as the moisture content increases because the soil becomes more saturated and behaves more like a liquid, reducing the frictional resistance between particles. In this case the reduction in the friction angle from 16.5° to 14° to 12.2° is consistent with the decreasing moisture content. The higher the moisture content, the lower the effective stress because the pore pressure is higher, which reduces the effective stress contributing to shear strength. This explains why the first sample has the lowest effective stress.

In general, the moisture content explains the differences in shear strength and effective stress between the samples, with the higher moisture content in the first sample reducing effective stress and increasing cohesion, and the lower moisture contents in the second and third samples leading to more typical cohesive soil behavior. These variations are in line with the British Standards.

4.1.6 DIRECT SHEAR BOX TESTCONSOLIDATED DRAINED CONDITIONS

The test appeared to have followed a proper strain rate, as indicated by the reported normal stresses and corresponding shear stresses. At least three different normal stresses were used, ensuring a valid shear strength envelope.

The obtained values (33.6°, 34.7°) for the friction angle are reasonable for sandy clay soils. The cohesion values are within the expected range for loose, moist sandy clays. The values of cohesion indicate that soil has a low cohesion which is typical for sandy soils with little clay content. The slightly higher cohesion in the second sample suggests a minor increase in the clay content. Typical sandy clays exhibit an angle of 25°-35° and cohesion of 0-10kPa so these results align with the values in literature.

The linear relationship between shear stress and normal stress confirms Mohr-Coulomb behavior. There was no abrupt strength drop which suggests that there's was no significant strain softening, indicating a relatively ductile failure.

4.2 HYDROLOGICAL SURVEY

The hydraulic conductivity was the average obtained from the second and third sample. Hence 0.0133m/day

The change in the max surface storage changed the loss repartition, as well as the infiltration graph.

Table 8: The results for loss from infiltration, surface, capony and evapo-transipration.

Loss	Milimeters	Percentage
Infiltration	492.9	67.47
Surface	191.25	26.18
Capony	42.8	5.86
Evapo-Transpiration	3.57	0.49

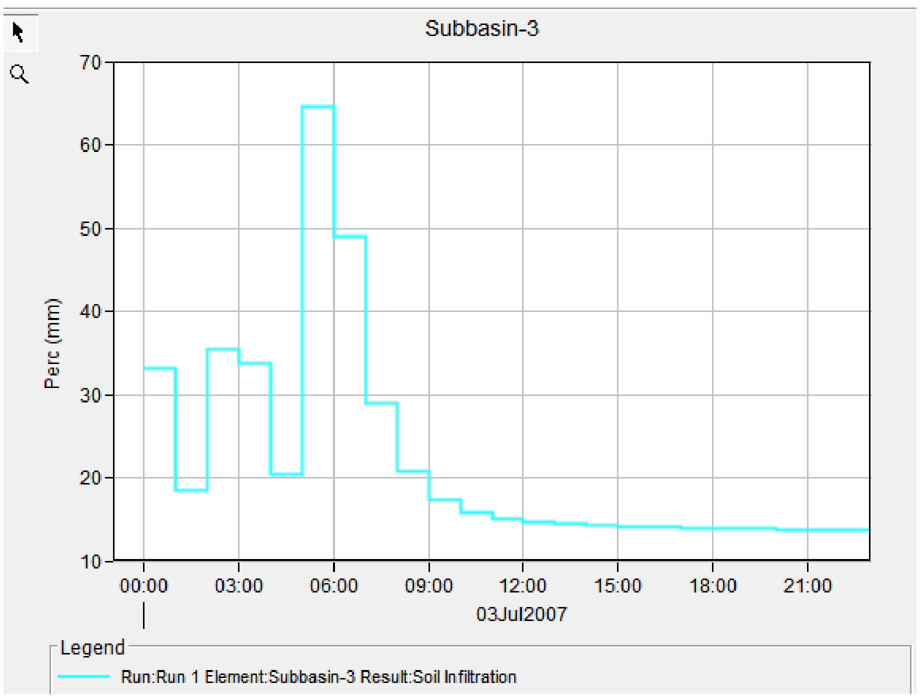

Figure 16: The results for sub basin 3

4.3 DESIGN OF THE DRAINAGE SYSTEM

4.3.1 Conceptual model domain and conceptual model

Model domain and conceptual model

The model domain is defined with ModeFlow cells 5 m by 5 m in the x-y direction, which is rotated (-33˚) so that the grid is parallel to the slope. Isotropic condidions kx=ky=kz= 0.0133m/day, specific yield= 0.001, initial head of domain=model top.

This is a single layer model where the maximum thickness is 275 meters at the highest elevation (1711m AMSL) and minimum thickness is 6 meters at the lowest elevation (1440m AMSL). The bottom of the modeled layer is at 1436 meters above mean sea level. Boundary condition is no flow upslope, specified head at 1470m AMSL, and recharge throughout domain.

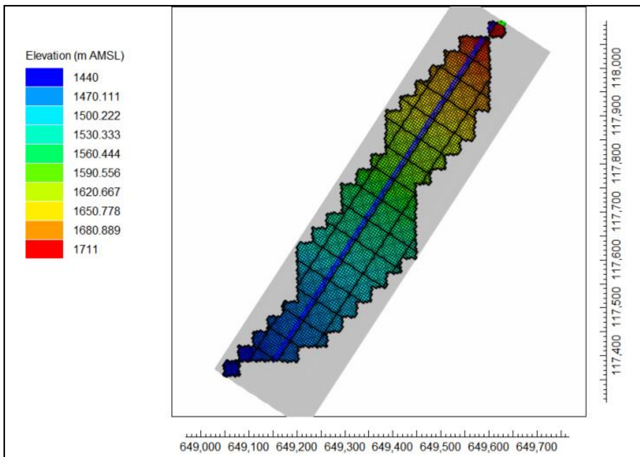

Figure 17: Plan view of model domain with the blue line passing through B-B

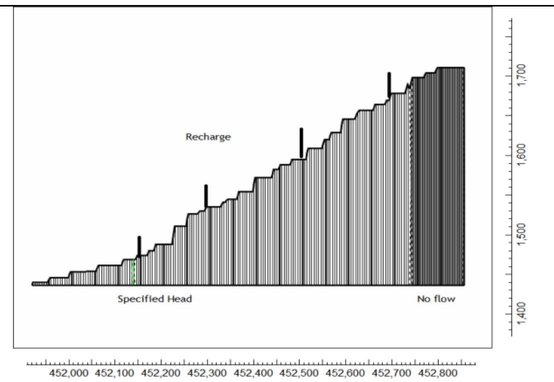

Figure 18: Profile view of domain through B-B with the boundary conditions.

4.3.1.1 Drain configuration

The drain configuration used was fan shaped since that is what pgives optimal results of the design.

We tested two arrays, one with 8 drains 6˚ between each other, length 100m, second 4 arrays, 12˚ between each other, length 200m elevation 1665m AMSL.

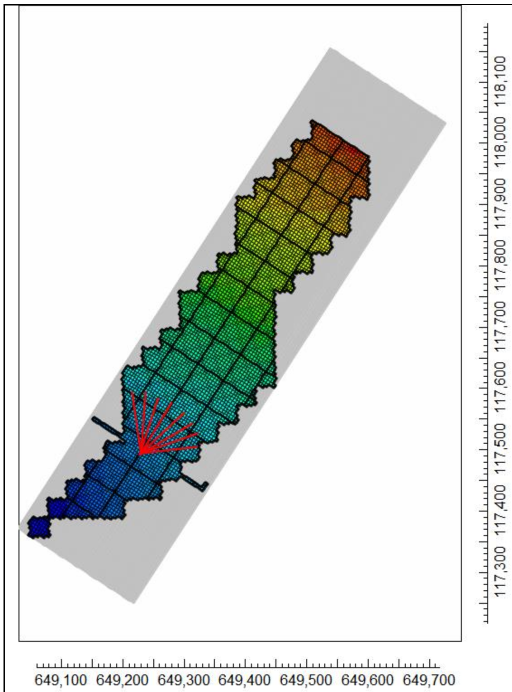

Figure 19: Drain configuration 1

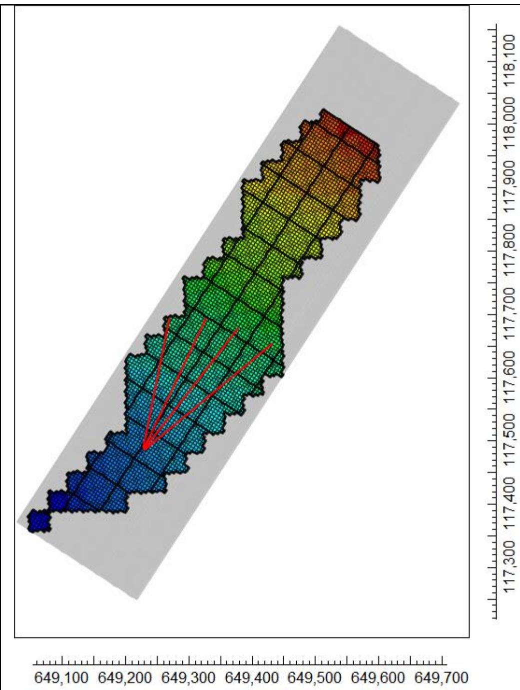

Figure 20: Drain configuration 2

4.3.1.2 Factor of safety

Tests were done for both unconsolidated undrained conditions (cohesion 37.04 and angle 14.0°), with a unit weight of 18.97KN/m^3) and consolidated drained conditions with (cohesion angle 4, saturated unit weight 21.75 KN/m^3), where the initial condition assumed water level at ground surface, then the steady recharge was 0.02m/day, isotropy meaning VKA=1) state and transient conditions (recharge 25 years, 24 hour rainfall event, maximum time at period 23, recharge= 0.0590m/day. The image below shows the first run under initial conditions.

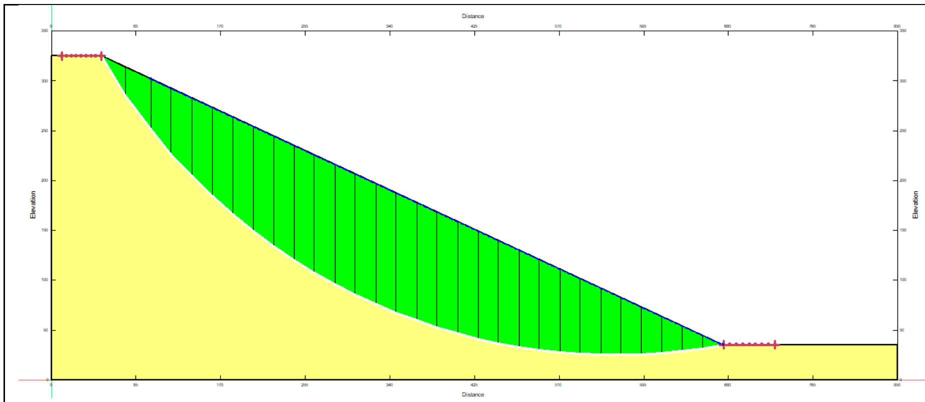

Figure 21: Slip surfaces unconsolidated undrained conditions

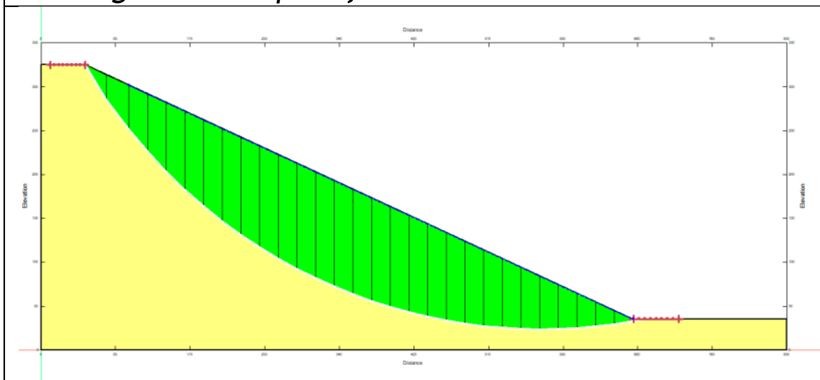

Figure 22: Slip surfaces under consolidated drained conditions

Steady state conditions:

The steady state conditons help represent a stable groundwater regime undre a constant recharge, allowing for the assessment of the long-term effectiveness of the drainage system.

The first array is not effective at lowering ground water. Ground water surface as seen below is obtained from model top minus the groundwater head for steady state. The positive is below and the negative is above.

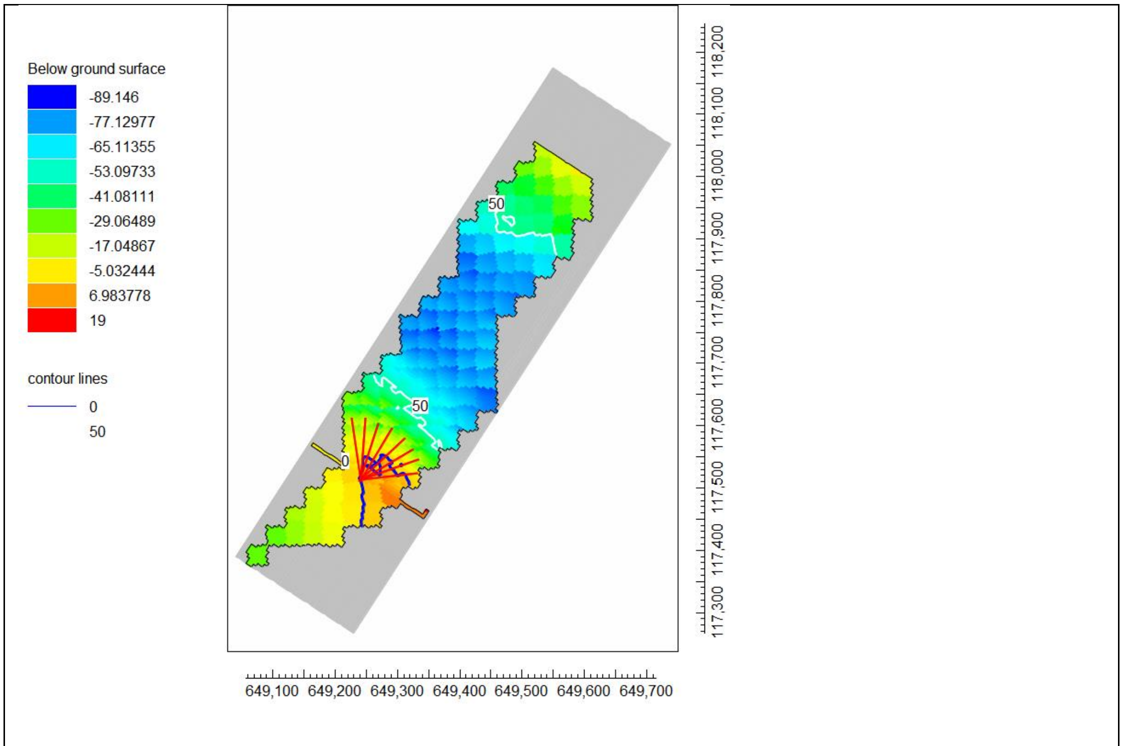

Figure 23: Groundwater below the ground surface with drain array 1

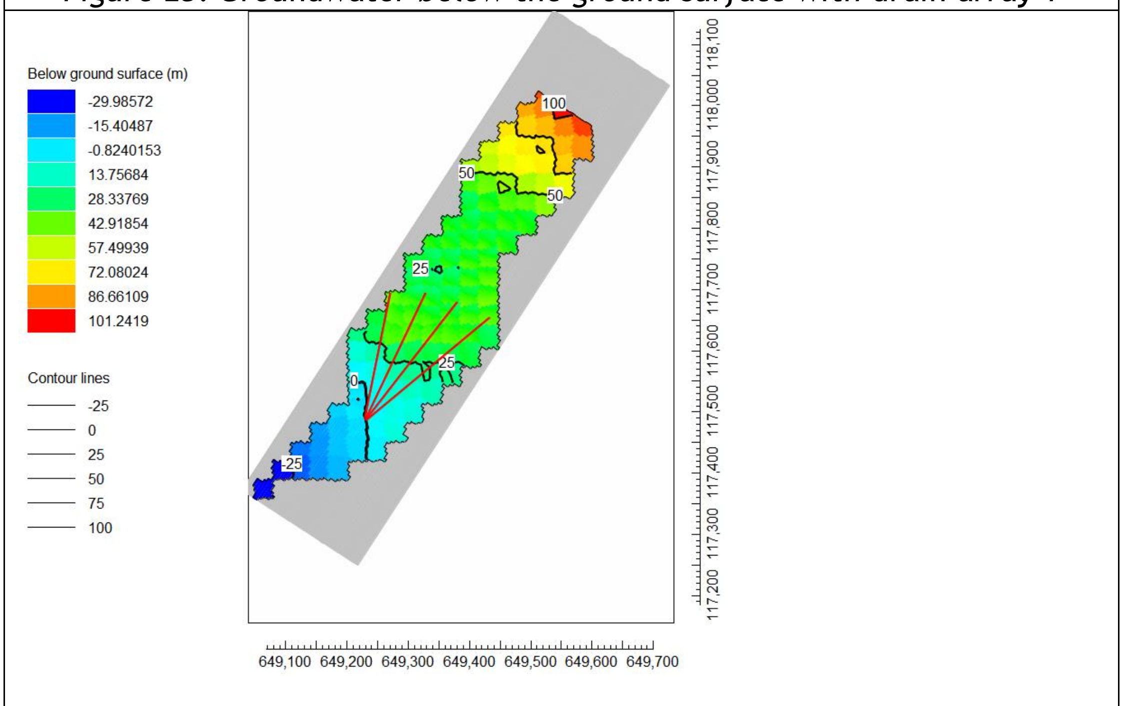

Figure 24: Groundwater below type surface for drain array 2

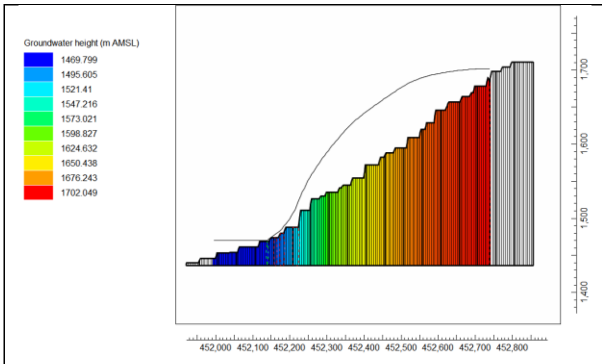

Figure 25: Groundwater level in steady state coondition with array 1.

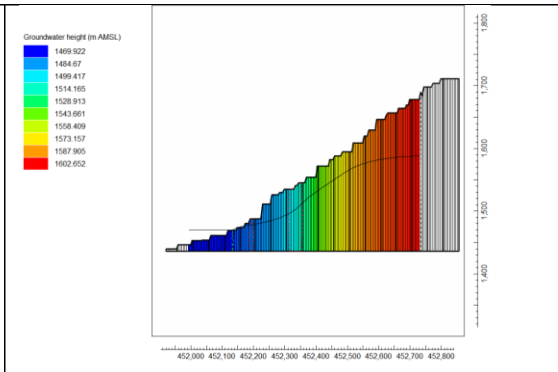

Figure 26: Groundwater level in steady state condition with array 2.

Transient condition

The transient conditions were computed to simulate how groundwater levels respond over time to a specific event in this case a 24 hour peak rainfall event that occurred during the 25 years. The recharge rate for this event was specified as 0.0590m/day. The analysis for these conditions was done for three scenarios ; without drains, with drain array 1 and with drain array 2. The figures show potential flooding under transient conditions wthout any drains.

This was computed without drains and for arrays 1 and 2. The map shows flooding, where the array 1 is not effective and array 2 prevents flooding upslope and not down the slope.

Drain configuration 1 consists of 8 drains, each drain with a length of 100m. The drains are spaced at 6 degree angles from each other, installed at an elevation of 1665m ASML. The configuration is a fan shaped one originating from a single point and spreading outwards.

Drain configuration 2 consists of four arrays of drains each with a spacing of 12 degree angles. Each drain length is 200m and they are installed at an elevation of 1665m ASML. This is also a fan shaped arrangement potentially covering a wider area or multiple zones.

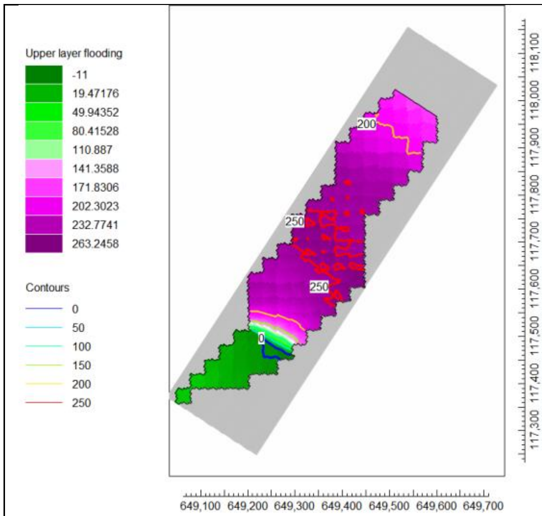

Figure 27: Transient conditions without drains.

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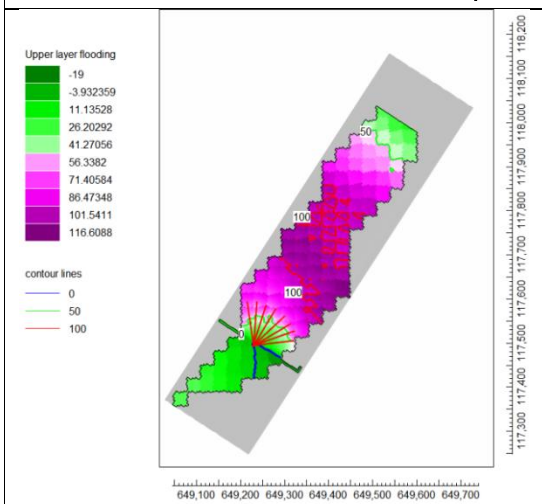


Figure 28: Transient conditions with drain array 1.

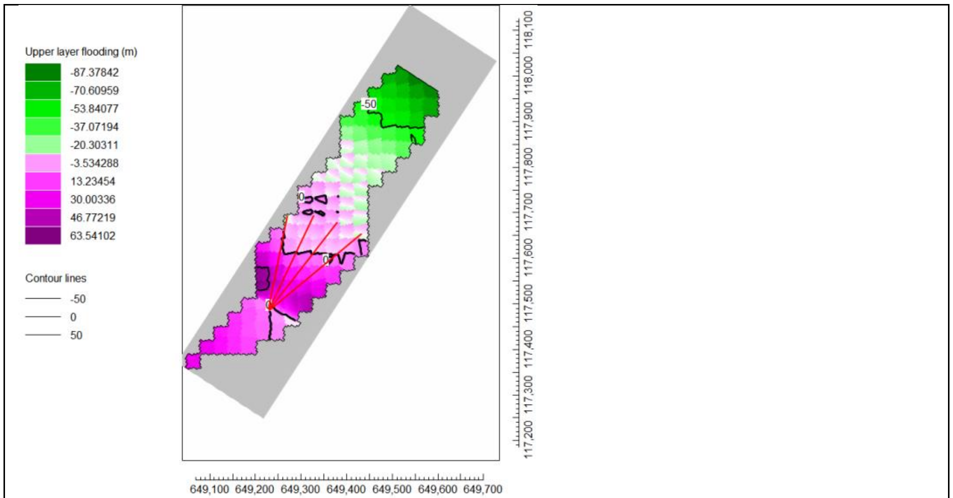


Figure 29: Transient conditions with drain array 2.

Improvements to drain array 1

From the previous discussion, drain array 2 demonstrated higher efficiency than drain array 1. Howewver, installing horizontal drains with lengths up to 200 meters poses practical challenges. To address this, a modified version of drain array 1 was developed to evaluate whether performance could be improved while keeping drain lengths within practical limits. In the revised configuration an additional set of four drains each approximately 90 meters long was introduced. These drains were inclined at 10 degree intervalsand installed at an elevation of 1537m AMSL.

Figure 30 shows the plan view of the modified drain layout within the model domain. The grid is composed of 5m by 5m cells color coded based on the digital elevation model data. The red lines denote drain positions. While original drain array 1 remains at 1469m AMSL, the new drain array is located at a higher elevation of 1537m AMSL.

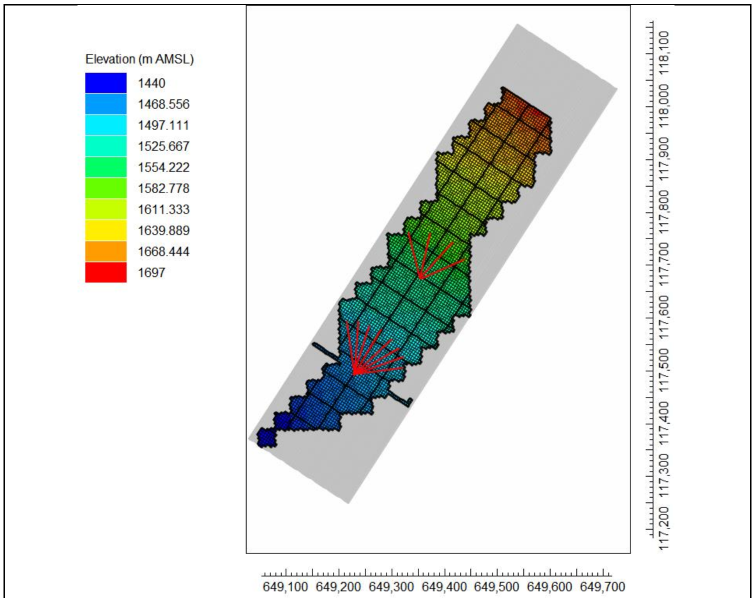


Figure 30: An improved drain configuration.

Steady state conditions

Using the same simulation parameters as previous runs Kx= 0.0133 m/day ; VKA =1 and recharge = 0.002 m/day, the enhanced configurations showed a notable reduction in flood risk. However, groundwater levels still exceeded the surface elevation between the two drain arrays. Figure 31 (a) presents a plan view where grid cells are shaded based on the difference between cell top elevation and groundwater head. The positive values indicate areas where groundwater is below the ground surface. The negative values signify flooded areas where the groundwater head is above the ground surface. Flooding was confined to the zone between the two arrays. Figure 31 (b) displays the piezometric line (black horizontal line) in a side view, which is lower than that observed with only drain array 1, indicating improved system performance.

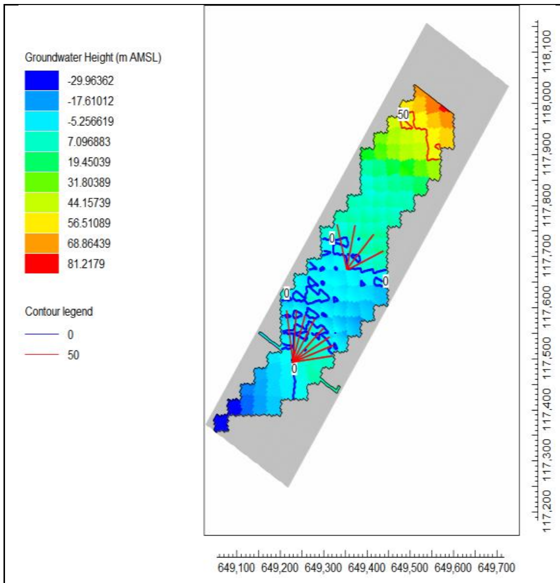


Figure 31(a): Steady state simulation for the improved drain configuration (plan view).

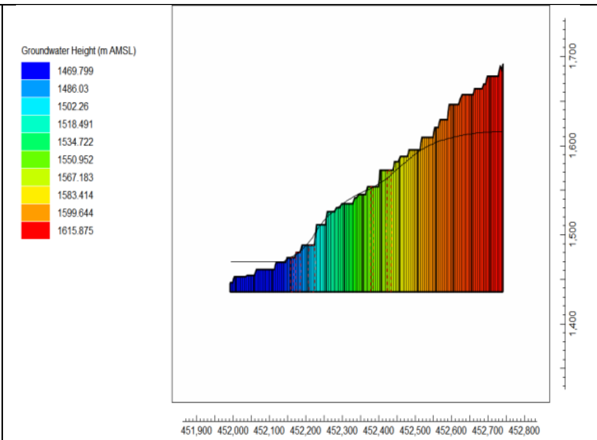


Figure 31(b): Steady state simulation for the improved drain configuration (side view).

Transient conditions

Under the transient simulation, the system exhibited further improvements in flood mitigation. No flooding was observed at the slope tip. However flooding persisted at the slope toe and in the area between the two drain arrays. Figure 32 shows the the post transient siulation results. And as before the sells are color coded based on the difference between groundwater head and surface elevation. The positive values indicate flooding (groundwter above surafce). And the negative values indicate no flooding (groundwater belwo surface).

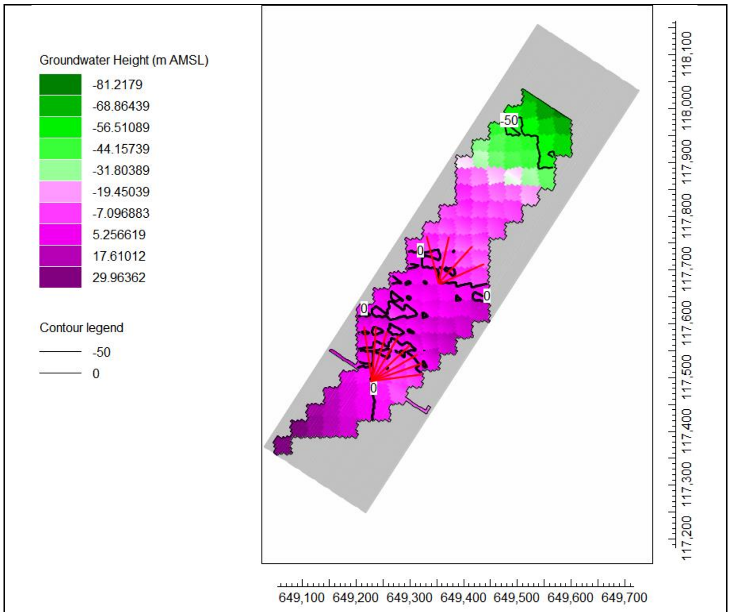


Figure 32: Transient similation for improved drain configuration..

While the improved configuration outperformed the original drain array 1, it remained less effective than drain array 2. The simulations revealed that the longer continuous drains positioned at lower elevations are more effective in reducing groundwater levels. The shorter, inclined drains have a limited zone of influence and cannot effectively control groundwater at elevations outsise that zone. Among all the configurations tested, drain array 2 deleivered the most favorable groundwater conditions and was therefore used for the geotechnical slope stability analysis.

Geotechnical analysis

We used the piezometric line for array 2 since it lowered ground water. The following table shows the summary.

Table 8: The summary from the different drain arrays.

Drainage type	UU	CD
Initial (gw at ground surface)	0.351	0.897
Steady state	0.570	1.401
Transcient	0.524	1.207

Slot size

This refers to the width of the perforations (slots) in the drain that allow water to enter while minimizing soil particle entry. To prevent clogging and allow sufficient drainage, the slot size should be smaller than the size of most soil particles. D85 was used, which is the particle diameter at which 85% of the soil particles is finer. The slot size was calculated from the formula below and a value of 0.025mm was obtained.

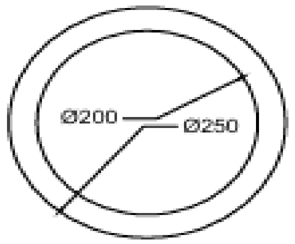
$$\text{Slot width} = \frac{D_{85}\text{ of soil}}{2}$$

$$\text{Slot width} = \frac{0.05}{2} = 0.025\,mm$$

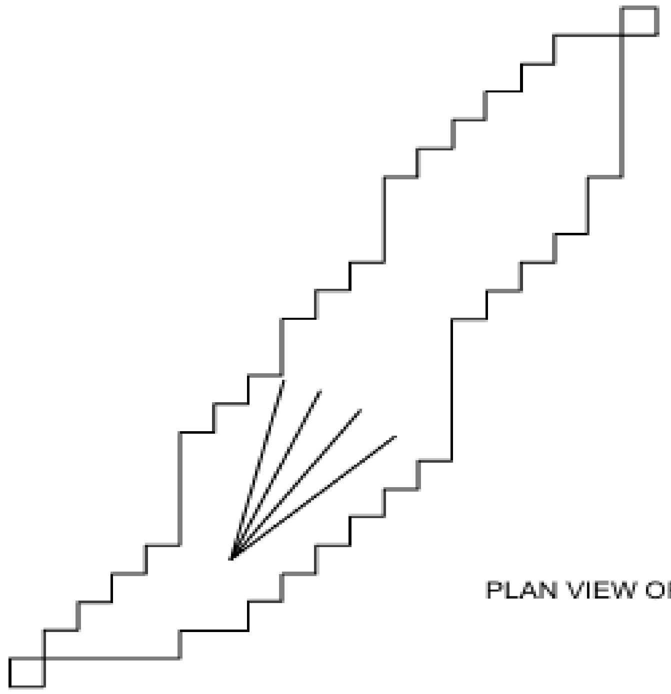
Drain length and spacing

From the literature review, the drains should not penetrate through the slip zone and they should not extend more than 3-5m past the slip surface.

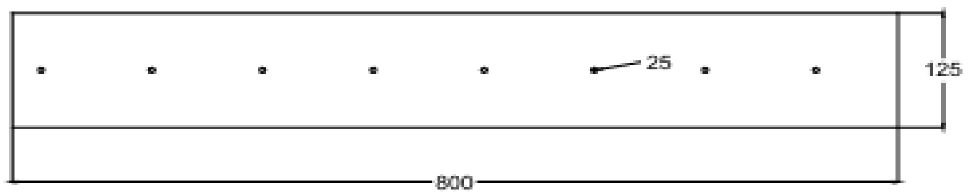
The drain length considered was 800mm and the spacing between the drains was 8m interval



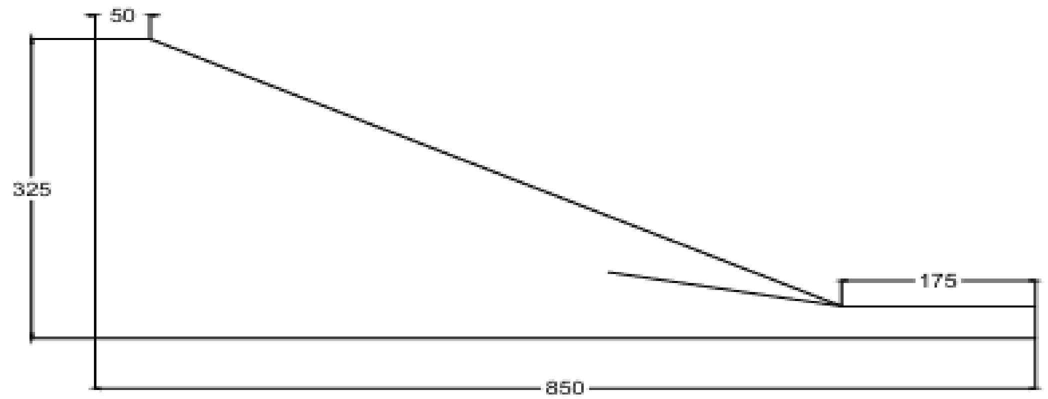
DRAIN CROSS SECTION



PLAN VIEW OF SLOPE



SIDE VIEW OF DRAIN



CROSS SECTION OF THE SLOPE

TITLE: HORIZONTAL SUB DRAINAGE SYSTEM APPROACH TOWARDS LANDSLIDE RISK MITIGATION

DRAWING TITLE: FAN SHAPED DRAIN CONFIGURATION

AUTHOR: AHABWE MARTHA

REG NO: S21B32/117

CHAPTER FIVE : CONCLUSIONS AND RECOMMENDATIONS

5.0 CONCLUSION

The site characterization provided essential insights into the geological, geotechnical and environmental conditions of the study area. The study revealed that the soil is fine grained with mainly clay composition which is consistent with literature. The soil has a low permeability,and this indicates the fact that the area is highly susceptible to landslides due to the increase in the pore pressure. The soil's shear strength varies based on moisture content with higher moisture content leading to reduced friction angle and increase in cohesion.

The hydrological survey provided critical data on the watershed characteristics, rainfall intensity, and the movement of water within the study area. The analysis using HEC-HMS revealed that given the peak rainfall, approximately 38% of the total precipitation is lost through infiltration, surface runoff, canopy interception and evapotranspiration. This understanding was crucial in the assessment of the watershed, particularly the infiltration which helped assess the potential for increased pore water pressure and subsequent slope stability, therefore informing the design requirements of the sub horizontal drainage system.

Based on the findings from the site characterization and hydrological survey, a sub-horizontal drainage system was designed to mitigate water accumulation and improve site stability. The design considered factors such as permeability, drain spacing, drain length, drain configuration, strength parameters). The analysis of the slope using software suggests that proper drainage configuration (fan-shaped) can effectively reduce the groundwater fluctuation.

5.1 RECOMMENDATIONS

Basing on the challenges faced during the study, further studies should be done on the efficiency of the sub horizontal drainage system in ore complex geological configurations. The research could explore the effcectiveness of this mitigation approach in areas with varying subsurface conditions, such as fractured bedrock, multiple soils layers with different permeabilities or even the presence of geological discontinuities.

Since this study focused on the design aspect, future research should prioritize long term monitoring of installed horizontal sub drainage systems to evaluate their actual performance in reducing groundwater levels and enhancing slope stability over extended periods of time. This would involve establishing monitoring wells to track groundwater table fluctuations, conducting periodic slope stability analyses to assess changes in the factor of safety, evaluating the effectiveness of the filetr material in preventing clogging over time and documenting any maintenance requirements and their impact on system performance.

Future studies could investigate the synergistic effects of combining horizontal sub drainage systems with other landslide mitigation techniques like those mentioned in chapter two, such as surface drainage improvements, terracing, afforestation with appropriate tree species or the use of geosynthetics for reinforcement and erosion control. In addition, assessing the cost effectiveness and combined impact of such integrated approaches would be valuable.

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APPENDICES

APPENDIX A : RAINFALL DATA AND BOREHOLE DATA

Year	Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2000	January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.1	1.7	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	March	0	0	0	0	13.4	2.9	17.5	5.8	1.5	1.5	3.7	7.3	0	0	0	14.8	8.9	0	0	0	0	0	0	0	0	0	0	0	0	0	9.5
	April	9.2	0	0	10.3	2.3	0	8	10.2	6.8	13.7	0	0	0	0	22.8	9	3.6	0	0	3.6	0	16.1	6.9	2.3	9.2	4.5	20.9	6	13.4	19.4	
	May	15.9	7.4	8.5	7.4	9.5	0	12.8	8.5	13.9	5.3	14.2	1.1	2.2	1.6	2.2	9.6	0	0	0	0	0	0	0	0	17.3	0	0	9.8	9.8	17.7	14
	June	0	0	0	4.1	12.4	0	0	9.2	12.9	0	3.3	6.5	0	0	0	0	0	0	0	22.2	3.3	0	0	13.1	16.4	5.8	9.6	11.5	9.6	7.7	
	July	0	0	10.5	5.3	0	0	0	0	27.3	31.8	16.5	14.1	0	0	2.4	8.1	6.1	0	0	14.2	13.9	17	1.5	0	12.3	0	0	0	0	0	0
	August	9.1	9.1	0	0	0	1.9	3.7	9.3	15	22.4	3.4	25.5	20.4	17	1.7	15.5	8.6	13.7	1.7	8.6	4.8	9.6	0	0	0	7	7	7	0	0	0
	September	6.9	1.7	0	6.9	0	0	0	8.3	0	6.6	0	0	0	0	9.9	5.2	1	3.1	0	6.2	13	7	0	1	0	1.5	0	3	0	7.4	
	October	4.7	10.6	3.5	11.7	0	8.4	13.2	20.3	8.4	6	13.5	0	5.1	5.1	8.4	1.2	6.2	18.6	11.1	40.9	0	0	0	0	7.3	0	0	0	0	0	21
	November	10.5	9.2	7.9	5.3	1.3	6	12	6	5	0	3.6	0	0	4.8	3.6	23.1	12	9.4	7.7	10.3	20.7	4.5	5.4	2.7	0	0	0	0	0	0	
	December	0	7.8	15.5	2.9	0	3.6	0	0	0	2.7	0	4.6	0	0	0	0	0	0	0	0	0	4.4	0	0	0	0	0	5	0	0	0
2001	January	0	0	0	0	0	0	0	0	0	0	6.2	4.5	2.2	0	3.4	0	0	0	0	4.2	4.9	2.6	7.8	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	10.9	0	8.9	0	0	0	0	0	0	0	0	0	0	10.7	2.1	0	0	0	0	0			

	March	0	0	0	0	24.2	18.7	2.9	0	8.6	0	0	0	12.7	0	7.3	0	3.3	9.9	15.8	5.3	3.7	0	3.7	0	9.2	13.4	0	3.7	3.7	9.8	2.4
	April	0	11.7	0	2.3	7	5.9	1.5	4.4	5.9	0	0	0	7.1	0	9.5	0	0	0	5.5	5.5	9.4	0	1.2	13	7.1	6.8	10.2	17	1.7	0	
	May	1.1	14.9	9.6	7.4	13.8	9.5	0	12.6	12.6	10.5	2.4	7.1	0	7.1	0	0	0	0	9.6	0	0	12.9	4.3	0	4.3	2.3	0	11.3	6.8	11.3	0
	June	0	2.4	7.3	0	26.9	12.3	1.5	12.3	10.8	4.6	1.7	5	0	0	15.1	0	0	11.1	7.4	0	0	0	8	4	12	35.2	7	15.8	17.6	0	
	July	0	0	15.8	0	0	20.8	0	0	0	0	0	14.4	0	4.8	12	0	12.5	17.8	10.7	5.3	6.3	4.7	7.9	4.7	15.8	0	0	0	0	0	0
	August	0	4.5	9.1	0	4.5	0	0	0	0	14.7	0	6.7	6.7	8.9	2.2	6	8	6	8	0	0	5.3	0	10.5	8.8	13.5	8.4	10.1	20.2	5.1	0
	September	2.6	0	9.1	19.5	3.9	1.6	14.4	0	0	0	0	6.7	0	0	0	2.8	0	4.6	5.5	11.1	11.5	10.6	8	0	11.5	4.8	0	1.2	13.1	0	
	October	0	1.7	0	0	10.4	1.3	6.4	11.5	6.4	11.5	0	11	0	0	6.6	0	0	0	0	17.6	0	9.5	4.8	7.1	8.3	16.4	4.1	16.4	17.8	12.3	9.6
	November	9.7	0	13.8	4.2	0	3.1	1	2	19.3	1	0.9	11.1	7.7	12.8	11.6	10.7	0	9.8	9.8	12.4	5.1	6.3	0	0	0	0	0	0	0	0	
	December	0	0	1.3	0	10.3	0	4.8	0	0	0	0	0	3.9	0	0	0	0	0	0	0	0	0	0	0	0	3.3	0	1.1	1.1	0	0
2002	January	4.7	10.3	0.9	8.4	19.7	3.6	0	0	0	0	1.4	5.6	0	1.4	0	1.2	0	0	1.2	3.5	0	5.6	6.3	0	0	4.8	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	0	8.9	0	0	0	2.9	0	5.8	11.5	0	0	0	0	0	0	0	4	14.1			
	March	3.7	7.5	24.2	0	24.2	14.9	12.8	0	4.3	0	0	0	0	16.6	0	0	8.2	7.5	3	4.5	0	0	0	0	0	0	0	0	0	0	0
	April	0	11.9	0	0	15.9	4.9	0	0	0	9.9	5.8	26.2	8.7	10.2	2.9	0	1.4	8.2	10.9	8.2	7.3	5.5	0	0	0	0	3	6	0	6	
	May	0	11.3	20.5	17.5	15.4	18.9	20	1.1	3.2	2.1	0	0	7.2	1.4	2.9	0	3.4	5.1	8.4	11.8	26.4	9.3	14	7.8	12.4	0	0	0	0	0	0
	June	8.3	8.3	0	0	0	0	3.5	5.3	5.3	10.6	6.6	3.3	4.9	8.2	0	12.3	0	14.8	9.8	0	4.4	13.1	4.4	0	0	11.5	0	6.9	4.6	2.3	
	July	0	17.8	0	0	0	0	0	32.3	0	0	3	14.8	0	3	0	0	16.9	6.3	0	2.1	0	2.4	11.9	0	0	0	0	0	0	0	21
	August	0	0	0	20.1	0	12.5	5	0	0	5	13.2	0	0	0	5.3	0	0	0	9.2	0	8.8	3.5	12.3	0	0	0	2.8	0	0	13.8	0

	September	8.2	2.1	2.1	0	0	0	0	0	0	9.8	9.1	7.8	6.5	1.3	3.9	2.9	5.8	0	0	0	0	0	2.2	4.5	7.9	3.4	0	2.3	6.8	10.1	
	October	22.7	4.5	1.1	4.5	3.4	8	2.7	8	5.3	6.6	8.4	0	4.2	2.1	4.2	1.3	0	9.3	18.6	14.6	9.8	4.3	0	22.8	17.3	10.5	0	6	0	0	23
	November	0	1.5	0	16.3	4.4	12.1	2.2	0	0	5.5	0	0	2.4	8.8	1.2	4.4	8.7	1.1	2.2	0	0	3.7	5.6	13	5.6	6.4	0	0	0	0	
	December	0	0	0	0	0	0	0	0	0	0	0	0	0	6.2	2.1	0	0	8.4	3.1	6.9	0	1.6	5.6	0	0.8	3.6	7.1	6	10.1	0	1.2
2003	January	0	2.9	8.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.7	5.4	7.4	3.5	3	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	5.4	5.4	0	0	0	0	13.1	0	12.8	0	0	0	0	0	0	0	0	0	9.5	0	1.9			
	March	13.4	0	0	0	0	0	0	0	10	0	0	0	16.6	0	0	0	0	0	0	0	0	9.5	5.5	6.3	0	0	0	17.6	9.4	2.3	11
	April	0	0	0	0	0	6.6	4.4	0	0	0	0	5.9	23.8	0	17.8	0	17.6	5.4	6.8	0	7.9	14.7	6.8	3.4	4.5	0	8.8	0	0	22.9	
	May	0	3.2	11.7	14.9	16	6.6	0	14.3	2.2	9.9	3.9	16.6	0	9.8	5.9	7.3	2.4	0	4.9	0	0	11.6	5.8	9.6	0	8.2	20.5	0	2	12.3	0
	June	6	0	9	0	9	5.2	0	5.2	5.2	10.4	4.3	2.9	1.4	20.9	8.6	14.5	7.3	12.1	0	4.8	13.1	0	6.6	6.6	6.6	13.4	11.5	11.5	1.9	5.8	
	July	7.3	16.9	2.4	12.1	19.4	2.3	29	8.1	13.9	0	8.1	16.1	0	0	0	0	8.1	2	12.1	6.1	8.9	1.8	12.5	1.8	0	0	0	0	6.5	13	0
	August	0	0	0	14.3	0	4.7	9.3	0	0	11.7	2.3	11.5	4.6	2.3	2.3	22.7	3.2	9.7	4.9	29.2	2.9	8.8	8.8	2.9	26.4	11.5	22.9	0	8.8	0	1.8
	September	3.2	3.2	0	8.1	3.2	5.1	9	3.8	3.8	7.7	1.6	0	8.1	3.2	3.2	5.6	8.4	9.3	0	0	8.1	0.9	7.2	19.7	1.8	0	5.5	0	4.1	4.1	
	October	2.8	4.4	14.5	18.9	1.1	2.5	1.2	16	16	8.6	0	26.2	6.4	7.9	0	1.3	37	4	1.3	1.3	3	0	12.1	0	0	0	14.4	0	11.2	0	4.8
	November	5	18.7	18.7	1.2	2.5	0	0	0	21	8	0	0	0	1.8	5.5	6.7	0	0	1.7	0	0	4	0	5.3	1.3	0	0	5.7	24.1	8	
	December	4.1	0	0	4.1	12.3	0.6	3.1	5	5.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	January	0	5.7	0	0	0	0	0	0	0	0	0	0	11.8	0	1.2	7.9	0	7.9	1.3	0	0	0	0	15.2	2.5	0	0	0	5.1	5.8	1.5
	February	9.8	0	0	0	0	0	0	0	0	0	0	0	0	0	8.9	0	0	15.2	15.2	0	0	9.6	21.6	12	0	0	6.9	10.4	10.4		

	March	0	19.5	0	0	0	0	0	8.4	0	0	0	0	13.2	5.7	0	0	0	0	0	0	0	0	0	0	0	2.5	16	0	0	9.8	3.7
	April	0	0	5.3	17.7	15.1	8.6	0	5.4	23.2	16.2	0	0	8.1	8.1	4.1	0	8.3	10.7	26.1	10.7	4.9	0	0	13.5	8.6	2.1	0	0	0	19.2	
	May	0	9.4	7	5.9	4.7	3.2	9.5	9.5	12.7	8.5	11.7	7.8	0	12.7	3.9	0	8.3	0	0	0	0	0	0	0	0	0	0	0	21.9	0	0
	June	0	0	18.4	0	0	0	0	0	0	0	0	9.8	0	0	0	10.6	8.5	14.9	10.6	25.5	9.8	6.6	0	16.4	0	0	0	0	0	0	
	July	0	0	0	0	11.8	0	0	0	0	0	0	0	10.2	0	0	2.2	6.7	0	0	13.4	3.5	10.5	12.2	0	0	16.6	22.9	0	16.6	0	9.4
	August	14.5	10.9	12.1	0	14.5	0	2.8	0	0	16.6	19	1.9	9.5	5.7	1.9	0	15.4	15.4	0	0	0	12.8	0	1.8	7.3	0	10.2	0	3.4	0	0
	September	6.2	4.1	2.1	0	0	0	12.9	0	0	0	0	8.7	2.2	0	0	4	1	0	12.1	0	5.8	7.7	1	6.7	3.8	1.1	8.5	4.2	5.3	10.6	
	October	19.5	5.7	4.6	4.6	0	6.1	0	3	7.6	3	2.5	12.5	0	0	0	7.7	0	1.9	3.8	1.9	0	0	0	13.2	0	1.5	6	6	10.5	13.5	3
	November	1.5	7.4	0	10.4	3	0	0	0	8.1	4.1	10.1	0	4	4	0	0	0	2.2	6.5	7.6	0	10.6	7.9	8.8	11.5	0	0	0	0	0	
	December	3.7	0	8.7	0	0	1.9	1	0	2.9	0	0	0	0	0	10.7	9.4	2.3	5.5	0	0	4.5	1.5	3	0	0	0	0	0	4.1	0	2
2005	January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.2	3.7	1.8	6.2	9.2	0	5.5
	February	11.1	0	0	0	0	0	0	0	0	0	0	0	0	13.1	0	0	0	0	0	0	0	0	0	0	0	14.7	13.6	14.7			
	March	14.9	5	0	7.4	0	0	13.9	0	0	0	0	4.8	0	9.6	0	18.9	13	11.8	9.4	9.4	11.5	2.6	0	2.6	24.2	0	7.8	2.6	0	0	0
	April	0	0	0	12.3	7.4	10.7	5.4	0	4	1.3	15.7	0	14.1	7.9	0	0	0	0	0	7.8	1.3	5.1	11.6	5.1	0	12.4	17	1.5	12.4	9.3	
	May	9.4	10.4	11.5	14.6	10.4	24.7	9.3	12.4	2.1	5.1	3.1	10.3	5.2	7.2	1	10.3	0	6.9	3.4	6.9	31.7	11.7	0	0	1.7	18.6	2.1	10.3	0	10.3	0
	June	8.3	8.3	0	0	0	0	0	3.5	7	0	0	0	0	8.6	0	0	9.9	0	0	4.9	29.6	11.9	0	0	0	0	6.9	9.2	6.9	2.3	
	July	5.3	0	0	0	10.5	17.7	5.9	2.9	0	0	0	0	0	0	15.5	0	0	0	0	8.8	14.3	4.8	3.2	9.5	6.4	9.8	45.3	15.7	23.6	0	9.8
	August	0	0	14.3	0	0	0	0	0	0	16.3	10	0	6	10	6	13.8	13.8	8.6	10.4	0	8.1	0	13	0	9.7	16.4	0	10.3	0	0	0

	September	0	6.9	0	3.5	5.2	12.7	8.9	3.8	0	5.7	0	7.9	5.3	1.3	13.1	9.5	13.8	4.3	9	0	1.5	1.5	6	0	0	0	0	0	0	5.7	
	October	5.6	0	5.6	0	0	0	0	0	0	0	10.6	1.5	9.1	25.8	4.6	12.7	0	11.3	2.8	5.6	14.4	0	12.2	14.4	3.3	6.7	6.7	0	0	5	8.4
	November	4.4	8.9	3	0	5.9	0	9.9	1.4	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	9.3	
	December	1	1	1	15.4	2.1	2.8	1.4	0	0	0	5.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	January	0	0	0	0	0	0	0	0	0	0	0.8	4.9	0	0	0.8	6.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	0	0	10.3	11.6	12.9	0	0	17.3	2.9	0	0	0	4.3	0	8.6	10.7	1.2	13			
	March	0	0	0	0	0	1.6	6.5	12.9	1.6	0	0	15.9	1.8	0	3.5	0	8.4	17.6	0	1.4	1.3	18.4	2.5	15.3	3.8	11.5	0	0	0	1.9	0
	April	20.3	0	17.9	16.2	0	0	1.2	7.4	11.7	7.4	6.5	0	6.5	0	0	9.9	11.1	4.9	14.8	3.7	14.5	18.6	14.5	7.2	15.5	20.4	0	3.7	0	3.7	
	May	1.1	5.6	14.1	5.6	5.6	0	7.4	9.5	10.6	14.8	17.8	2.8	1.9	12.2	15	23.4	21.2	1.5	8.8	0	0	0	4.2	2.1	16.6	0	12.6	19.9	28.9	19.9	7.2
	June	9.8	0	0	4.9	0	0	12.7	2.1	2.1	0	1.6	9.3	0	9.3	7.8	0	0	0	0	0	0	0	28.6	6.4	0	11.7	7.8	0	17.6	3.9	
	July	0	0	0	0	0	0	0	20.1	0	1.7	9.7	0	5.8	0	0	0	0	8.9	0	13.4	0	0	18.2	0.9	7.8	3.6	16.8	0	6	0	8.4
	August	1.1	9.2	19.5	16.1	20.7	39.1	28.6	0	20	0	11.8	0	0	0	0	0	10	5.7	0	0	4	0	0	0	4	5.9	9.8	0	6.9	7.8	0
	September	0	2.3	9	0	0	0	4.2	3.3	7.5	0	0.8	4	9.7	0	1.6	5.2	3.8	2.3	7.5	3.3	3.8	2.7	2.7	2.7	4.3	4.3	0	3.2	8.5	12.8	
	October	5.7	8	3.4	7.4	10.9	0	0	6	9	5.3	0	0	0	0	0	0	0	0	0	0	0	9.4	10	6.5	5.9	9.8	16.8	22.4	4.9	7.7	0
	November	11.6	0	1	1	0	7.1	0	0	0	0	6.1	1.8	0	2.4	1.2	6.1	20.6	12.3	0	8.8	16.2	18.8	6.8	2.6	10.2	0.7	2.2	10.3	2.9	0	
	December	0	0	0	0	0	6.7	6.4	0	0	0	0	0	10.3	0.4	0	0	0	0	0	4	0	4.2	1.9	2.3	0.4	0	4.1	0.2	7.5	3.3	1
2007	January	0	0	0	0	0	0	0	0	0	0	0	2.2	0.4	0	3.1	1.4	0	6.1	0	0	0	0	0	0	0	0	0	0	7.8	8.4	0
	February	0.7	11	20.6	19.9	12.5	5.8	4.4	5.1	3.6	3.6	1	3.1	9.4	0	0	0	0	0	0	0	0	0	0	0	8.3	0	10.8	7.4			

	March	9.3	21	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	2.9	5.7	0	0	0	0	0	0	0	0	0	0	0	0
	April	0	0	0	0	0	8.7	0	0	8.1	18.5	10.7	2.8	19.2	17.1	12.1	0	4.4	1.9	6.3	25.4	1.4	1.4	2.2	0	12.9	5.6	0	0	0	9.9	
	May	4.9	1.8	1.8	6.1	8	2.8	0	0	7.7	4.9	3.1	3.1	2.6	10.4	6.7	11.3	6.4	14.5	1.6	0	0	0	2	16.4	5.1	18.6	0	2.8	14.9	16.7	18
	June	19.6	13.9	3.5	5.2	2.3	9.4	2.2	11.5	38.2	2.2	11.5	10.2	16.9	14.9	4.1	0	6.8	21.8	0	0	0	0	0	0	0	0	0	9.6	0	0	
	July	0	9.5	52.4	1.2	0	0	0	10.2	0	0	0	4.6	4.6	7.6	3.1	1	6.9	2.9	6.9	13.7	0	6.9	0	8.1	0	15.6	12.7	14.6	37	33.1	5.8
	August	6.9	6.9	1.4	15.2	4.2	2.2	3.3	13	11.9	0	0.9	24.1	23.2	6	7.7	10.6	0.9	9.7	17.7	2.7	5.1	1.7	10.1	3.4	6.8	0	5.2	6	9.5	6	24
	September	8.8	6.8	4.7	4.7	4.1	12.6	9.7	8	16.6	13.7	14.3	7.2	4.2	7.2	13.1	2.4	4.9	0	2	9.8	4.3	1.9	7.2	5.8	5.3	0.6	0	11.3	2.5	1.9	
	October	1.2	12.1	11	0	8.7	0	6.5	5.1	7.6	3.3	6.4	0	0	19.1	0	4.5	0	0	7.9	0	6.4	13.4	1.7	3.5	8.7	0	5.9	0	0	5.9	0
	November	0	0	15.5	5.4	9.5	0	4.1	0	0	7.6	6.8	7.8	0	2.1	0	6.8	0	0	0	0	0	6	0	4.6	0	0	0	0	6.3	1.6	
	December	0	0	0	0	0	0	0	5.8	10.9	0.3	0	12.9	0	0	0	0	0	0	0	0	0	0	3.6	0	0	0	0	0	0	0	0
2008	January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.9	0	0	0	0	0	0	0	1.6	3.1	1.7	3	0	0.7	2.3	9
	February	9.8	0	0	0	0	5.5	18.6	0	0	2.1	9.4	4.2	0	0	0	0	0	0	0	0	0	0	0	0	0	6.9	0	0	0		
	March	1.4	0	0	0	22	10	0	0	0	0	0	0	7	11.3	3.5	3.4	0	0	19.8	6.8	0	15	0	1.6	4.7	14.1	0	0	5.1	3.2	5.1
	April	10.2	0	0	0	0	0	0	0	0	14.3	24.9	0	14.7	2.2	9.5	0	0	9.6	26.4	16.2	6.5	3.2	1.9	9.1	1.9	0	0	0	0	11	
	May	11.2	0	1.3	5.9	0	0	0.7	0	13.2	0	0.5	15.3	7.4	2	8.9	0	0	3.5	0	22.7	8.5	10.1	12.4	28.7	12.4	2.1	8.4	9.4	9.4	7.3	3.1
	June	1.1	5.4	14	21.5	19.4	9.4	8.5	0	8.5	0.9	0	0	0	13.2	3.8	13.5	10.5	0	0	0	0	0	0	0	0	0	0	0	0	11.9	
	July	0	0	29.1	9.3	2.6	7.1	16.6	1.2	13	10.7	2.2	8.6	21.6	11.9	0	8.4	0	9.3	15.9	3.7	11.7	15.8	18.8	2.3	4.5	1.3	0	0	17.7	5.1	6.3
	August	6.3	21.5	7.6	6.3	2.5	1.9	7.7	15.5	12.6	6.8	9.1	2.7	20	12.7	0.9	0	7.9	15.8	11.4	8.8	7.6	14.4	0	9.1	10.6	10	2.5	6.7	25.1	4.2	12

	September	1.6	9.4	3.9	0	3.9	2.2	0	1.1	4.3	3.2	5.3	4.7	4.7	0.7	10.7	0	3.4	6.3	1.9	7.8	4	9	4.5	12.5	7.6	6.4	1.9	0.6	0	7	
	October	7.7	0	16.5	20.4	0	0	4	9.3	13.3	4	6.6	14.1	2.8	0	0	3.5	4.3	10.4	0	0	1.1	0	7.9	25.3	6.7	21.7	1.4	0	20.3	9.8	8.4
	November	10.5	8.7	18.7	16.3	6	8.4	14.9	4.5	0	2.2	5.7	0	0	6	0	4.9	0.5	3.2	8.1	0	0	0	0	0	0	0	0	9.6	2.6	0	
	December	0	5.2	0	0	0	0	0	0	0	0	4.9	0	0	0	0	0	0	0	3.2	4.8	0	0	0	0	6.2	1.4	3.4	0	0	0	0
2009	January	0	0	0	0	0	0	0	4.2	0	0	0	0	0	0	0	0	0	0	0	3.7	1.4	0	0	4.5	1.4	0	8.5	0.7	0	0	2.9
	February	8.5	13.2	0	4.7	0	7.3	0	0	0	0	0	0	0	0	0	0	0	14.2	0	0	0	0.8	17.6	0	0	0	0	0			
	March	0	0	0	0	12.6	0	0	0	0	0	0	6.6	4.1	13.2	0	0	14.6	3.4	0	0	0	10.2	0	0	0	0	0	0	6.1	21.1	28
	April	22.1	16.4	11.5	0	2.5	2.3	7.6	0	0	6.8	0	15.9	6.1	6.1	15.2	3.8	2.3	4.6	0	10.7	1.3	10.8	5.1	0	7	0	5.5	16.6	0	25.2	
	May	9	0	0	0	0	0	0	1.7	2.3	22	22.1	0	15.2	16.6	7.4	21.5	7.2	0	21.5	14.3	12.7	14.6	0	0	4.5	15.9	14	20.6	6.5	3.7	7.5
	June	0	5.5	0	0	8.3	4.4	4.4	2.9	0	0	0	0	0	11.5	11.5	0	15.9	6.3	0	0	0	0	0	0	0	3.8	0	28.5	8.5	5.7	
	July	3.4	10.3	0	0	0	0	0	0	13.1	0	0	0	0	1.6	17.4	16.3	0	0	0	0	0	0	9	8.1	7.2	0	0	0	0	0	0
	August	0	0	0	14.7	7.3	0	0	11.6	0	0	0	0	16.6	5.5	20.3	9.1	8.2	6.4	7.3	6.4	8.1	10.1	0	0	0	0	1.3	6.6	0	9.3	0
	September	0	21	5.4	0	2.7	4.8	0	2.4	0.8	8	0	0	9.6	14.4	0	1.7	0.4	14.4	10.5	5.7	0	2.1	7.4	7.9	0	4.6	8.2	1	15.9	5.6	
	October	4	6.3	8	8	8	13.4	2.7	7.4	2	4	13.7	6.9	0	0	9.4	6.6	21.6	19	0	0	0	0	0	11.7	0	0.8	8.4	7.6	19	1.5	0
	November	0	0	0	0	11.4	4.8	5.5	0	0	1.4	0	2.6	7.8	0	0	14.4	0	0	1.1	0	0	0	0	0	0	2.8	0	9.1	6.3	0	
	December	0	2.3	4.5	0	0	0	0	0	3.6	13.1	18.4	9	0	0	1.7	4.5	4.5	0	0	0	0	0	7	5.1	8.5	8.6	10.3	11.7	7.4	0	7.4
2010	January	15	2	6.5	5	1	2.2	0	0	1.1	2.7	7.2	0	0	0	0	0	1.6	2.4	0	0.8	4.4	0	0	0	0	0	0	0	0	0	0
	February	0	0	0	6.7	13.3	9.7	15.9	0	0	0	0	0	0	0.9	16.1	26.8	0	1.9	0	16.9	8.9	13.3	9.4	6.4	40.8	0	15	9			

	March	1	11.6	29.1	6.8	1.9	5.1	2.6	11.1	0	1.7	0	0	0	0	0	0	0	0	14.3	0	5.6	13	20.4	1.9	8	12.9	5.3	0	2.9	16.4	2.9
	April	6.2	7.8	0	1.6	0	0	0	0	0	0	0	14.7	22.4	13.3	19.6	0	14.9	3.5	4.3	2.8	4.8	10.2	12.6	1.2	0	9.4	0	1.3	2.7	2.7	
	May	3.2	0	0	1.6	8	9	18.5	9.5	6.3	0.5	12.5	4.8	6.2	8.7	8.7	14	5.8	0	7.4	4.1	0	9.9	6.3	10.8	5.4	14	0	1.2	7	7	0
	June	0	0	18.9	15.1	0	4.4	11.5	0	2.6	6.2	4.2	9.8	2.8	25.1	3.8	22.7	21.1	17.9	11.6	0	1.6	17.2	17.2	0	0	0	0	0	0	0	
	July	2.5	12.5	32.5	2.5	0	0	0	11.2	0	0	5.7	10.3	0	8	11.5	3.2	0	0	0	6.4	2.5	10.7	3.3	0	16.4	5.1	5.1	18.3	0	19.3	31
	August	19.3	3	7.4	0	0	0	0	2.5	0	9.9	19.3	0	4.1	0	7.1	5.7	10	0	0	0	3.2	0	3.2	5.6	20.8	7.1	0	5.3	23	1.8	7.1
	September	4.9	0	7.4	4.9	0	10.8	1.3	0	4.7	7.4	12.7	7.3	8.5	3.6	9.7	5.8	5.3	5.8	2.4	0	10.6	2.4	6.3	5.3	0	0	8.5	4.3	0	0	
	October	0	0	0	0	16	7.2	9.1	2	11.1	3.3	0.8	10.6	11.8	7.6	21.2	0	5.1	13.4	22.3	17.2	4	8.6	13.7	5.7	5.1	9	13.1	3.3	0.8	2.5	0
	November	12.1	10.2	3.2	6.4	8.3	3	0	10.7	0	1.8	3	2	6.5	7.5	0	0	0	0	0	0	0	2.2	7.2	0	0	0	0	0	0	0	
	December	10	0	0	0	0	5.4	2.6	5.4	6	4.9	7.5	3.5	0	0	0	0	0	0	0	0	0.3	0	0	7.4	7.7	8	4.6	4.9	1.8	2.2	0
2011	January	0	0	0	0	0	0	0	0	0	0	0.7	3.1	4.5	0	0	0	0	0	8.3	0	0	0	0	0	0	0	0	0	0	0	0
	February	6.3	3.2	4.8	0	0	0	0	0	0	0	0	0	10	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0			
	March	0	0	0	0	0	0	14.9	0	0	0	0	0	0	0	8.1	7.7	0	1.9	0	0	8.6	7.9	7.2	2.9	0	0	10.7	6.6	2.4	10.7	6
	April	9.5	0	0	0	0	0	13.8	6.2	0	0	0	0	0	0	0	0	7.3	0	0	0	2.9	5.8	0.6	11.1	12.2	11.4	13.8	0	9.8	6.5	
	May	20.5	0	3.2	0	18.3	15.1	22.2	9.1	7.1	13.1	0	0	12.8	0	0	15.9	0	9.9	4.6	13.7	0	0	0	11.1	19.4	6.9	10.3	2.3	0	1.1	10
	June	16.6	12.2	11.1	13.3	0	2.2	3.7	9.6	11.1	26.6	9.3	14.6	23.3	16.6	4	11.3	6.3	0	2.5	15	0	0	10.6	16.6	12.1	16.7	32.5	11.4	8.8	7	
	July	28.5	41	9.1	5.7	0	9.7	5.5	0	5.5	9.7	0	0	14.3	6.5	5.2	7.5	0	0	4.3	12.8	10.7	11.5	1.5	9.2	14.5	0	25	10	30	8.5	15
	August	2.8	7.1	1.4	0	21.9	11.8	16.7	11.3	1.5	0	10.5	2.6	22.8	15.8	2.6	9.9	11.7	10.8	0	7.2	6.5	8.9	0.8	7.3	8.1	0.8	13.4	17.6	3.3	7.5	18

	September	14.1	4.4	3.1	6.9	13.2	9.8	13.8	14.9	12.1	6	9	6.6	1.2	15	12	4.2	11.9	0	7	0	0	0	4.7	14	9.8	0	8	11	14	10	
	October	13.3	1.2	2.3	4.6	11	5.6	16.6	4	0	4	6.8	6.8	21.2	15.1	3	0	2	22.5	10.2	2.7	0	4.1	11.5	3.4	0	4.3	10.1	3.6	10.8	10.1	12
	November	3.7	9.9	9.3	4.3	20.5	6.7	8.6	13.8	10.9	0	0	4.8	0	0	0	1.1	0	4.5	1.1	0	0.5	0	2.3	15.9	8	5.5	10.5	10.5	9.4	13.8	
	December	0	7.3	8.3	2.9	1	0	0	3.2	0	0	0	0	2.5	1.6	0	3.7	2.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	January	0	0	0	0	0	0	0	0	0	0	5.3	0	0	0	0	0	0	0	0.5	6.1	0	0	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.5	0	0	0	0	0	0	0	7.6	0.8	2.5	1.7		
	March	1.9	0	11.5	0	3.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.9	27
	April	8.3	12.4	14.9	0	14.1	5.1	11.4	1.7	15.9	4.6	3.5	12.5	2.1	13.9	41	19	0	13.5	8.6	4.9	15.5	5.6	0	3.1	1.2	20.6	11.5	0	2.5	4.9	
	May	13.8	1.6	8.5	8.5	16.4	7.4	11.6	7.9	7.9	7.9	0	4	14.5	1	12	10.1	9.2	0.8	4.2	5	1.7	8.3	24.9	0	11.6	0	9.7	0	0	0	0
	June	0	10.9	9.7	17	0	2.2	5.8	15.9	25.9	14.4	5.5	9.1	0	0	3.6	0	0	19.4	0	12.9	15.3	9.8	25.1	0	0	5	5	13	9	5	
	July	13.3	10.7	9.3	0	6.7	0	9.8	0	17.2	15.3	6.3	0	0	0	12.6	5.2	16.6	14	0.9	14.9	0	18.2	15	4.8	0.8	0	13.4	7.2	15.5	15.5	19
	August	19.5	12.2	0	17	2.4	0	1.1	9.9	18.6	0	3.9	21.2	3.9	6.8	0	0	1	3.9	14.4	11.6	0	6.9	8.5	4.6	18.5	0	15.8	8.8	7.5	8.8	4.4
	September	8.9	19.1	3.2	0	7.6	0	6.6	10.8	10.2	12.6	5.2	9.2	12.7	23.1	8.7	2.1	4.8	1.1	6.9	0	2	6	3	9.4	1	11.6	3.2	6.8	4.7	4.7	
	October	3.2	6.4	0	0	0	0	2.3	0	0	16.9	0	24.9	0	9.6	4	0	0	0	0	0	11.2	0	0	0	0	9.5	18.3	0.7	0	15.4	1.5
	November	7	5.1	12	14.5	3.8	2	11.3	6.4	12.7	0	0	0	6.2	2.5	2.5	9.4	4.7	0	4.7	0	0	7.7	1.7	1.7	3.9	0	7.8	14.3	0	0	
	December	0	0	0	0	13.3	4.5	4.1	0	0	0	0	0	0	0	0	4.3	0	0	0	0	0	0	2.9	2.3	0	0.3	0.7	7.7	0	5.4	0
2013	January	0	2.8	4.2	0	0	0	0	6.6	0	3.1	0	0	0	0	0	0	0	3.7	0	0	0	0	0	0	0	0	0	0.4	0.4	7	0.4
	February	18.7	0	0	0	0	0	0	0	0	0	0	0	3.3	6.6	0	0	0	0	0	0	8.8	0	0	0	0	0	0	0			

	March	0	0	0	0	0	0	9.8	11.1	12.5	10.5	2.3	6.2	10.1	9.3	0	0	1.5	7.4	14.8	0	15.8	0.6	9.5	16.4	0.6	19.4	15.6	14.5	1.6	8.1	14
	April	0	13.5	11.7	10.8	0	19	10.6	7.4	16.4	11.1	12	6.4	10.4	2.4	4	0.7	0	1.4	2.1	22.9	0	9.1	2.8	0	7	10.4	14.4	0	11.2	8	
	May	9.5	6.1	3.9	0.6	13.9	14.3	10.1	8.5	7.9	1.6	5.7	7	0	1.3	0	0	0	4.8	4.8	0	0	0	0	0	18.7	13.2	9.6	4.8	0	0	0
	June	9.7	0	0	0	3.2	0	0	0	13.2	11.5	2.9	7.9	15.1	8.6	4.3	19.4	35.5	1.1	6.5	2.2	0	0	0	0	0	0	5.6	0	5.6	0	
	July	0	1.5	16.7	9.1	1.5	0	0	0	0	0	10.1	0	0	17.6	0	0	1.7	21.8	16.5	13.1	0	6.7	5.7	8.6	0	0	1	25.4	44.1	0	8.1
	August	16.1	0	0	0	14.6	6.5	14.8	9.3	10.2	13.9	12.9	0	0	9.9	9.9	12.6	12.6	0.9	5.4	7.2	12.8	5.6	5.6	8.8	0	0	0	0	0	4.8	9.6
	September	11	4.5	7.8	7.8	4.5	1.3	3.3	9.4	4.7	6	3.9	16.2	0.6	6.5	1.9	3.6	9.9	4.5	4.1	4.5	0.9	0.9	6.8	14	13.5	11.2	12.2	5.8	0	0	
	October	0	10.5	8.8	4.1	7.6	3	16.3	4.8	22.4	4.8	22.7	7.6	11.3	2.3	9.1	6.3	9.4	0	0	7.1	1.8	10.2	0	5.4	12	9.4	13	0	23.1	4.3	0
	November	0	0	0	0	0	3.4	1.7	0	5.6	7.8	3.5	2.6	5.6	10.4	18.6	0	0	8.7	7.6	0	0	8.9	7.5	9.9	0	4.1	0	0	0	6.2	
	December	0	0	0	0	0	5.5	0	0	2.3	0	7.5	0	1.8	1.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	6.1	6.8
2014	January	12.2	3.1	0	0	0	0	3.9	2.1	2.1	0	0	0	0	0	0	0	0	2.9	0.8	5.4	0	3.6	3.6	0	0	0	0	0	0	0	0
	February	0	0	0	0	16.8	9.5	0	0	1.4	0	0	7.9	0	0	0	0	0	0	14.2	16.3	2.9	6.4	0	13.2	0.7	0	0	0			
	March	0	0	0	0	0	0	8.4	0	0	0	6.4	1.4	17.2	6.4	5	13.3	0	0	0	0	0	0.6	27.3	13.3	0.6	0	0	3.4	2.3	5.7	0
	April	2.8	0.9	6.5	15.7	7.4	14.4	2.3	0	0	0	0	10.6	10.2	3.4	5.1	0	0	0	0	8.3	6.9	6.2	4.8	1.4	0	6	0	8	0	10	
	May	9.4	0.6	4.4	2.8	18.3	17	10.8	9.2	9.5	8.2	14.6	6.8	5.8	1.9	8	0	8.4	5	15.9	0	7.8	9.5	14.7	6.1	0	7.5	7.5	11.7	0	6.4	4.3
	June	2.5	12.3	8.6	11.1	1.2	0	0	0	3.1	14.5	4.5	5.6	3.3	0	0	0	0	3.8	10.1	20.2	16.7	6.3	0	0	0	0	0	2.6	18	0	
	July	0	14.8	0	0	0	0	17.3	0	0	3.5	0	0	0	0	12	0	0	0	0	12.5	20.8	5.4	11.2	7.7	0	9.2	19.6	10.4	1.2	0	0
	August	1.6	0	0	19.4	4.9	9.5	23.8	0	5.7	9	2.4	4.8	8.4	0	6	1.9	13.2	4.7	7.5	5.7	13.9	2.5	0	4.1	9.8	4.1	12.3	4.9	20.5	9.8	17

	September	8	19.1	0.9	8.6	11.7	9.3	0	2.5	2.5	0	5.9	0	0	11.1	2.2	0	4.7	0	7.5	10.3	4.1	5	10.9	6.8	6.8	1.8	0	6.7	4.3	4.9	
	October	0	4.2	0	7.8	4.9	5.2	5.8	9	13.5	1.3	0.8	4	5.5	7.9	23	6.5	2.6	0	13.8	24.9	13.9	0	4.2	4.8	5.4	3.7	1.8	0	0.9	0	15
	November	0	17.8	2.2	2.2	0	5.6	9.3	0	7.1	5.6	8.8	0.5	1.1	4.8	0	12.4	2.4	1.4	1.9	8.8	3.1	4	10.6	11.9	9.7	5.5	0	3.1	6.8	11.7	
	December	11.4	6.5	5.5	0	0	0	0	1.2	3.1	3.5	0	0	0	0	0	3	0	0	0	2	0	0	0	8.1	0.8	0	0	0	0	0	0
2015	January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15.8	0	4.3	0	0	0	0	0	0	0	4.9	2.4	0			
	March	0	0	0	5.7	8.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.7	14	11.3	9.2	0	10.9	8	6.9	9.2
	April	1.5	15.8	50.2	9.1	13.6	10.7	1.3	13.8	0	0	0	0.8	0	0	31	6.9	4.6	4.6	1.5	3.8	20.5	5.9	18	3.8	1.6	18.6	1.6	0	2.8	19	
	May	13.3	5.8	7.2	3.3	5	23.9	0	7.7	1.6	8	9.3	2.2	0	0	0	13.8	0	8.4	13.8	6.1	10.4	0	0	0	0	1.1	5.7	1.1	8.6	11.5	2.3
	June	11.1	0	19.6	21.7	14.8	3	0	11.9	3	1	0	8.3	6.3	7.9	3.9	23.2	21.1	13.2	8.4	7.4	6.6	0	0	0	25.6	12.9	3.4	0	6.2	4.5	
	July	15.8	0	0	0	0	0	0	0	0	10.7	0	0	0	0	0	0	0	16.9	8.9	4	5.8	2.9	5.8	6.2	11.6	19.3	4.6	12.5	0	5.7	0
	August	18.2	23.7	0	0	9.7	5.5	4.1	0	7.5	2.7	0	0	9.9	0	0	7.7	13.4	4.6	0	0	10.8	13.2	5	0	0	0	0	0	0	0	22
	September	7.6	15.8	0	3.4	0.7	13.2	0	8.8	1.4	0.7	0	0	11.5	13.5	0	0	0	10.5	3.7	3.5	2.7	4.6	2.2	0	7	5.9	3.9	0	0	5.2	
	October	12.2	2.3	0	0	0	0	0	0	4.6	14.6	27	0	22.1	7.5	0	17.3	6.4	10.6	9.9	11.2	10.4	9.6	4.9	4.1	4.9	5.4	10.4	21.7	33.8	13.7	13
	November	5.9	1.2	9.1	27.5	2.2	0	5.5	6.6	3.2	7.1	11	5.5	0	0	5.3	14.8	0	14.8	4.5	1.4	8.3	1.7	0	0	0	17	4.6	2.8	1.9	0	
	December	8.3	5.9	0	9	7.3	0	6	0	0	0	0	7.2	1	0	0	0	1.2	4.8	1.2	0	0	0	0	0	0	1.6	7.3	0	0	0	0
2016	January	0	0	0	6.6	0	0	0.7	1.6	1.2	9.1	2.7	3.8	5.4	3	5.4	0	8.5	0	6.6	3.9	2.6	1.3	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.1	0	0		

	March	0	16.8	0	0	0	0	3.2	20	9.8	0	0	0	0	0	0	0	10.7	5.1	0	0	0	8.6	7.1	5.9	0	0	0	0	0.6	12.7	18
	April	28.6	0	16.4	23.1	0	6.4	18.4	5	3.1	10.3	13.2	7.5	14.3	0	9.4	15.4	7.4	2.7	3.7	1.7	5	3.6	4.2	12.8	15.8	20.2	7.3	2.8	2.8	9.3	
	May	0	5	17.5	13.8	11.9	7.6	0	0	0.7	7.3	11.7	12.7	5.5	5	7.7	0	7.7	6	0	13.7	3	9	0	0	2.2	0	0	0	0	0	0
	June	8.9	0	0	3.6	0	0	0	0	0	0	0	0	0	5.6	6.3	0	4.4	0	15	0	4.8	0	23.8	0	26.5	11.1	0	0	0	0	
	July	13.3	0	0	0	0	0	3.5	0	3.5	13.2	11.5	0	0	0	0	0	9.2	4.3	6.3	13	6.8	1	5.4	0	6.8	12.5	6	11.3	0	6	0
	August	0	20.4	3.6	19.8	10.2	16.4	23.7	0	2.9	1.9	7	4	15.4	6	0	0	0	0	0	0	3.5	5.9	9.4	0	0	0	11.4	0	0	0	0
	September	0	0	0	0	0	0	0	0	12.6	0	0	0	5.1	8.3	7.2	0	5.9	4.7	6.4	1.7	1.8	2.5	0.8	7.3	8	9.9	10.2	12.4	1.3	4.3	
	October	4.3	16.7	12.4	9.7	9.2	0	8	0	0	0	13	0	0	0	0	0	0	0	0	9.1	3.3	5.9	7.2	5.2	0	15.2	10.6	12.1	0	0	0
	November	3.8	7	16.5	12.7	1.3	6.9	5.2	3.4	0	1.7	0	0	0	0	0	10.3	4.4	1.5	7.3	0	0	0	4.7	13.6	8.4	0	7.3	9.1	11.6	0	
	December	0	0	0	0	0	0	0	0	0	0	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2017	January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	109.2	0	0
	February	312	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99.06	322.6	223.5	373.4	328	132.1	0	279	66.04	0	215.9	0			
	March	0	0	431.8	144.8	0	183	0	0	294.6	0	0	0	0	0	508	597	53.34	35.56	17.78	35.56	188	40.64	0	0	271.8	106.7	299.7	157.5	0	0	0
	April	0	0	0	0	640.1	213	363.2	15.24	0	0	0	0	0	0	0	516	439.4	198.1	30.48	198.1	91.4	30.48	368.3	0	215.9	0	475	673.1	0	119.4	
	May	124	383.5	398.8	149.9	0	366	243.8	190.5	0	215.9	0	0	170.2	152.4	0	102	226.1	182.9	182.9	162.6	333	0	0	0	0	243.8	0	0	121.9	213.4	122
	June	66	302.3	0	0	401.3	102	127	0	251.5	0	0	0	0	0	264.2	0	0	188	281.9	0	274	353.1	315	0	0	256.5	0	256.5	332.7	76.2	
	July	43.2	642.6	210.8	1217	782.3	315	66.04	429.3	83.82	0	0	271.8	0	980.4	309.9	315	292.1	68.58	393.7	147.3	58.4	510.5	99.06	295	157.5	142.2	99.06	480.1	210.8	154.9	84
	August	0	208.3	0	0	167.6	27.9	68.58	431.8	147.3	147.3	180.34	114.3	139.7	243.8	114.3	0	180.3	215.9	0	0	88.9	0	243.8	188	111.8	335.3	124.5	292.1	221	0	721

	September	345	160	149.9	0	0	419	160	0	228.6	221	175.26	66.04	340.4	124.5	0	91.4	236.2	35.56	109.2	180.3	208	132.1	106.7	249	17.78	0	111.8	0	348	388.6	
	October	213	231.1	0	0	0	35.6	0	0	71.12	246.4	459.74	137.2	157.5	391.2	68.58	17.8	442	594.4	0	0	165	119.4	76.2	15.2	391.2	195.6	332.7	0	78.74	254	38
	November	0	167.6	856	518.2	30.48	76.2	261.6	50.8	411.5	0	0	137.2	0	0	0	0	167.6	22.86	0	0	0	0	0	246	101.6	0	0	0	0	312.4	
	December	0	0	0	0	203.2	0	0	0	0	0	0	0	0	0	0	0	93.98	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2018	January	0	157.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	101.6	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	248.9	373.4	300	0	180.3	0	0	0	33.02	198.1			
	March	399	0	0	167.6	66.04	0	0	0	0	309.9	320.04	71.12	160	17.78	444.5	83.8	83.82	475	101.6	83.82	0	0	50.8	25.4	304.8	0	0	0	162.6	53.34	0
	April	231	231.1	442	358.1	0	193	741.7	165.1	0	246.4	447.04	71.12	482.6	0	696	185	0	111.8	149.9	149.9	163	205.7	132.1	325	0	241.3	381	200.7	381	0	
	May	201	15.24	243.8	129.5	215.9	516	215.9	271.8	0	27.94	55.88	40.64	0	348	83.82	165	292.1	281.9	538.5	309.9	732	40.64	0	0	439.4	0	238.8	612.1	53.34	25.4	79
	June	137	221	332.7	248.9	525.8	0	467.4	45.72	0	45.72	93.98	0	0	0	353.1	465	33.02	266.7	33.02	0	0	269.2	0	404	906.8	411.5	482.6	205.7	137.2	342.9	
	July	871	528.3	0	0	0	104	0	104.1	276.9	312.4	0	335.3	0	0	302.3	0	0	0	0	0	0	0	0	0	0	0	0	0	279.4	238.8	0
	August	0	0	0	0	0	0	340.4	0	114.3	0	0	0	0	0	0	0	0	0	185.4	449.6	665	144.8	558.8	269	0	500.4	348	0	109.2	238.8	130
	September	0	185.4	302.3	116.8	200.7	0	0	0	236.2	0	78.74	642.6	203.2	0	15.24	45.7	73.66	0	134.6	45.72	0	0	129.5	0	0	116.8	91.44	0	477.5	271.8	
	October	168	287	0	50.8	0	0	53.34	53.34	190.5	383.5	96.52	355.6	172.7	452.1	269.2	259	370.8	386.1	530.9	0	0	0	0	0	0	218.4	91.44	398.8	345.4	144.8	145
	November	236	383.5	104.1	0	0	40.6	0	25.4	223.5	335.3	152.4	0	101.6	0	0	15.2	0	45.72	284.5	0	119	0	0	0	0	0	0	0	0	0	
	December	0	0	0	0	0	0	0	132.1	111.8	261.6	228.6	38.1	0	0	205.7	0	0	0	0	0	0	0	0	0	0	0	45.72	0	15.24	73.66	0
2019	January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	206	0	0	10.16	0	0	0	60.96	76.2	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	210.8	0	0	0	0	462.3	0	0	0	0	0	0	0	269.2	0	0	93.98	142	0	0	0	0			

	March	0	60.96	88.9	449.6	149.9	91.4	215.9	30.48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	279.4	129.5	0	0	93.98	0
	April	0	27.94	0	569	0	0	0	0	259.1	139.7	0	0	33.02	0	358.1	0	358.1	0	0	0	627	454.7	81.28	307	81.28	375.9	355.6	63.5	208.3	0	
	May	0	60.96	297.2	259.1	15.24	0	276.9	248.9	134.6	99.06	500.38	213.4	99.06	73.66	0	142	0	383.5	142.2	241.3	269	248.9	269.2	249	269.2	63.5	320	0	63.5	0	191
	June	27.9	553.7	193	665.5	0	269	25.4	0	218.4	0	0	0	0	0	0	297	149.9	0	0	0	0	160	53.34	107	266.7	175.3	99.06	200.7	350.5	175.3	
	July	0	167.6	167.6	294.6	0	0	149.9	0	688.3	419.1	302.26	91.44	271.8	0	149.9	0	452.1	0	0	0	373	22.86	185.4	0	0	403.9	939.8	0	0	134.6	28
	August	498	0	106.7	0	248.9	130	271.8	467.4	50.8	0	22.86	154.9	287	548.6	0	0	0	332.7	76.2	91.44	22.9	137.2	0	231	182.9	195.6	315	22.86	238.8	388.6	196
	September	0	241.3	73.66	55.88	203.2	165	213.4	0	165.1	180.3	220.98	99.06	48.26	188	188	0	15.24	236.2	58.42	0	0	106.7	73.66	0	99.06	205.7	81.28	172.7	81.28	246.4	
	October	142	292.1	0	284.5	312.4	198	226.1	106.7	271.8	650.2	444.5	556.3	370.8	241.3	129.5	165	701	58.42	165.1	182.9	173	363.2	78.74	0	22.86	0	160	60.96	160	198.1	259
	November	671	137.2	426.7	274.3	76.2	546	73.66	279.4	0	60.96	381	518.2	76.2	0	0	99.1	20.32	0	0	109.2	206	581.7	170.2	122	33.02	208.3	0	0	83.82	251.5	
	December	439	40.64	0	0	0	48.3	104.1	86.36	86.36	40.64	0	0	99.06	0	0	0	254	0	0	0	7.62	45.72	91.44	53.3	388.6	101.6	38.1	38.1	38.1	20.32	0
2020	January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	112	0	0	0	0	0	0	0	0	190.5	83.82	406.4	315	96.52	76.2	0
	February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	211	0	0	88.9	0	0	281.9	185.4	205.7		
	March	658	0	76.2	419.1	0	147	0	383.5	17.78	218.4	271.78	0	139.7	0	665.5	0	0	375.9	226.1	0	0	0	0	325	510.5	0	177.8	111.8	88.9	0	0
	April	0	0	0	0	0	0	0	0	0	266.7	0	408.9	551.2	657.9	106.7	632	190.5	157.5	78.74	0	0	154.9	45.72	63.5	406.4	248.9	165.1	320	40.64	279.4	
	May	203	236.2	167.6	180.3	167.6	142	142.2	86.36	373.4	0	38.1	0	132.1	0	111.8	239	22.86	144.8	144.8	0	279	228.6	127	0	0	0	119.4	315	40.64	0	0
	June	0	0	0	0	652.8	0	83.82	83.82	226.1	0	0	0	0	88.9	421.6	0	0	0	58.42	342.9	0	0	0	305	304.8	391.2	129.5	104.1	236.2	0	
	July	0	0	340.4	226.1	0	191	558.8	543.6	271.8	652.8	312.42	0	25.4	312.4	807.7	508	553.7	0	0	0	150	43.18	0	0	584.2	0	208.3	0	177.8	254	312
	August	0	210.8	0	0	421.6	249	408.9	421.6	0	0	213.36	256.5	213.4	662.9	469.9	516	172.7	160	203.2	289.6	0	223.5	93.98	48.3	177.8	134.6	88.9	236.2	180.3	203.2	269

	September	203	172.7	0	81.28	0	353	0	96.52	0	114.3	0	86.36	0	127	170.2	0	104.1	0	91.44	221	107	142.2	76.2	165	271.8	188	106.7	266.7	0	221	
	October	27.9	254	27.94	137.2	462.3	0	55.88	0	350.5	165.1	0	215.9	236.2	647.7	78.74	0	0	81.28	0	467.4	38.1	137.2	137.2	137	289.6	0	416.6	294.6	797.6	485.1	0
	November	0	40.64	0	60.96	365.8	340	203.2	177.8	0	38.1	109.22	0	25.4	139.7	279.4	63.5	388.6	38.1	25.4	63.5	0	106.7	0	269	40.64	292.1	292.1	480.1	243.8	0	
	December	0	66.04	381	66.04	0	0	0	172.7	0	0	132.08	0	0	0	0	0	0	180.3	0	0	0	78.74	0	0	0	0	0	0	0	0	135
2021	January	330	15.24	0	0	0	0	0	0	297.2	30.48	38.1	25.4	63.5	0	0	0	0	0	0	0	0	104.1	0	0	0	0	0	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	495.3	15.24	330.2	281.9	236.2	203.2	462	0	462.3	0	0	0	104.1	185.4	124	40.64	0	0	0			
	March	0	0	0	457.2	0	0	0	292.1	58.42	0	0	0	0	0	0	0	190.5	0	213.4	0	48.3	342.9	0	0	0	182.9	134.6	0	398.8	0	33
	April	66	221	0	398.8	332.7	183	0	271.8	332.7	0	474.98	548.6	147.3	0	274.3	424	213.4	198.1	30.48	485.1	389	335.3	200.7	373	226.1	20.32	76.2	442	632.5	345.4	
	May	109	325.1	188	93.98	472.4	450	487.7	170.2	154.9	182.9	142.24	243.8	175.3	335.3	0	127	0	0	284.5	0	0	0	0	0	0	0	109.2	0	403.9	0	0
	June	0	71.12	375.9	579.1	172.7	0	0	0	0	0	0	0	0	0	185.4	188	48.26	236.2	0	0	0	0	0	0	0	0	0	223.5	0	0	
	July	0	370.8	91.44	91.44	0	0	0	0	284.5	0	104.14	0	0	419.1	68.58	381	292.1	157.5	279.4	134.6	213	0	0	0	0	0	0	0	157.5	0	236
	August	0	0	0	363.2	0	185	0	421.6	157.5	106.7	0	45.72	563.9	475	203.2	0	254	0	50.8	0	292	93.98	0	0	53.34	0	99.06	48.26	0	221	442
	September	160	0	142.2	142.2	195.6	15.2	198.1	243.8	396.2	182.9	111.76	160	96.52	271.8	223.5	160	309.9	12.7	160	45.72	170	215.9	147.3	297	101.6	241.3	119.4	119.4	119.4	172.7	
	October	0	248.9	320	175.3	132.1	213	241.3	0	177.8	0	464.82	485.1	96.52	213.4	20.32	157	297.2	17.78	436.9	0	0	0	0	0	0	0	0		0	0	0
	November	33	444.5	358.1	317.5	0	104	284.5	0	0	15.24	0	0	40.64	109.2	274.3	0	0	0	248.9	309.9	343	124.5	0	0	0	0	0	0	0	0	
	December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	109	0	0	0	0	117	0	241.3	307	188	38.1	0	58.42	106.7	0	38
2022	January	135	0	0	0	0	0	0	0	0	0	0	0	0	175.3	30.48	305	30.48	0	7.62	43.18	104	0	114.3	0	0	0	0	0	0	165.1	0
	February	0	281.9	0	0	0	0	0	0	0	185.4	0	198.1	73.66	0	99.06	22.9	167.6	358.1	287	332.7	0	116.8	0	284	350.5	231.1	0	0			

	March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	193	76.2	0	0	0	33	256.5	50.8	325	170.2	127	48.26	205.7	396.2	0	0
	April	0	0	0	0	518.2	267	0	0	0	0	261.62	139.7	330.2	523.2	802.6	185	447	370.8	215.9	0	191	231.1	259.1	340	259.1	246.4	370.8	266.7	185.4	0	
	May	295	147.3	162.6	0	104.1	284	170.2	271.8	27.94	0	0	104.1	43.18	104.1	193	71.1	251.5	0	0	0	0	91.44	180.3	589	0	137.2	756.9	574	574	228.6	0
	June	445	0	0	0	185.4	0	248.9	109.2	55.88	0	185.42	0	0	0	0	470	0	408.9	292.1	0	0	40.64	444.5	404	0	170.2	0	43.18	0	170.2	
	July	554	0	0	0	0	0	0	0	0	0	0	0	238.8	0	375.9	0	345.4	0	264.2	53.34	295	68.58	271.8	0	0	0	0	0	165.1	330.2	0
	August	373	0	0	373.4	203.2	0	0	0	0	0	0	78.74	0	500.4	157.5	269	170.2	0	99.06	243.8	234	254	58.42	292	154.9	0	0	411.5	515.6	596.9	391
	September	102	121.9	20.32	101.6	121.9	229	350.5	30.48	289.6	167.6	139.7	185.4	139.7	279.4	248.9	198	93.98	45.72	116.8	162.6	12.7	76.2	149.9	137	188	53.34	27.94	40.64	299.7	287	
	October	130	144.8	363.2	116.8	144.8	277	0	535.9	0	96.52	109.22	132.1	0	264.2	241.3	627	0	312.4	147.3	198.1	384	0	0	0	0	0	515.6	228.6	190.5	0	76
	November	63.5	368.3	431.8	208.3	48.26	145	0	360.7	353.1	210.8	134.62	556.3	154.9	246.4	256.5	290	162.6	35.56	0	205.7	0	167.6	180.3	91.4	38.1	7.62	149.9	284.5	205.7	0	
	December	0	0	0	172.7	0	0	0	43.18	127	127	27.94	185.4	284.5	27.94	99.06	218	55.88	152.4	0	104.1	68.6	0	68.58	0	0	119.4	10.16	147.3	0	0	0
2023	January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	11.1	1.4	0	0	0	0
	February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	11.1	1.4	0			
	March	4.3	19.7	2	14.3	0	0	0	0	0	0.5	28.1	13	3	0	8.7	0	4.4	1.1	18	6.2	0	4	3.4	0.8	3	2.5	0	26	2.2	49	32
	April	0	0.5	0.2	3.6	0.5	0	0	26.6	5	9.2	0	0	28	16.2	0	13.4	9.2	44.5	0	0	0	9.3	0.2	7.4	16.5	0	0.1	9.4	2.8	1.5	
	May	8.5	2.6	1.7	3.2	8.5	8.2	0	0.1	0.6	16.2	20.3	0	0.1	20	13.5	0.1	2	0.1	2.3	0	5.3	0.7	1	0.9	4.5	9	12.1	3.5	3	22	0.7
	June	1.7	13	0	0	0	0	3.2	28.5	0	6.1	6.4	13.1	4.3	3.5	12.1	0.1	3.2	46.5	1.3	0.1	11.3	0.1	19.5	7.5	6.5	0	0	26	12	8	
	July	10	3	0	3.1	0	0	0	0	0	0	0.1	2.7	0	7.8	0.7	1.4	0	0	0.6	1.1	0	0	8	13	1	0	0	0	23	0.6	0.1
	August	0	11.5	5.7	1.1	0.6	2	0.6	0	0.7	27.7	4.5	0.5	1.3	4.6	0	0	0.8	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0

	September		0	8.5	0	35.7	13.5	3.7	1	0	40.2	67	0.1	0.7	1.1	7.5	5.7	18	2.5	13.5	0.7	5	1.5	13	0.6	6.4	47.3	17	6.7	1.5	4.5	23.5	
	October		15.1	17.4	0.5	0	5.5	4.5	2	0.5	9.7	12	13.7	0.7	11.5	13.4	3.3	2.5	0	7.2	0	1.4	0.5	7.6	4.1	1.1	9.4	17.4	tr	31.3	19.1	8.3	16
	November		75.1	2.4	7.7	6.6	4.6	0.7	7.6	0.5	4.5	0.1	25.7	8.1	0	0.5	16.1	8.6	12.1	0	15.5	6.8	9.8	1.1	0	45.1	0	0	2.1	1.6	8.1	0.6	
	December		6.9	0	0	0.1	0	4.6	2.3	1.5	2.3	3	0.1	4.8	0	0	1.1	0.6	0	0	0	0.5	0.1	2.1	0	0	0	0	2.1	0	0	29.3	18
2024	January		8.1	1.1	2.3	2.4	0	2.6	2	4.2	2.2	2.6	22.4	0.1	2.1	1	0	0	0.1	0	0	1.5	tr	0	0	0	6.6	0.5	tr	0	0	0.8	0
	February		4.5	0	1	1	2	1	0	0	11.4	11	3.7	0	1.4	28.5	4.3	0	0	0	0	2.1	0	0	0	0	0	8.1	23	1.1	0.1		
	March		25	0	20	5.4	4.5	4	15.7	4.8	0.1	17.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	6.3	3	16.1	18.5	38.4	2.5	23
	April		4.5	22.7	35.5	1.1	28.7	12.8	3.3	0.5	0	0.7	0	0	2.9	0	2.6	8.5	3.8	14.5	2.8	34.1	6.5	6.9	6.8	7.8	4.7	0.1	32.5	33	2.5	8.8	
	May		24	7.5	4.2	15.5	0.1	0	0.7	0.5	44.7	20	5.7	0.1	0.9	0.1	2.5	0.1	0	15.7	6.7	16.3	9.7	18.9	23	0.9	0	0	0	0	0	0	0
	June		0	0	1.3	3.4	0	2.4	15.3	3.5	1.4	0	0	2.6	0	0	2.5	3.5	3.7	0	4.6	2	44.6	1.5	4.4	11.4	1.1	0	1.4	3	2	0	
	July		0	1	0	0	tr	2.1	5.1	0	3.4	tr	4.2	3.2	8.4	0	0.8	9.1	0	1	28.3	0	0	20.5	0.6	0.7	0	0	0.5	0	4.3	0	0
	August		0	0	30.1	0	2.4	0	0	7.2	30.2	6.1	7.7	12.5	1	0.7	tr	2.7	14.1	0.7	2.8	0	2.3	tr	0	tr	3.9	6.1	0	17.8	13.4	25	0
	September		3.5	0	11.1	22.3	0.8	3	2.4	0	4.2	1.2	12.4	0.6	4.1	tr	0	19.3	26.6	2.2	4.2	0	5	2.8	0.1	5.7	3.4	0	9.4	2.6	2.7	2.1	
	October		20	0	0	0	27	57	16.2	2.7	tr	10	1.2	0.6	6.5	26.4	17.4	tr	tr	16.3	0	18.4	7.4	13.4	32.5	1	15.1	11.4	0	1.3	18.4	tr	2.1
	November		2.2	9.2	tr	tr	3.3	11	9.2	0.1	0	0	6.8	0	0	3.4	8.2	0	tr	0	tr	3.9	1.4	24	2.4	30.4	0	21	13.7	16.2	3.7	0	
	December		0.5	5.9	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.6	0.0	0.0	0.5	16.0	2.0	16.3	tr	1.3	2.3	2.5	tr	0.0	0.0	0.0	0.0	0.0
2025	January		0	0	0	0	0	0	0	0	0	7.9	0	0	0	0	0	0	0	0	0	0	0	0	0.8	5.1	3.2	1.8	2.7	0	0	0	0

	February	13	0	0	0	0	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data

Borehole Number	Li/BUD/004	Li/BUD/003	MBL/05/440	Li/BUD/006	DWD32763	MBL/05/030	MBL/05/045	MBL/05/032	Li/BUD/001	Li/BUD/005	Li/BUD/002	DWD51922	DWD41494
Water Point	Deep Well	Deep Well	Deep Well	Deep Well	Borehole	Deep Well	Deep Well	Deep Well	Deep Well	Deep Well	Deep Well	Borehole	Borehole
Latitude					0.362853	0.0833333		0.1				1.01240031	1.183333333
Longitude					33.779708	32.116667		32.1				34.3705157	33.98333333
Altitude(m)					0.362853	0.0833333		0.1				1.01240031	1.183333333
UTM Zone	36S	36S	36N	36S	36	36N	36N		36S	36S	36S	36N	36N
WM Zone													
District	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA	BUDUDA
County	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA	MANJIYA
Subcounty	SHAFATSA	BUMAYOILA	BUSKIKA	BUDUDA	TOWN COUNCIL	BAKIGAI	BUKIGAI	BAKIGAI	BUDUDA	BUDUDA TC	BUSKIKA	BUBIITA	BUKIGAI
Parish	BUWALI	BUNADUTU	BUFUTSA	BUDUDA T/C	NASHULA	BUNAMUBI	BULOBI	BUMATANDA	BUSHINYEKWA	BULOLIM/WARD	BUSHUNYA	BUWALI	BUMATANDA
Village	BUBISKWA	NAGOBE	NANGOKO	BUDUDA CELL	BUNAEMEBE	BUNAMUBI	NAMAWULULU	BUMUKOYA	WAMARA	BULOLI	BUMATAYA	BUWASHI	BUMUKOYA
Source Name													
Owner Ship					Communal							Communal	Communal
Owner Contact Number												0	1010101010
Water Use					Communal							Domestic	Domestic
Organisation												DRACO (UGANDA) LIMITED	DRACO (U) LTD
Site Investigation Method											Electrical Resistivity Method		
Date of Investigation												29-01-2018	41671

Recommended Depth of Borehole(m)												55	
Date of Completion	34004	34004	34004	34004	34004	34004	34004	34004	34004	34004	34004	43314	18-01-2014
Drilling Method												Direct Air Rotary	Direct Air Rotary
Casing Material					PVC							PVC	127
Casing Diameter(mm)					127							127	
Total Casing Length(m)	0	0	0	0	2.75	0	0	0	0	0	0	45	
Height of Surface Casing(m)	0	0	0	0		0	0	0	0	0	0	0	
Datum Elevation(m a.g.l)	0	0	0	0		0	0	0	0	0	0		
Borehole Seal Type												Cement	
Well Development Method					Airlift							AirLift	Airlift
Duration of Development(hrs)					1							1	1
Borehole Filters												Gravel Pack	
Depth at slot size1												34.5	
Depth at slot size2												40	
Depth at slot size3												48.25	
Depth at slot size4													
Depth at slot size5													
Slot Size1												1	
Slot Size2												1	
Slot Size3												1	
Slot Size4													
Slot Size5													
Total Drilled	0	0	0	0	55	0	0	0	0	0	0	52	66

Depth(m b.g.l)													
Date of Installation												23-02-2018	21-01-2014
Pump Type												Hand pump	Hand pump
Name of Pump												U2	U-2
Pump Capacity(m3/hr)												1	1
Pump Installation Depth(m.b.gl)												18	27
Riser Pipe material												PVC	PVC
Riser Pipe Diameter(mm)												32	32
Pump Rod Material												Stainless steel	Stainless steel
Pump Rod Diameter(mm)												12	12
Depth to Bedrock(m b.g.l)	0	0	0	0	33	0	0	0	0	0	0	42	24
Overall Geological Setting													
Lithology Depth1												1	3
Lithology Depth2												6	15
Lithology Depth3												18	24
Lithology Depth4												42	66
Lithology Depth5												52	
Lithology Depth6													
Lithology Depth7													
Lithology Description1												BLACK TOP SOIL	CLAY SOIL
Lithology Description2												BROWN HARD CLAY	LATERITIC CLAY
Lithology Description3												SAND	WEATHERED CLAY FORMATION
Lithology Description4												WEATHERED GRANITE	FRACTURED HARD AMPHOBOLITE
Lithology Description5												FRESH GRANITE	

Lithology Description6													
Lithology Description7													
DepthToWaterStrike1												27	24
EstimatedYield1												5	0.3
AquiferType1												Fractured Bedrock	Other
OtherAquifer1													INTERFACE
DepthToWaterStrike2													
EstimatedYield2													
AquiferType2													
OtherAquifer2													
DepthToWaterStrike3													
EstimatedYield3													
AquiferType3													
OtherAquifer3													
DepthToWaterStrike4													
EstimatedYield4													
AquiferType4													
OtherAquifer4													
DepthToWaterStrike5													
EstimatedYield5													
AquiferType5													
OtherAquifer5													
Table Height(m a.g.l)												0.5	
Length of Drilling Rods(m)												3	
Length of Drill Bit(m)												0.5	
Measuring Point(m a.g.l)												0.5	0.7
Pump Installation Depth(m.b.MP)												50	42
Static Water Level(m.b.MP)												10.78	17.88

Disharge(m3/hr) Step1													
Disharge(m3/hr) Step2													
Disharge(m3/hr) Step3													
Disharge(m3/hr) Step4													
Disharge(m3/hr) Step5													
Step Test Drawdown(m b.g.l)												3.53	4.41
Step Test Duration(min)												180	180
Step Test Recovery(%)												0.9887	0.9252
Constant Test Pump Installation Depth(m b.M.P)													
Constant Test Static Water Level(m b.g.l)													
Constant Test Dynamic Water Level(m b.g.l)													
Constant Test Discharge(m b.g.l)													
Constant Test Duration(min)													
Constant Test Recovery(%)													
Depth(m)1													
BackfillMaterial1													
Depth(m)2													
BackfillMaterial2													
Depth(m)3													
BackfillMaterial3													
Depth(m)4													
BackfillMaterial4													
Depth(m)5													

BackfillMaterial5													
Transmissivity(m 2/day)													
Specific Capacity(m3/hr/ m)												0.2857	1
Water Quality Certificate Issued by												NWSC	NWSC
Sample Number												K639//2018	K064/14/C
Serial Number												ES/RF/2018 /235	INV/2014/3 8-2
Bi-Carbonates												278.16	130
Calcium												46.4	0
Chloride												0	4.5
Color(apparent)												6	0
Conductivity												403	340
Fluoride												0	0.25
Magnesium												8.64	9.6
Manganese												0	0.006
Nitrate												0	0.02
PH												6.91	6.69
Sodium												0	0
Sulphates												3	7
Sulphide												0	0
Total Alkalinity												228	130
Total Dissolved Solids												257.92	173
Total Hardness												152	140
Total Iron												0.016	0.13
Total Suspended Solids												0	0
Turbidity												0.62	0.1

APPENDIX B: LABORATORY TEST RESULTS

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SOIL: PARTICLE DENSITY (USING A PYKNOMETER)

Ref: BS EN ISO 17892-3:2018

Project Name: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD

Student: AHABWE MARTHA AND CYNTHIA MAYALA

Technician: BAKAKI MICHAEL

Testing Date: 1/25/2024

Sample Reference:		G/S/25/163,1	G/S/25/163,2	G/S/25/163,3	G/S/25/165,1	G/S/25/165,2	G/S/25/165,3
Pyknometer No:		c	k	z	3	9	Q
Mass of bottle (g)	M_1	111.3	111.5	123.9	122.4	100.9	114.9
Mass of bottle + soil (g)	M_2	161.7	161.5	173.7	172.7	151	165
Mass of bottle + soil water (g)	M_3	412.4	412.9	417.9	413.3	389.7	406.4
Mass of bottle + water (g)	M_4	381	381.5	388.1	383.6	359	376.1
Specific Gravity, Gs		2.65	2.69	2.49	2.44	2.58	2.53

Sample Reference:		G/S/25/164,1	G/S/25/164,2	G/S/25/164,3
Pyknometer No:		L	M	10
Mass of bottle (g)	M_1	113.3	110.5	103.4
Mass of bottle + soil (g)	M_2	163.2	160.2	153.2
Mass of bottle + soil water (g)	M_3	416.2	400.6	397
Mass of bottle + water (g)	M_4	386.3	369.5	365.9
Specific Gravity, Gs		2.50	2.67	2.66

Tetsted by: Laboratory Engineer

Checked by: Senior Laboratory Engineer

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DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

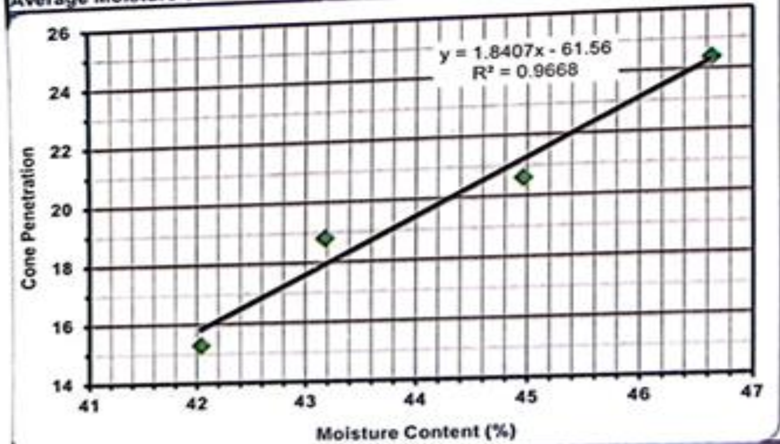
BS 1377-2:1990

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA and AHABWE MARTHA

Sample Location:	SHIKURUWE Village		
Sample Reference:	163,1	**Testing Date:**	25/Jan/25
Sample Depth (m):	1m	**Technician:**	BAKAKI MICHAEL
Sampling Date:	1/20/2025	**Client Reference**	TP01

	LIQUID LIMIT								PLASTIC LIMIT		
TEST NO.	1		2		3		4		1	2	Average
Initial dial gauge reading mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Final dial gauge reading mm	15.33	15.33	18.83	18.83	20.63	20.63	24.41	24.41			
Average penetration mm	15.3		18.8		20.6		24.4				
Container No.	90	153	BH1	87	BY	33	180	178	WX	181	
Mass of wet soil + container (a)	28.02	28.18	29.54	29.90	29.81	29.20	32.14	32.42	22.66	22.01	
Mass of dry soil + container (b)	23.70	23.64	24.34	25.09	24.49	24.21	26.26	26.31	20.59	20.01	
Mass of container (c)	13.48	12.78	12.39	13.86	12.69	13.08	13.62	13.24	13.68	12.58	
Mass of moisture (d = a-b)	4.32	4.54	5.20	4.81	5.32	4.99	5.88	6.11	2.07	2.00	
Mass of dry soil (e = b-c)	10.22	10.86	11.95	11.23	11.80	11.13	12.64	13.07	6.91	7.43	
Moisture content (w =100X(d)/(e)	42.27	41.80	43.51	42.83	45.08	44.83	46.52	46.75	29.96	26.92	
Average Moisture content	42.0		43.2		45.0		46.6		28.4		



Natural moisture content		%
Sample Preparation		
a) as received		°C
b) air dried		
c) washed on 0.425 mm		°C
d) oven dried	105-110	
e) unknown		
Proportion pasing 0.425 mm		%
Liquid limit; LL	44.3	%
Plastic limit PL	28.4	%
Plastic Index PI	15.9	%

LINEAR SHRINKAGE

Initial length L_o mm	140	mm	Oven-dried length L_D mm	127.5	mm
Linear shrinkage, LS = $100X(1-L_D/L_o)$ %	9.1	%	Shrinkage Product, SP=LSX%<425 µm	0	

Checked by:

Laboratory Engineer

Approved by:

Senior Laboratory Engineer

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DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

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BS 1377-2:1990

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA and AHABWE MARTHA

Sample Location: SHIKURUWE Village

Sample Reference: 163,2

Sample Depth (m): 1m

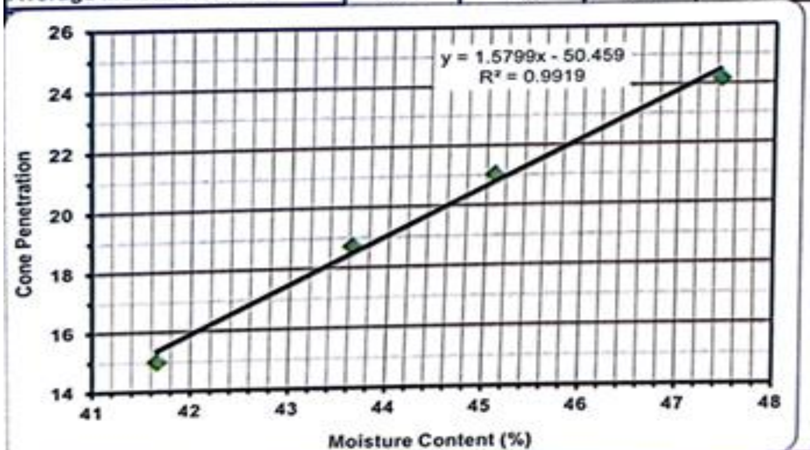
Sampling Date: 1/20/2025

Testing Date: 25/Jan/25

Technician: BAKAKI MICHAEL

Client Reference TP01

TEST NO.	LIQUID LIMIT								PLASTIC LIMIT		
	1		2		3		4		1	2	Average
Initial dial gauge reading mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Final dial gauge reading mm	15.03	15.03	18.75	18.75	21.07	21.07	24.20	24.20			
Average penetration mm	15.0		18.8		21.1		24.2				
Container No.	BL	35	BH3	21	26	BM2	X05	192	13	89	
Mass of wet soil + container (a)	28.28	28.69	29.60	29.82	28.93	28.71	32.97	32.22	22.64	22.64	
Mass of dry soil + container (b)	23.70	24.25	24.52	24.86	23.89	23.84	26.64	26.17	20.45	20.54	
Mass of container (c)	12.61	13.68	12.79	13.57	12.60	13.14	13.14	13.56	12.84	12.49	
Mass of moisture (d = a-b)	4.58	4.44	5.08	4.96	5.04	4.87	6.33	6.05	2.19	2.10	
Mass of dry soil (e = b-c)	11.09	10.57	11.73	11.29	11.29	10.70	13.50	12.61	7.61	8.05	
Moisture content (w =100X(d)/(e)	41.30	42.01	43.31	43.93	44.64	45.51	46.89	47.98	28.78	26.09	
Average Moisture content	41.7		43.6		45.1		47.4		27.4		



Natural moisture content		%
Sample Preparation		
a) as received		
b) air dried		°C
c) washed on 0.425 mm		
d) oven dried	105-110	°C
e) unknown		
Proportion pasing 0.425 mm		%
Liquid limit; LL	44.6	%
Plastic limit PL	27.4	%
Plastic Index PI	17.2	%

LINEAR SHRINKAGE

Initial length L_o, mm	140	mm	Oven-dried length L_D, mm	127.5	mm
Linear shrinkage, LS = $100X(1-L_D/L_o)$ %	9.1	%	Shrinkage Product, SP=LSX %<425 µm	0	

Checked by:

Laboratory Engineer

Approved by:

Senior Laboratory Engineer

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GETLAB LTD
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DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

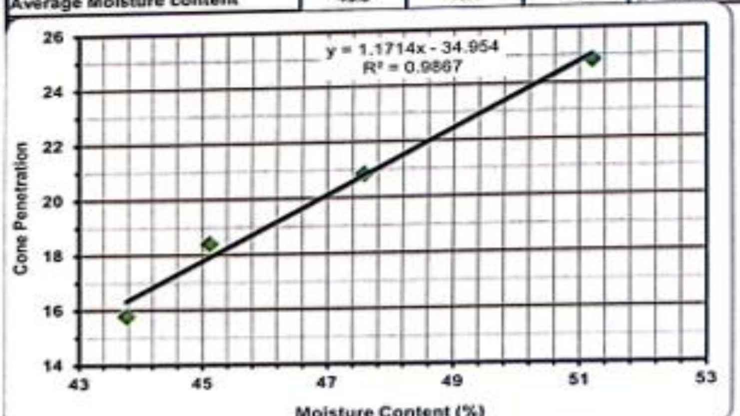
BS 1377-2:1990

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA and AHABWE MARTHA

Sample Location:	SHIKURUWE Village		
Sample Reference:	163,3	**Testing Date:**	25/Jan/25
Sample Depth (m):	1m	**Technician:**	BAKAKI MICHAEL
Sampling Date:	1/20/2025	**Client Reference**	TP01

	LIQUID LIMIT								PLASTIC LIMIT		
TEST NO.	1		2		3		4		1	2	Average
Initial dial gauge reading mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Final dial gauge reading mm	15.82	15.82	18.44	18.44	20.88	20.88	24.85	24.85			
Average penetration mm	15.8		18.4		20.9		24.9				
Container No.	SG3	S5	MS	17	176	24	SG4	46	AY	155	
Mass of wet soil + container (a)	23.63	23.87	25.99	25.67	29.57	29.90	31.33	31.99	21.32	21.96	
Mass of dry soil + container (b)	20.50	20.43	22.07	21.92	23.85	24.53	25.26	25.73	19.54	20.20	
Mass of container (c)	13.35	12.57	13.50	13.49	11.88	13.19	13.41	13.49	13.38	13.29	
Mass of moisture (d = a-b)	3.13	3.44	3.92	3.75	5.72	5.37	6.07	6.26	1.78	1.76	
Mass of dry soil (e = b-c)	7.15	7.86	8.57	8.43	11.97	11.34	11.85	12.24	6.16	6.91	
Moisture content (w =100X(d)/(e)	43.78	43.77	45.74	44.48	47.79	47.35	51.22	51.14	28.90	25.47	
Average Moisture content	43.8		45.1		47.6		51.2		27.2		



Natural moisture content		%
Sample Preparation		
a) as received		
b) air dried		°C
c) washed on 0.425 mm		
d) oven dried	105-110	°C
e) unknown		
Proportion pasing 0.425 mm		%
Liquid limit; LL	46.9	%
Plastic limit PL	27.2	%
Plastic Index PI	19.7	%

LINEAR SHRINKAGE

Initial length L_o, mm	140	mm	Oven-dried length L_D, mm	127.5	mm
Linear shrinkage, LS = $100X(1-L_D/L_o)$ %	9.1	%	Shrinkage Product, SP=LSX-%<425 μm	0	

Checked by:	***Approved by:***
Laboratory Engineer	**Senior Laboratory Engineer**

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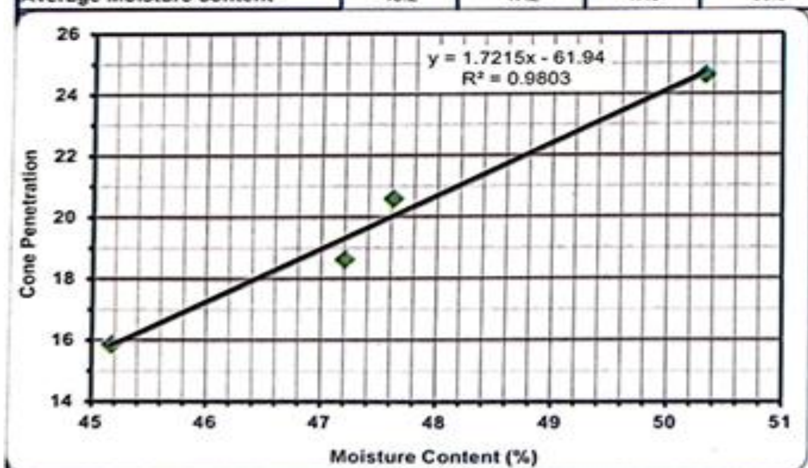
DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

Project:	HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION
STUDENT	MAMFA MAYALA and AHABWE MARTHA
Sample Location:	SHIRUWE Village
Sample Reference:	164,1
Sample Depth (m):	1m
Sampling Date:	1/20/2025
Testing Date:	25/Jan/25
Technician:	BAKAKI MICHAEL
Client Reference	TP02

	LIQUID LIMIT								PLASTIC LIMIT		
TEST NO.	1		2		3		4		1	2	Average
Initial dial gauge reading mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Final dial gauge reading mm	15.89	15.89	18.66	18.66	20.63	20.63	24.65	24.65			
Average penetration mm	15.9		18.7		20.6		24.7				
Container No.	T7	AO	190	106	BH6	SX	119	AT	MY	BH18	
Mass of wet soil + container (a)	28.62	28.09	29.15	29.54	29.37	29.53	30.17	30.50	24.34	24.32	
Mass of dry soil + container (b)	23.67	23.49	23.96	24.19	24.27	24.37	24.24	24.88	21.97	21.82	
Mass of container (c)	12.76	13.26	12.91	12.91	13.48	13.61	12.36	13.80	13.17	13.46	
Mass of moisture (d = a-b)	4.95	4.60	5.19	5.35	5.10	5.16	5.93	5.62	2.37	2.50	
Mass of dry soil (e = b-c)	10.91	10.23	11.05	11.28	10.79	10.76	11.88	11.08	8.80	8.36	
Moisture content (w =100X(d)/(e)	45.37	44.97	46.97	47.43	47.27	47.96	49.92	50.72	26.93	29.90	
Average Moisture content	45.2		47.2		47.6		50.3		28.4		



Natural moisture content		%
Sample Preparation		
a) as received		
b) air dried		°C
c) washed on 0.425 mm		
d) oven dried	105-110	°C
e) unknown		
Proportion pasing 0.425 mm		%
Liquid limit; LL	47.6	%
Plastic limit PL	28.4	%
Plastic Index PI	19.2	%

LINEAR SHRINKAGE

Initial length L_o, mm	140	mm	Oven-dried length L_D, mm	127.5	mm
Linear shrinkage, LS = $100X(1-L_D/L_o)$ %	9.1	%	Shrinkage Product, SP=LSX %<425 µm	0	

Checked by:

Laboratory Engineer

Approved by:

Senior Laboratory Engineer

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GETLAB LTD
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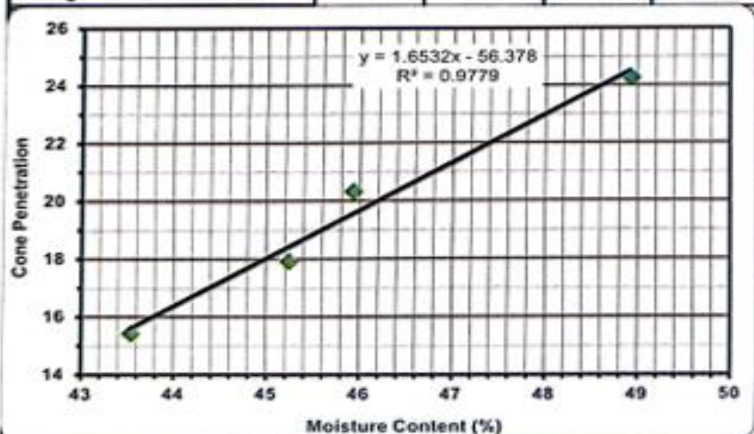
DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

Project:	HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION
STUDENT	MAMFA MAYALA and AHABWE MARTHA
Sample Location:	SHIKURUWE Village

Sample Reference:	164,2-1	**Testing Date:**	25/Jan/25
Sample Depth (m):	1m	**Technician:**	BAKAKI MICHAEL
Sampling Date:	1/20/2025	**Client Reference**	TP02

	LIQUID LIMIT								PLASTIC LIMIT		
TEST NO.	1		2		3		4		1	2	Average
Initial dial gauge reading mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Final dial gauge reading mm	15.45	15.45	17.96	17.96	20.36	20.36	24.28	24.28			
Average penetration mm	15.5		18.0		20.4		24.3				
Container No.	P4	50	142	193	54	156	121	BB	621	BM10	
Mass of wet soil + container (a)	29.75	29.37	29.86	28.42	29.70	29.85	31.10	31.17	23.50	23.50	
Mass of dry soil + container (b)	24.67	24.56	24.79	23.70	24.33	24.62	25.04	25.04	21.16	21.29	
Mass of container (c)	12.97	13.54	13.57	13.28	12.75	13.12	12.50	12.66	13.39	12.99	
Mass of moisture (d = a-b)	5.08	4.81	5.07	4.72	5.37	5.23	6.06	6.13	2.34	2.21	
Mass of dry soil (e = b-c)	11.70	11.02	11.22	10.42	11.58	11.50	12.54	12.38	7.77	8.30	
Moisture content (w =100X(d)/(e))	43.42	43.65	45.19	45.30	46.37	45.48	48.33	49.52	30.12	26.63	
Average Moisture content	43.5		45.2		45.9		48.9		28.4		



Natural moisture content		%
Sample Preparation		
a) as received		
b) air dried		°C
c) washed on 0.425 mm		
d) oven dried	105-110	°C
e) unknown		
Proportion pasing 0.425 mm		%
Liquid limit; LL	46.2	%
Plastic limit PL	28.4	%
Plastic Index PI	17.8	%

LINEAR SHRINKAGE

Initial length L_o mm	140	mm	Oven-dried length L_D mm	127.5	mm
Linear shrinkage, LS = 100X(1-L_D/L_o) %	9.1	%	Shrinkage Product, SP=LSX %<425 µm	0	

Checked by:

Laboratory Engineer

Approved by:

Senior Laboratory Engineer

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GETLAB LTD
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DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

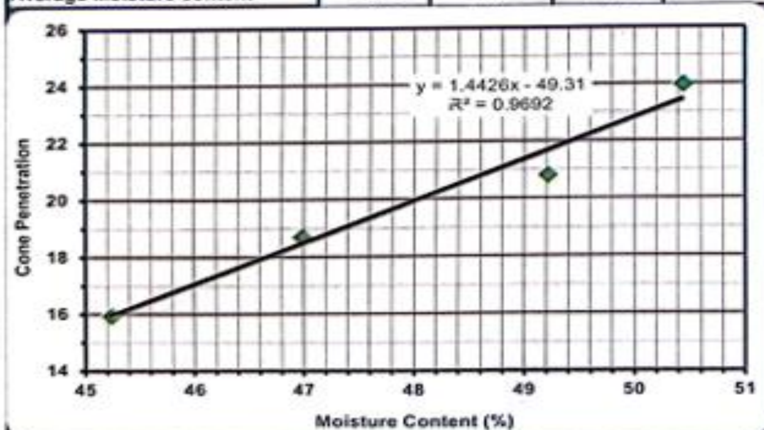
BS 1377-2:1990

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA and AHABWE MARTHA

Sample Location:	SHIKURUWE Village		
Sample Reference:	164.3	**Testing Date:**	25/Jan/25
Sample Depth (m):	1m	**Technician:**	BAKAKI MICHAEL
Sampling Date:	1/20/2025	**Client Reference**	TP02

	LIQUID LIMIT								PLASTIC LIMIT		
TEST NO.	1		2		3		4		1	2	Average
Initial dial gauge reading mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Final dial gauge reading mm	15.97	15.97	18.73	18.73	20.84	20.84	24.00	24.00			
Average penetration mm	16.0		18.7		20.8		24.0				
Container No.	114	162	BI	112	174	59	AH	180	BS	86	
Mass of wet soil + container (a)	28.19	28.03	29.72	29.10	29.63	29.15	30.59	30.60	23.63	23.60	
Mass of dry soil + container (b)	23.32	23.40	24.26	23.89	23.69	23.98	24.89	24.55	21.30	21.28	
Mass of container (c)	12.42	13.29	12.65	12.79	11.69	13.41	13.46	12.69	12.68	13.54	
Mass of moisture (d = a-b)	4.87	4.63	5.46	5.21	5.94	5.17	5.70	6.05	2.33	2.32	
Mass of dry soil (e = b-c)	10.90	10.11	11.61	11.10	12.00	10.57	11.43	11.86	8.62	7.74	
Moisture content (w =100X(d)/(e)	44.68	45.80	47.03	46.94	49.50	48.91	49.87	51.01	27.03	29.97	
Average Moisture content	45.2		47.0		49.2		50.4		28.5		



Natural moisture content		%
Sample Preparation		
a) as received		
b) air dried		°C
c) washed on 0.425 mm		
d) oven dried	105-110	°C
e) unknown		
Proportion pasing 0.425 mm		%
Liquid limit; LL	48.0	%
Plastic limit PL	28.5	%
Plastic Index PI	19.5	%

LINEAR SHRINKAGE

Initial length L_o mm	140	mm	Oven-dried length L_D mm	127.5	mm
Linear shrinkage, LS = 100X(1-L_D/L_o) %	9.1	%	Shrinkage Product, SP=LSX %<425 µm	0	

Checked by:

Laboratory Engineer

Approved by:

Senior Laboratory Engineer

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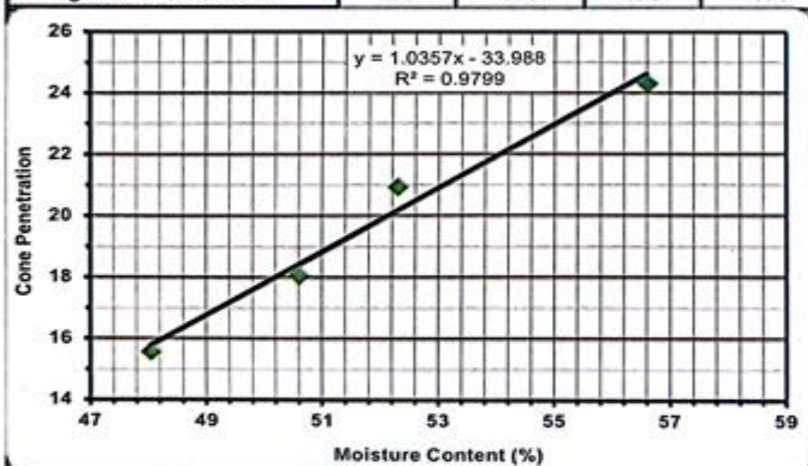
DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

Project:	HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION
STUDENT	MAMFA MAYALA and AHABWE MARTHA
Sample Location:	SHIRURUWE VILLAGE

Sample Reference:	165,1	**Testing Date:**	25/Jan/25
Sample Depth (m):	1m	**Technician:**	BAKAKI MICHAEL
Sampling Date:	1/20/2025	**Client Reference**	TP03

	LIQUID LIMIT								PLASTIC LIMIT		
TEST NO.	1		2		3		4		1	2	Average
Initial dial gauge reading mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Final dial gauge reading mm	15.60	15.60	18.10	18.10	20.96	20.96	24.33	24.33			
Average penetration mm	15.6		18.1		21.0		24.3				
Container No.	44	165	70	BM6	AI	74	69	SG3	156	142	
Mass of wet soil + container (a)	28.17	28.85	29.07	29.43	29.07	29.04	30.45	30.40	22.36	22.77	
Mass of dry soil + container (b)	23.96	22.81	23.91	23.67	23.72	23.76	24.42	24.24	20.15	20.72	
Mass of container (c)	13.94	11.64	13.71	12.29	13.51	13.64	13.77	13.35	13.12	13.58	
Mass of moisture (d = a-b)	4.21	6.04	5.16	5.76	5.35	5.28	6.03	6.16	2.21	2.05	
Mass of dry soil (e = b-c)	10.02	11.17	10.20	11.38	10.21	10.12	10.65	10.89	7.03	7.14	
Moisture content (w =100X(d)/(e)	42.02	54.07	50.59	50.62	52.40	52.17	56.62	56.57	31.44	28.71	
Average Moisture content	48.0		50.6		52.3		56.6		30.1		



Natural moisture content		%
Sample Preparation		
a) as received		
b) air dried		°C
c) washed on 0.425 mm		
d) oven dried	105-110	°C
e) unknown		
Proportion pasing 0.425 mm		%
Liquid limit; LL	52.1	%
Plastic limit PL	30.1	%
Plastic Index PI	22.1	%

LINEAR SHRINKAGE

Initial length L_o, mm	140	mm	Oven-dried length L_D, mm	127.5	mm
Linear shrinkage, LS = $100X(1-L_D/L_o)$ %	9.1	%	Shrinkage Product, SP=LSX %<425 µm	0	

Checked by:	*Approved by:*
Laboratory Engineer	**Senior Laboratory Engineer**

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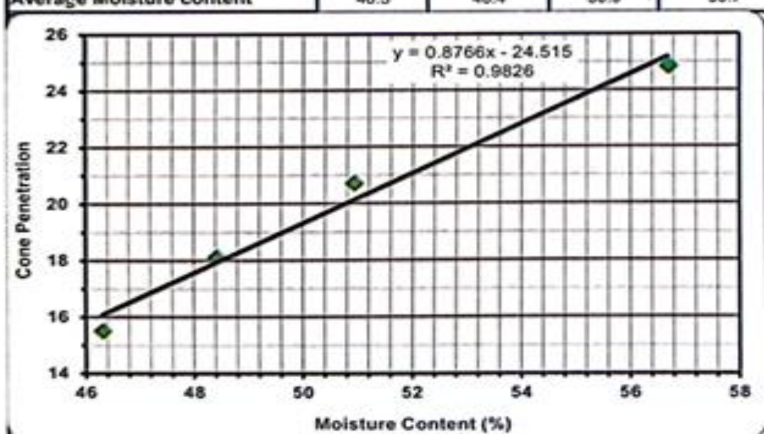
DETERMINIATION OF LIQUID LIMIT & PLASTIC LIMIT

BS 1377-2:1990

Project:	HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION
STUDENT	MAMFA MAYALA and AHABWE MARTHA
Sample Location:	SHIKURUWE Village
Sample Reference:	165,2
Sample Depth (m):	1m
Sampling Date:	1/20/2025
Testing Date:	25/Jan/25
Technician:	BAKAKI MICHAEL
Client Reference	TP03

	LIQUID LIMIT								PLASTIC LIMIT		
TEST NO.	1		2		3		4		1	2	Average
Initial dial gauge reading mm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Final dial gauge reading mm	15.55	15.55	18.15	18.15	20.75	20.75	24.86	24.86			
Average penetration mm	15.6		18.2		20.8		24.9				
Container No.	69	AV	990	TN	23	67	154	164	59	BM7	
Mass of wet soil + container (a)	30.53	30.54	31.93	31.62	32.94	32.86	34.52	34.07	22.82	22.64	
Mass of dry soil + container (b)	25.21	24.85	25.81	25.55	26.27	26.24	26.65	26.13	20.82	20.43	
Mass of container (c)	13.76	12.52	13.09	13.09	13.33	13.08	12.90	11.99	13.68	13.56	
Mass of moisture (d = a-b)	5.32	5.69	6.12	6.07	6.67	6.62	7.87	7.94	2.00	2.21	
Mass of dry soil (e = b-c)	11.45	12.33	12.72	12.46	12.94	13.16	13.75	14.14	7.14	6.87	
Moisture content (w =100X(d)/(e)	46.46	46.15	48.11	48.72	51.55	50.30	57.24	56.15	28.01	32.17	
Average Moisture content	46.3		48.4		50.9		56.7		30.1		



Natural moisture content		%
Sample Preparation		
a) as received		
b) air dried		°C
c) washed on 0.425 mm		
d) oven dried	105-110	°C
e) unknown		
Proportion pasing 0.425 mm		%
Liquid limit; LL	50.8	%
Plastic limit PL	30.1	%
Plastic Index PI	20.7	%

LINEAR SHRINKAGE

Initial length L_o, mm	140	mm	Oven-dried length L_D, mm	127.5	mm
Linear shrinkage, LS = $100X(1-L_D/L_o)$ %	9.1	%	Shrinkage Product, SP=LSX %<425 µm	0	

Checked by:

Laboratory Engineer

Approved by:

Senior Laboratory Engineer

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F/FORM/SO/01 ISSUE 02 GETLAB LTD

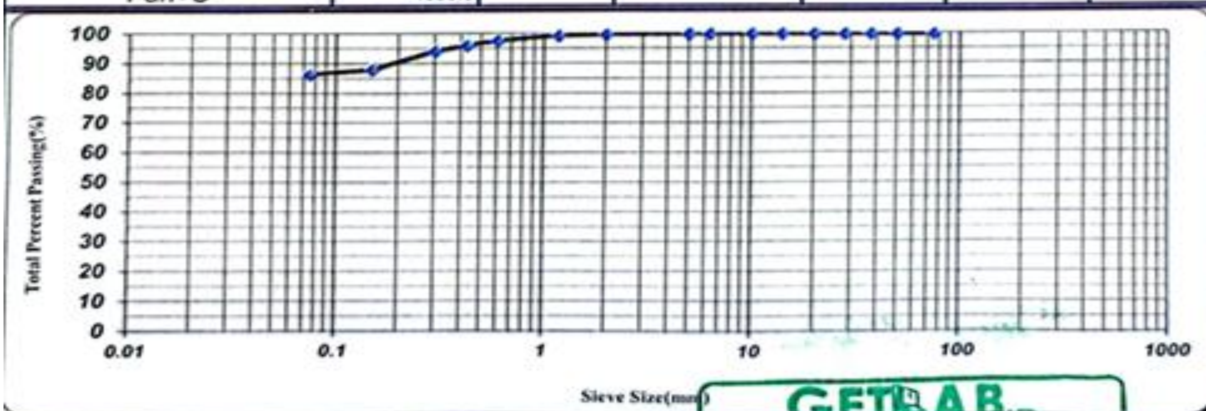
SOIL: PARTICLE SIZE DITRIBUTION

Ref: BS EN ISO 17892: Part 4: 2018

Project:	HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION
STUDENT	MAMFA MAYALA AND AHABWE MARTHA
Sample Location:	Shikuruwe village, naposhi parish, Bushika sub county bududa district
Sample Reference:	G\S\24\163.1
Sample Description.:	SANDY CLAYS
Sampling Depth (m) :	1m
Testing Date:	1/21/2025
Technician	BAKAKI MICHAEL
Client reference	TP01

Dry mass before washing(A) :	1601.1	Dry mass after washing(B) :	171.5	C = D - B =	1099.58
Mass of dry sample (D), m_1	1271.1	Moisture content:	26.0		

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	0.0	0.0	100.0			
6.3	0.0	0.0	100.0			
5	0.0	0.0	100.0			
2	1.6	0.1	99.9			
1.18	5.4	0.4	99.4			
0.600	21.5	1.7	97.8			
0.425	19.3	1.5	96.2			
0.300	24.2	1.9	94.3			
0.150	78.4	6.2	88.2			
0.075	21.3	1.7	86.5			
Pan	0.2					
Pan+C	1099.8					



Checked by:

Laboratory Engineer

Approved by:

Senior laboratory engineer

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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district

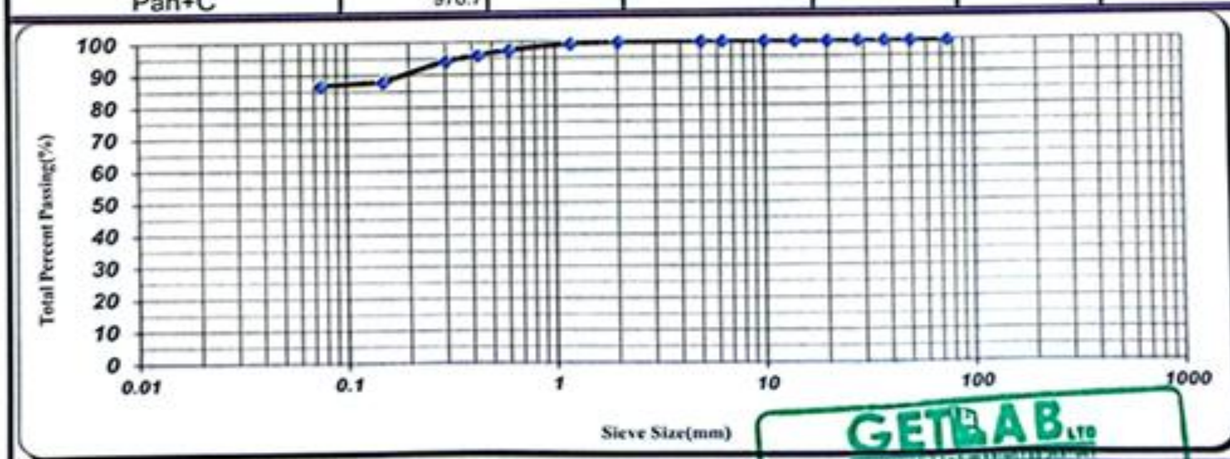
Sample Reference: G\S\24\163.2 — Testing Date: 1/21/2025

Sample Description.: SANDY CLAYS — Technician BAKAKI MICHAEL

Sampling Depth (m) : 1m — Client reference TP01

Dry mass before washing(A) :	1423.9	Dry mass after washing(B) :	146.5	C = D - B =	976.56
Mass of dry sample (D), m_1	1123.1	Moisture content:	26.8		

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	0.0	0.0	100.0			
6.3	0.0	0.0	100.0			
5	0.0	0.0	100.0			
2	0.9	0.1	99.9			
1.18	4.9	0.4	99.5			
0.600	19.7	1.8	97.7			
0.425	17.1	1.5	96.2			
0.300	18.8	1.7	94.5			
0.150	71.4	6.4	88.2			
0.075	13.5	1.2	87.0			
Pan	0.1					
Pan+C	976.7					



Checked by:

Laboratory Engineer

Approved by:

Senior laboratory engineer

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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4; 2018

Project:	HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION		
STUDENT	MAMFA MAYALA AND AHABWE MARTHA		
Sample Location:	Shikuruwe village, naposhi parish, Bushika sub county bududa district		
Sample Reference:	G\S\24\163.3	Testing Date:	1/21/2025
Sample Description.:	SANDY CLAYS	Technician	BAKAKI MICHAEL
Sampling Depth (m) :	1m	Client reference	TP01

Dry mass before washing(A) :	1536.8	Dry mass after washing(B) :	165.4	C = D - B =	1047.70
Mass of dry sample (D), m,	1213.1	Moisture content:	26.7		

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	0.0	0.0	100.0			
6.3	0.0	0.0	100.0			
5	0.1	0.0	100.0			
2	1.6	0.1	99.9			
1.18	5.3	0.4	99.4			
0.600	22.2	1.8	97.6			
0.425	19.4	1.6	96.0			
0.300	21.7	1.8	94.2			
0.150	78.0	6.4	87.8			
0.075	16.6	1.4	86.4			
Pan	0.1					
Pan+C	1047.8					

Checked by:		Approved by:	
Laboratory Engineer		Senior Laboratory Engineer	

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SOIL: PARTICLE SIZE DITRIBUTION

Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district

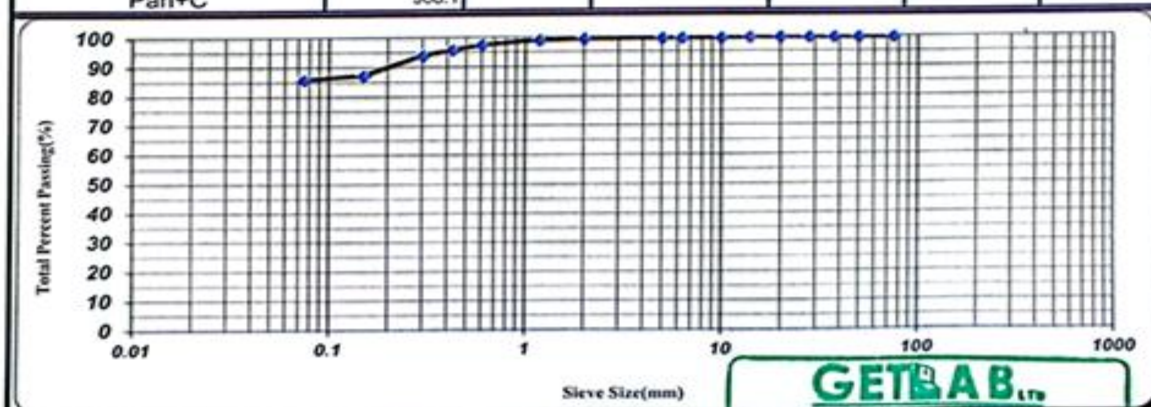
Sample Reference: G\S\24\164,1 | Testing Date: 1/21/2025

Sample Description.: SANDY CLAYS | Technician BAKAKI MICHAEL

Sampling Depth (m) : 1m | Offset: TP02

Dry mass before washing(A) :	1484.2	Dry mass after washing(B) :	158.9	C = D - B =	967.92
Mass of dry sample (D), m_1	1126.8	Moisture content:	31.7		

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	3.7	0.3	99.7			
6.3	0.0	0.0	99.7			
5	0.1	0.0	99.7			
2	1.2	0.1	99.6			
1.18	3.9	0.3	99.2			
0.600	18.0	1.6	97.6			
0.425	17.8	1.6	96.0			
0.300	21.6	1.9	94.1			
0.150	75.4	6.7	87.4			
0.075	16.1	1.4	86.0			
Pan	0.2					
Pan+C	968.1					



Checked by: | *Approved by:*

Laboratory Engineer | Senior Laboratory Engineer

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F/FORM/SO/01 | ISSUE 02 | GETLAB LTD

SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

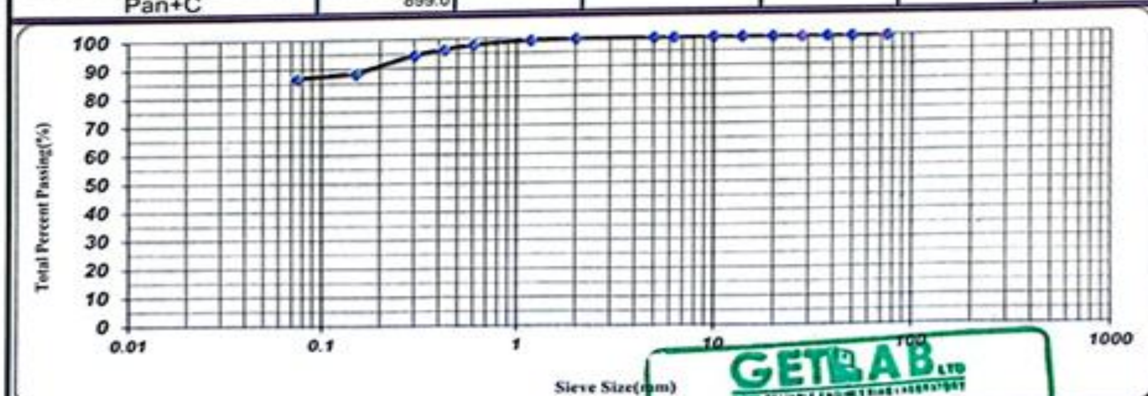
Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA AND AHABWE MARTHA

Sample Location:	Shikuruwe village, naposhi parish, Bushika sub county bududa district		
Sample Reference:	G\S\24\164.2	Testing Date:	1/21/2025
Sample Description.:	SANDY CLAYS	Technician	BAKAKI MICHAEL
Sampling Depth (m) :	1m	Client reference	TP02

Dry mass before washing(A) :	1356.4	Dry mass after washing(B) :	134.6	C = D - B =	898.88
Mass of dry sample (D), m_t	1033.5	Moisture content:	31.2		

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	0.0	0.0	100.0			
6.3	0.5	0.0	100.0			
5	0.0	0.0	100.0			
2	0.4	0.0	99.9			
1.18	3.7	0.4	99.6			
0.600	15.5	1.5	98.1			
0.425	15.4	1.5	96.6			
0.300	18.2	1.8	94.8			
0.150	64.4	6.2	88.6			
0.075	15.9	1.5	87.0			
Pan	0.1					
Pan+C	899.0					



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Laboratory Engineer	Senior Laboratory Engineer

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Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district

Sample Reference: G\S\24\164.3 | Testing Date: 1/21/2025

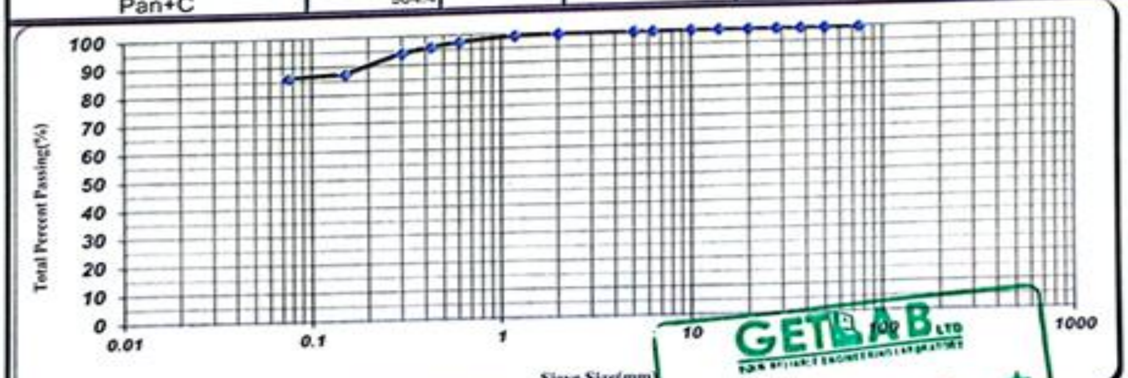
Sample Description.: SANDY CLAYS | Technician BAKAKI MICHAEL

Sampling Depth (m) : 1m | Client reference TP02

Dry mass before washing(A): 1355.2 | Dry mass after washing(B): 141.9 | C = D - B = 904.28

Mass of dry sample (D), m_1 1046.2 | Moisture content: 29.5

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	0.0	0.0	100.0			
6.3	0.9	0.1	99.9			
5	0.0	0.0	99.9			
2	0.5	0.0	99.9			
1.18	3.9	0.4	99.5			
0.600	17.6	1.7	97.8			
0.425	15.8	1.5	96.3			
0.300	19.4	1.9	94.4			
0.150	71.9	6.9	87.6			
0.075	12.1	1.2	86.4			
Pan	0.1					
Pan+C	904.4					



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Laboratory Engineer

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Senior Laboratory Technician

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SOIL: PARTICLE SIZE DITRIBUTION

Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

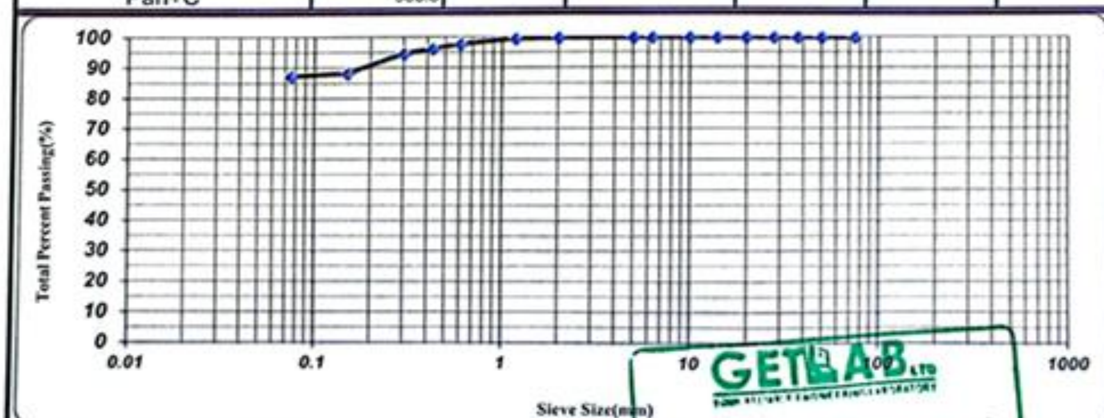
STUDENT MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district

Sample Reference:	G\S\24\165.1	Testing Date:	1/21/2025
Sample Description.:	SANDY CLAYS	Technician	BAKAKI MICHAEL
Sampling Depth (m) :	1m	Client reference	TP03

Dry mass before washing(A) :	1490.2	Dry mass after washing(B) :	143.4	C = D - B =	983.49
Mass of dry sample (D), m_1	1126.9	Moisture content:	32.2		

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	0.0	0.0	100.0			
6.3	0.0	0.0	100.0			
5	0.0	0.0	100.0			
2	0.7	0.1	99.9			
1.18	4.0	0.4	99.6			
0.600	19.0	1.7	97.9			
0.425	17.0	1.5	96.4			
0.300	18.4	1.6	94.8			
0.150	72.0	6.4	88.4			
0.075	11.0	1.0	87.4			
Pan	0.3					
Pan+C	983.8					



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Laboratory Engineer

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SOIL: PARTICLE SIZE DITRIBUTION

Ref: BS EN ISO 17892: Part 4: 2018

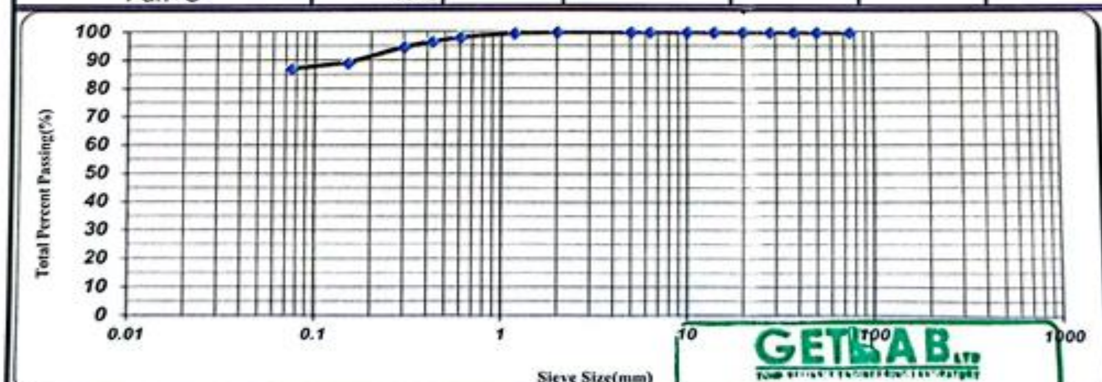
Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

STUDENT MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district

Sample Reference:	G\S\24\165.2	Testing Date:	1/21/2025
Sample Description.:	SANDY CLAYS	Technician	BAKAKI MICHAEL
Sampling Depth (m) :	1m	Client reference	TP03
Dry mass before washing(A) :	1160.0	Dry mass after washing(B) :	111.8
C = D - B =	764.11		
Mass of dry sample (D), m_1	875.9	Moisture content:	32.4

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	0.0	0.0	100.0			
6.3	0.0	0.0	100.0			
5	0.0	0.0	100.0			
2	0.0	0.0	100.0			
1.18	3.3	0.4	99.6			
0.600	13.1	1.5	98.1			
0.425	12.3	1.4	96.7			
0.300	16.8	1.9	94.8			
0.150	49.1	5.6	89.2			
0.075	17.8	2.0	87.2			
Pan	0.1					
Pan+C	764.2					



Checked by:	*Approved by:*
Laboratory Engineer	Senior Laboratory Engineer

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F/FORM/SO/01

ISSUE 02

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SOIL: PARTICLE SIZE DITRIBUTION
Ref: BS EN ISO 17892: Part 4: 2018

Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

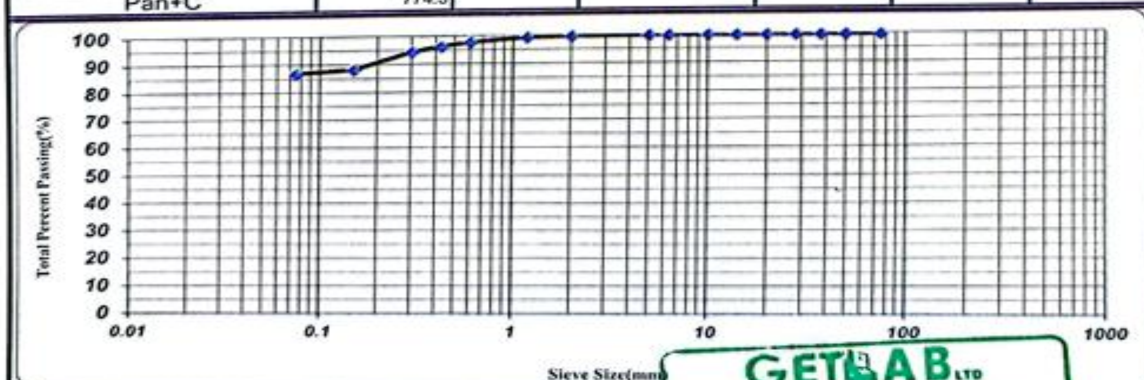
STUDENT MAMFA MAYALA AND AHABWE MARTHA

Sample Location: Shikuruwe village, naposhi parish, Bushika sub county bududa district

Sample Reference:	G\S\24\165.3	Testing Date:	1/21/2025
Sample Description.:	SANDY CLAYS	Technician	BAKAKI MICHAEL
Sampling Depth (m) :	1m	Client reference	TP03

Dry mass before washing(A) :	1183.3	Dry mass after washing(B) :	114.0	C = D - B =	774.24
Mass of dry sample (D), m₁	888.2	Moisture content:	33.2		

Sieve size (mm)	Mass retained (grams)	% retained	% Passing	Specification upper limit	Specification lower limit	Remarks
75	0.0	0.0	100.0			
50	0.0	0.0	100.0			
37.5	0.0	0.0	100.0			
28	0.0	0.0	100.0			
20	0.0	0.0	100.0			
14	0.0	0.0	100.0			
10	0.0	0.0	100.0			
6.3	0.0	0.0	100.0			
5	0.0	0.0	100.0			
2	1.2	0.1	99.9			
1.18	3.3	0.4	99.5			
0.600	14.0	1.6	97.9			
0.425	12.9	1.5	96.5			
0.300	16.3	1.8	94.6			
0.150	55.2	6.2	88.4			
0.075	11.7	1.3	87.1			
Pan	0.1					
Pan+C	774.3					



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Checked by:

Laboratory Engineer

Approved by:

30 JAN 2025

Senior Laboratory Engineer

Technology Laboratory Ltd
P. O. Box 100001, Kasangati

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DIRECT SHEAR BOX TEST OF SOILS (BS EN ISO 17892-7:2017)

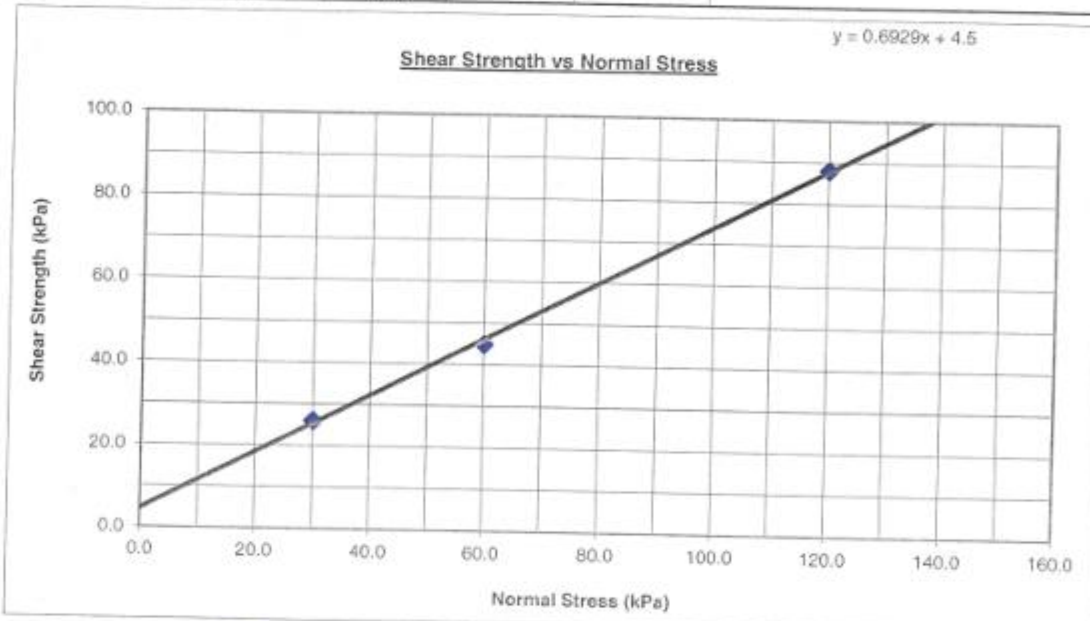
Project: HORIZONTAL SUBDRAINAGE SYSTEM APPROACH TOWARS LANDSLIDE HAZARD MITIGATION

Client MAMFA MAYALA AND AHABWE MARTHA

Location Pit 01, Sample 2 | **Date Tested:** 27/02/25

Depth (m): 1.00

Bulk Density	Normal Stress	Shear Strength	Cohesion	Angle of Internal Friction	Soil Description
γ_b	δ_n	τ_s	C	ϕ	
Mg/m^3	kPa	kPa	kPa	(Degree)	
1.96	30.0	26.0	4.5	34.7	Moist loose reddish brown sandy clays
	60.0	45.0			
	120.0	88.0			



Approved by:

Laboratory Engineer

Sen. Laboratory Engineer

GETLAB LTD
04 MAR 2025
Geotechnical Engineering & Technology Laboratory Ltd
P. O. Box 100001, Kasangati

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DETERMINATION OF THE UNDRAINEGD STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8
TEST REPORT

Project Location	Shikuruwe village, naposhi parish, Bushika sub county bududa district		
Client	MAMFA MAYALA AND AHABWE MARTHA	Sample Depth	1.0
BH/TP Location	TP01	Sample Type	U -Sample
Sample Description	SANDY CLAYS	Sampled by	W.M
Tested by	BAKAKI MICHAEL OWEN	Sampling Date	N.A
Checked by	Lab Engineer	Test Date	Tuesday, January 21, 2025

DETERMINATION OF MOISTURE CONTENT

CONTAINER NO.	Mass of Wet Soil + Container	Mass of Dry Soil + Container	Mass of Container	Mass of Moisture	Mass of Dry Soil	Moisture Content	Average
ALL	239.9	186.7	39.3	53.3	147.4	36.1	36.3
ROO	225.2	177.3	46.0	47.9	131.3	36.5	

SPECIMEN DETAILS		*Specimen 1*		*Specimen 2*		*Specimen 3*		*Average*
Height [mm]	76	Mass (g)	198.9	Mass (g)	198.9	Mass (g)	198.9	198.9
Diameter [Do]	38	Volume (cm^3)	86.2	Volume (cm^3)	86.2	Volume (cm^3)	86.2	86.2
Initial Length [Lo]	76	Bulk Density (Mg/m^3)	2.307	Bulk Density (Mg/m^3)	2.307	Bulk Density (Mg/m^3)	2.307	2.307
Area [Ao]	1134.6	Unit Weight (KN/m^3)	22.6	Unit Weight (KN/m^3)	22.6	Unit Weight (KN/m^3)	22.6	22.63
Rate of Strain ε, (%/min)	2	Dry Density (Mg/m3)	1.692	Dry Density (Mg/m3)	1.692	Dry Density (Mg/m3)	1.692	1.692

SPECIMEN 1

Force	t	ΔL	ΔL/L	ε	1−ε	Area	$\sigma_1-\sigma_3$	ε
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
150	1.4	1.4	0.0184	0.0184	0.982	1155.9	129.8	1.8
162	3.3	1.9	0.0250	0.0434	0.957	1186.1	136.6	4.3
165	5.1	1.8	0.0237	0.0671	0.933	1216.2	135.7	6.7
167	6.6	1.5	0.0197	0.0868	0.913	1242.5	134.4	8.7
171	8.2	1.6	0.0211	0.1079	0.892	1271.8	134.5	10.8
175	9.8	1.6	0.0211	0.1289	0.871	1302.5	134.4	12.9
182	11.5	1.7	0.0224	0.1513	0.849	1336.9	136.1	15.1
185	13.1	1.6	0.0211	0.1724	0.828	1370.9	135.0	17.2
190	14.6	1.5	0.0197	0.1921	0.808	1404.4	135.3	19.2
195	16.7	2.1	0.0276	0.2197	0.780	1454.1	134.1	22.0

SPECIMEN 2

Force	Displacement	ΔL	ΔL/L	ε	1−ε	Area	$\sigma_1-\sigma_3$	ε
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
185	1.6	1.6	0.0211	0.0211	0.979	1159.0	159.6	2.1
230	3.3	1.9	0.0250	0.0461	0.954	1189.3	193.4	4.6
242	5.1	1.8	0.0237	0.0697	0.930	1219.6	198.4	7.0
247	6.6	1.5	0.0197	0.0895	0.911	1246.1	198.2	8.9
249	8.5	1.9	0.0250	0.1145	0.886	1281.2	194.3	11.4
251	10.2	2.0	0.0263	0.1408	0.859	1320.5	190.1	14.1
252	11.5	1.7	0.0224	0.1632	0.837	1355.8	185.9	16.3
253	13.4	1.9	0.0250	0.1882	0.812	1397.5	181.0	18.8
254	14.6	1.5	0.0197	0.2079	0.792	1432.3	177.3	20.8
255	16.6	2.0	0.0263	0.2342	0.766	1481.6	172.1	23.4

SPECIMEN 3

Force	Displacement	ΔL	ΔL/L	ε	1−ε	Area	$\sigma_1-\sigma_3$	ε
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
221	1.7	1.7	0.0224	0.0224	0.978	1160.5	190.4	2.2
320	3.5	2.1	0.0276	0.0500	0.950	1194.3	267.9	5.0
345	5.3	2.0	0.0263	0.0763	0.924	1228.3	280.9	7.6
353	6.6	1.5	0.0197	0.0961	0.904	1255.1	281.2	9.6
356	8.6	2.0	0.0263	0.1224	0.878	1292.8	275.4	12.2
359	10.2	2.0	0.0263	0.1487	0.851	1332.7	269.4	14.9
361	11.5	1.7	0.0224	0.1711	0.829	1368.7	263.8	17.1
363	13.4	1.9	0.0250	0.1961	0.804	1411.3	257.2	19.6
365	15.1	2.0	0.0263	0.2224	0.778	1459.0	250.2	22.2
368	16.8	2.2	0.0289	0.2513	0.749	1515.4	242.8	25.1

Prepared by;
Lab Technician

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Approved by;
Lab Engineer

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DETERMINATION OF THE UNDRAINED STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8
TEST REPORT

Project Location	Shikuruwe village, naposhi parish, Bushika sub county bududa district		
Client	MAMFA MAYALA AND AHABWE MARTHA	Sample Depth	1.0
BH/TP Location	TP01	Sample Type	U -Sample
Sample Description	SANDY CLAYS	Sampled by	W.M
Tested by	BAKAKI MICHAEL OWEN	Sampling Date	N.A
Checked by	Lab Engineer	Test Date	Tuesday, January 21, 2025

CONDITIONS AT FAILURE

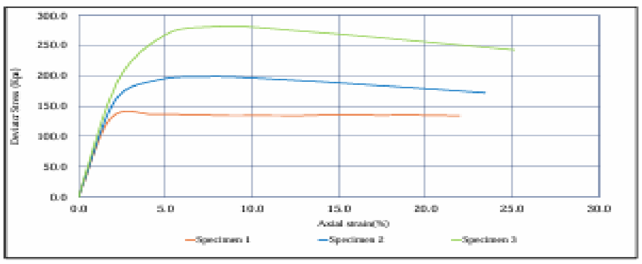
STRESSES	*Specimen 1*	*Specimen 2*	*Specimen 3*
Cell pressure (Kpa)	50	100	200
Corr. Deviator Stress (Kpa)	136.6	198.4	281.2
Shear strength (Kpa)	68.3	99.2	140.6

The Cell Confining Pressures of 50Kpa,100kpa & 200Kpa have been used while conducting the Test

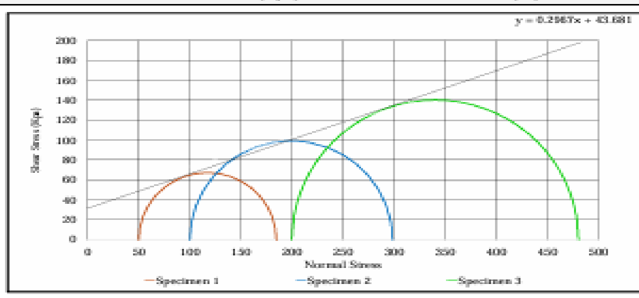
EFFECTIVE STRESS (σ_v)	22.63	(Kpa)

	Specimen 1	*Specimen 2*	*Specimen 3*
Mode of failure	Barelling	Barelling	Barelling

DEVIATOR STRESS(Kpa) AGAINST AXIAL STRAIN (%)



SHEAR STRESS(Kpa) AGAINST NORMAL STRESS(%)



UNDRAINED PARAMETERS

C	43.7
ϕ	16.5

COMMENT

No Comment

Prepared by;
Lab Technician

Approved by;
Lab Engineer

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DETERMINATION OF THE UNDRAINEGD STRENGTH IN TRIAXIAL COMPRESSION

Tested in accordance to BS: 1377:1990: Part 7: Clause 8

TEST REPORT

Project Location	Shikuruwe village, naposhi parish, Bushika sub county bududa district		
Client	MAMFA MAYALA AND AHABWE MARTHA	Sample Depth	1.0
BH/TP Location	TP02	Sample Type	U -Sample
Sample Description	SANDY CLAYS	Sampled by	W.M
Tested by	BAKAKI MICHAEL	Sampling Date	N.A
Checked by	Lab Engineer	Test Date	Tuesday, January 21, 2025

DETERMINATION OF MOISTURE CONTENT

CONTAINER NO.	Mass of Wet Soil + Container	Mass of Dry Soil + Container	Mass of Container	Mass of Moisture	Mass of Dry Soil	Moisture Content	Average
BIT	249.7	212.2	61.4	37.5	150.8	24.9	24.7
A54	242.4	205.6	55.2	36.8	150.4	24.5	

SPECIMEN DETAILS		*Specimen 1*		*Specimen 2*		*Specimen 3*		*Average*
Height [mm]	76	Mass (g)	200.4	Mass (g)	200.4	Mass (g)	200.4	200.4
Diameter [Do]	38	Volume (cm^3)	86.2	Volume (cm^3)	86.2	Volume (cm^3)	86.2	86.2
Initial Length [Lo]	76	Bulk Density (Mg/m^3)	2.324	Bulk Density (Mg/m^3)	2.324	Bulk Density (Mg/m^3)	2.324	2.324
Area [Ao]	1134.6	Unit Weight (KN/m^3)	22.8	Unit Weight (KN/m^3)	22.8	Unit Weight (KN/m^3)	22.8	22.80
Rate of Strain ε, (%/min)	2	Dry Density (Mg/m3)	1.864	Dry Density (Mg/m3)	1.864	Dry Density (Mg/m3)	1.864	1.864

SPECIMEN 1

Force	t	ΔL	ΔL/L	ε	$1-\varepsilon$	Area	$\sigma_1-\sigma_3$	ε
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
84	1.4	1.4	0.0184	0.0184	0.982	1155.9	72.7	1.8
102	3.3	1.9	0.0250	0.0434	0.957	1186.1	86.0	4.3
126	5.1	1.8	0.0237	0.0671	0.933	1216.2	103.6	6.7
141	6.6	1.5	0.0197	0.0868	0.913	1242.5	113.5	8.7
152	8.2	1.6	0.0211	0.1079	0.892	1271.8	119.5	10.8
155	9.7	1.5	0.0197	0.1276	0.872	1300.6	119.2	12.8
156	11.6	1.9	0.0250	0.1526	0.847	1338.9	116.5	15.3
156	13.2	1.6	0.0211	0.1737	0.826	1373.0	113.6	17.4
156	14.8	1.6	0.0211	0.1947	0.805	1408.9	110.7	19.5
156	16.3	1.5	0.0197	0.2145	0.786	1444.3	108.0	21.4

SPECIMEN 2

Force	Displacement	ΔL	ΔL/L	ε	$1-\varepsilon$	Area	$\sigma_1-\sigma_3$	ε
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
106	1.8	1.8	0.0237	0.0237	0.976	1162.1	91.2	2.4
151	3.5	2.1	0.0276	0.0513	0.949	1195.9	126.3	5.1
168	5.2	1.9	0.0250	0.0763	0.924	1228.3	136.8	7.6
177	6.6	1.5	0.0197	0.0961	0.904	1255.1	141.0	9.6
198	8.4	1.8	0.0237	0.1197	0.880	1288.9	153.6	12.0
210	10.2	2.0	0.0263	0.1461	0.854	1328.6	158.1	14.6
226	11.6	1.9	0.0250	0.1711	0.829	1368.7	165.1	17.1
240	13.5	1.9	0.0250	0.1961	0.804	1411.3	170.1	19.6
254	14.8	1.6	0.0211	0.2171	0.783	1449.2	175.3	21.7
255	16.3	1.5	0.0197	0.2368	0.763	1486.7	171.5	23.7

SPECIMEN 3

Force	Displacement	ΔL	ΔL/L	ε	$1-\varepsilon$	Area	$\sigma_1-\sigma_3$	ε
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
131	2.0	2.0	0.0263	0.0263	0.974	1165.2	112.4	2.6
220	3.4	2.0	0.0263	0.0526	0.947	1197.6	183.7	5.3
254	5.2	1.9	0.0250	0.0776	0.922	1230.1	206.5	7.8
282	6.8	1.7	0.0224	0.1000	0.900	1260.6	223.7	10.0
285	8.5	1.9	0.0250	0.1250	0.875	1296.7	219.8	12.5
294	10.2	2.0	0.0263	0.1513	0.849	1336.9	219.9	15.1
296	11.6	1.9	0.0250	0.1763	0.824	1377.4	214.9	17.6
298	13.4	1.8	0.0237	0.2000	0.800	1418.2	210.1	20.0
296	14.9	1.7	0.0224	0.2224	0.778	1459.0	202.9	22.2
300	16.5	1.7	0.0224	0.2447	0.755	1502.2	199.7	24.5

Prepared by;
Lab Technician

Approved by;
Lab Engineer

GEOTECHNICAL ENGINEERING AND TECHNOLOGY LABORATORY LTD
GETLAB LTD

DETERMINATION OF THE UNDRAINED STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8
TEST REPORT

Project Location	Shikuruwe village, naposhi parish, Bushika sub county bududa district		
Client	MAMFA MAYALA AND AHABWE MARTHA	Sample Depth	1.0
BH/TP Location	TP02	Sample Type	U -Sample
Sample Description	SANDY CLAYS	Sampled by	W.M
Tested by	BAKAKI MICHAEL	Sampling Date	N.A
Checked by	Lab Engineer	Test Date	Tuesday, January 21, 2025

CONDITIONS AT FAILURE

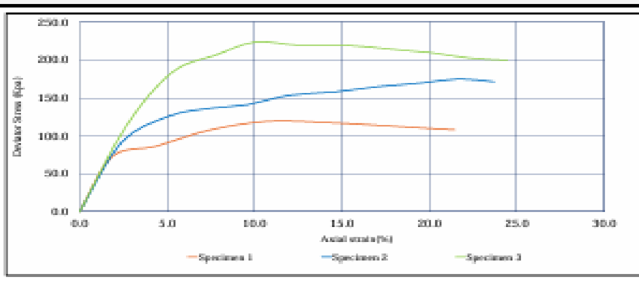
STRESSES	*Specimen 1*	*Specimen 2*	*Specimen 3*
Cell pressure (Kpa)	50	100	200
Corr. Deviator Stress (Kpa)	119.5	175.3	223.7
Shear strength (Kpa)	59.8	87.6	111.8

The Cell Confining Pressures of 50Kpa,100kpa & 200Kpa have been used while conducting the Test

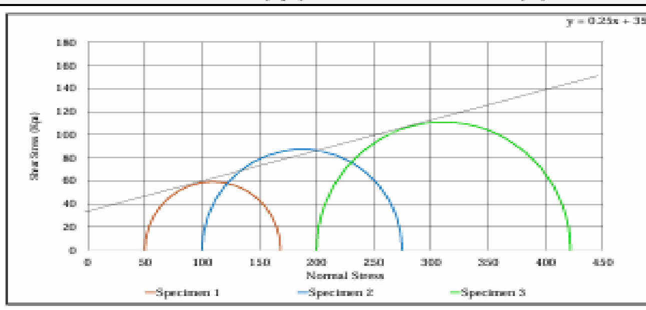
EFFECTIVE STRESS (σ_y) 22.80 (Kpa)

	Specimen 1	*Specimen 2*	*Specimen 3*
Mode of failure	Barelling	Barelling	Barelling

DEVIATOR STRESS(Kpa) AGAINST AXIAL STRAIN (%)



SHEAR STRESS(Kpa) AGAINST NORMAL STRESS(%)



UNDRAINED PARAMETERS

C	35.0
ϕ	14.0

COMMENT

No Comment

Prepared by;
Lab Technician

Approved by;
Lab Engineer

GETLAB LTD
YOUR RELIABLE ENGINEERING LABORATORY

DETERMINATION OF THE UNDRAINEGD STRENGTH IN TRIAXIAL COMPRESSION

Tested in accordance to BS: 1377:1990: Part 7: Clause 8

TEST REPORT

Project Location	Shikuruwe village, naposhi parish, Bushika sub county bududa district		
Client	MAMFA MAYALA AND AHABWE MARTHA	Sample Depth	1.0
BH/TP Location	TP03	Sample Type	U -Sample
Sample Description	Sandy clays	Sampled by	W.M
Tested by	BAKAKI MICHAEL OWEN	Sampling Date	N.A
Checked by	Lab Engineer	Test Date	Tuesday, January 21, 2025

DETERMINATION OF MOISTURE CONTENT

CONTAINER NO.	Mass of Wet Soil + Container	Mass of Dry Soil + Container	Mass of Container	Mass of Moisture	Mass of Dry Soil	Moisture Content	Average
JUE	225.5	192.0	54.4	33.5	137.6	24.3	23.7
AE	268.6	229.2	58.6	39.4	170.6	23.1	

SPECIMEN DETAILS		*Specimen 1*		*Specimen 2*		*Specimen 3*		*Average*
Height [mm]	76	Mass (g)	210.5	Mass (g)	210.5	Mass (g)	210.5	210.5
Diameter [Do]	38	Volume (cm^3)	86.2	Volume (cm^3)	86.2	Volume (cm^3)	86.2	86.2
Initial Length [Lo]	76	Bulk Density (Mg/m^3)	2.441		2.441	Bulk Density (Mg/m^3)	2.441	2.441
Area [Ao]	1134.6	Unit Weight (KN/m^3)	23.9	Unit Weight (KN/m^3)	23.9	Unit Weight (KN/m^3)	23.9	23.95
Rate of Strain ε, (%/min)	2	Dry Density (Mg/m3)	1.973	Dry Density (Mg/m3)	1.973	Dry Density (Mg/m3)	1.973	1.973

SPECIMEN 1

Force	Displacement	ΔL	ΔL/L	ε	1−ε	Area	$\sigma_1-\sigma_3$	ε
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
75	1.3	1.3	0.0171	0.0171	0.983	1154.3	65.0	1.7
88	3.3	2.0	0.0263	0.0434	0.957	1186.1	74.2	4.3
106	5.1	1.8	0.0237	0.0671	0.933	1216.2	87.2	6.7
116	6.6	1.5	0.0197	0.0868	0.913	1242.5	93.4	8.7
124	8.5	1.9	0.0250	0.1118	0.888	1277.4	97.1	11.2
133	10.1	1.6	0.0211	0.1329	0.867	1308.5	101.6	13.3
136	11.6	1.5	0.0197	0.1526	0.847	1338.9	101.6	15.3
143	13.1	1.5	0.0197	0.1724	0.828	1370.9	104.3	17.2
146	14.8	1.7	0.0224	0.1947	0.805	1408.9	103.6	19.5
153	16.5	1.7	0.0224	0.2171	0.783	1449.2	105.6	21.7

SPECIMEN 2

Force	Displacement	ΔL	ΔL/L	ε	1−ε	Area	$\sigma_1-\sigma_3$	ε
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
106	1.5	1.5	0.0197	0.0197	0.980	1157.4	91.6	2.0
127	3.3	2.0	0.0263	0.0461	0.954	1189.3	106.8	4.6
141	5.1	1.8	0.0237	0.0697	0.930	1219.6	115.6	7.0
151	6.7	1.6	0.0211	0.0908	0.909	1247.9	121.0	9.1
155	8.6	2.0	0.0263	0.1171	0.883	1285.1	120.6	11.7
158	10.2	1.7	0.0224	0.1395	0.861	1318.5	119.8	13.9
160	11.5	1.4	0.0184	0.1579	0.842	1347.3	118.8	15.8
166	13.4	1.8	0.0237	0.1816	0.818	1386.3	119.7	18.2
171	14.6	1.5	0.0197	0.2013	0.799	1420.6	120.4	20.1
178	16.8	2.0	0.0263	0.2276	0.772	1469.0	121.2	22.8

SPECIMEN 3

Force	Displacement	ΔL	ΔL/L	ε	1−ε	Area	$\sigma_1-\sigma_3$	;λ
N	mm	mm	mm	mm	mm	mm^2	Kpa	%
0	0.0	0.0	0.0000	0.0000	1.000	1134.6	0.0	0.0
172	1.8	1.8	0.0230	0.0230	0.977	1161.3	148.1	2.3
173	3.4	2.1	0.0276	0.0507	0.949	1195.1	144.8	5.1
192	5.3	2.0	0.0263	0.0770	0.923	1229.2	156.2	7.7
212	6.5	1.4	0.0184	0.0954	0.905	1254.2	169.0	9.5
217	8.5	1.9	0.0250	0.1204	0.880	1289.9	168.2	12.0
223	10.3	1.8	0.0237	0.1441	0.856	1325.6	168.2	14.4
226	10.7	0.6	0.0079	0.1520	0.848	1337.9	168.9	15.2
232	12.3	0.7	0.0092	0.1612	0.839	1352.6	171.5	16.1
236	15.0	1.9	0.0250	0.1862	0.814	1394.1	169.3	18.6
241	16.7	1.9	0.0250	0.2112	0.789	1438.3	167.6	21.1

Prepared by:
Lab Technician

Approved by:
Lab Engineer

GEOTECHNICAL ENGINEERING AND TECHNOLOGY LABORATORY LTD
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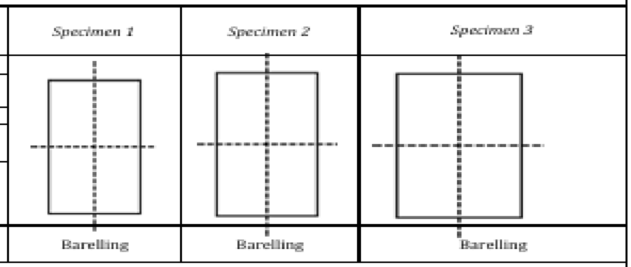
DETERMINATION OF THE UNDRAINED STRENGTH IN TRIAXIAL COMPRESSION
Tested in accordance to BS: 1377:1990: Part 7: Clause 8
TEST REPORT

Project Location	Shikuruwe village, naposhi parish, Bushika sub county bududa district		
Client	MAMFA MAYALA AND AHABWE MARTHA	Sample Depth	1.0
BH/TP Location	TP03	Sample Type	U -Sample
Sample Description	Sandy clays	Sampled by	W.M
Tested by	BAKAKI MICHAEL OWEN	Sampling Date	N.A
Checked by	Lab Engineer	Test Date	Tuesday, January 21, 2025

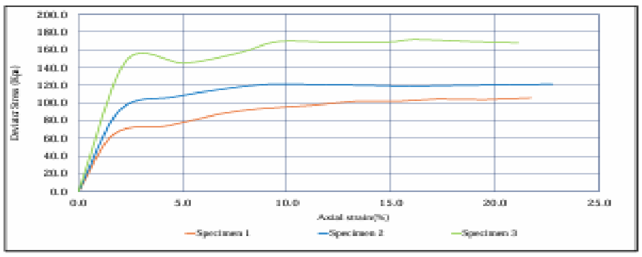
CONDITIONS AT FAILURE

STRESSES	*Specimen 1*	*Specimen 2*	*Specimen 3*
Cell pressure (Kpa)	50	100	200
Corr. Deviator Stress (Kpa)	105.6	121.2	171.5
Shear strength (Kpa)	52.8	60.6	85.8
The Cell Confining Pressures of 50Kpa,100kpa & 200Kpa have been used while conducting the Test			
EFFECTIVE STRESS (σ_v)		23.95	(Kpa)

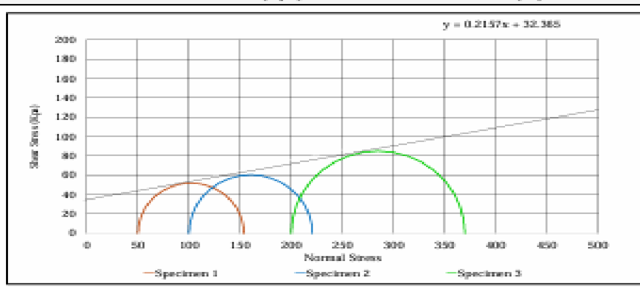
	Specimen 1	*Specimen 2*	*Specimen 3*
Mode of failure	Barelling	Barelling	Barelling



DEVIATOR STRESS(Kpa) AGAINST AXIAL STRAIN (%)



SHEAR STRESS(Kpa) AGAINST NORMAL STRESS(%)



UNDRAINED PARAMETERS

C	32.4
ϕ	12.2

COMMENT

No Comment

Prepared by;
Lab Technician

Approved by;
Lab Engineer

GEOTECHNICAL ENGINEERING AND TECHNOLOGY LABORATORY LTD
GETLAB LTD

Test Report

CHC

PROJECT: N/A

CLIENT: MARTHA AND MAYALA

Document No: CHC-R-001

SUMMARY OF LABORATORY TEST RESULTS

Lab No.	Location.	TP No.	Provided Trial Pit Cordinates	Depth (m)	Sample Type	Particle Content (Hydrometer) — Fine Particles — Clay (%)	Particle Content (Hydrometer) — Fine Particles — Silt (%)	Particle Content (Hydrometer) — Sand (%)	Particle Content (Hydrometer) — Gravel (%)	Atterberg Limits — LL	Atterberg Limits — PL	Atterberg Limits — PI	Atterberg Limits — LS	USCS Group Symbol	Soil Description	Bulk Density g/cm³	NMC %	Compaction — MDD (kg/m³)	Compaction — OMC (%)	Coefficient of Permeability, k m/s
C250265001		100	N/A	N/A	DS	/	/	/	/	/	/	/	/	/	/	1.94	35.8	/	/	2.44E-09
C250265002	N/A	101	N/A	N/A	DS	/	/	/	/	/	/	/	/	/	/	1.93	37.0	/	/	1.58E-07
C250265003		102	N/A	N/A	DS	/	/	/	/	/	/	/	/	/	/	1.94	34.4	/	/	1.51E-07

Note	Abbreviations:	DS---Disturbed sample TP--- Trial Pit LL---Liquid Limit PL---Plastic limit PI---Plasticity Index USCS---Unified soil classificaton system GM---Grading Modulus PP---Plasticity Product
	Test Standard:	1 Atterberg Limits BS EN ISO 18972-2018 Part 12 2 Particle size Distribution BS EN ISO 17892-4-2016 3 USCS reference to the ASTM D 2487-17e 4 Permeability BS EN ISO 17892 - 11 : 2019 5 Consoldated Undrained Shear strength BS EN ISO 17892-9.2018 6 Chemical Tests: BS 1377-3.2018

END

Note: Soil description is made according to Unified Soil Classification System/ American Society for Testing and Materials

Approved:Kivumbi Frank
Lab Materilas Engineer.

CHC ANALYSIS UG LIMITED

WORK SHEET

CHC

Report No : C25026S

Document No.CHC-WS-028

DETERMINATION OF PERMEABILITY OF SOIL (FALLING HEAD)

Test method: BS EN ISO 17892-11:2019

Project:	N/A		
Project location		Sample depth (m)	N/A
Lab number	C25026S001	Trial Pit Number	N/A
Sample Description	Soil		
Preparation method	Prepared in accordance with BS 1377-1-2016		

		Test Records			
DETAILS OF THE SPECIMEN		Wet Weight of the sample +Ring	323	Initial Moisture content (%)	35.8
Specimen Diameter(D) cm	6.00	Dry Weight of the sample +Ring	265.0	Final Moisture content (%)	35.6
Specimen Height (L) cm	4.00				
Specimen area (A) cm2	28.3	Bulky Density (kg/m3)	1938	Void Ratio e	0.89
Water Temperature(T) °C	24.5	Dry Density (kg/m3)	1402		
Stand Pipe Area a (cm2)	0.33	Specific Gravity	2.65	Degree of saturation	106
Hydrauli gradient	1.25				
MDD (kg/m3)	1355	Compaction(%)		103	

Serial No.	Lab No.	Start Time/Date	End Time/Date	Change inTime(sec) Δt	Discharge Q (ml)	Δht1(cm)	Δht2 (cm)	k(m/s)	Average
1	C25026S001	1:27pm (28/1/2025)	3:27pm (28/1/2025)	7200	1.659	90.0	85.0	3.73E-09	2.44E-09
		3:27pm (28/1/2025)	9:29am (29/1/2025)	64920	8.030	85.0	60.8	2.42E-09	
		9:29am (29/1/2025)	1:01pm (29/1/2025)	12720	0.630	60.8	58.9	1.17E-09	

Technician:Barbrah Checked Titus Date: 29/01/2025

CHC ANALYSIS UG LIMITED

WORK SHEET

CHC

Report No : C250265

Document No.CHC-WS-028

DETERMINATION OF PERMEABILITY OF SOIL (FALLING HEAD)

Test method: BS EN ISO 17892-11:2019

Project:		N/A							
Project location					Sample depth (m)		N/A		
Lab number		C250265002			Trial Pit Number		N/A		
Sample Description		Soil							
Preparation method		Prepared in accordance with BS 1377-1-2016							
			Test Records						
DETAILS OF THE SPECIMEN			Wet Weight of the sample +Ring		321	Initial Moisture content (%)		37.0	
Specimen Diameter(D) cm		6.00	Dry Weight of the sample +Ring		263.2	Final Moisture content (%)		35.8	
Specimen Height (L) cm		4.00							
Specimen area (A) cm2		28.3	Bulky Density (kg/m3)		1928	Void Ratio e		0.91	
Water Temperature(T) °C		24.5	Dry Density (kg/m3)		1386				
Stand Pipe Area a (cm2)		0.33	Specific Gravity		2.65	Degree of saturation		104	
Hydrauli gradient		6.15							
MDD (kg/m3)		1325	Compaction(%)			105			
Serial No.	Lab No.	Start Time/Date	End Time/Date	Change inTime(sec) Δt	Discharge Q (ml)	Δht1(cm)	Δht2 (cm)	k(m/s)	Average
1	C250265002	1:41pm (28/1/2025)	1:52pm (28/1/2025)	660	8.163	90.5	65.9	2.26E-07	1.58E-07
		1:52pm (28/1/2025)	2:34pm (28/1/2025)	2520	15.131	65.9	20.3	2.19E-07	
		2:37pm (28/1/2025)	2:56pm (28/1/2025)	1140	9.955	90.5	60.5	1.66E-07	
		2:58pm (28/1/2025)	4:02pm (28/1/2025)	3840	12.610	60.5	22.5	1.21E-07	
		4:03pm (28/1/2025)	4:25pm (28/1/2025)	1320	8.661	90.5	64.5	1.21E-07	
		4:25pm (28/1/2025)	5:31pm (28/1/2025)	3960	11.913	64.5	28.6	9.64E-08	

Technician:Barbrah   Checked Titus   Date: 29/01/2025

30 JAN 2025

CHC ANALYSIS UG LIMITED

WORK SHEET

CHC

Report No : C250265

Document No.CHC-WS-028

DETERMINATION OF PERMEABILITY OF SOIL (FALLING HEAD)

Test method: BS EN ISO 17892-11:2019

Project:	N/A				
Project location			Sample depth (m)	N/A	
Lab number	C25026S003		Trial Pit Number	N/A	
Sample Description	Soil				
Preparation method	Prepared in accordance with BS 1377-1-2016				
		Test Records			
DETAILS OF THE SPECIMEN		Wet Weight of the sample +Ring	324	Initial Moisture content (%)	34.4
Specimen Diameter(D) cm	6.00	Dry Weight of the sample +Ring	265.9	Final Moisture content (%)	35.0
Specimen Height (L) cm	4.00				
Specimen area (A) cm2	28.3	Bulky Density (kg/m3)	1935	Void Ratio e	0.88
Water Temperature(T) °C	24.5	Dry Density (kg/m3)	1410		
Stand Pipe Area a (cm2)	0.33	Specific Gravity	2.65	Degree of saturation	105
Hydrauli gradient	5.50				
MDD (kg/m3)	1385	Compaction(%)		102	

Serial No.	Lab No.	Start Time/Date	End Time/Date	Change inTime(sec) Δt	Discharge Q (ml)	Δht1(cm)	Δht2 (cm)	k(m/s)	Average
1	C25026S003	1:37pm (28/1/2025)	1:43pm (28/1/2025)	360	7.30	90.0	68.0	3.66E-07	1.51E-07
		1:43pm (28/1/2025)	2:35pm (28/1/2025)	3120	15.30	68.0	21.9	1.70E-07	
		2:38pm (28/1/2025)	2:57pm (28/1/2025)	1140	8.50	91.0	65.4	1.36E-07	
		2:58pm (28/1/2025)	4:02pm (28/1/2025)	3840	12.34	65.4	28.2	1.03E-07	
		4:03pm (28/1/2025)	4:30pm (28/1/2025)	1620	7.47	91.0	68.5	8.23E-08	
		4:30pm (28/1/2025)	5:31pm (28/1/2025)	3660	7.30	68.5	46.5	4.97E-08	

Technician:Barbrah Checked Titus Date: 29/01/2025

WORK SHEET

Water Content

CHC

Documet No:CHC-WS-S001

Project: C250265

Reference:	BS EN ISO 17892-1-2014 /Amd 1:2022				Instrument Name:		Electronic Balance		
					Instrument No:		CHC-LAB-0181		
Room conditions		Temperature:			25°C		Humidity:	55%RH	
Lab No	BH/TP No.	Sample type &No	Depth	Container No.	M_{con}	$M_{con+wetsoil}$	$M_{con+drysoil}$	Moisture content	Average
					g	g	g	%	
C250265001	100	DS	N/A	95	50.64	207.51	166.29	35.6	35.8
				94	50.04	202.26	162.08	35.9	
C250265002	101	DS	N/A	36	47.48	166.63	134.48	37.0	37.0
				38	52.82	166.54	135.84	37.0	
C250265003	102	DS	N/A	100	49.41	192.02	155.56	34.3	34.4
				99	49.75	193	156.23	34.5	

Technician: BARBRAH Checked: TITUS Date: 28/01/2025

CHC ANALYSIS CO LIMITED
P.O BOX 1424
30 JAN 2025
TECHNICAL AND MATERIALS TESTING LABORATORY

WORK SHEET

Bulk Density

CHC
Documet No CHC-WS-5002

Project No. C250265

Reference:	CHC Test 1.2:Ref.BS EN ISO 17892-2-2014			Instrument Name:		Balance	
				Instrument No:		CHC-LAB-0181	
	Room conditions		Temperature:	25°C	Humidity:	55%RH	
Lab No.	Ring No.	M_{ring}	$M_{ring+soil}$	M_{soil}	V_{ring}	ρ	Average
		g	g	g	cm^3	g/cm^3	ρ
C250265001	T	100.92	320.11	219.19	113.10	1.94	1.938
C250265002	S	102.25	320.34	218.09	113.10	1.93	1.928
C250265003	B	102.15	321.05	218.90	113.10	1.94	1.935

Technician:BARBRAH Checked:FRANK Date: 1/28/2025

APPENDIX C: PICTURES

Figure 33: Soil sampling from Shikuruwe village in Bududa Disrict.

Figure 34: Mixing the soil sample for atterberg limits test.

Figure 35: Falling head permeability test.

Figure 36: Cone penetrometer for determining atterberg limits.