ANALYSIS OF LANDSLIDE TRIGGERED BY HEAVY RAINFALL: A CASE STUDY KINDO DIDAYE, WOLAITA ZONE

HALELUYA TESFAYE

MASTER OF SCIENCE

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Declaration

I declare that the thesis, Analysis of Landslide triggered by heavy rainfall: A case study in Kindo Didaye, has been composed by myself and that the work has not be submitted for any other degree or professional qualification. I confirm that the work submitted is my own, except where work which has formed part of jointly-authored publications has been included.

Name: Halleluya Tesfaye

Signature:

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This is to certify that the thesis prepared by **Ms. Haleluya Tesfaye Chufa** entitled **"Analysis of Landslide triggered by heavy rainfall: A case study in Kindo Didaye"** and submitted in fulfillment of the requirements for the Degree of Master of Science complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Thesis Defense Date: January 29,2019

1. **Dr Yoseph Biru** ______ 20/03/21

Thesis advisor Signature Date

Singed by Examining Board:

1. **Dr Tensay Gebremedhin** ______ 21/03/21

External Examiner Signature Date

2. **Dr Brook Abate** ______ 22/03/21

Internal Examiner Signature Date

3. **Dr Melaku Sisay** ______ ______

ERA PG Coordinator Signature Date

4. **Alemayehu Feyisa** ______ ______

Department Head of civil Engineering Signature Date

5. **Dr Sisay Demeku** ______ 24/08/21

Dean, college of architecture and civil engineering Signature Date

College of Architecture & Civil Engineering

Addis Ababa Science & Technology University

Dedication

This study is dedicated to my beloved husband and my parents, who have been my of source inspiration and gave me strength when I thought of giving up, who continually provide his moral, spiritual, emotional and financial support.

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This research had been done by the support of many people and institution. Different contributions had come in many different ways and each help supported to bring this research to be completed on time.

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Abstract

Landslide and its impacts are a common natural hazard that affects the day to day activity of human being. Especially in developing countries like Ethiopia the effect is high. The increasing number of population in highlands of Ethiopia and the weather change together makes the country vulnerable to the landslide to occur. Nowadays Heavy Rainfall is one of the results of weather change that is commonly occurring in Ethiopia. Not only this but also landslide as a result of this heavy rainfall is common incident in Ethiopia. The mountainous parts of Ethiopia are highly affected by such kinds of incident. In the study area, Kindo Didaye which is mountainous, landslide after heavy rainfall is repeatedly occurring. This incident is affecting the life of the people living in the area. It destroys their farm land, kills their cattle, and displaces the people. This research will analyze the landslide which is triggered by heavy rainfall in Kindo Didaye. For the study primary and secondary data were used. The primary data was collected from highly affected areas of the Woreda. The secondary data were taken from Wolaita Sodo University, hydraulics department staff who worked in the area. Using the primary data collected from the area different laboratory tests such as moisture content, sieve analysis, direct shear test, hydrometer analysis, Atterberg limit, and specific gravity tests were conducted. The moisture content of the soil showed that there was high amount of water in the soil. From the sieve analysis and specific gravity test the researcher found out that more that 50% of the soil is sandy soil. The hydrometer analysis showed there is silt content in the soil. The Atterberg limit test shows that more than 80% of the soil is well graded silty sand. And the direct shear test of the sample shows that more than 80% of the sample is loose angular sandy soil. The overall test result of the laboratory test shows that the type of the soil is silty sand.For the present study slope stability analysis was carried out for a slope section found 20km from Bele, (capital city of Kindo Koyisha). As the slope is natural, slope analysis of infinite slope in sandy soil was calculated. The results of the slope stability analysis indicate that the slope section is unstable with factor of safety is 0.9.This research investigated the type of soil found in the area, how heavy rainfall triggers landslide and finally possible mitigation measures are proposed.

Key words

Landslide, Wolaita Sodo, Kindo Didaye, Debris Flow, Mitigation, Rain fall, Heavy rainfall

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List of Abbreviation

SNNPR	South Nation Nationalities and people
LL	Liquid limit
Km	Kilo meter
Cu	Uniformity Coefficient
CC	Coefficient of Curvature
Tp	Test pit
Ms	Mass of Solid
Mw	Mass of Water
FOS	Factor of safety
PL	Plasticity limit
USCS	Unified Soil Classification System

1. Chapter one

1.1. Introduction

Landslides are rock, earth, or debris flows on slopes due to gravity. Landslides can occur on any terrain with the given right conditions of soil, moisture, and the angle of slope. Integral to the natural process of the earth's surface geology, landslides serve to redistribute soil and sediments in a process that can be in abrupt collapses or in slow gradual slides (Samuel Molla, 2011).

Landslide occurrence is on the increase worldwide the consequences of which can be loss of life, loss of livestock, damaging or destroying residential and industrial developments, villages or even entire towns, destroying agricultural and forest land and negatively influencing the quality of water in rivers and streams. The worldwide increased population and economic pressures in mountainous areas have forced human activities to shift to practices such as deforestation, urban development and agriculture into potentially hazardous regions (Kitutu, 2010).

Landslide is generally considered as fairly well predictable hazards due to this, such hazards can be reduced significantly (Hansen, 1984). Especially in recent years, there have been advances in better understanding of the initiations of landslides and in techniques of slope instability hazard assessments, prediction and mitigation (Hansen, 1984)

According to Schuster (1995), world-wide landslide activities are expected to continue in the 21st century for the following reasons: (a) increased urbanization and development in landslide-prone areas, (b) continued deforestation of landslide-prone areas, and (c) increased precipitation caused by changing climatic conditions

There are many different types of landslides, such as, spread, slides, topples, slides, and flows. In order to characterize and classify a landslide, the type of movement needs to be described (Varnes, 1978).

Based on the factors affecting, landslides can be natural or human-made, and they can occur in developed areas, undeveloped areas, or any area where the terrain was altered for roads, houses, utilities, buildings, and even for lawns in one's backyard (Wieczorek, 2002).

Landslide often requires a trigger before being released. The term landslide trigger refers specifically to an external stimulus, natural causes such as intense rainfall, rapid snowmelt, earthquake, volcanic eruption, or stream or coastal erosion and there are human-made causes, such as; grading, terrain cutting and filling, excessive development. These stimuli initiate an immediate or near-immediate landslide movement by rapidly increasing shear stresses or pore water pressures, by ground acceleration due to seismic activity, by removing lateral support, by reducing the strength of slope materials, or by initiating debris-flow activity.

Rainfall-triggered landslides are part of a natural process of hill slope erosion that can result in catastrophic loss of life and extensive property damage in mountainous, densely populated areas. In the United States, an average of 25 to 59 lives is lost each year, and annual property damage is estimated at $3.6 billion dollar in 2001. In Kenya, landslides occur mainly during the long or short rainy seasons at which loss of lives and damage to infrastructure has been noted Worldwide damage from natural disasters overall was estimated at $479 billion in the 1990s,the average annual damage costs had risen to $70 billion by the year 2000 (Jane Njoki, 2014).

In Ethiopia, rainfall triggered landslide is a common problem in many areas; along road cuts, hilly and mountainous regions of the highlands of Ethiopia. Ayalew (1999), Temesgen et al. (2001), Nyssen et al. (2002),Ayalew and Yamagishi (2004), (Molla, 2011) indicated that landslides in different parts of Ethiopia have been affecting human lives, infrastructures, agricultural lands and the natural environment. Landslide generated problems have claimed about 300 lives, damaged over 100 km of asphalt road demolished more than 200 dwelling houses and devastated in excess of 500 he of land in Ethiopia in the years 1991-1998(Ayalew, 1999),(Molla, 2011).

Nowadays global climate change is highly and widely affecting our country Ethiopia. This El nino and lanino weather change disturbs the rain season by increasing and decreasing its amount in months when it should be low and high respectively (Emergency protection and food security,2016).

In early to mid-2015, there were predictions that a major El Niño event would cause adverse weather conditions across East Africa, with severe droughts and floods. Although these predictions did not play out across the whole region, Ethiopia suffered its worst drought in decades due to a combination of pre-El Niño declines in rainfall in specific areas, followed by poor and erratic summer rains. It is known that when rainfall intensity increases, flash floods will increase. This, as a result of climate change, will cause landslides, deforestation, soil degradation. Resulting from these global changes, frequency and geographical spread of landslides will increase. Coupled with increased human activity in the County, the tendency is for the landslides to affect areas that presently are generally less vulnerable. Additionally, landslides monitoring and warning mechanisms will need to be put in place (Kitutu, 2010).

Ethiopia is currently involved in massive infrastructural development (including roads and railways), urban development and extensive natural resources management. In this whole socio-economic development, landslides and landslide-generated ground failures need to be given due attention in order to reduce losses from such hazards and create safe geo-environment (Woldearegay, 2013).

During the months of March and May 2016, in our country Ethiopia floods with landslide resulted in loss of lives, livelihoods and infrastructure in Amhara, Somali, Afar, Oromia, SNNPR and Hareri Region and Dire Dawa Administrative Council. The flood incidence caused displacement of over 195,000 people in flash and river flood prone areas (Partners, 2016), (Emergency protection and food security, 2016).

In SNNPR, Kindo Didaye was one of the landslide hazardous area. It caused many people to die, not only this, their farm land was affected, roads in different direction also destroyed by this incident.

The incident was happened on Monday, the 9thof May 2016. The landslide caused many people die, left multitudes homeless, disconnected a major road linking Wolaita zone with Dawro zone and a bridge which connects Wolaita town with Sidama zone have been damaged by floods. Meanwhile there has been many question left unanswered, regarding the main cause and the corresponding action taken to the problem. The following pictures show some of the mainly affected areas by landslide in Patata kebele area and Girba River crossings.

According to Ayalew (1999), more than 60% of Ethiopia’s population is settled in the highlands. In such areas it made landslide generated hazards common problems in the country. The study area, Kindo Didaye, is mountainous.The report from local people and office of Woreda agriculture and natural resources indicates that from 2005 to 2016 alone, landslide have resulted death of 51 people and damaged agricultural lands, houses and infrastructures in Kindo Didaye area.

This research, the analysis of landslide triggered by heavy rainfall in Kindo Didaye, tries to answer all the things about the landslide which helps to reduce loss in the future, to create safe geo-environment for the future generation.

1.2. Statement of the problem

Landslides among other disasters such as droughts, pests, and diseases have a tendency to reduce crop and animal productivity. It is a common problem in many areas especially along road cuts. This can cause damage to human beings as well as properties. Such areas have to be clearly identified including the different processes that cause the failure, mechanism of failure and the possible remedial measures for that landslide problem.

The causes of failure, stability study for the conditions on individual slopes, appropriate remedial measures that can withstand the slope for a long period of time will be discovered by this research.

1.3. Objective

1.3.1. General objective

The general objective of this research is to analyze the landslide triggered by heavy rainfall in Kindo Didaye, Wolaita Zone using different methods supported by different geotechnical data like shear strength parameters of the geo-material present in the area.

1.3.2 Specific Objectives

- To determine the geotechnical properties of the slope mass
- To determine the possible cause for the failure of the slope section
- To analyze stability conditions using existing and secondary surface data

1.4. Research Questions

Research question are:

1. What factors lead to the landslide?
2. How did the landslide occur?
3. What are the extents of landslide in the area?

1.5. Scope of the Study

This research focuses on the effect of heavy rainfall in causing landslide. The property of the soil in the area after the landslide occurred is tested and the type of the soil is known. Possible mitigation measures are listed. The ground water level of the area could not be measured because the device was not accessible, and the nearby device found in Arbaminch University was not functional yet, so the researcher couldn't get the chance to use the device.

1.6. Significance of the Study

The research will be conducted to analyze the occurrence of heavy rainfall and landslide. As Kindo Didaye is one of mountainous area of Ethiopia, whenever there was heavy rainfall there was landslide. The research will provide information on how heavy rainfall and landslide are related in the area and can cause landslide.

The research will be conducted to identify and characterize the soil in order to come up with mitigation measures. Feasible and economical remedial measures may help to reduce the risk of occurrence of landslide in the future.

The research will provide information on the different engineering properties of the soil found in Kindo Didaye and the possible mitigation measure that can overcome or minimize the effect of landslide in the area.

During the second half of the 20th century the number of damaging landslides have been substantially increasing worldwide, as well as the number of studies on landslides. However, research on landslides in East Africa is still rather restricted, although it is a region where land sliding is a widespread phenomenon. Steep slopes, high annual rainfall, increasing population pressure and deforestation, earthquakes and extreme rainfall make most areas in East Africa very sensitive to landslides. Moreover, most of the landslides have a significant economic, social and geomorphologic impact (Kissi 2012).

In East Africa, landslides have been reported in Uganda, Kenya, Tanzania, Rwanda, D.R.Conga, and Ethiopia. All these landslides are caused by various causal factors; however some factors are common for most of the landslide sensitive areas. These factors can be divide in preconditions, inherent static factors that act as catalysts to allow other factors to act more effectively; preparatory factors, which make the slope susceptible to movement without actually initializing it; and triggering factors, which finally initiate the movement . For East Africa, the most important preconditions for landslides are steep slopes, deep weathered soils with high clay content and high annual rainfall. The most important preparatory factors reported for landslides in East Africa are all kinds of human activities such as deforestation and other land use changes but also constructions and excavations. Finally, most important triggering factors are earthquakes and extreme rainfall (Kissi, 2012).

According to Anbalagan (1992) and Raghuvanshi et al. (2014), landslide causative factors categorized into intrinsic or inherent and external or dynamic factors. By understanding these causative factors and nature of past landslide of terrain it is possible to divide the terrain into homogenous area domains and their ranking according to actual or potential landslide susceptibility (Varnes, 1984; Wachal and Haduk, 2000). Due to damage on transportation networks, buildings and structures, public works projects, and personal property and human and animal life (Dai et al, 2002; Woldearegay, 2013) study of landslide has come to be worldwide attention (Varnes, 1984).

2. Chapter Two

2.1. Literature Review

Varnes (1984), Wachal and Haduk (2000), Highland and Bobrowsky (2008) described landslide as any down slope movement of rock and regolith near the earth's surface under influence of gravity with little or no true sliding. Landslide frequently occurs in tropic zone in which high both of quantity and quality of rainfall deal with the increasing of landslide events (Nugroho, 2012).

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2.2. Factors Influencing Landslides

2.2.1. Intrinsic Factors

Intrinsic parameters are the inherent or static causative parameters which define the favorable or unfavorable stability conditions within the slope (Anbalagan, 1992; Raghuvanshi et al., 2014) and include slope geometry, slope material, structural discontinuities, land use and land cover and groundwater into causative parameters (Raghuvanshi et al., 2014).

2.2.1.1. Slope Geometry

Intrinsic parameter includes the relative relief and slope morphometry of the slope (Raghuvanshi et al., 2014). Slope morphometry expresses the steepness of the slope and it causes slope instability within the slope (Hoek and Bray, 1981). According to Hoek and Bray (1981) the slope will be prone to instability when the slope morphometry is steep. Varnes (1984) explained that the chance of occurrence of landslide increases with an increase in slope steepness though landslide occurs in all slope. The relative relief tells the difference between maximum and minimum elevation of individual section. As the relative relief is higher the slope is prone to instability (Bekele Abebe et al., 2010, Raghuvanshi et al., 2014).

2.2.1.2. Slope Material

According to Varnes, 1984 slope material can be soil, rock or both soil and rock. The composition, fabric, texture and other properties of slope material influence shear strength, Permeability and susceptibility to chemical and physical weathering of slope material. The grain size, shape, sorting, the amount and type of cement also determine the strength and stability of slope material. The unconsolidated slope materials are more susceptible to instability than consolidated one because they have less cohesion and friction, have higher infiltration rates than consolidated slope materials (Varnes, 1984).

Slope material and slope morphometry determine the type of landslide with in the slope. In areas where the slope morphometry is steep and the slope material is covered by hard bed rock like basalt, welded ignimbrite, limestone and sandstone landslide like rock falls, topplings and rockslides/avalanches are common (Varnes, 1978;Temesgen et al,1999).

As Varnes (1978) and Berhanu Temesgen et al. (1999) explained when the slope material deeply weathered volcanic rocks like pyroclastic rocks, rapid landslides mostly involving the eluvial-colluvial cover (debris slides and avalanches, debris flows, earth flows and mudflows) happen.When the slope material is like alluvial and coluvial deposits at the foot of the steep slopes, and thick weathered layers on volcanic bed-rock the rotational slides, sometimes passing to earth flows or mud-flows are often produced. Rapid translational slide is probable in slope where hard competent layer overlain by soft clayey bed that dipping downslope. In thick alluvial and coluvial deposits slow translational slides may happen (Varnes, 1978; Cruden and Varnes, 1996).

2.2.1.3. Structural Discontinuities

According to Bell (2007) a discontinuity represents a plane of weakness within a rock mass across which the rock material is structurally discontinuous. Both primary and secondary discontinuities such as bedding, joints, foliation, cleavage, folds and faults are potentially weak planes in a slope that intense influence up on the stability of the slope especially if their inclination facilitates downhill movement of the slope in which they occur (Blyth and de Freitas, 2005). As Blyth and de Freitas (2005) described the strength of joints and other geological surfaces is usually less than that of the intact rock they bound; often they are the weakest component of slope geology. Therefore, it is vital to know their orientation, spacing, continuity, roughness, separation, and nature of filling material in relation to slope angle, direction, and strength along such potential weak planes. Fault zones increase landslide potential by creating steep slopes and sheared and weak zones (Wachal and Haduk, 2000).

2.2.1.4. Land Use and Land Cover

Land use or land cover highly affects slope stability. Vegetation increases the stability of slope by increasing shear strength, and the action of climatic agents on natural mass. By protecting the mass from action of sunshine, wind and rain it reduces soil erosion.

Vegetation cover also prevents the excesses seepage of water into the slope though it depends on soil depth, slope and type of vegetation. The roots of plants also increase the shear strength the slope by binding the soil mass. Regions with dense vegetation are found to be less prone to slope instability than sparse vegetation, agriculture and urbanization. The areas with less vegetation cover are more prone to erosion and weathering because the type of ground cover affects the stability. (Varnes, 1987; Berhanu Temesgen et al., 1999; Turrini and Visintainer, 1998; Wachal and Haduk, 2000; Bekele Abebe et al., 2010; Raghuvanshi et al., 2014; Kifle Woldearegay, 2013).

2.2.1.5. Groundwater

Saturation of groundwater in slope reduces the shear strength of the material and also creates pore water pressure which plays important role in slope stability condition (Waltham, 2009; Highland and Bobrowsky, 2008). As Waltham (2009) explained that groundwater with in jointed rock mass, and in soil mass reduces the shear strength of slope material by developing of joint water and pore water pressure.

2.2.2. External factors

According to Varnes (1984), Dai and Lee (2001) and Raghuvanshi et al. (2014) the external causative factors are relatively variable or dynamic, temporary and imposed by new events which include rainfall, volcanic activity, seismic vibration and manmade activities.

2.2.2.1. Rainfall

Rainfall is a primary cause of landslides and worse slope stability problems (Temesgen et al., 1999; Collision et al., 2000; Dai and Lee, 2001).According to Varnes (1984), Espizua and Bengochea (2002) and Woldearegay (2013) the rainfall intensity and duration play an important role by triggering landslide like debris flows, mudflows, and medium to large-scale rockslides though it depends on climatic conditions, topography, the geological structure of slopes, and permeability of material. It plays vital role by decreasing the shear strength of material by saturating the slope material. It also cause the sliding of rock along discontinuities plane by lubricating discontinuities surface and developing pore water pressure in rock slope (Highland and Bobrowsky, 2008). The rainwater can cause the slope instability by increasing the weight on slope especially in areas where the slope material is soil mass (Hoek and Bray, 1981).

2.2.2.2. Seismicity

Earthquakes are also major cause of landslide in many parts of the world. As stated by Highland and Bobrowsky (2008) due to ground shaking and shaking caused the rapid infiltration water strong seismic ground motion is triggering mechanism of large landslides. Ground shaking decreases the shear resistance of slope material and also generates the high excess pore water pressure which adds slope instability condition (Highland and Bobrowsky, 2008).

2.2.2.3. Man-made Factors

Human activities like changing or disturbing drainage pattern, destabilizing the slopes, removing vegetation, overstepping of slopes by undercutting the bottom slope, loading the top of slope and irrigation may result directly or indirectly initiate the slope instability condition (Highland and Bobrowsky, 2008).

2.3. Triggering Factors

A triggering factor is an external stimulus that triggers the movement and one of the renowned triggering factors is rainfall. Rainfall is an important factor in triggering landslides.

Precipitation conditions determine infiltration and run-off. Prolonged rains with a lower intensity result in a higher and deeper infiltration and lower run-off in sloping areas. On the other hand, in these regions, torrential rains increase run-off and result in a lower amount of infiltration. Nevertheless they promote the wetting of soil along fissures which serve as natural rainwater collectors (UNESCO/UNEP, 1988; Smedema et al., 1983). The amount of rainfall has a considerable influence on the moisture content and the pore pressure in the soils (Ayalew, 1999). Higher moisture content can increase the specific mass of rocks by 20 to 30% and at the same time lower their shear resistance by 50% and even more, due to increased pore-water pressure (UNESCO/UNEP, 1988). This greatly reduces shear strength and hence slope failure.

2.3.1. Rainfall-triggered Landslides

The relationship between climatic factors such as rainfall and landslides has been observed by Ayalew, (1999). Climate can have a dramatic influence on mass wasting events. Heavy precipitation can initiate certain types of mass wasting by creating hydrostatic pressure and serve to lubricate slides once they are in motion. Ngecu and

Mathu (1999) reported that the landslides that affected Kenya in the period of 1997 to 1998 were as a result of continuous heavy rainfall leading to over saturation of soils. Rainfall is one of those factors that have been found to trigger landslides because high rainfall events result in high water saturation in soils reducing the strength of the soil.

Landslide problem has been little researched on in Ethiopia, especially in southern part. There is lack of information on rainfall threshold, nature of occurrence and characteristics which are vital information for GIS data base creation for easy landslide monitoring (Charlotte, 2010). Extraordinarily heavy rainfall in May 9, 2016 due to the El Nino weather phenomenon caused major landslides in Ethiopia, Wolaita zone, Kindo Didaye wereda. On that incident, The landslide caused many people to die, left multitude homeless, disconnected a road linking Wolaita zone with Dawro zone and a bridge which connects Wolaita town with Sidama zone have been damaged by floods and also the landslide affected 725 hectar of arable land.

Flow-like landslides triggered by rainfall occur in most mountainous landscape of the world (Version, 2000). They pose significant natural hazards and have a high damaged potential (Brenner, 2003). There are many statistically meaningful analyses that have been published to demonstrate threshold value of rainfall and landslide triggering (Caine 1980; Glade at al, 2000: Wieczorek et al, 2000, Mikos, Cetina&Brilly 2004; Shakoor& Smith myer 2005). Water exerts a considerable influence on cohesion, strength and viscosity of soil materials and hence a powerful influence on slope stability. Crozier (1986) argues that low pressures cells particularly tropical cyclones are the major source of landslide – triggering rainstorms- because of their intensity. This is supported by Temple and Rapp (1972) who found that the tropical cyclones were responsible for the extra ordinary heavy rainfall which in 1970 resulted in over thousands landslides at Mgeta Valley, Tanzania. When the rain water reaches the ground it starts to infiltrate, pore water pressure rises, and because of the loss of cohesion of the solid particles, their weight may be supported by pore water. The slope stability is endangered. A sudden rise of pore water pressure can be so great that the overburden of the soil and water effectively floats on the pore water beneath and the pore water will burst out of the voids.

Such a burst will trigger slope failure. Pore water pressure may also rise if the ground water level rises after a heavy rainfall.

2.4. Classification of Landslides

There have been known various classifications of landslides. The most accepted classification is that proposed by Varnes, (1978). The landslide classification based on Varnes' (1978) system has two terms: the first term describes the material type, and the second term describes the type of movement.

The material types used by the various schemes are Rock, Earth, Soil, Mud and Debris, being classified as follows:

Rock: is “a hard or firm mass that was intact and in its natural place before the initiation of movement”.

Soil: is “an aggregate of solid particles, generally of minerals and rocks that either was transported or was formed by the weathering of rock in place. Gases or liquids filling the pores of the soil form part of the soil”. **Earth**: “describes material in which 80% or more of the particles are smaller than 2mm, the upper limit of sand sized particles”.

Mud: “describes material in which 80% or more of the particles are smaller than 0.06mm, the upper limit of silt sized particles”.

Debris: “contains a significant proportion of coarse material; 20% to 80% of the particles are larger than 2mm, and the remainders are less than 2mm”.

The five types of movement are described in the sequence:

- ✓ Fall,
- ✓ Topple,
- ✓ Slide,
- ✓ Lateral Spread, and
- ✓ Flow

Falls

Falls are abrupt movements of masses of geologic materials, such as rocks and boulders that become detached from steep slopes or cliffs. (Highland and Bobrowsky, 2008). Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.

The triggering mechanism of fall are undercutting of slopes by streams and rivers or differential weathering, excavation during road building and earthquake shaking. It is common in on steep slopes, or vertical slopes also in coastal area, along rocky bank of river and streams, road cuts, and jointed, fractured and weathered bedrock (Wachal and Haduk, 2000).

TOPPLES

Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks.

Topples is triggered by gravity, water or ice occurring in cracks within the mass, vibration, undercutting, differential weathering, excavation or stream erosion. It occurs in columnar jointed volcanic terrain, as well as along streams and river courses where the banks are steep. It can consist of rock, coarse and fine materials. The rate of movement ranges from extremely slow to extremely rapid. It can be extremely destructive especially when failure is sudden or velocity is rapid (Highland and Bobrowsky, 2008).

SLIDES:

A slide is a down slope movement of soil or rock mass occurring predominantly on the surface of rupture or on relatively thin zones of intense shear strain (Wachal and Haduk ,2000; Highland and Bobrowsky, 2008). It can be rotational slide and translational slide. In rotational slide surface of rupture is curved or spoon-shaped and it is triggered by intense rainfall or snow melt. They are common in loose unconsolidated soils and their rate of movement ranges from extremely slow to moderately fast (Highland and Bobrowsky, 2008).

In translational slide the surface of rupture is planar surface and it is triggered by intense rainfall, snow melt, and human induced disturbances. Translational slides commonly fail along geologic discontinuities such as faults, joints, bedding surfaces or the contact between rock and soil (Highland and Bobrowsky, 2008).

Spread

Spread is as an extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying material. The dominant mode of movement is lateral accommodated by shear or tensile fractures. They often occur on gentle slopes. They are more common in fine grained soils, such as clay, especially if the soil has been remodeled or disturbed by construction, grading or similar activities. Lateral spreads typically damage pipelines, utilities, bridges, and other structures having shallow foundations (Highland and Bobrowsky, 2008).

Flow

As Wachal and Haduk (2000) described flows as rapid but viscous movement of soil, bedrock, or debris. The component velocities in the displacing mass of a flow resemble those in a viscous liquid. Often, there is a gradation of change from slides to flows, depending on the water content, mobility, and evolution of the movement (Highland and Bobrowsky, 2008). Flows can be classified into debris flow or earth flows. A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as slurry that flows down slope. Debris flows include <50% fines. Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snow melt that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Debris-flow source areas are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies. Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows (Highland and Bobrowsky, 2008).

Earth flows can occur on gentle to moderate slopes, generally in fine-grained soil, commonly clay or silt, but also in very weathered, clay-bearing bedrock. It is triggered by prolonged or intense rainfall or snowmelt, sudden lowering of adjacent water surfaces causing rapid drawdown of the ground-water table, stream erosion at the bottom of a slope, excavation and construction activities, excessive loading on a slope, earthquakes, or human-induced vibration. It possibly results in human fatalities, destruction of buildings and linear infrastructure, and damming of rivers with resultant flooding upstream and water siltation problems downstream (Highland and Bobrowsky, 2008).

Complex Movements

Complex movement is a combination of falls, topples slides, spreads and flows (Highland and Bobrowsky, 2008).

2.5. Landslide Mitigation Measures

2.5.1. Accurate Prediction Measure

Landslides can be predicted with reasonable accuracy except those that result from seismic waves. The geomorphological, environmental and human factors are fairly well studied. What requires further assessment will be the level of resilience of the people in case a landslide occurs. Mitigation is defined as sustained, deliberate measures implemented in advance to avoid or reduce the impact of hazards and impending disasters according to (Haque and Burton, 2005). Landslide hazard mitigation will be depended on actions that are carried out before the disaster occurs generally involving landslide mapping, construction of control structures, warning systems and regional planning. Most effective approaches include a combination of these strategies.

2.5.2. Landslide Maps

As summarized by the National Research Council (NRC, 2003) landslide maps include maps that depict potential areas for landslide occurrence, susceptibility (likelihood of landslide occurrence), vulnerability (extent of potential loss), and risk (probability of harmful consequences). The list should also include inventory maps – which delineate landslide locations from single or multiple triggering events (Wieczorek, 1984). Inventory maps are basic data upon which other maps are developed. The development of landslide maps can be less costly than warning systems and control structures and the maps serves as important tools for planers and civil defense officials.

2.5.3. Landslide Warning Systems

Landslides warning systems provide a rapid means to monitor and communicate hazard information to vulnerable communities. Warning systems are used to mainly to protective lives, by indicating that landslides are likely to occur and provide time for notification and evacuation of vulnerable population. This systems however do not substantially reduced property damage (NRC, 2003). Furthermore despite their wide spread occurrence and potentially deadly nature, it remains difficult to predict precisely when where landslides are likely to occur mainly because of hill slope heterogeneity (Keefer and Larsen, 2007).

2.5.4. Control Structure

In areas with high landslide hazards where population is dense or where property values is great, engineering solutions such as retention walls, sabo dams, and debris – flow catchments basins have been used to protect lives and property (Chan, 2000). A sabo dam is a small, low-head dam used on perennial stream channels to capture or slow the velocity of debris-flow materials. Retention walls stop, deflect or capture landslide debris before it reaches developed areas or near a hill slope. They are most commonly used at hill slope base to protect critical infrastructure (Turner and Schuster, 1996). Large debris - flow catchments basins are used for example in Los Angeles, California region where debris flow are common and property values are high. Control structures may lead to greater vulnerability by fostering new or additional development in or close to hazardous areas (Mileti, 1999).

2.6. Landslide Problems in Ethiopia

Landslides are common in many hillsides and road cuttings of in different parts of Ethiopia. It is one of the major environmental problems for the development of Ethiopia, representing a limiting factor for urbanization and infrastructural projects and, generally, for all the activities performed on and at the foot of slopes (Ayalew, 1999).

According to FAO (1986), the Ethiopian landmass is divided into highlands and lowlands. The Ethiopian highlands (which include areas with altitude over 1500m a.m.s.l) cover about 44% of the Ethiopian landmass. These highlands represent the most densely populated areas; with over 60% of the population living in these areas.

As reported by several authors (Mesfin, 1970; Chernet, 1993; Ayalew, 1999), the highlands of Ethiopia are associated with high rainfall variability. The mean annual rainfall varies from about 500mm to 2000mm, with major precipitation in the months of June to September, and with minor rainfall in the months of February to May. Many rivers originate in these highland terrains and flow through deep gorges, draining extensive areas of the region (Woldearegay, 2013).

According to comprehensive study of landslide processes in the city of Dessie by Tenalem Ayenew and Barbieri, (2005), hydrological conditions (both surface and ground-water), geotechnical characteristics of soils and rocks and gully erosion associated with heavy rainfall are major causes for the debris slides, earth and soil slumps, rock and debris falls and toppling and complex landslides in Dessie area.

Bekele Abebe et al., (2010) studied landslides in the Ethiopian highlands and the rift margins. Findings show that the high relief and rugged topography, the occurrence of clayey horizons within the sedimentary sequences, the dense network of tectonic fractures and faults, the thick eluvial mantles on volcanic out-crops, and the thick colluvial–alluvial deposits at the foot of steep slopes are the predisposing factors for a large variety of mass movements. Heavy summer rainfall is the main triggering factor of most landslides, some of which undergo a step-like evolution with long-lasting quiescence intervals. In last decade landslide have been occurred area such as the northern Omo River basin, the lower Wabe-Shebele River valley, the Wendo Genet slope, the Blue Nile Gorge, the town of Dessie, the Wudmen area in Weldiya, the Gilgel Gibe River, the Uba Dema village in Sawla, and parts of Tigray Kifle Woldearegay (2013) made the study on review of the occurrences and influencing factors of landslides in the highlands of Ethiopia eith implications for infrastructural development. Findings of this study show rainfall is major triggering factor for debris/earth slides, debris/earth flows and, medium to large-scale rockslides are rainfall induced landslides of different types and sizes.

2.6.1. Common types of Landslide in Ethiopia

Most frequent types of landslides are: -

On steep slopes modeled in hard bed rock areas fast mass movements such as rock falls, toppling, and rock slides/avalanches are common (Asfawossen,2009;Dikau et al.,1996,Varnes,1978).

According to Charlotte, 2009-2010, Landslide related researches in Ethiopia are not common. There were different articles prepared by different authors. But most of the articles were focus on the northern part of Ethiopia. There was a gap of knowledge about landslide around Southern Ethiopia.

Even though there was the shortage of information (research) on landslide triggered by rainfall in our country, there were some researchers who prepared articles and tried to show the necessity of the study area. Many of the articles are methodological research or Synthesis.

On steep slopes on weathered areas debris slides and avalanches, debris flows, earth flows and mud flows are common ((Bekele Abebe 2009); (Bekele Abebe 2009);(Varnes, 1978);(Dikau, 1996).

Rapid collapse phenomena, such as topples, frequently affects the alluvial banks of deeply incised rivers and gullies (Bekele Abebe 2009);(Varnes, 1978);(Dikau, 1996).

On clayey materials rotational slides, sometimes earth flows or mud flows are often generated (Bekele Abebe , 2009);(Dikau, 1996; Varnes, 1978).

3. Chapter Three

3.1. Material and Methods

3.1.1. Description of the Study Area

Wolaita Sodo is one of the 13 zonal administrations of the Southern Nation Nationality Region in Ethiopia, located 320 kilometers of Addis Ababa via Alaba Butajira road. Wolaita Sodo is limited north west by Tambaro, eastward by Bilate river which divides it from Arsi-Oromo, south ward by Lake Abaya and Kucha, westward by Omo river. The study area of this research is located 450km from the Addis Ababa, Ethiopia. Figure 1 mainly depicts the map of the affected Woreda, Kindo Didaye.

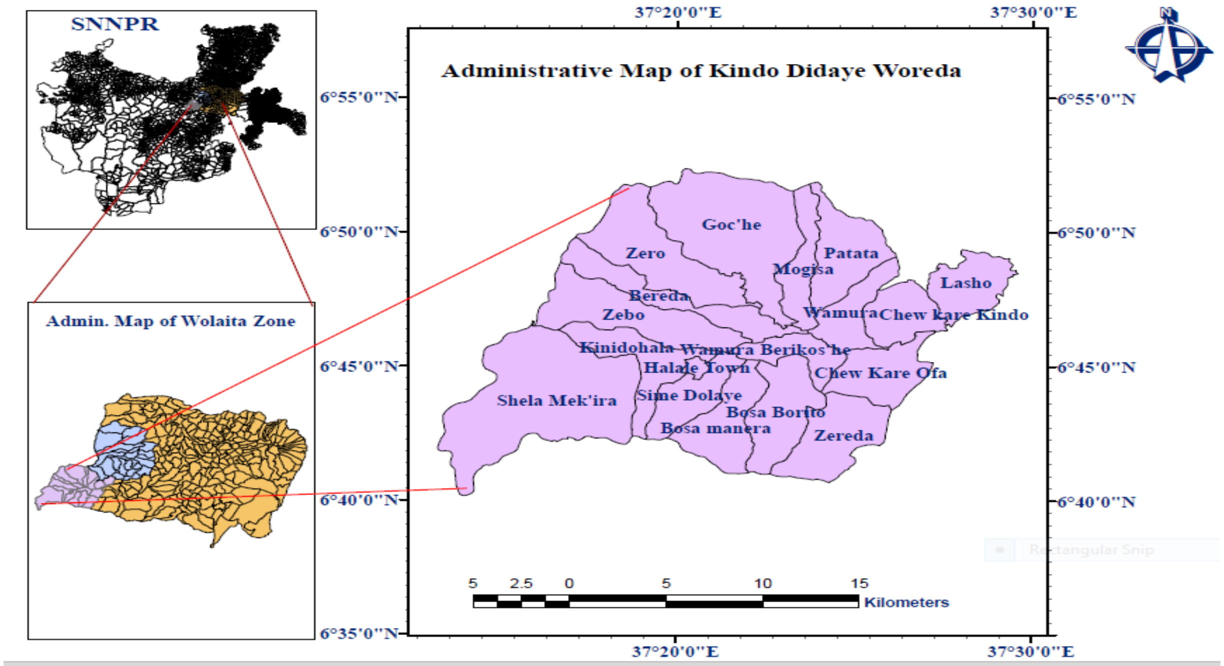

Figure 1Administrative map of Kindo Didaye

All livelihood systems of the areas are highly dependent on agricultural production which in turn is fully dependent on rainfall. This high variability of rainfall and natural resources degradation have made livelihood systems in this densely populated areas highly vulnerable to external shocks.

According to the Agricultural Development Department of the zone, the year is divided in to two seasons: the wet season (balguwa) from June to October, and the dry season (boniya) from October to June, broken in February by a short period of rain. The average rainfall of the entire region is 1350mm per year. The climate is stable, with temperature variation between 24 and 30^{o}c during the day and 16 to 20^{o}c at night, all year round.

Daniel Gemechu (1977) customarily categorized climatic zones under five Classes. The rise <800m catagorized under desert climatic zone (Bereha), starting with 800m-1500 m tropical (Kola), from 1500-2300 m subtropical (Weynadega), from 2300-3300 m Temprate (Dega), > 3300 m elevated (Kur). Those rise of the study zone ranges starting with 859 to 2826 m. Accordingly, climate zone of the investigation territory will be arranged under tropical (800-1500 m), subtropical (1500-2300 m) what's more calm (2300-3330 m).

From 1986 to 2014, the recorded mean annual rainfall of the study area is about 1378 mm. The highest monthly average precipitation recorded was 400.3 mm in the month of May, 1993. The area is characterized by unimodal rainfall pattern. From October to February the area receives low rainfall whereas from May to September it receives high rainfall (Wolaita Sodo university Hydraulics department, Geology department).

The monthly average temperature of the study area from 1986-2014 is 22.6^{o}C. The monthly maximum temperature of study the area is 30.3^{o}C in the month of March, 1988 whereas minimum monthly temperature which was recorded in the month of September, 1986 is 12.1^{o}C (Wolaita Sodo university Hydraulics department, Geology department).

3.1.1.1. Physiographic and Drainage Pattern

The investigation territory is situated in southwest Ethiopian level with the range of rise from 859 m to 2826 m. The study area extends from the highland in north part to deeply eroded southern part of Deme River valley. For the most part, the height declines from northeast to south-west. The examination region is bordered in West side by Didaye Ridge, North side by Watame and Gaza Ridge, East side by Koyisha Mountain and towards South by Deme Waterway. The physiography of the investigation territory is an after effect of volcanism and erosion. The territory is changed by erosion, bringing about exceedingly analyzed geography with soak gorges after volcanism which has shaped edges in the territory.

The examination region is situated inside Omo river basin. Deme River is a major river which streams from southeast course lastly joins Omo River. Mayle, Becha, Kila and Zala Kare are a tributary waterway which spill out of NE-SW lastly joins the Deme River. Mayle, Becha and Kila waterways are parallel to each other. Numerous little tributaries from diverse bearing are streaming into these waterways. In spite of the fact that there are some critical tributaries from various headings the general bearing of stream is southwards, towards Deme River. The seepage example of the present investigation territory is parallel and dendritic.

3.1.1.2. Vegetation

Scattered bushes, wild grass and some trees are the types of vegetation which cover most parts of the ridges in the study area. The gorges and river sides are relatively densely vegetated, the steeper parts are sparsely vegetated and foot of the mountain is cultivated by different kinds of crops and vegetables. The dominant crop production in the area is sorghum, maize, teff, enset, mango, banana, casaba and vegetables.

Slope Morphology

According to Raghuvanshi et al. , 2014 , slope morphology is categorized in to five class such as, scarpment/cliff (>45°), steep slope (36°–45°), moderately steep slope (26°–35°), gentle slope (16°–25°) and very gentle slope (< 15°).

In Kindo Didaye 42% of the slope fall under gentle slope,20% fall under steep ,16% fall under very gentle slope class,13% moderately steep, and 9% escarpment.

3.2. Determination of the Landslide Occurred

The first important vital thing for analysis of landslides is determining which of the specific forms of landslide have occurred. Landslides need to be evaluated based on physical observation and comparison of the materials with the different types of slope movement. Distinctive types of landslides, such as rock fall, debris topple, earth block slide, earth lateral spread, debris flow, and complex slump-earth flow (Varnes, 1978; Cruden and Varnes, 1996) often involve various geologic materials; they initiate and continue their movement in different physical methods, and are often started by a variety of events.

3.3. Laboratory Tests

The following tests were done in this thesis:-

- ✓ Moisture Content,
- ✓ Particle Size Analysis (sieve analysis and hydrometer analysis)
- ✓ Atterberg Limits (Liquid limit and plasticity limit)
- ✓ Soil Shear Strength

The above laboratory tests selected to know the effect of heavy rainfall in the property of the soil in Kindo Didaye.

3.4. Methods of Data Collection

The study focuses on the effect of heavy rainfall on causing landslide so sample was collected from the area specifically affected by landslide. The entire sample collected was disturbed sample. During sample collection, visual identification of around Kindo Didaye was done and accordingly soil sampling (disturbed) from six test pits, at the depth of 1-1.5m below finished grade line road(a road linking Kindo Didaye and Dawero) were collected. The disturbed sampling was done by simple hand digging of the pits of size 1m by 1m. Sample collected from the area using different samplers such as shovel, trial pits. Figure shows the location of geo-material collected for the laboratory test.

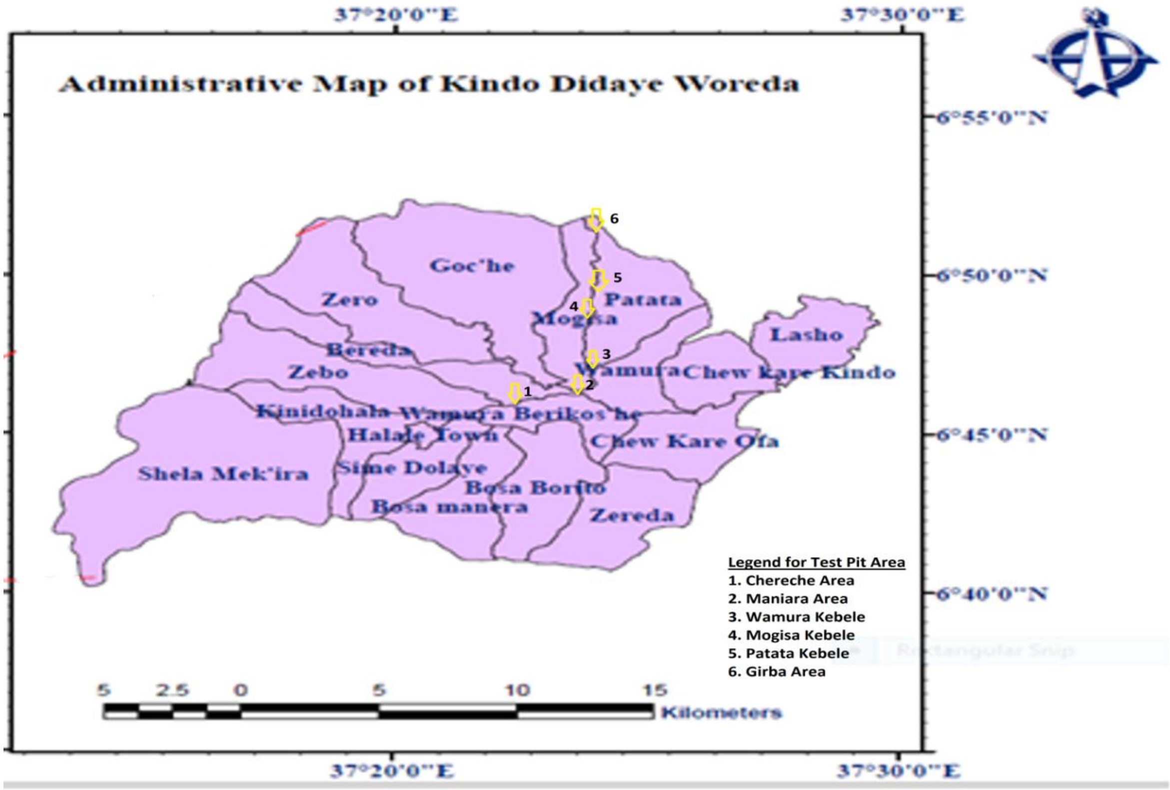

Figure 2 Test Pit Area location

3.5. Methods of Data Analysis

As first approach, a series of laboratory tests which include: Specific gravity, hydrometer analysis, sieve analysis, moisture content, Particle size analysis and Atterberg limits tests are done for classifying the soil under study. These were described in detail in the following section.

Specific Gravity (ASTM D854)

The sample is passing through 425µm and oven dried. The ratio of the weight of the soil to the weight of water, of equal volume of the soil, gave the specific gravity.

Moisture Content (ASTM D2216)

Representative specimens obtained from large bulk samples were weighed as received, then oven-dried at 105°C for 24 hours. The sample was then weighed again, and the difference in weight was assumed to be the weight of the water driven off during drying.

The difference in weight was divided by the weight of the dry soil, giving the water content on a dry weight basis.

Atterberg Limits (ASTM D 4318)

Casagrande device was used to determine the liquid limit of the sample using the material passing through a 425 µm (No. 40) sieve and soaked for 24hrs to enable the water for permeating through the soil. The plastic limit of each soil was determined by using soil passing through a 425µm sieve and rolling 3-mm diameter threads of soil until they began to crack. The plasticity index was then computed for the sample based on the values obtained for liquid and plastic limit.

Particle Size Distribution

Oven dried soil was placed in water for a period of 24 hours for deflocculates the soil particles. The sample was then washed through sieve No. 200 to determine the percentage of sand-sized particles in the specimens. The weight of the soil retaining on the sieve represent the sand and gravel sized particle.

A hydrometer analysis was also performed on the soil content passing sieve No. 200 to measure the amount of silt and clay size particles. The other approach was carrying out the slope stability analysis using soil parameters.

4. Chapter Four

4.1. Results and Discussion

The results of the laboratory tests that were performed at each test pit sample are presented and discussed in this chapter.

4.1.1. Grain Size Analysis Test

ASTM Designation D422-63 was followed to carry out wet sieve and hydrometer analysis on disturbed sample and percent finer against size of soil particle in millimeter on a semi-log scale is plotted .From this curves the proportion and type of soil grains are determined.

Table 1 Test pit1 Sieve Analysis summary

Type of soil	Result in percent
Gravel	7.87%
Sand	88.90%
Fine	3.22%

From the above summary we can see that more than 50 % of soil sample is retained on sieve No 200 (0.075 mm). Therefore the soil is coarse grained soil.

More than 50% of the sample is sand (less than 50 % of coarse fraction is retained on sieve No 4 (4.75 mm)) so the soil is sandy soil, using USCS.

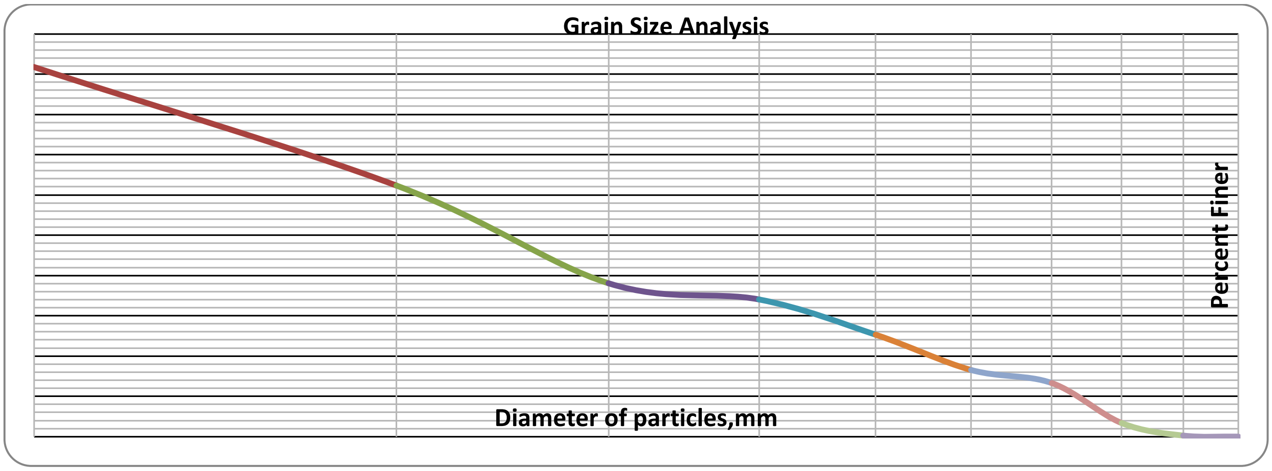

Figure 3 Sieve Analysis graph for test pit 1

Table 2Uniformity Coefficient and coefficient of curvature

D10	0.24
D30	1.7
D60	4
Cu	16.67
Cc	3

When Cu>4, the soil is well-graded. In the above case Cu=16.66, so the soil sample is well graded. Based on unified soil classification system, the soil is well-graded sand, SW.

Table 3 Grain size analysis of the study area

Type of Soil	TP2	TP 3	TP 4	TP 5	TP 6
Gravel	6.36%	23.80%	24.66%	13.66%	23.94%
Sand	79.78%	58.82%	68.89%	70.93%	69.43%
Fine	13.21%	14.63%	5.92%	14.53%	6.14%

From Table 3 we can see that more than 50 % of the entire soil sample is retained on sieve No 200 (0.075 mm). Therefore the soil is coarse grained soil. More than 50% of the sample is sand (less than 50% of coarse fraction is retained on sieve No 4 (4.75 mm)) so the soil in the area is sandy soil.

Table 4 Uniformity coefficient and coefficient of curvature of the test samples

	TP2	TP 3	TP 4	TP 5	TP 6
D10	0.13	0.11	0.11	0.14	0.22
D30	0.29	0.3	0.3	0.25	1.6
D60	2.2	2	2	1.5	5.2
Cu	16.92	18.18	18.18	10.71	23.63
Cc	0.29	0.40	0.40	0.29	2.23

The above table shows that the uniformity coefficient of all the samples leis in the range of well graded soil which is Cu>4.

Therefore the soil type of the area is well-graded sandy soil.

4.1.2 Atterberg Limit Test

The laboratory procedure for doing the test was discussed in the previous chapter. The results obtained were shown in table below.

Table 5 Liquid limit determination of test pit 1

Trial	1	2	3	4
No. of blow	20	22	28	35
Can no.	L-1	L-2	L-3	L-4
Weight of can (gram) w1	27	27	20	20
Weight of can+moist soil (gram)w2	55.5	50	45	49.7
Weight of can+dry soil (gram) w3	46.5	43	38	42
Mass of soild,Ms	19.5	16	18	22
Mass of water,Mw	9	7	7	7.7

Water content,w (%)	46	43.75	38.88889	35

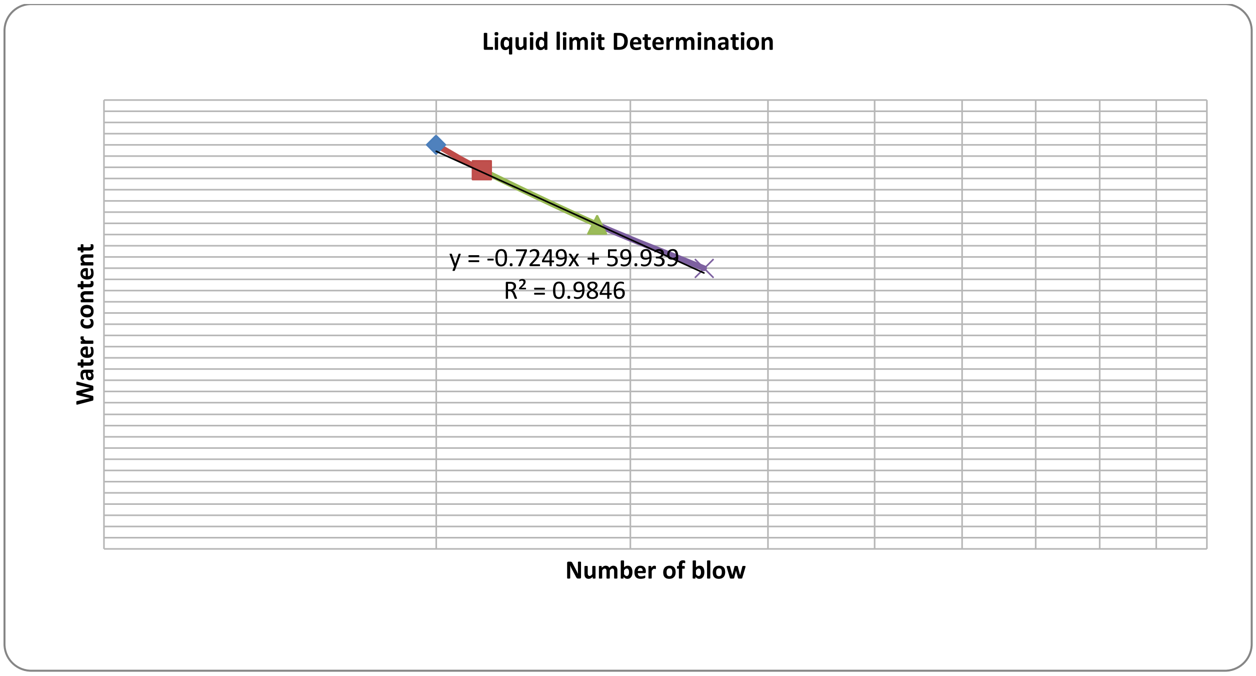

Figure 4 liquid limit determination graph for test pit 1

Table 6 Atterberg limit result of the samples

Pit	Depth (m)	Liquid limit (%)	Plastic limit (%)	Plasticity index
Pit 1	1.5	41.3	24.2	17.1
Pit2	1	51.8	40.97	10.83
Pit3	1.2	57.6	38.09	19.51
Pit4	1.3	46.9	41.66	5.24
Pit5	1	43.58	51.78	8.2
Pit6	1.5	51.6	42.85	8.75

The fine-grained soils in the sample are more than 5%. The below shows the percent of the fine grained soil.

Table 7 content of the fine grained soil in the sample

Type of Soil	TP 1	TP 2	TP 3	TP 4	TP 5	TP 6
Fine	3.22%	13.21%	14.63%	5.92%	14.53%	6.14%

Table 8 Summary of Atterberg Limit test

Pit	**Liquid limit (%)**	**Plastic limit (%)**	**Plasticity index**	**IP calculated**	**Type of Soil**
Pit 1	41.3	24.2	17.1	15.549	Well graded clayey sand
Pit2	49.5	40.97	10.83	21.535	Well graded silty sand
Pit3	48	38.09	19.51	20.44	Well graded silty sand
Pit4	46.9	41.66	5.24	19.637	Well graded silty sand
Pit5	43.58	51.78	8.2	17.2134	Well graded silty sand
Pit6	46.8	42.85	8.75	19.564	Well graded silty sand

More than 80% of soil of the sample is silty sand. From the grain size analysis we know that the soil is well-graded sandy soil. In this test, it is found that the type of fine grained soil which is silty soil.

Compressibility of the soil is also found from this test. If the liquid limit is more than 50%, the soil is highly compressible. This is the property of fine grained soils.

If the liquid limit of the soil is 50% or less, the soil has low compressibility property. It is the property of coarse grained soils.

4.2. Moisture Content

The moisture content of the sample is listed below

Table 9 Moisture content of the samples

Sample	TP1	TP2	TP3	TP4	TP5	TP6
Moisture content	44	57	55	60	45	75

4.3. Specific Gravity

The specific gravity of the sample tested is listed below.

Table 10 Specific gravity of the samples

Samples	TP1	TP2	TP3	TP4	TP5	TP6
Specific gr.	2.671	2.636	2.664	2.659	2.666	2.634

The result of the test lies in the range of 2.63-2.67. This shows that our soil type is sandy soil.

4.4. Direct Shear Test

The final result of the direct shear test is listed below.

Table 11 Direct Shear Test

	TP1	TP2	TP3	TP4	TP5	TP6
C	42	47.4	55.8	48.6	50	50
ϕ	29	35	28.72	36	33	28
Type of soil	Loose angular	Loose angular	Loose round	Loose angular	Loose angular	Loose angular

From the above direct shear test result we can see that almost all the type of the soil is loose angular sand.

A loose state of packing of grains means the soil has high void ratio. When the amount of rain increases in the area this void in the soil will be filled with water. Gradually this causes landslide.

Shearing along horizontal plane will result in a collapse of the relatively open structure as grains move downwards into spaces. This causes a volume decrease, which can be measured as a downward movement of the top surface and in free-draining submerged sands results in water being expelled from the soil structure (K.H. Head, 1994, p 215-216).

4.5. Hydrometer

The result from hydrometer analysis of the sample is listed below.

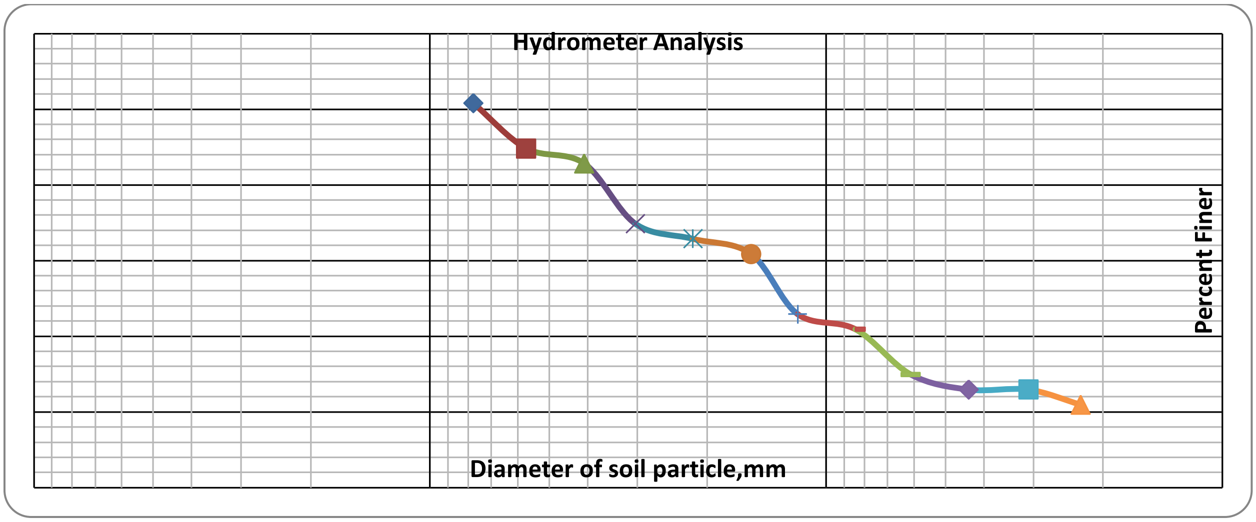

Figure 5 Diameter of Particle Vs Percent Finer of test pit 1

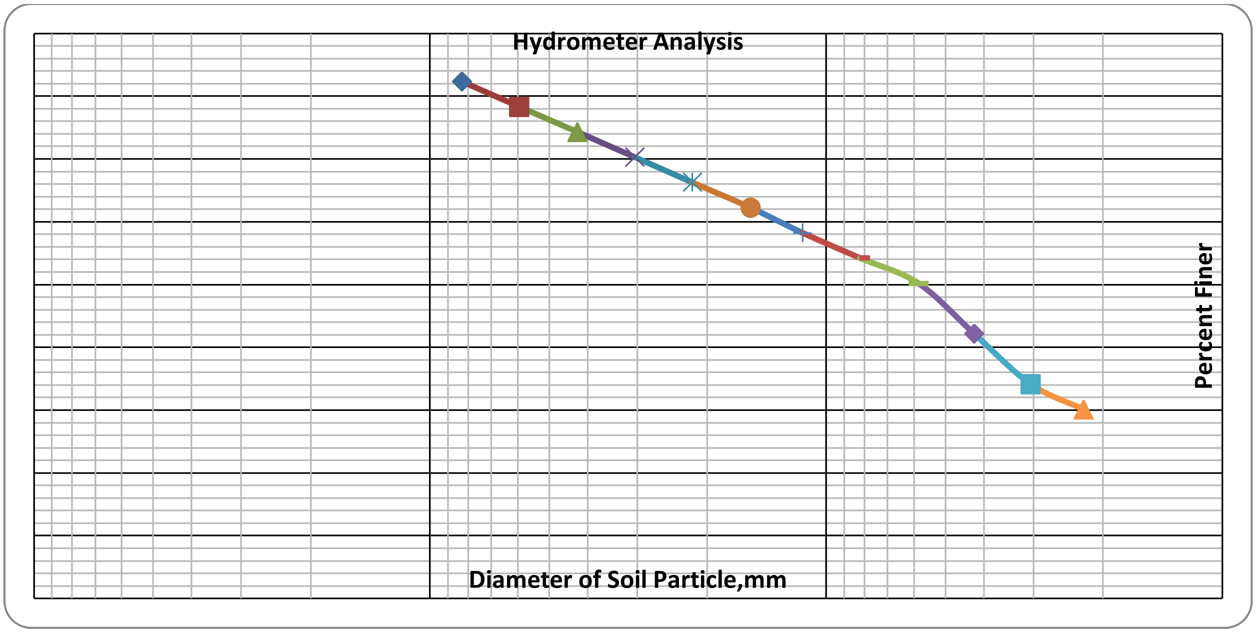

Figure 6 Diameter of Particle Vs Percent Finer of test pit 2

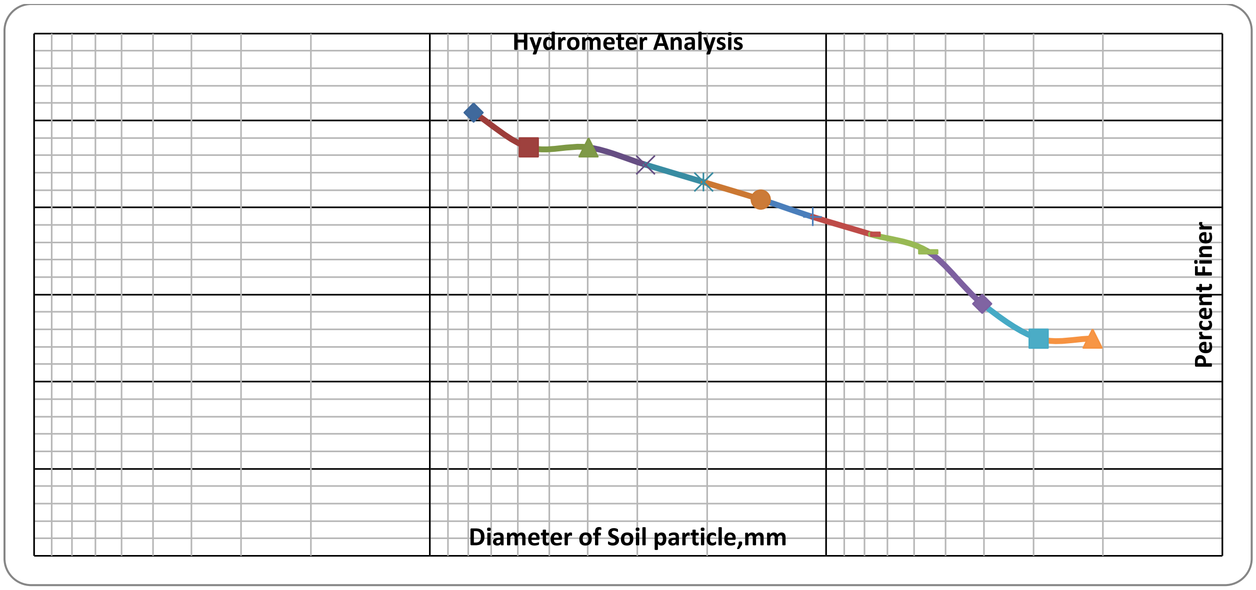

Figure 7 Diameter of Particle Vs Percent Finer of test pit 3

(The result of the other samples is listed in Appendix)

From the hydrometer analysis the soil contains high amount of silt.

Generally, test result shows that the type of soil in Kindo Didaye area is Sandy soil:

- ✓ Well-graded

- ✓ Contains silty soil
- ✓ Loose soil

In mountainous areas, like Kindo Didaye, if a soil mass at its bottom contains sand, when it gets too much rain it becomes water logged (moisture content increases). The moisture content increases because there is high void ratio in the soil and this void space will be filled with water when the amount of rainfall increases and the soil becomes more fluid. If there is denser material at the top of this, falls or slides down. This happens when dense materials such as bed rock or heavy clay, underlying soft layer so that the water can only drain horizontally through softer soil. This is a one case that shows for a decrease of material strength of the soil found in Kindo Didaye.

Other cases that are grouped in the decrease of material strength of the area are: Changes in intergranular forces (increases the pore pressures by changing properties of the soil) and changes in structure caused by the decrease in the strength of failure plane and fracturing due to unloading.

When rainfall increases in the area, the moisture content increases. And the void in the soil is filled with water. As the amount of water increases in the void pore pressure in the void increases. This pore pressure changes the property of the soil. The strength of the soil will decrease and making the soil to become more fluid.

As a result of this the type of landslide that occurred in the area was debris flows. The flow was a rapid movement. As a result of the heavy rain the soil lost its strength and formed slurry and destroyed the area as it flows down slope. Debris flow consists of material that is wet enough to flow rapidly and that contains at least 50 percent sand, silt, and clay-sized particles. In this study the soil type is sandy soil. As heavy rainfall hit the ground it makes the soil wet and finally debris flow occurs.

4.6. Slope Stability Analysis

The type of soil found in Kindo Didaye is Silty sand, so stability analysis method applied in this infinite slope is explained below. For this study primary data from the laboratory test and secondary data slope profile coordinate from Wolaita Sodo University Geology department was used.

The primary data used was the value of angle of internal friction for each sample. The secondary data used was the dimension of the landslide affected areas.

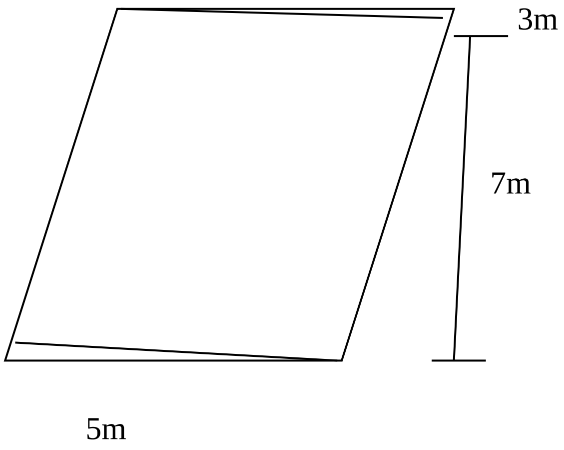

Figure 8 Dimension of the landslide at pit 1

$Factor\ of\ safety = \frac{tan\Phi}{tan\beta}$ Where Φ = angle of internal friction and β=angle between infinite slope and the horizontal plane.

Based on this, factor of safety of test pit 6 will be:-

$$Factor\ of\ safety = \frac{tan28}{tan28.9} = 0.96$$

Table 12 Factor of Safety of all the other Slide sections

Test pit	1	2	3	4	5
Φ	29	35	28.72	36	33
β	30	37.88	29.9	42.24	36.7
FOS	0.96	0.9	0.95	0.8	0.87

Factor of safety for all the slide section is less than 1. This implies that the study area is highly unstable.

Visually in the field, it was clearly observed that there were recent movements in the area, and show that the area is under unstable condition. In an area called ‘kereke’ big slope mass moving down. Based on the information collected during the field work, this sliding mass is damaging the road and maintenance is going on frequently. Besides, the displacements along the road section show that the slope section is unstable and it need attention and follow up to maintain the road before any significant damage would occur on the road and people living around the road.

5. Chapter Five

5.1. Conclusion

Landslide in Kindo Didaye woreda has been a common problem, especially in the rainy season. These landslides have caused many people to die, damages to infrastructure and agricultural lands in the area. Detailed investigation of the type of landslides and the materials involved in the slope instability and identification of the causes of the slope instability are necessary for the developmental works in the area.

In the present study, sample was collected from the study area and laboratory tests were conducted by the researcher. The shear strength parameters of the soil have been determined from laboratory test, using digital shear strength machine. Moisture content, Atterberg limit, specific gravity, grain size analysis (Sieve analysis and hydrometer analysis) were conducted and used to classify the type of the soil in the study area. The type of soil present at the slope section is silty sand soil.

For the present study a slope stability analysis was carried out for a critical slope section found 20 km from Bele (capital city of the Kindo Koyisha woreda). The data used for the slope stability analysis were obtained from primary data, such as laboratory test results and secondary data from Wolaita Sodo University hydraulics department and geology department.

The major triggering factor for the slope stability problems identified in the area is rainfall. The property of the soil in the study area excavation during the road construction (a road connecting Kindo Didaye wereda to Dawero zone) also played a great role in the slope stability problem.

5.2. Recommendation

Landslide in Kindo Didaye is killing many people, destroying agricultural land, and affecting different infrastructure and the day to day activity of the people living in the area.

Adequate mitigation measures, as listed above, must be applied in the area. As the population in the area increases, the need for more land for settlement, infrastructure and agriculture which is free from the risk of landslide is needed. The following are the list of recommendations:

- ✓ Many landslide problems exist in Kindo Didaye wereda. So detailed slope stability analysis works are recommended in other parts the wereda in order to identify and describe clearly the different types of slope failures. This will help to calculate and predict the factor of safety for the current and worst anticipated conditions for the different slope sections separately. Besides, it helps to recommend the remedial measures that are to be taken in order to reduce the damages expected to be caused by individual slope failures.
- ✓ For all the samples the factor of safety is less than 1. Thus, attention should be given to protect the infrastructures and human life from damage, so that, effective remedial measures that are discussed in the previous chapter should be adopted.
- ✓ The study area consists of agricultural lands and individual houses. It may be essential to resettle the local people to other places, in order to adopt the remedial measures.
- ✓ As the slope section is covered by agricultural lands, the agricultural activities may also play a great part in the instability of the slope section. Therefore, the agricultural lands on the slope sections should be replaced by other stable lands; or any appropriate compensation should be given for the land owners. So that, trees and grass may be planted on the unstable lands, and thus loss of crops due to landslide problem will be protected.

Appendix 1

Grain size analysis test

Test pit 1

Table 13: Sieve Analysis for test pit 1

`Sieve size	Mass of empty sieve	Mass of sieve +soil retained	Soil retained	% Retained	% Passing
19	564	564	0	0	100
9.5	414	477.5	63.5	8.23605707	91.7639429
4.75	448.5	675.5	227	29.4422827	62.3216602
2.36	392.5	579.5	187	24.2542153	38.0674449
2	392.5	423.5	31	4.02075227	34.0466926
1.18	358	425.5	67.5	8.75486381	25.2918288
0.6	322	389.5	67.5	8.75486381	16.536965
0.3	285	310	25	3.24254215	13.2944228
0.15	270	346.5	76.5	9.92217899	3.37224384
0.075	381	405	24	3.11284047	0.25940337
pan	245.5	247.5	2	0.25940337	0
		Total	**771**		

Table 14 Summary of sieve Analysis

Type of soil	Result in percent
Gravel	7.87%
Sand	88.90%
Fine	3.22%

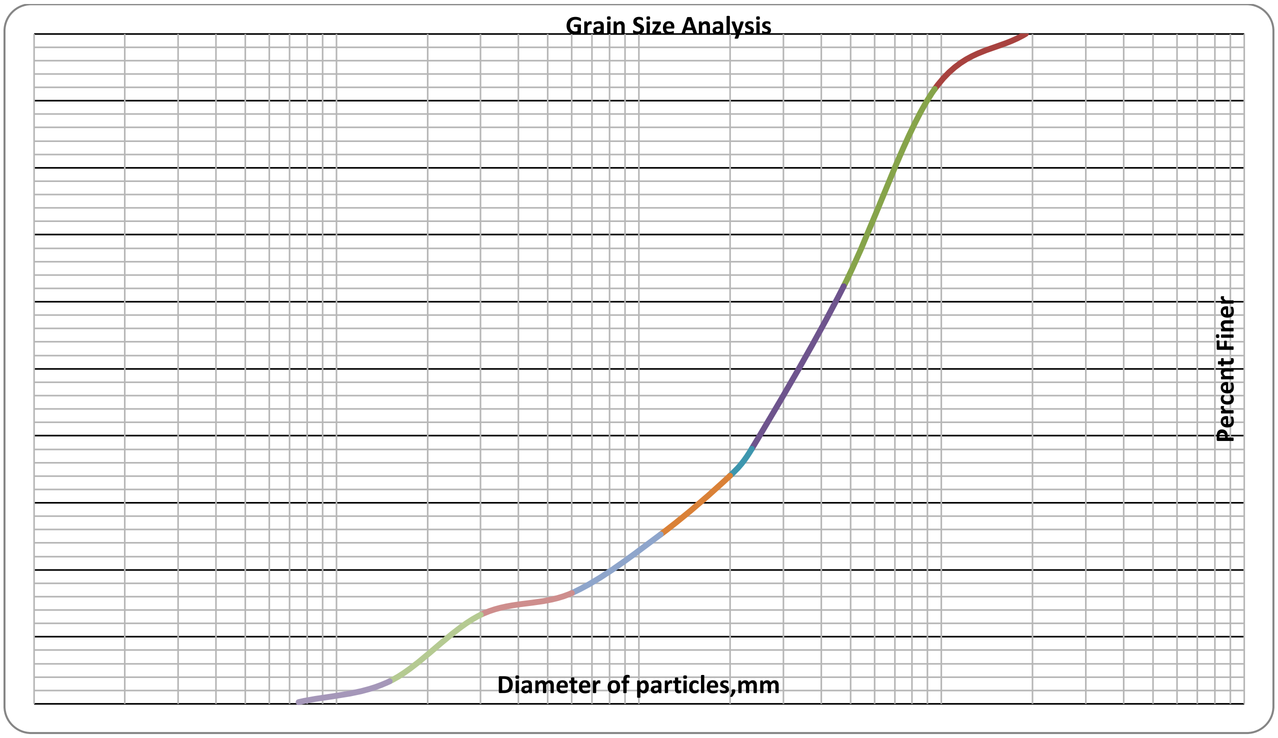

Figure 9 Diameter of particles Vs percent passing for test pit 1

Table 15 Uniformity Coefficient and coefficient of curvature for test pit 1

D10	0.24
D30	1.7
D60	4
Cu	16.6666667

Cc	3.01041667

Test pit 2

Table 16 Sieve Analysis for test pit 2

Sieve Size	Mass Of Sieve	Mass Of Sieve +Soil	Retained	% Retained	% Passing
19	564	564	0	0	100
9.5	414	434	20	6.36942675	93.6305732
4.75	448.5	502	53.5	17.0382166	76.5923567
2.36	392.5	437	44.5	14.1719745	62.4203822
2	392.5	402	9.5	3.02547771	59.3949045
1.18	358	381.5	23.5	7.48407643	51.910828
0.6	322	351.5	29.5	9.39490446	42.5159236
0.3	285	318	33	10.5095541	32.0063694
0.15	270	327	57	18.1528662	13.8535032
0.075	381	422.5	41.5	13.2165605	0.63694268
pan	245.5	247.5	2	0.63694268	0
		total	314		

Table 17 Summary of Sieve Analysis

Type Of Soil	Result in Percent
Gravel	6.36%
Sand	79.78%
Fine	13.21%

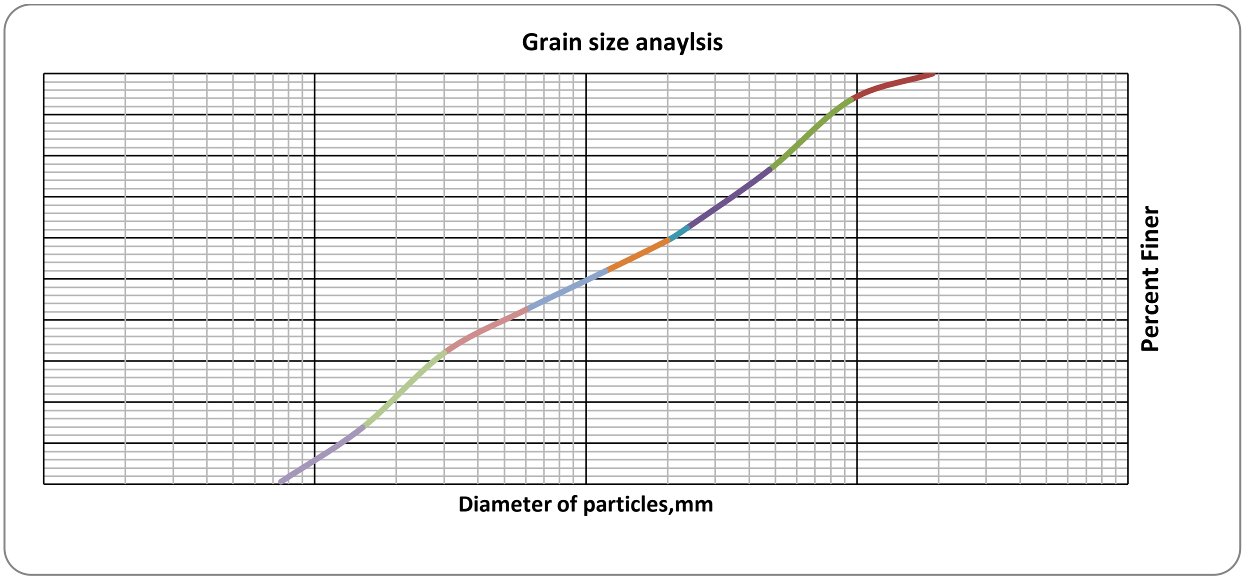

Figure 10 Diameter of particles Vs percent passing for test pit 2

Table 18 Uniformity Coefficient and coefficient of curvature for test pit 2

D10	0.13
D30	0.29
D60	2.2
Cu	16.9230769
Cc	0.29405594

Test pit 3

Table 19 Sieve Analysis for test pit 3

Sieve Size	Mass of Sieve	Mass of Sieve +Soil	Retained	% Retained	% Passing
19	564	578	14	3.83036936	96.1696306
9.5	414	487	73	19.9726402	76.1969904
4.75	448.5	485.5	37	10.123119	66.0738714
2.36	392.5	408.5	16	4.37756498	61.6963064
2	392.5	396	3.5	0.95759234	60.7387141
1.18	358	371	13	3.55677155	57.1819425
0.6	322	360	38	10.3967168	46.7852257
0.3	285	345	60	16.4158687	30.369357
0.15	270	317.5	47.5	12.995896	17.373461
0.075	381	434.5	53.5	14.6374829	2.73597811
pan	245.5	255.5	10	2.73597811	0
		total	365.5		

Table 20 Summary of sieve Analysis

Type Of Soil	Result in Percent
Gravel	23.80%
Sand	58.82%

Fine	14.63%

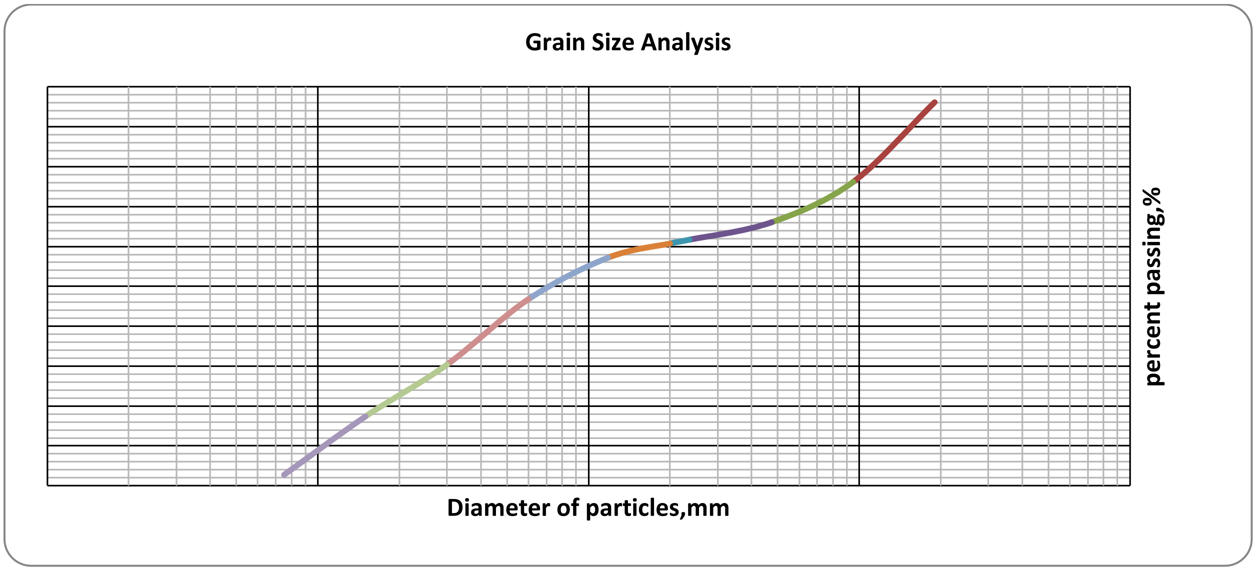

Figure 11 Diameter of particles Vs percent of passing

Table 21Uniformity coefficient and coefficient of curvature

D10	0.11
D30	0.3
D60	2
Cu	18.1818182
Cc	0.40909091

Test pit 4

Table 22 Sieve Analysis for test pit 4

Sieve Size	Mass of Sieve	Mass of Sieve +Soil	Retained	% Retained	% Passing
19	564	607.5	43.5	5.60206053	94.3979395

9.5	414	562	148	19.0598841	75.3380554
4.75	448.5	618	169.5	21.8287186	53.5093368
2.36	392.5	551.5	159	20.4764971	33.0328397
2	392.5	428	35.5	4.57179652	28.4610431
1.18	358	436.5	78.5	10.1094656	18.3515776
0.6	322	375.5	53.5	6.88989053	11.4616871
0.3	285	323	38	4.89375402	6.56793303
0.15	270	271	1	0.128783	6.43915003
0.075	381	427	46	5.92401803	0.515132
pan	245.5	249.5	4	0.515132	0
		total	776.5		

Table 23 Summary of sieve analysis for test pit 4

Type of Soil	Result in Percent
Gravel	24.66%
Sand	68.89%
Fine	5.92%

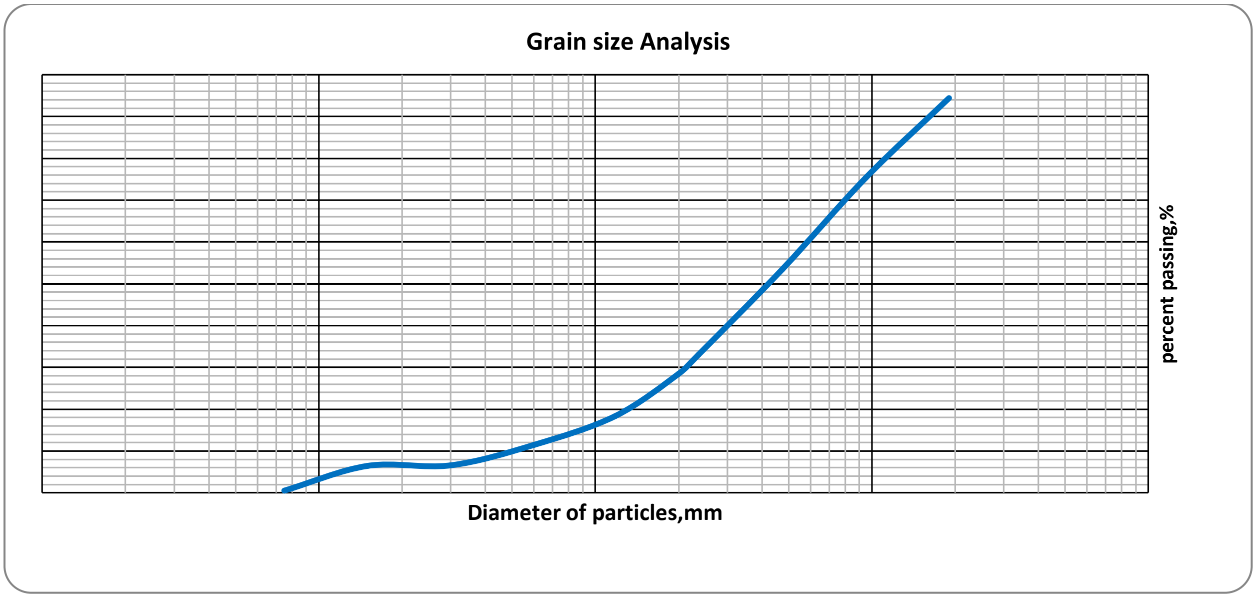

Figure 12 Diameter of particles Vs percent of passing

Table 24 Uniformity coefficient and coefficient of curvature

D10	0.11
D30	0.3
D60	2
Cu	18.1818182
Cc	0.40909091

Test pit 5

Table 25 Sieve Analysis for test pit 5

Sieve Size	Mass of Sieve	Mass of Sieve +Soil	Retained	% Retained	% Passing
19	564	564	0	0	100
9.5	414	437.5	23.5	13.6627907	86.3372093

4.75	448.5	473.5	25	14.5348837	71.8023256
2.36	392.5	406	13.5	7.84883721	63.9534884
2	392.5	394	1.5	0.87209302	63.0813953
1.18	358	364.5	6.5	3.77906977	59.3023256
0.6	322	331.5	9.5	5.52325581	53.7790698
0.3	285	313	28	16.2790698	37.5
0.15	270	308	38	22.0930233	15.4069767
0.075	381	406	25	14.5348837	0.87209302
pan	245.5	247	1.5	0.87209302	0
		total	172		

Table 26 Summary of Sieve Analysis for test pit 5

Type of Soil	Result in Percent
Gravel	13.66%
Sand	70.93%
Fine	14.53%

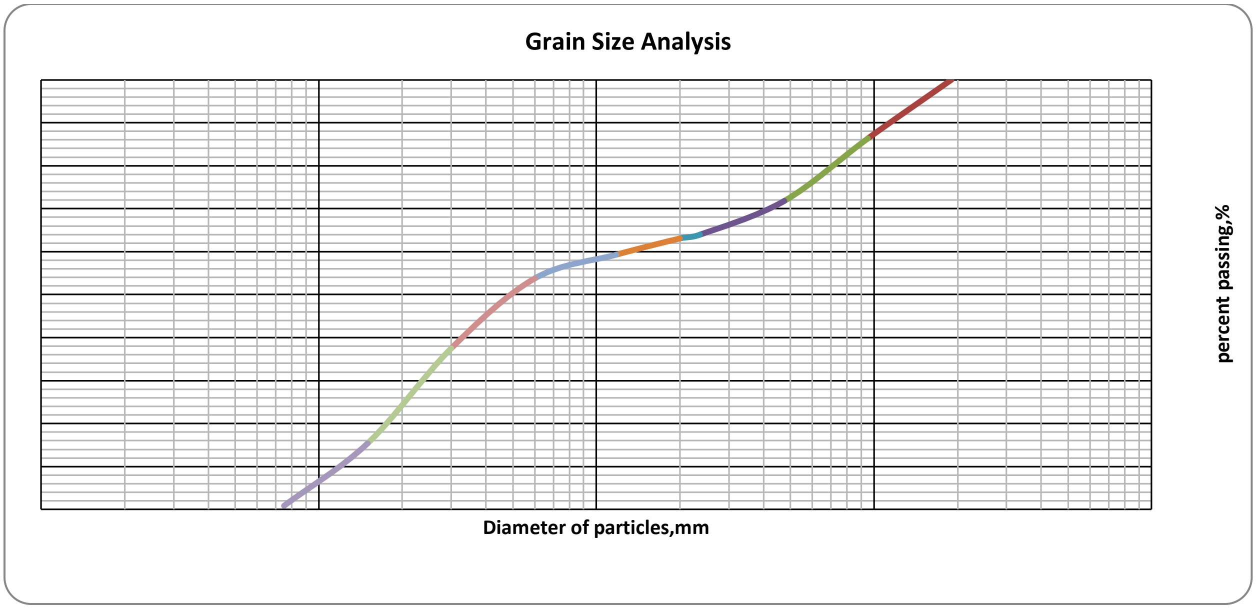

Figure 13 Diameter of particles Vs percent passing

Table 27Uniformity coefficient and coefficient of curvature

D10	0.14
D30	0.25
D60	1.5
Cu	10.7142857
Cc	0.29761905

Test pit 6

Table 28 Sieve Analysis for test pit 6

Sieve Size	Mass of Sieve	Mass of Sieve +Soil	Retained	% Retained	% Passing
19	564	598.5	34.5	8.3032491	91.6967509
9.5	414	479	65	15.6438026	76.052948

					3
4.75	448.5	539.5	91	21.9013237	54.1516245
2.36	392.5	459.5	67	16.1251504	38.0264741
2	392.5	406	13.5	3.24909747	34.7773767
1.18	358	390	32	7.70156438	27.0758123
0.6	322	350	28	6.73886883	20.3369434
0.3	285	311	26	6.25752106	14.0794224
0.15	270	301	31	7.46089049	6.61853189
0.075	381	406.5	25.5	6.13718412	0.48134777
pan	245.5	247.5	2	0.48134777	0
		total	415.5		

Table 29Summary of Sieve Analysis

Type of Soil	**Result in Percent**
Gravel	23.94%

Sand	69.43%
Fine	6.14%

Table 30 Diameter of particles Vs percent passing

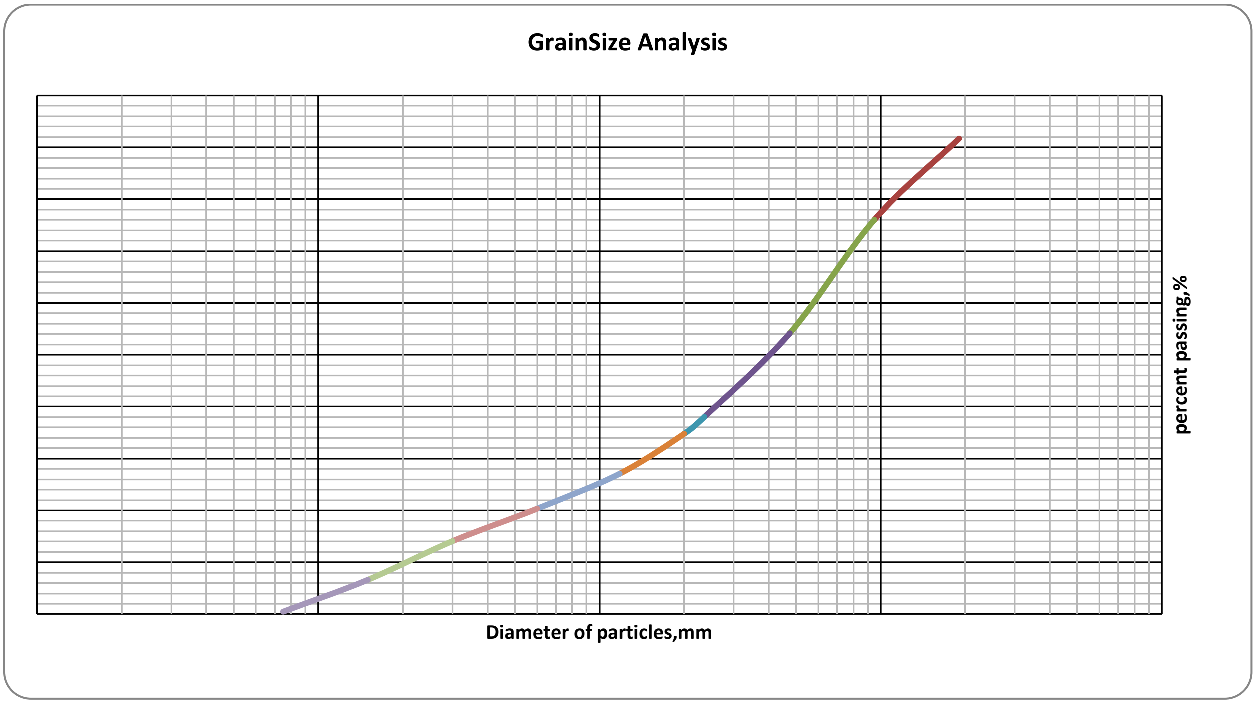

Table 31 Uniformity coefficient and coefficient of curvature

D10	0.22
D30	1.6
D60	5.2
Cu	23.6363636
Cc	2.23776224

Appendix 2

Atterberg limit

Liquid limit determination

Test pit 1

Table 32 Liquid limit determination for test pit 1

Trial	1	2	3	4
No. of blow	20	22	28	35
Can no.	L-1	L-2	L-3	L-4
Weight of can (gram) w1	27	27	20	20
Weight of can+moist soil (gram)w2	55.5	50	45	49.7
Weight of can+dry soil (gram) w3	46.5	43	38	42
Mass of soild,Ms	19.5	16	18	22
Mass of water,Mw	9	7	7	7.7
Water content,w (%)	46	43.75	38.88889	35

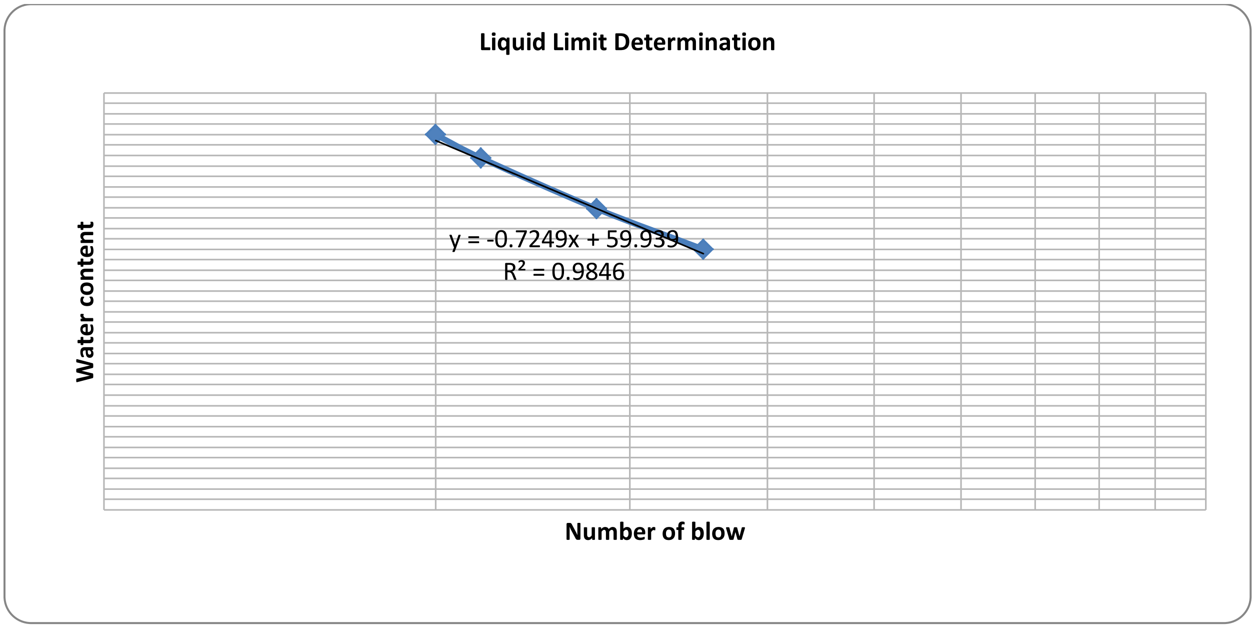

Figure 14 Water content Vs number of blow for test pit 1

Liquid limit=41.3

Plastic limit determination

Table 33 Plastic limit determination for test pit 1

Plastic Limit Determination		
Trial	1	2
can no.	3	4
weight of can	9	9
weight of can+moist soil	15	18
weight of can+dry soil	14	16
Mass of soild,Ms	5	7
Mass of water,Mw	1	2
Water content,w (%)	20	28.57143
PL	24.28571429	

Test pit 2

Table 34 Liquid limit determination for test pit 2

Trial	1	2	3	4
No. of blow	15	21	23	40
Can no.	4	5	6	7
Weight of can (gram)	15	15	9	20
Weight of can+moist soil (gram)	52.5	50	43.6	61.4

Weight of can+dry soil (gram)	39.5	38	31.6	47.4
Mass of soild,Ms	24.5	23	22.6	27.4
Mass of water,Mw	13	12	12	14
Water content,w (%)	53	51	50	45

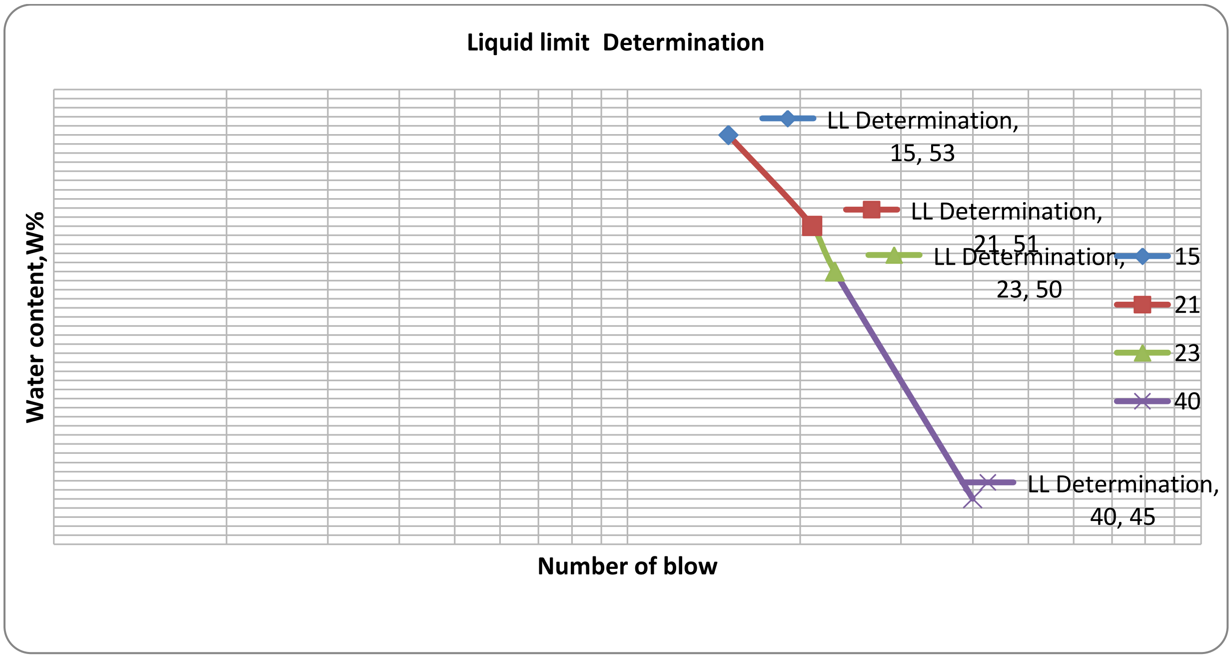

Figure 15 Water content Vs Number of Blow for test pit 2

Liquid limit=49.5

Plastic limit determination

Table 35 Plastic limit determination for test pit 2

Trial	1	2
Can No.	16	61
Weight of Can	9	28

Weight of can+moist soil	20	41
Weight of can+dry soil	17	37
Mass of soild,Ms	8	9
Mass of water,Mw	3	4
Water content,w (%)	37.5	44.444
PL	40.97222222	

Test pit 3

Liquid limit determination

Table 36 Liquid limit determination for test pit 3

Trial	1	2	3	4
No. of blow	17	21	26	35
Can no.	20	2	13	15
Weight of can (gram)	8	8	8	9
Weight of can+moist soil (gram)	35	37.23	51.11	38
Weight of can+dry soil (gram)	27	27.23	35.11	26
Mass of soild,Ms	19	19.23	27.11	17
Mass of water,Mw	8	10	16	12
Water content,w (%)	35	43	50	60

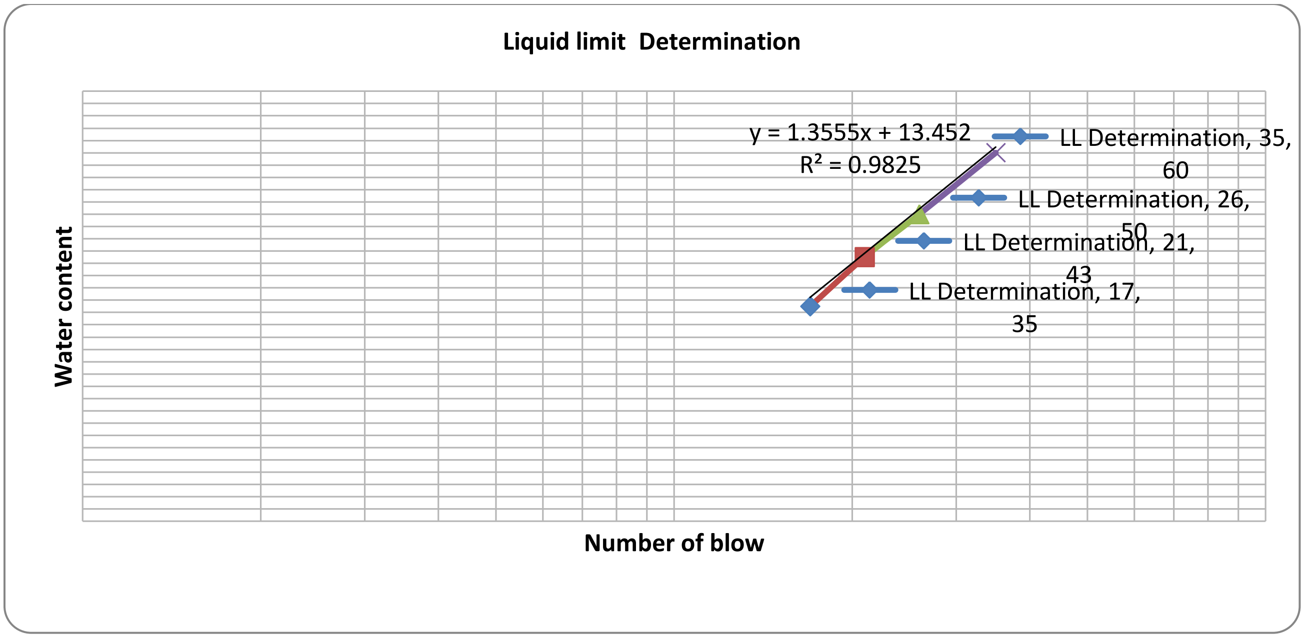

Figure 16 Water content Vs number of blow for test pit 3

Liquid limit=48

Plastic limit determination

Table 37 Plastic limit determination for test pit 3

Trial	1	2
can no.	47	39
weight of can	9	10
weight of can+moist soil	17	20
weight of can+dry soil	15	17
Mass of soild,Ms	6	7
Mass of water,Mw	2	3
Water content,w (%)	33.333	42.857
PL	38.0952381	

Test pit 4

Liquid limit determination

Table 38 Liquid limit determination for test pit 4

Trial	1	2	3	4
No. of blow	19	22	35	40
Can no.	5.1	5.2	5.3	5.4
Weight of can (gram)	15	14	9	8
Weight of can+moist soil (gram)	41	42.5	33	37
Weight of can+dry soil (gram)	33	33.5	25	27.6
Mass of soild,Ms	18	19.5	16	19.6
Mass of water,Mw	8	9	8	10
Water content,w (%)	45	46	50	51

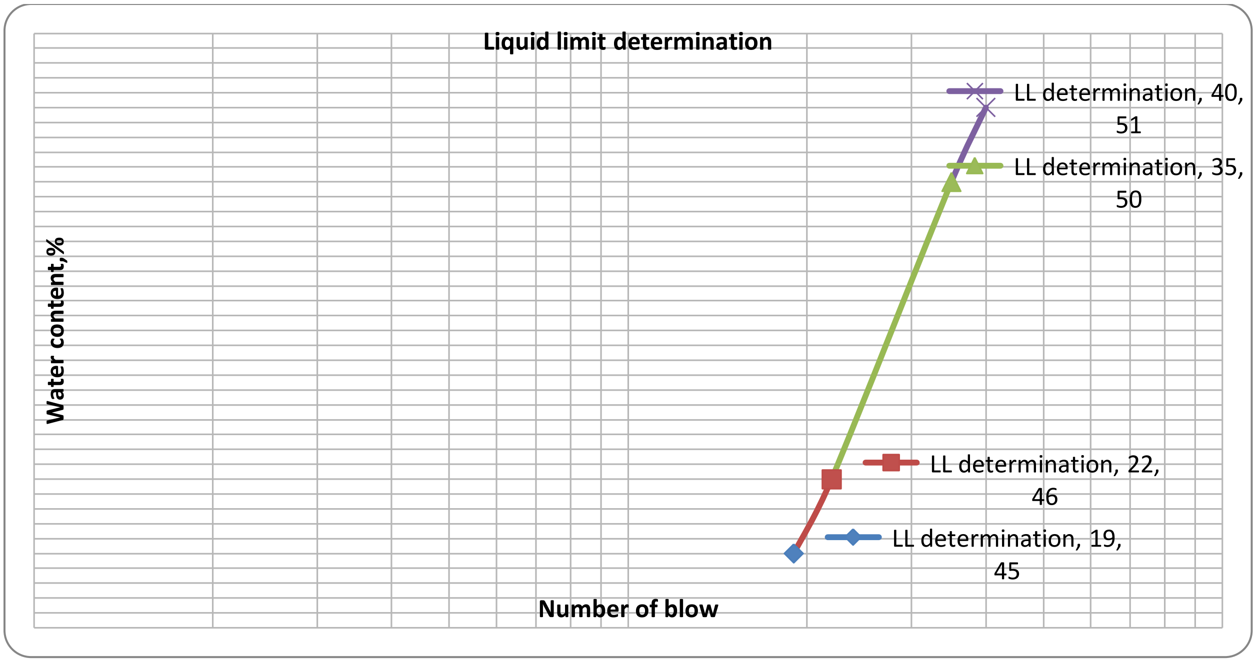

Figure 17 water content Vs number of blow

Liquid limit=46.9

Plastic limit determination

Table 39 Plastic limit determination for test pit4

Trial	1	2
can no.	44	34
weight of can	9	9
weight of can+moist soil	13	15
weight of can+dry soil	12	13
Mass of soild,Ms	3	4
Mass of water,Mw	1	2
Water content,w (%)	33.333	50

PL	41.66666667

Test pit 5

Liquid limit determination

Table 40 Liquid limit determination for test pit 5

Trial	1	2	3	4
No. of blow	10	24	30	40
Can no.	5.4	5.3	5.2	5.1
Weight of can (gram)	15	9	13	15
Weight of can+moist soil (gram)	43	31	36	46
Weight of can+dry soil (gram)	33	24	29	36
Mass of soild,Ms	18	15	16	21
Mass of water,Mw	10	7	7	10
Water content,w (%)	55.555556	44	41.5	38

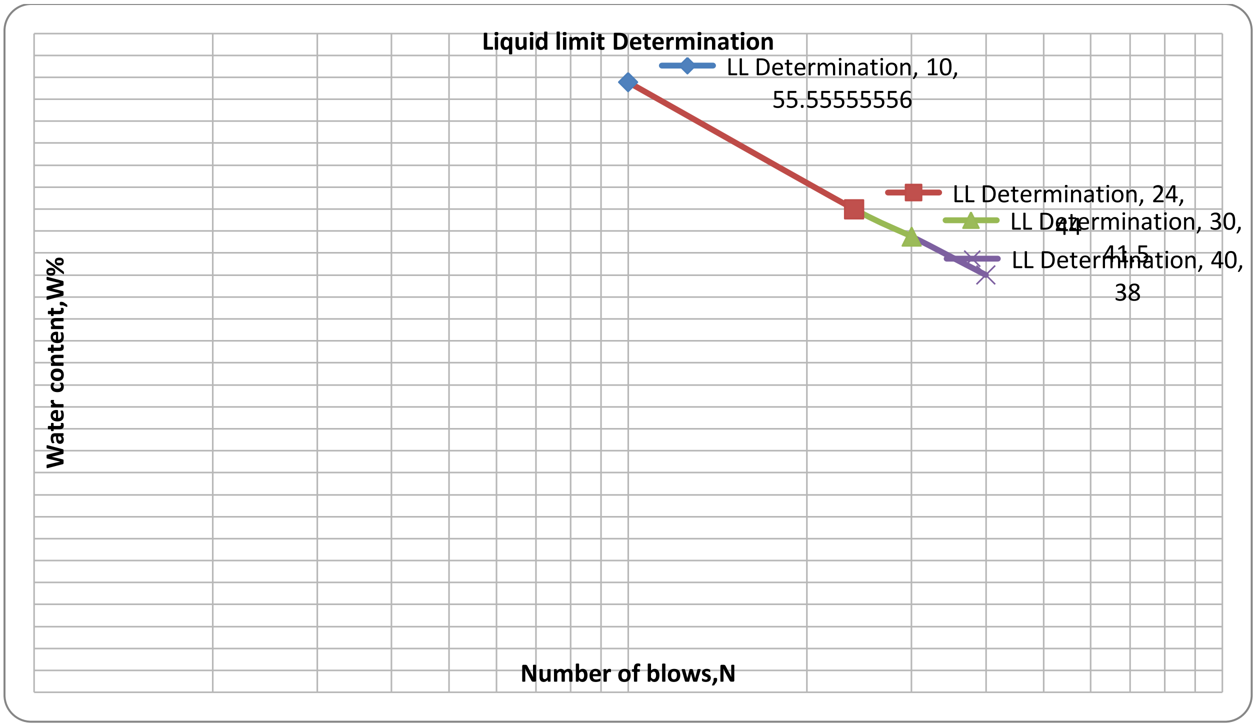

Figure 18 Water content Vs number of blow

Liquid limit=43.58

Plastic limit determination

Table 41 Plastic limit determination of test pit 5

Trial	1	2
can no.	52	25
weight of can	9	9
weight of can+moist soil	18	16
weight of can+dry soil	16	13
Mass of soild,Ms	7	4
Mass of water,Mw	2	3
Water content,w (%)	28.57143	75

PL	51.78571429

Test pit 6

Liquid limit determination

Table 42 Liquid limit determination of test pit 6

Trial	1	2	3	4
No. of blow	13	20	22	34
Can no.	15	13	47	24
Weight of can (gram)	9	9	9	9
Weight of can+moist soil (gram)	40	38	44	42
Weight of can+dry soil (gram)	29	28	32	31
Mass of soild,Ms	20	19	23	22
Mass of water,Mw	11	10	12	11
Water content,w (%)	55	51.5	49	45

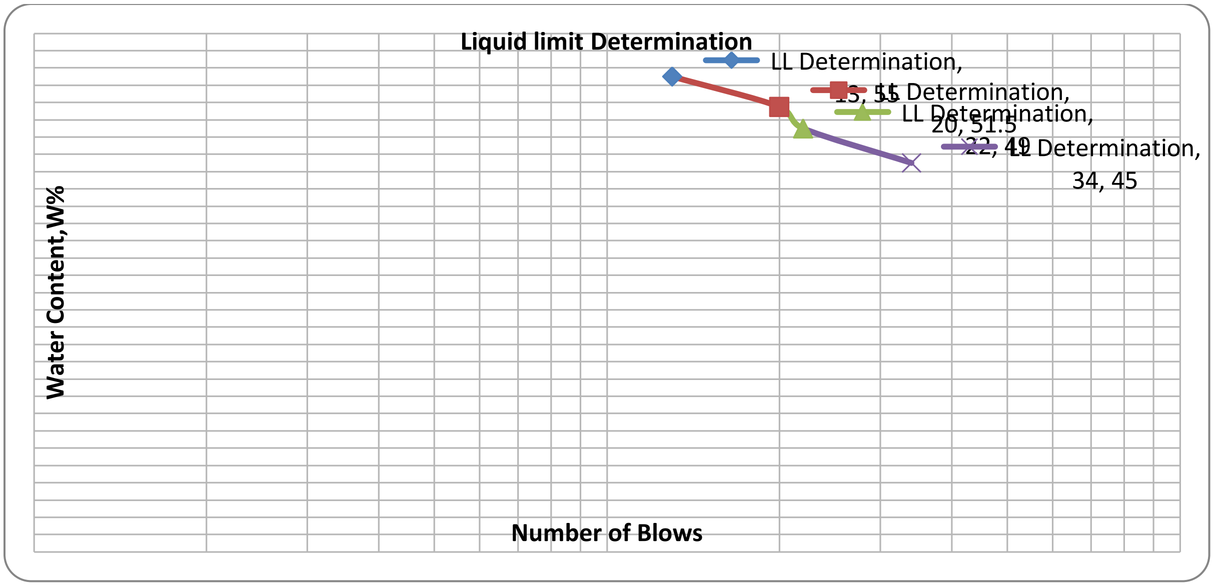

Figure 19 Water content Vs number of blow

Liquid limit=46.8

Plastic limit determination

Table 43 Plastic limit of test pit 6

Trial	1	2
can no.	32	42
weight of can	9	9
weight of can+moist soil	20	18
weight of can+dry soil	16	16
Mass of soild,Ms	7	7
Mass of water,Mw	4	2
Water content,w (%)	57.1429	28.571
PL	42.85714286	

Appendix 3

Specific gravity

Test pit 1

Table 44 Specific gravity of test pit 1

Trial	1	2	3
Mass of empty pycnometer (gram),Wp	22	22	22
Mass of pycnometer+water (gram),WA	123	121	123
Mass of pycnometer+dry soil (gram),Wps	41	36	32
Mass of pycnometer +soil+water (gram),WB	135	130	129
Weight of sample of oven dry soil,Wo=Wps-Wp	19	14	10
WA-WB	-12	-9	-6
Wo+(WA-WB)	7	5	4
Specific Gravity	2.714285714	2.8	2.5
Average Specific Gravity	2.671428571		

Test pit 2

Table 45 Specific gravity of test pit 2

Trial	1	2	3
Mass of empty pycnometer (gram),Wp	22	22	22
Mass of pycnometer+water (gram),WA	123	123	123
Mass of pycnometer+dry soil (gram),Wps	53	52	48

Mass of pycnometer +soil+water (gram),WB	143	142	138
Weight of sample of oven dry soil,Wo=Wps-Wp	31	30	26
WA-WB	-20	-19	-15
Wo+(WA-WB)	11	11	11
Specific Gravity	2.818182	2.727273	2.363636
Average Specific Gravity	2.636364		

Test pit 3

Table 46 Specific gravity of test pit 3

Trial	1	2	3
Mass of empty pycnometer (gram),Wp	22	22	22
Mass of pycnometer+water (gram),WA	123	123	123
Mass of pycnometer+dry soil (gram),Wps	50	49	54.3
Mass of pycnometer +soil+water (gram),WB	140.5	140	143
Weight of sample of oven dry soil,Wo=Wps-Wp	28	27	32.3
WA-WB	-17.5	-17	-20
Wo+(WA-WB)	10.5	10	12.3
Specific Gravity	2.66666667	2.7	2.626016

Average Specific Gravity	2.66422764

Test pit 4

Table 47 Specific gravity of test pit 4

Trial	1	2	3
Mass of empty pycnometer (gram),Wp	22	22	22
Mass of pycnometer+water (gram),WA	123	123	122
Mass of pycnometer+dry soil (gram),Wps	39.5	37.6	47
Mass of pycnometer +soil+water (gram),WB	134	133	137
Weight of sample of oven dry soil,Wo=Wps-Wp	17.5	15.6	25
WA-WB	-11	-10	-15
Wo+(WA-WB)	6.5	5.6	10
Specific Gravity	2.692308	2.785714	2.5
Average Specific Gravity	2.659341		

Test pit 5

Table 48 Specific gravity of test pit 5

Trial	1	2	3
Mass of empty pycnometer (gram),Wp	22	22	22
Mass of pycnometer+water (gram),WA	123	123	123
Mass of pycnometer+dry soil (gram),Wps	33.8	35.8	42

Mass of pycnometer +soil+water (gram),WB	130	132	135.5
Weight of sample of oven dry soil,Wo=Wps-Wp	11.8	13.8	20
WA-WB	-7	-9	-12.5
Wo+(WA-WB)	4.8	4.8	7.5
Specific Gravity	2.458333	2.875	2.666667
Average Specific Gravity	2.666667		

Test pit 6

Table 49 Specific gravity of test pit 6

Trial	1	2	3
Mass of empty pycnometer (gram),Wp	22	22	22
Mass of pycnometer+water (gram),WA	123	123	123
Mass of pycnometer+dry soil (gram),Wps	34	42	45
Mass of pycnometer +soil+water (gram),WB	130.4	135.7	137
Weight of sample of oven dry soil,Wo=Wps-Wp	12	20	23
WA-WB	-7.4	-12.7	-14
Wo+(WA-WB)	4.6	7.3	9
Specific Gravity	2.608696	2.739726	2.555556
Average Specific Gravity	2.634659		

Appendix 4

Direct shear test

Test pit 3

Table 50 Shear stress of test pit 3, normal stress 27.25 Kpa

Horizontal Dial Reading (Mm)	Proving Ring Dial Gauge Reading	Correction Factor (N/Div)	Shear Force (N)	Area of Specimen (M2)	Shear Stress(KN/M2)
0	0	2.03	0	0.0036	0
20	18	2.03	36.54	0.0036	10.15
40	32	2.03	64.96	0.0036	18.0444444
60	43	2.03	87.29	0.0036	24.2472222
80	52	2.03	105.56	0.0036	29.3222222
100	60	2.03	121.8	0.0036	33.8333333
120	68	2.03	138.04	0.0036	38.3444444
140	78	2.03	158.34	0.0036	43.9833333
160	86	2.03	174.58	0.0036	48.4944444
180	90	2.03	182.7	0.0036	50.75
200	94	2.03	190.82	0.0036	53.0055556
220	98	2.03	198.94	0.0036	55.2611111
240	99	2.03	200.97	0.0036	55.825

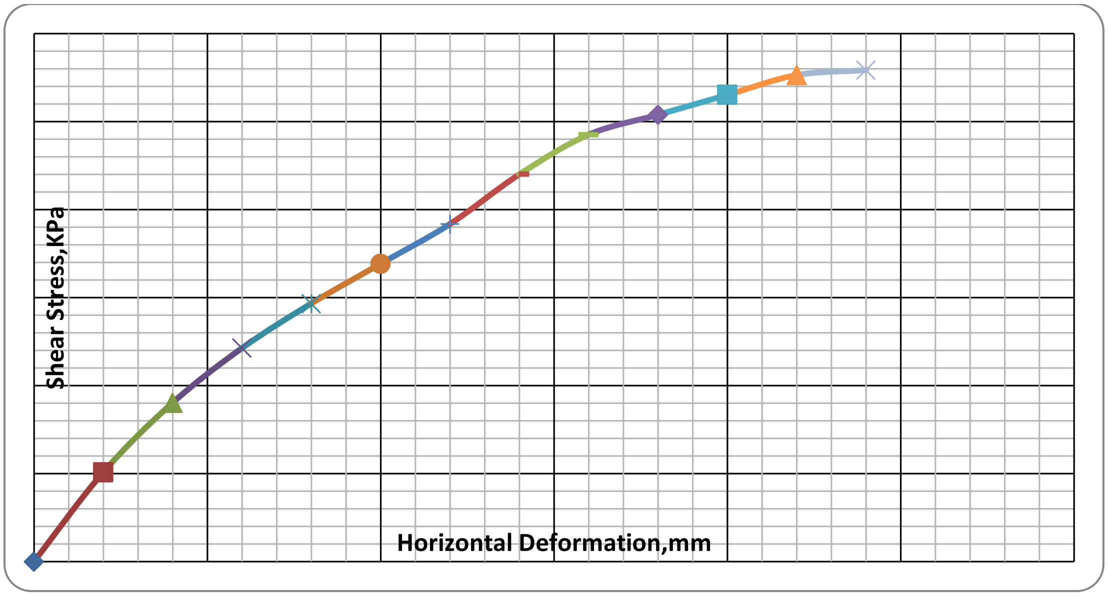

Figure 20 Horizontal deformation VS Shear stress for test pit 3,normal stress 27.25 Kpa

Table 51 Shear stress value of test pit 3, normal stress 54.5 kpa

Horizontal Dial Reading (Mm)	Proving Ring Dial Gauge Reading	Correction Factor (N/Div)	Shear Force (N)	Area of Specimen (M2)	Shear Stress(KN/M2)
0	0	2.03	0	0.0036	0
20	2	2.03	4.06	0.0036	1.12777778
40	11	2.03	22.33	0.0036	6.20277778
60	30	2.03	60.9	0.0036	16.9166667
80	45	2.03	91.35	0.0036	25.375
100	55	2.03	111.65	0.0036	31.0138889
120	63	2.03	127.89	0.0036	35.525
140	75	2.03	152.25	0.0036	42.2916667
160	79	2.03	160.37	0.0036	44.5472222
180	83	2.03	168.49	0.0036	46.8027778
200	86	2.03	174.58	0.0036	48.4944444
220	90	2.03	182.7	0.0036	50.75
240	92	2.03	186.76	0.0036	51.8777778
260	95	2.03	192.85	0.0036	53.5694444
280	96	2.03	194.88	0.0036	54.1333333
300	98	2.03	198.94	0.0036	55.2611111
320	99	2.03	200.97	0.0036	55.825

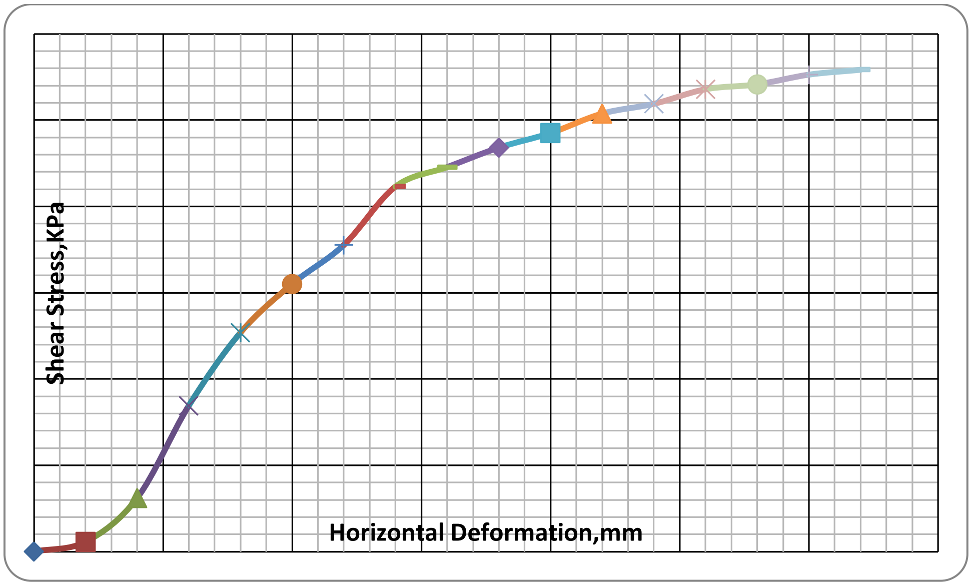

Figure 21Horizontal deformation Vs Shear stress, normal stress 54.5 kpa

Table 52 Shear Stress of test pit 3, normal stress 81.75kpa

Horizontal Dial Reading (Mm)	Proving Ring Dial Gauge Reading	Correction Factor (N/Div)	Shear Force (N)	Area of Specimen (M2)	Shear Stress(KN/M2)
0	0	2.03	0	0.0036	0
20	1	2.03	2.03	0.0036	0.56388889
40	31	2.03	62.93	0.0036	17.4805556
60	66	2.03	133.98	0.0036	37.2166667
80	85	2.03	172.55	0.0036	47.9305556
100	94	2.03	190.82	0.0036	53.0055556
120	97	2.03	196.91	0.0036	54.6972222

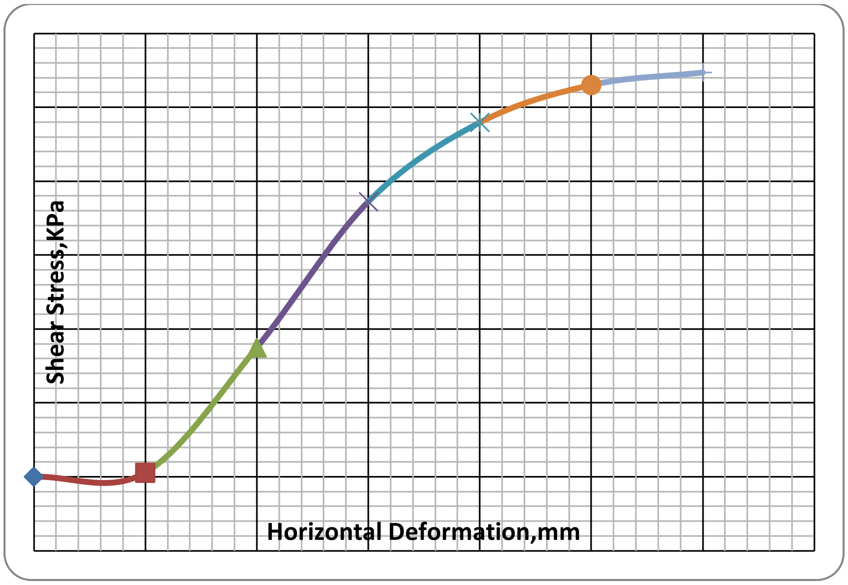

Figure 22 Horizontal deformation Vs Shear stress, Normal stress 81.75 kpa

Table 53: Normal Stress and Shear stress values of test pit 3

Test No	Normal Stress	Shear Stress
1	27.25kpa	55.82
2	54.5 Kpa	55.82
3	81.75KPa	54.69

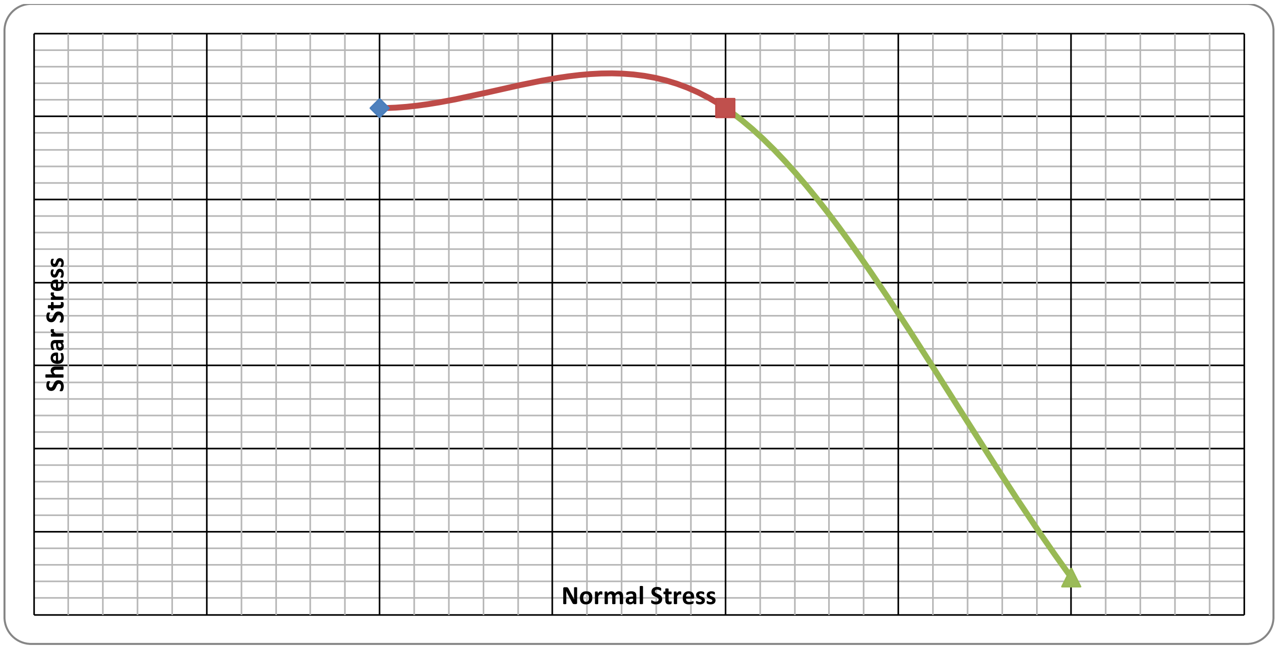

Figure 23 Graph of Normal Stress Vs Shear Stress

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