DETERMINATION OF MAJOR CAUSATIVE FACTORS OF LANDSLIDES AND LANDSLIDES PRONE AREAS IN KEGALLE DISTRICT

By

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DECLARATION

The analysis describes in this thesis was carried out by my self at the National Building Research Organization, under the supervision of Mrs. Kumari M. Weerasinghe, Engineer, Land Slide Studies and Services Division, National Building Research Organisation and Mr. E.P.N.Udayakumara, Lecturer, Department of Natural Resources, during the industrial training from 03 rd April 2006 to 14th July 2006.

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ABSTRACT

Frequently experienced slope instability such as landslides cause a serious threat to life, property, and infrastructure in Kegalle District. According to the research done on this subject, factors such as slope angle range, bedrock lithology, soil overburden, drainage patterns, land use practices and type of land form have been identified as the major causative factors of slope instability. However, the degree of impact of these causative factors varies from region to region because of the differences in climatic and human activities in each region. This study was performed to identify the most vulnerable factor attributes, that have influenced the landslides observed within the Kegalle District. During this study fifteen landslides within Kegalle District were investigated and the results reveal that, Charnokite Gneiss is the most vulnerable bedrock type followed by Biotite Gneiss. Most landslides occur on scarp slopes within the range of 30 to 40 degree angles. Higher the overburden deposit thickness is, grater the slope's susceptibility to fail. Within the investigated areas most landslides had occurred in the overburden thickness range of 2 to 3 meters. In the investigated areas land uses and human settlements with the highest landslide frequency were studied. Due to the limitations in accessibility to landslides and the time duration for this study, the number of sites investigated was limited to fifteen. However, it is advisable to study a larger number of landslides, in order to strengthen the out come of this study further.

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CHAPTER 1

INTRODUCTION AND OBJECTIVES

1.1. INTRODUCTION

District of Kegalle is situated in the central mountain area of Sri Lanka. This district has a special significance with respect to landslides. Geomorphological studies reveal that, in most of the mountainous areas, mostly consisting of critical slope angles, bed rock lithology also plays a significant role in the occurrences of landslides. Among landslide porn slopes in Kegalle district, Bulathkohupitiya, Yatiyanthota, Dehiovita, Ruwanwelle, Kotiyakubura are the most critical areas where the population density is comparatively high.

During every rainy season, most of the hill slopes in the Kegalle District experience landslides, slope failures or rock falls, causing considerable damage to human lives, their property and infrastructure. These catastrophic events are entirely due to natural and man made factors. Heavy rain is the most critical triggering agent of landslides. It has been reported that most of the mass movements in Kegalle resulted in the inducement of bad land use practices, and other man made activities. Therefore, determination and introduction of suitable land use practices and remedial measures have become a level task, which needs to be achieved.

Many researches have been conducted by the universities and the National Building Research Organisation (NBRO) on minimizing the impacts of landslides on life property and economy of our country. The literature on these researches reveals that landslides occur due to both natural and manmade causes. Bedrock geology, overburden deposits, hydrology and geomorphology of the slope play a major role in causing a landslide naturally. Unplanned cultivation and human settlements are the manmade factors that destabilize the slopes.

The degree of impact of the causative factors of landslides varies from region to region, due to the differences in climatic conditions and the human activities. The objective of this research is to evaluate the degree impact of such factors for the slope instability observed in the Kegalle District.

1.2. OBJECTIVES OF THE STUDY

i. To evaluate the impacts of geological, geotechnical, land use, human settlement or other relevant parameters in causing landslide or other form of slope instability.

ii. To determine the most vulnerable causative factor of landslides, slope failures and rock falls, observed within the Kegalle district.

iii. To analyze the degree of impacts of major causative factor attributes on causing landslides and other slope failures observed within the Kegalle District.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION OF MASS MOVEMENT

Geologists use the term mass movement for processes in which masses of materials move down slopes under the force of gravity.

Mass movement is one type of erosion, in which the removal of surface materials by geological agents such as water, wind or ice. However, mass movements are different from other erosion agents in several ways. The most important difference is that the material is moved as masses rather than discrete particles, which take place in most common forms of erosion. Mass movements of one kind or another occur in many land environments, in parts of the oceans basins, and have been identified even on the Moon and the Mars. They are vital in moving rock and regolith down the slope and into transportation systems such as glaciers, streams, rivers, and costal currents, which then can move these sedimentary particles great distances. The mass movement processes differ from other erosional agents also by its relatively small transport distance and the resulting less changes caused to the sediments.

Some mass movements occur so fast that, initial roar of the rock masses ripping loose from the slope is followed by the particles cascading on to the land at the base of the slope, in a minute or less. Other types of mass movements are slower, with the regolith flowing over days, weeks or even months. Still other types of mass movements are so slow that the only way to sense their occurrence is by noting that originally vertical features such as trees, utility poles, and fences have been tilted or moved down slope over a period of years. (Coch, N.K, and Ludman.A (1991))

2. 2 CLASSIFICATION SYSTEM

2. 2.1 Types of mass movements.

The best classification of mass movements is that proposed by D.J. Varne in 1978.
Three major types of mass movements can be distinguished, based on the type of movement involved.

(1) Falls involve sediment and rock that move through the air and land at the base of a slope.
(2) Slides are movements of rock or sediments unit, principally along one planar surface.
(3) Flows are plastic or semi liquid movements of rock or sediment, either in air or water.

Above major types are further subdivided based on the material involved and the speed of movement.

Table 2.1 Characteristic of mass-movement processes. (Coch, N.K and Ludman.A, 1991)

Mass wasting type	Character of movement	Subdivision	Speed and type of material
falls	Particles fall from cliff and accumulate at the base	Rock fall	Extremely rapid; develops in rocks
		Soil fall	Extremely rapid; develops in sediments
slides	Masses of rock or sediment slide down slope along planer surface.	rockslide	Rapid to very rapid sliding of rock mass along a curved surface
		slump	Extremely slow to moderate sliding of sediment or rock mass along a curved surface.
flows	Displaced mass flows as a plastic or viscous fluid	Creep	Extra-slow movement of surface regolith and rock
		solifluction	very slow to slow movement of water saturated regolith as a lobate flows
		Mud flow	Very slow to rapid movement of fined grained sediment and rock particles with up to 30% of water.
		Debris flow	Very rapid flow of debris commonly start as a slump in the upslope area

		Debris avalanche	Extremely rapid flow fall and sliding of rock debris

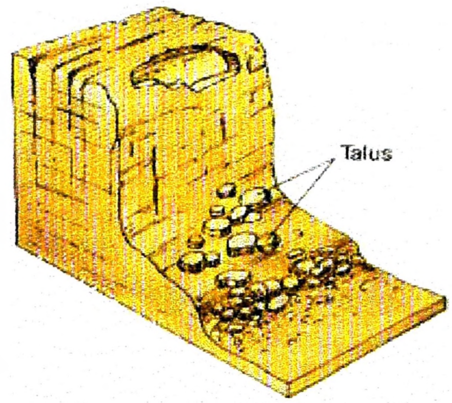


Fig.2.1.Rock fall

The fall of rock particles through the air from a cliff is called rock fall (Fig. 2.1). Rock fall can be a dry process, triggered by root wedging, or a wet process, triggered by frost wedging in which ice formation in crevices loosens the rock particles so that they fall from the face of the cliff. Rock fall is an extremely rapid process and this is a serious geological hazard. It can demolish structures near the basis of cliffs and is a danger to motorists where a highway cuts through rocks. The pile of rock fragments deposited by rock fall at the base of a slope is called talus.

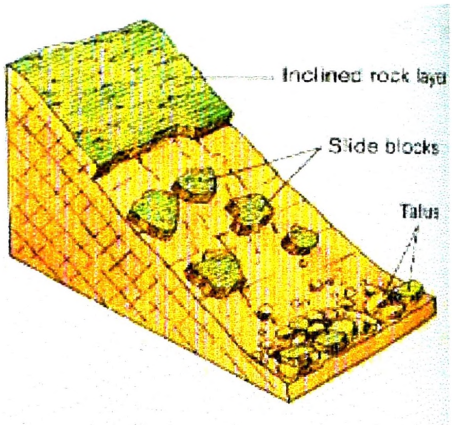


Fig.2.2.Rock Slide

The down slope movement of rock masses along a planer surface is called rock slide (Fig. 2.2). The sliding surface is commonly a bedding plane, but rockslides have developed on a wide variety of other planar surfaces, such as exfoliation sheets or fractures cutting across layered rocks. Any area where such planar rock surfaces are inclined toward an open space, such road cut or valley, has a potential for rockslide development.

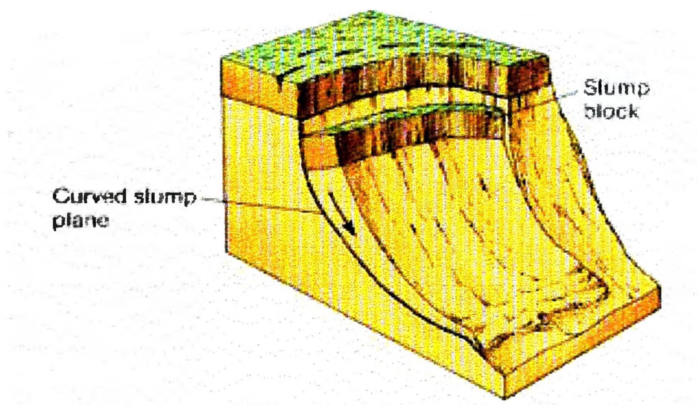


Fig.2.3.Slump

Sliding of a mass of a material along a curved surface is slump (Fig. 2.3). Although slumping is most common in unconsolidated sediments, it also occurs in some poorly consolidated rock sequences. One of the commonest causes of slumping is erosion at the base of the slope, which removes support for the material above. This erosion may be due to the undermining of riverbank by steam flow or cutting away of a costal cliff bases by storm waves. When the slope fails, the slump block rotates downward and a scrap is formed at the top of the slope.

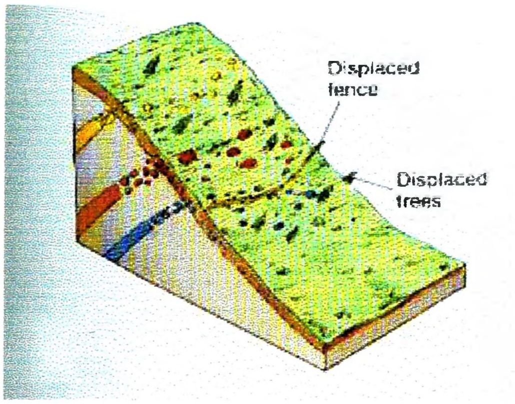


Fig.2.4.Soil Creep

Major characteristic of creeping area is displacement of trees, fences or utility poles over a long period of time (Fig. 2.4). This is an extremely slow down slope movement of regolith, soil and rock under the influence of gravity.

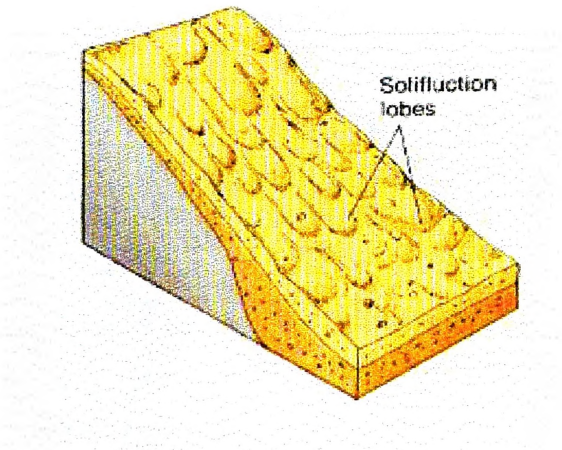


Fig.2.5.Solifluction

The down slope movement of water saturated regolith is called solifluction (Fig. 2.5). Movement rates are faster than that in a creep and may reach up to a few centimeters per years. Solifluction may occur in any climate in which regolith become saturated with water.

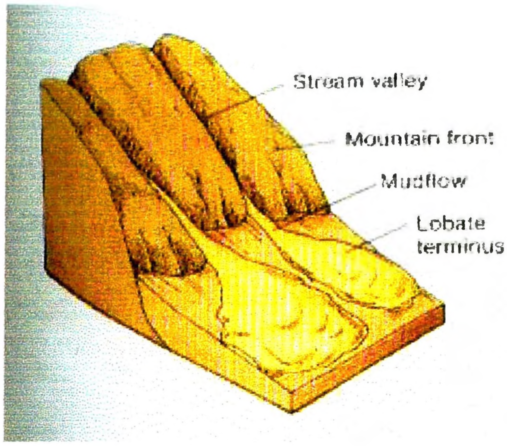


Fig.2.6.Mud Flow

Flows that contain significant amount of water (up to 30%) and a large proportion of fine – grained material are called mudflow (Fig. 2.6).

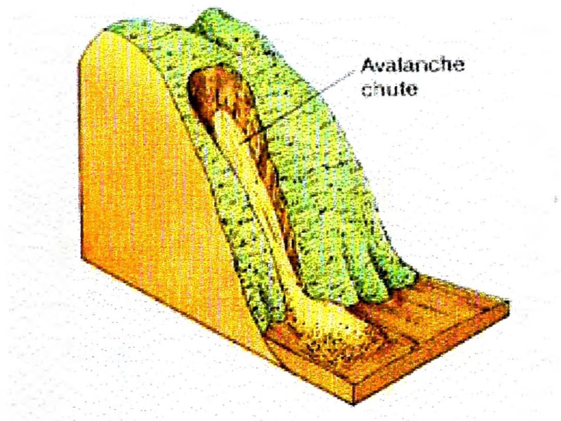


Fig.2.7.Avalanche

The general term avalanche is used for the most rapidly flowing, sliding, and falling mass movement processes (Fig. 2.7). Very rapid to extremely rapid movement of rock and sediment are referred to as debris avalanches. (Coch, N.K, and Ludman. A 1991)

2.3 ANATOMY OF LANDSLIDE (Rittre, D, F, Kochel, R, C.and Miller, J, R 1995)

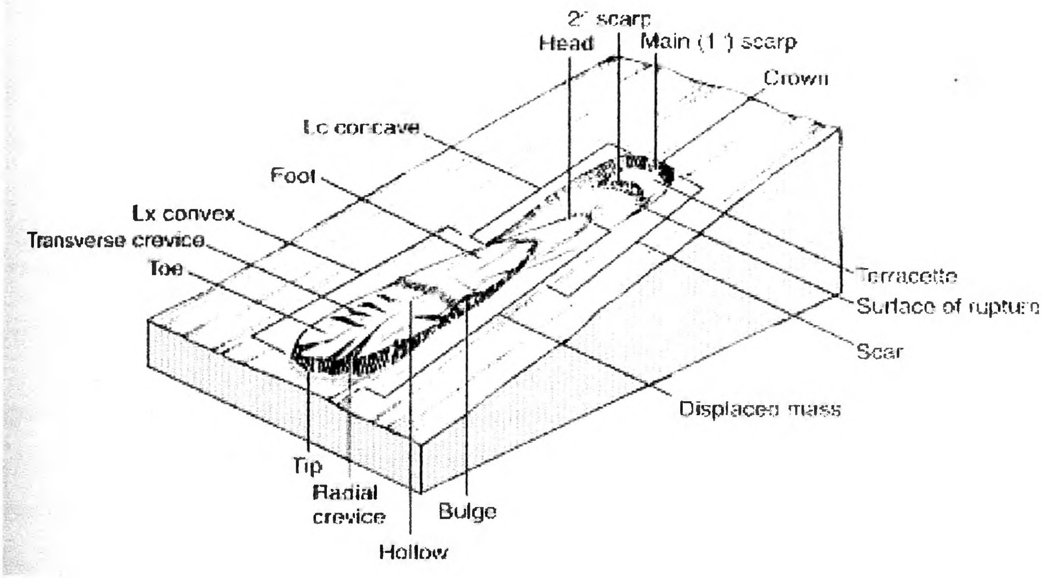


Fig.2.8.Anotomy of Landslide

2.4 SLOPE STABILITY

2.4.1 Factor of Safety

A body of a material on a slope will remain in equilibrium as long as the resultant of applied shear stresses does not exceed the shear strength of the slope material. The various mass movements are alike in that aspect, because all slope failures begin when the shear stress tending to displace material exceeds the resisting shear strength. Stability, therefore, represents some balance between driving forces (shear stress) and resisting forces (shear strength) and can be expressed as a safety ratio or factor of safety.

$$F = \frac{\text{Resisting force (shear strength)}}{\text{Driving force (shear stress)}}$$

Slopes, with Factor of Safety (F) greater than 1, are stable, but as the ratio decreases towards unity, a critical condition evolves and failure becomes imminent. (Rittre, D, F, Kochel, R, C.and Miller, J, R 1995)

2.4.2 Causative factors of landslides

Landslides are caused due to several factors including geological, geomorphological, physical and human. The most common natural and man made causes are described bellow.

2.4.2.1 Natural factors

The Role of Rainfall and Water

Water plays a big role in triggering landslides; it acts like WD-40 on a rusty screw. Water lubricates the surface between the soil (or sometimes weathered rock) and the bedrock, and makes it easier for the soil to slide off the solid underlying hillside. If the soil is already saturated, a period of heavy rain can trigger a slide.

Keith Mills, a geological specialist at the Oregon Department of Forestry, says that two to five inches of rainfall in six hours, after a few days prior to rain, is enough to trigger a debris flow. Water combined with gravity is a powerful force in moving earth.

How heavy is water? "When it rains two inches in 24 hours, you have about 10 pounds of water on every square foot of soil," explains Tom Horning, a geological hazards specialist at Horning Geosciences in Seaside, Oregon. "That's about 50,000 pounds of water on a 50-by-100-foot lot. After four or five days, you could have 125 tons of water, and that water's got to go somewhere."

Soil and Bedrock

Soil composition and bedrock also determine where debris flows occur. The looser the soil, the more likely it will move if nothing is there to hold it down.

Soils with greater clay content stick together better because the clay particles absorb water slowly and stick together. Soils with more organic material -- such as forest soils -- act like sponges to soak up excess water. When the spongy layer is removed by logging or burning, or compacted by heavy machinery, excess water flows over the surface and erodes the top layer of soil. When the underlying bedrock is porous, such as sandstone or some volcanic-formed rock, soils drain faster. Impermeable bedrock, such as granite, keeps water in the soil. Over time, the excess water is transferred down to the water table or to stream channels, and some is stored for future use by plants.

Jointed bedrock is subjected to increased landslide risk depending on which way the cracks form. Joints formed horizontally, create cracks between layers of rocks during normal earth movements. Water seeps through the porous bedrock (such as sandstone) to such existing cracks or layers in the rock. Horizontal joints, parallel to the topsoil, provide little resistance to sliding. The water lubricates the layers, creating a slip plane, and causes them to slide against one another like two pieces of paper. Vertical cracks in bedrock, however, can actually help stabilize the slope by absorbing and diverting water. If roots can get down into the cracks, the soil is further stabilized.

Bedrock type can also determine slide potential. Some rock, such as shale and volcanic-formed rocks, weather into sticky clay soils. Sandstones, granites, and micas wear down into coarse porous soils that are easily moved.

Slope

The steeper the slope, the more likely it is to slide. Landslides can occur on very gentle slopes, but these usually take years, for the soil to creep slowly downhill, moving fence posts and realigning railroad tracks. Wash gullies, which funnel eroded soil downhill, form more often on slopes greater than 40 percent (22 degrees). Quicker debris flows take place on slopes greater than 50 percent (27 degrees). The landslide observed in November, 2005, along the lower Umpqua River, occurred on a slope steeper than 60 percent (31 degrees).

How do these percentages translate into angle degrees? A rough estimate of a 100 percent slope would be about 45 degrees. A 200 percent slope is about 90 degrees.

2.4.2.2. Manmade causes

Unplanned land use practices

When a hillside is cut for construction of a road or a building, an imbalance occurs between the shear stress, the forces, which want to tear the soil from the bedrock, and the forces that resist the downhill movement. Shear stress forms along the slip plane, the interface between soil and solid bedrock. Heavy rain also break down the resistance to a point where shear stress takes over and the hill comes tumbling down Resistance is also provided by roots holding soil to the slope, or soil particles clinging to one another and the bedrock. Normally, rain percolates through the soil -- or a porous layer of rock -- to the water table, and flows downhill from there. If the bedrock is not absorptive, the water runs downhill through the soil along the slip plane.

When a road is cut into a slope, the water flowing downhill seeps out of the side of the cut and across the road surface, then continues on its path to the bottom of the hill. If lots of rain falls in a very short period of time, the soil above the road gets supersaturated with water and becomes a big muddy mass. If the mass is not held to the slope by vegetation, it may start to move downhill, picking up loose rocks and vegetation. Eventually, the flow reaches the road cut and dumps everything onto the surface. If the debris flow has enough speed and force, it can move across the road and continue its path downhill.

Vegetation and Deforestation

The effect that vegetation cover has on hill slopes and their slide potential is complicated. Trees intercept rain, lessening the impact that individual raindrops have on soil, and shade from trees keeps the forest floor moist and cool. Rain hitting the bare ground loosens soil and small pieces of rock. On the contrary, plants absorb the force of the rain and take up water for their own growth.

Roots hold soil down. Trees have larger and deeper root systems than grasses or shrubs, are therefore more effective in retaining soil. When trees are cut, their roots die and quickly begin to decay. As a result, they lose their ability to hold soil. The roots eventually decay to the point where they become part of the soil.

Meanwhile, grasses, shrubs, and new trees begin to grow on the site where trees were cut. As the new trees grow, their roots gain strength in retaining soil. For a few years, the grasses and shrubs are the most important factor in holding down soil.

Donald Satterlund and Paul Adams, forest researchers at Washington and Oregon State Universities, report that root cohesion -- the ability of roots to hold the soil to the slope -- reaches its lowest point 10 years after a clear cut. Yet, even after 10-years, the new growth is unable to take up the slack left by decaying roots. The rotting roots have reached the point where only the largest main pieces of the roots remain

However, strong winds blowing on treetops can weaken the hold of the roots on the soil. The tree trunk acts like a crowbar: Wind pushes down on the treetop "handle" and pries up the soil with the roots. The resultant loss in slope stability can create a slump.

Bare soil erodes rapidly. Removal of vegetation also increases increase runoff. If water is flowing over the soil, it has a greater ability to move loose soil, rocks, and plant material.

Mining, quarrying, development processes such as building of roads, dams, buildings and even other apparently beneficial structures, and water conservation measures tend to destabilize the landscape.

Accelerated soil erosion caused by inappropriate land use and land management practices also result in gully formation and rock fall. In the absence of any vegetated cover gullies will be formed, dividing the slope in to small vertical stripes.
(http://www.wildfirenews.com/forests/foest/analysis.html)

2.5 REMEDIAL MEASURES

2.5.1 Retention of earth slopes

Walls are used to retain slopes where space is not available for a flat enough slope or where excessive volumes of excavation are required or to obtain more positive stability under certain conditions. The type of walls may be divided into four general classes, with some wall types included in more than one classes.

(1) Gravity walls provide slope retention by either their weight alone or their weight combined with the weight of the soil mass acting on a portion of their base or the weight of the composite system. They are free to move at the top thereby mobilizing active earth pressure. They include rock filled buttresses, gabion walls, reinforced earth walls, concrete gravity walls, cantilever walls and counter fort walls.

(2) Non-gravity walls are restrained at the top and not free to move. They include basement walls, some bridge abutments and anchored concrete curtain walls.

(3) Rigid walls include concrete walls, cantilever walls and counter fort walls.

(4) Flexible walls include rock filled buttresses, gabion walls, crib walls, reinforced earth walls and anchored sheet pile walls.

The wall-type is tentatively selected on the basis of an evaluation of the height, material to be supported, wall purpose and a preliminary economic study. The general characteristics of retaining walls are summarized below.

Table.2.5.1.Retention wall types.

Wall type	Description
Rock-filled buttress	Construction of non-degradable, equi-dimensional rock fragments with at least 50% between 30-100cm and not more than 10% passing 50mm sieve.
Gabion wall	Wire baskets, about 50 cm each side are filled with broken stone about 10-15cm across. Baskets are then stacked in rows.
Crib wall	Constructed by forming interconnected boxes from timber, precast concrete or metal members and then filling the boxes with crushed stone or other coarse granular material.
Reinforced earth wall	Compacted back fill of select fill is placed as metal strips called ties are embedded in the fill to resist tensile forces. The strips are attached to a thin outer skin of precast concrete pane is to retain the face.
Concrete gravity wall	Mass of plain concrete.
Semigravity concrete wall	Small amount of reinforcement used to reduce concrete volume and provide capacity for greater heights.
Cantilever wall	Reinforced concrete with a stem connected to the base. The weight of earth acting on the heel is added to the weight of the concrete to provide resistance.
Counterfort wall	Cantilever wall strengthened by the addition of counterforts.
Buttress wall	Similar to counterfort walls except that the vertical braces are placed on the face of the wall rather than on the backfill side.
Anchored reinforced concrete curtain wall	Thin wall of reinforced concrete is tied back with anchors to cause the slope and wall to act as a retaining system.
Anchored steel sheet pile wall	Sheet piles driven or placed in an excavated slope and tied back with anchors to from a flexible wall.
Bored piles	Bored piles have used on occasion to stabilized failed slopes during initial stages and cut slopes.

Root piles	Three dimensional lattice of small diameter, reinforced concrete piles closely spaced to reinforce the earth mass.

In addition, available used items such as bitumen drums, tyres, sand bags and bamboo piles can also be used for retaining structures on sections of shallow slopes.

2.5.2 Earth work controls.

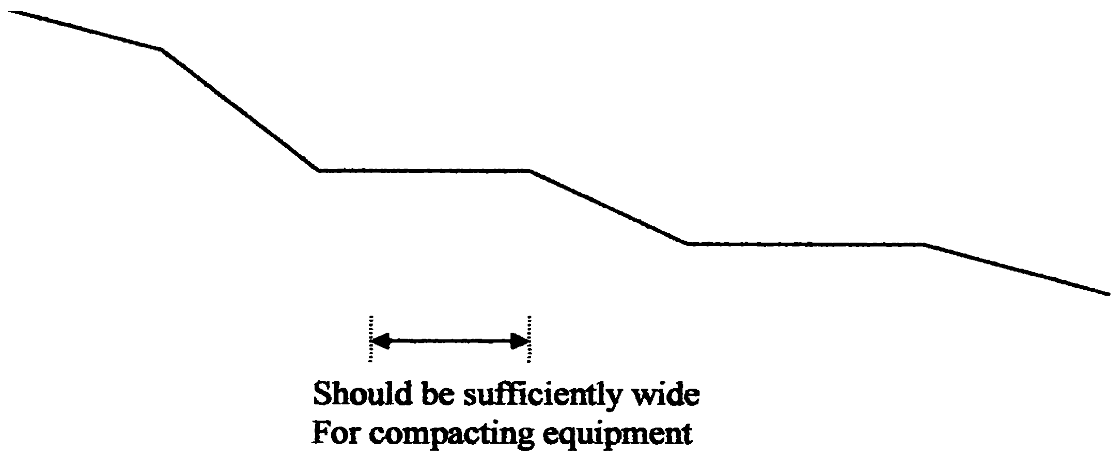
a) Cut and fill on hilly terrain should be kept to a minimum. Deep cut and fills should be avoided by including several levels (berms) in the profile. For residential construction, this may reduce or eliminate costly retaining structures and could prove to be aesthetically more pleasing.

b) Roots of trees and shrubs generally enhance the stability of shallow soil layers. Grass and ground cover reduce the potential for erosion. Natural vegetation should be retained wherever practicable. Therefore, when clearing for construction, only minimal areas required for building and access roads should be stripped.

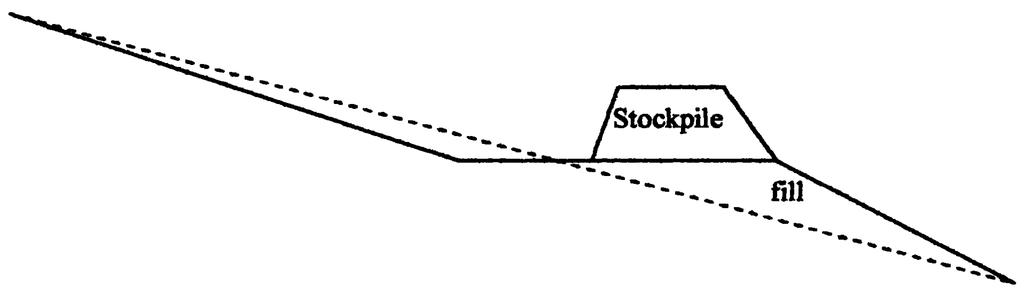
c) Prior to commencement of fill operations on a hill slope, the ground surface should be stripped off any vegetation including grass, shrub and small plants, and remove any unsuitable such as non-compacted fill, topsoil, building rubble, soft/loose soils. The fill should be keyed into the slop with appropriate drainage measures where necessary eg. Filling in the vicinity of a gully.

d) Fill layers should be sufficiently thin, appropriate to the compaction technique employed, to ensure that the full layer will be adequately compacted. For machine compaction, loose layer thickness of 200mm to 300mm is appropriate depending on the material characteristics. The maximum particle size should be less than two third the compacted layer thickness.

e) More than 1 m deep cut or fill slopes should be inspected by an experienced Geotechnical engineer and/or an Engineering Geologist



f) Stability during construction is equally important as long term stability. In particular, access road to the building site should be located away from embankment crests. Material and/or spoil stockpiles should also be located away from the crest without increasing the load on the slope.



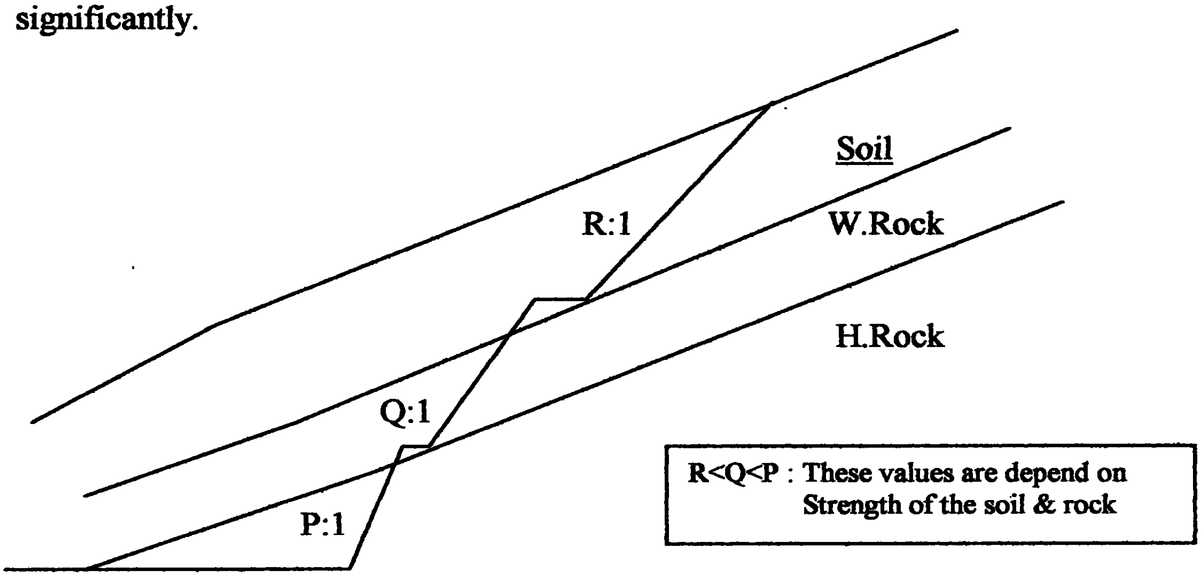
g) Excavations for roads etc should be parallel to the contour lines.

h) The formation of large flat areas may cause a large infiltration of rain water into the ground. To minimize infiltration, the platform should be should not be left open without any surface seal or drainage.

i) Although excavation in the residual soil and completely weathered rock may be carried out using conventional bulk excavation methods, care must be taken to avoid loosening of finished surface, which may lead to severe erosion and siltation. Trimming should be carried out with manual methods or with light earthmoving equipment as appropriate.

j) Trenches, for example for services, excavated on or above slopes provide a location where water infiltration into the hillside could eventually lead to slope instability. A trench cut into the toe of a slope can also undermine its stability and should be avoided. Trenches loosely backfilled with soil will act as sumps for rainwater and should not be allowed.

k) Variable angle slope designs are usually more effective and economical in cut slopes. By using this method volume of earthworks can be reduced significantly.



2.5.3 Surface and Subsurface Drainage Methods

Majority of landslides mostly occurs along with rainfall and consequently water is the main cause of landslides. Thus, it is imperative that, control of surface and subsurface water by appropriate drainage techniques is of prime importance in controlling landslides. The drainage techniques that could be adopted in stabilization of landslide areas are:

2.5.3.1 Surface drainage:

(1) Diversion drains are used for prevention of any water flowing into the sliding area across its periphery

(2) Interceptor drains are used for prevention of surface runoff from springs and rain within the sliding area

2.5.3.2 Subsurface drainage:

(1) Horizontal drains are more useful in draining deep seated slides where the ground water lies considerably deep and the slopes are steep

(2) Drainage wells are used at locations where it is not possible to provide horizontal drains from surface due to topography

(3) Trench drains are generally limited to locations where ground water can be intercepted at depths less than 5-8m and are used where horizontal drilling is not possible because of the site conditions

(4) Drainage tunnels are used for deep seated landslides where subsurface water is very deep and construction of horizontal drains and drainage wells are difficult due to site condition

Both surface and subsurface drainage are equally important in relation to construction on hilly areas and therefore adequate attention should be given.

a) Surface runoff should be directed away from the slope to reduce erosion problems and water infiltration. Drains along roads should be carefully controlled by locating appropriate culverts and similar.

b) Discharges of waste water directly onto and into slopes should be avoided.

c) All discharges should be connected to street drainage and/or natural water courses.

d) Adequate fall (grade) should be provided on surface drains to ensure free flowing of water instead of stagnation and to prevent blockage by siltation. Where necessary, silt traps should be provided.

e) Infiltration can be minimized by lining the channels and damage can be minimized by the use of flexible materials.

f) Subsurface drainage is provided to control the groundwater table and/or seepage flows. It is prudent to provide a filter around subsurface drains.

g) Subsurface drains should be provided behind retaining structures.

h) Subsurface drains should be constructed using flexible pipelines, so as to allow movement without structural damage. Maintenance access should be provided at appropriate locations.

i) Inflow of surface water should be prevented otherwise the capacity of the subsurface drain may not be adequate.

j) Regular maintenance should be carried out by the owner/occupant. These could include cleaning of drainage systems, repair of broken joints in drains and leaks in pipes.

k) Excavations of pits/trenches should not be left open for long and should be backfilled to prevent entry of water. Holes created by removal of trees should also be backfilled to avoid those becoming sumps.

2.5.3.3 Erosion Controls

Soil erosion may produce topographic changes, which may activate landslides. There are different kinds of erosion process:

(1) Splash erosion of rain against the soil surface. It is especially dangerous in high gradient slopes of highway cuts.

(2) Gully erosion as runoff water flows on the slope surface. At the beginning the gully deepens looking for a suitable gradient, which depends on the hydrological and geological characteristics of the site and afterwards advances laterally producing vertical slopes and landslides.

(3) Riverside erosion. The river water flow erodes and deepens the riverbed and activates lateral landslides.

Soil erosion can be controlled by considering the following principles:

(1) Match development to the terrain i.e. disturb as little land as possible by minimizing grading and tailoring the excavations to the natural ground contours

(2) Minimize soil exposure by:

- Optimizing construction stages by reducing size of exposed area and the length of the time the areas are exposed
- Soil grading in stage such that, only small areas are exposed to erosion at any given time
- Timing of grading to suit / coincide with a relatively dry season

(3) Retain existing vegetation where possible by not clearing the entire site without knowing the exact location of the structure. Vegetation provides many beneficial soil conservations, which may be summarized as follows:

(a) Interception of rainfall and restraint of surface air and water flows.

(b) Increasing shallow infiltration and provision of surface litter layer.

These combine on slope to reduce run off velocities and volumes, sediment detachment and transport.

(4) Revegetating and mulch-seeding or hydro-seeding on graded areas in association with Vetiver grass hedging planted on contour or diagonally are the most effective form of vegetation in the long run. This work should be started as soon as possible after vegetation sites are cleared.

(5) Divert runoff away from denuded areas

(6) Optimization of slope angle and length

(7) Minimize runoff velocities by:

- Grass lining of diversion trenches
- Use of broad and shallow flow areas
- Network of surface drains and use of geo-textiles
- Use rock fragments on slopes

(8) Drainage ways and outlets to handle concentrated flows in development sites

(9) Trap sediment on site by using sediment basins and silt fences

Table.2.5.5 Summary of approaches for potential slope stability problems

CATEGORY	PROCEDURE	BEST APPLICATION
Avoid problem	Relocate facility Remove unsuitable materials	As an alternative anywhere, where small volumes of excavation are involved and poor soils are encountered at shallow depths
	Install bridge	At side hill locations with shallow movements
Reduce driving force	Change line or grade	During preliminary design phase of project
	Drain surface	In any design scheme
	Drain subsurface	On any slope where lowering of ground water table will increase slope stability
	Reduce weight	At any existing or potential slide
Increase resisting forces	Use counterweight and buttress fill: toe berms	At an existing landslides; in combination with other methods
	Use structural systems	To prevent movement before excavation
	Install anchors	Where right of way is limited
Increase Internal strength	Drain subsurface	At any landslide where water table is above shear surface
	Use reinforced backfill	On embankments and steep fill slopes
	Install in situ reinforcement	As temporary structures in stiff soils
	Use biotechnical stabilization	On soil slopes of modest heights
	Treat chemically	Where sliding surface is well defined and soil reacts positively to treatment
	Use electroosmosis	To relieve excess pore pressure and increase shear strength at a desirable construction site
	Treat thermally	To reduce sensitivity of clay soils to action of water

2.5.6 Other considerations

a) The slopes should be protected against erosion and degradation. The most popular method of surface protection is natural vegetative cover because of the economy and its important landscape function. There are various other methods used such as application of geofabrics, geogrids etc.

b) Drainage lines and services should be located away from the crest, say at least a distance equal to the height of slope. Leaky pipes could more damage than rainfall

c) Where it is necessary to significantly reduce water infiltration on a slope, shotcreting and/or rigid protection methods (eg masonry) could be used to cover the slope with appropriate weep holes to relieve water pressures.

d) Where possible, foundations of structures should be located away from a slope so as to minimize any interaction effects. Where this is not possible, the effect on the foundation and the effect on the slope should both be considered by the engineer.

e) In sites where the building footprint crosses both cut and fill, it is desirable to take the footings below fill to the natural ground.

f) Flexible structures which can accommodate movements without significant apparent distress to a structure are most appropriate for hilly areas.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1. DESK STUDY

Desk study consists studying of;

i. All the available text books, technical reports which prepared by NBRO geologist about landslides in Kegalle district, research papers which prepared by NBRO geologist, news paper articles, in detail for better understanding of the proposed study.

ii. Landslide hazard zonation maps, geological maps, topographical maps, overburden deposit maps were analyzed in order to learn geology and geomorphology of the study area.

iii. Aerial photographs were interpreted to find out the existing subsurface structural geological condition.

iv. Based on the results of above i ,ii,iii stages in desk study, landslides that have already occurred and vulnerable hill slopes were selected for the study.

3.2 FIELD INVESTIGATION

i. Detailed geological investigations were carried out in the field in association with fifteen selected landslides that have been occurred between 1989 and 2006. Location of each landslide was determined by using GPS.

ii. During this field investigation, the geological parameters such as dip, and strike were measured using the Brunton Compas. Hand samples of bedrock were taken at each location and conducted laboratory tests for its hardness, color, luster and reaction with diluted Hydrochloric Acid for identification of rock types. Degree of weathering and the joint patterns were determined by means of the visual observations at the sites.

iii. Cut pits were used to determine the height of the overburden deposits. The overburden deposit thicknesses was measured using meter tape. This cut pits used in several location of investigated slope area. Information extracted by overburden maps prepared by NBRO were used to identify the type of overburden and verified at the field by visual observations.

iv. Geomorphological data of the investigated sites were collected based on the visual observations. Brunton Compas was used for measuring the slope angle at upslope middle and down slope locations.

v. Information extracted from ABMP maps on hydrological features, land use and human settlements were verified at the field by visual observations.

vi. The collected data, that are listed in Para 3.3 of this thesis, were then analyzed and the geological, geomorphological and land use attributes that have influenced most of the observed landslides were evaluated.

3.3. DATA COLLECTION

3.3.1. Landslide of Halmunawa area of Moraliya Estate in Ruwanwella

Location

This landslide is situated in the area called Halmunawa that belong to Moraliya Estate, Ruwanwella.

This area has been determined as an area prone to Landslides in landslide hazard zonation maps prepared by the National Building research Organisation (NBRO). The GPS Location of the investigated location is N 07^0 01.698' and E 080^0 14.22".

Bed Rock Geology

Charnokitic Gneiss is the major bed rock underlain by this landslide prone slope. Currently the bedrock is highly weathered with a dip angle of 22°W. A well developed joint system is observed in this bed rock.

Overburden Deposit

Residual soil is the overburden type in this particular location, having a varying thickness of 2 to 3 meters.

Geomorphology

Slope angle of this investigated slope varies from 36 to 38° .It was identified as an escarpment slope. Large boulders with 1-3 m^3 are resting over the unstable soil slope at the particular location.

Hydrological features

No specific hydrological features were observed.

Land use practices

This area is totally covered by newly planted rubber trees managed by individual planters.

Human Settlement and Human activities

Three houses located near the landslide threaten area, and small home garden can be seen near by those houses. Vertical cut slope could be seen behind those houses. Tension cracks are visible in the area.

3.3.2. Landslide of Thelkumuduwa in Galpatha

Location

The landslide is located in an area called Thelkumuduwa in Galpatha village. This area also has been identifieded as an area prone to Landslide in the landslide hazard zonation maps prepared by NBRO. The GPS reading is N 07^0 03.802^1 and E 080^0 17.123^1

Bed Rock Geology

Charnokitic Gneiss is the major bed rock found underneath this landslide prone slope. Dip angle is 80° N. Two major joint systems are observed in association with this bed rock.

Overburden Deposit

Residual soil exists as the overburden soil type of this area. Overburden thickness varies from 2 to 3 meters.

Geomorphology

Investigated slope area is spread about 5 hectares. This land slide prone slope is located in the western slope of a mountain ridge, which is having a North-South orientation. Upper part of a escarpment bed rock out crop is exposed. Slope angle varies from 35 to 40°.

Hydrological features

Small tributary is located lower parts of the slope. In the rainy season it can be identified well. Drainage system is not good.

Land use practices

This area is totally covered by rubber plantation that is managed by individual planters. There was a paddy field in the lower parts of slope.

Human settlement and activities

Permanent human settlements can be seen in the surrounding area and in the middle part of the landslide prone slope. A small house is located down slope area. People who are lived in this house have been evacuated after the landslide was triggered. Another two houses are located towards further down slope. These two houses are still occupied. Small vegetable cultivation can be seen near those houses.

3.3.3. Landslide of Athurupana area of Wathura in Kegalle

Location

GPS Location of the landslide observed in Athurupana in Wathura, Kegalle is N 07^0 10.014^1 and E 080^0 22.744^1

Bed Rock Geology

Biotite Gneiss is the major bed rock found underneath this particular location. This rock is highly weathered. Well developed joint system is observed with this bed rock. Thin layers of quartz feldspathic could be seen in out crop area of the main bed rock.

Overburden Deposit

Colluvium soil exists as the overburden soil type of this area. Overburden thickness varies from 2 to 3meters.

Geomorphology

Slope angles, of the landslide occurred, is within the range of 35-40 degrees. The huge massive Garnet- Biotite Gneiss rock is located on upper slope of the affected area. Rock boulders spread over the body and foot area of the landslide. Their volumes are about 3*3*4 m^3.

Hydrological Features

No hydrological features could be observed.

Land used practices

Presently, a small rubber plantation exists in this area, and there had being a small home garden before landslide occurred. Paddy cultivation can be seen few hundred meters away from landslide foot area.

Human settlement and human activities

A house has been destroyed as a result of this land slide. At present, no human settlement can be seen in this area.

3.3.4. Landslide of Uduvilla Kumburapolla Kanda in Dehiovita.

Location

This landslide located in Uduvilla, Kumburapolla Kanda in Nagarehena watta in Dehiovita. This area also has been identified as an area prone to Landslide by NBRO. The GPS reading of the location is N 06^0 59.217^1 and E 080^0 13.936^1

Bedrock Geology

Major Bed Rock type is Biotite gneiss. Dip angle is 38° E. Two major joint systems can be seen. One joint system is 120/55 SW direction to 5 meters long and other is vertically 5 meters long.

Overburden Deposit

Residual soil exists as the major soil type of overburden deposit in this area. Overburden thickness is about 1-2 meters.

Geomorphology of area

This land slide is located on the Eastern slope of Uduvilla, Kumburapolla mountain ridge which is trending towards North-South direction. In this area slope angle varies between 40-45 degrees range. A Previous landslide has also been occurred on the opposite side of the mountain slope.

Hydrological Features

Water spring can be seen near a tension crack observed in this area. Mud water is coming out of this spring.

Land used Practices

Rubber plantation and small home garden can be seen in this area. Recently cultivated rubber plantation was observed on the scar of the landslide.

Human settlement and human activities

Permanent houses can not be seen in this area except a few small cottages situated at the foot area of the landslide. People who live in these cottages have a direct threat in the future, because some rock boulders may fall down the slope in a future rainy periods.

3.3.5. Landslide of Galvana area in Debagama village in Dehiovita

Location

The GPS Location of this landslide observed in Galvana is N 06^0 58.754^1 and E 080^0 15.491^1

Bedrock Geology

Charnokite gneiss rock is the major bed rock type in this area. It's Dip angle is 32°W. Strike is 270° North to South direction.

Overburden Deposit

Residual soil is mainly existed in overburden of this investigated area. Its' thickness is about 1-2 meters value takes.

Geomorphology of area

This landslide is situated in North East slope of a mountain ridge. Slope angle varies between 30-45 degrees. Rock boulders are exposed in the head area of the landslide.

Hydrological Features

No hydrological features could be observed in the investigated area.

Land use Practices

Upper part of the slope is currently used for a rubber plantation. Small home gardens can be seen in the lower part of the slope. Vegetables and fruits are cultivated on these gardens.

Human Settlement and Human Activities

A house has been destroyed as a result of debris flow of the landslide. At present, small cottage exists in the slide area. Rubber plantation is poorly managed with a poorly maintained drainage system.

3.3.6. Landslide of Ganthuna Pallegama area in Ganthuna in Kegalle

Location

GPS reading at the landslide observed is N 07^0 07.283^1 and E 080^0 24.365^1

Bedrock Geology

Charnokite gneiss rock is the main bed rock type in this landslide occurred area. This rock is fresh and could be seen moderately weathered in some areas. Strike of the rock is 350° North to South direction. Dip angle is 40°W. Well developed joint system could be observed.

Overburden Deposits

Overburden deposits of this area mainly consist of Residual type soil. Its' thickness can be observed as about 1-2 meters.

Geomorphology of area

Investigated area is located on the North East face of the Sakrakanda mountain ridge. The slope angle of this area varies between 40-45 degrees.

Slightly displaced rock boulders could be seen on the body area of the landslide. Those rock boulders have already become unstable and may fall in the future. A major tension crack appears in the middle part of the slide area horizontally to the slope.

Hydrological Features

No hydrological features could be observed in this area.

Land use practices

Upper most area of the mountain slope is covered by the forest. Middle and lower parts of the slope are covered by a small tea cultivation.

Human Settlement and Human activities

Six houses, which had been located on the slide had been destroyed as result of the heavy mass movement. Those houses had been in a permanent settlement. At present, another new permanent human settlement could be seen near the landslide. At some places slope has been cut vertical to make the land flat.

3.3.7. Landslide of Karagala area in Kotiyakumbura in Kegalle.

Location

GPS Location of the observed slide is N 07^0 06.912^1 and E 080^0 18.231^1

Bedrock Geology

Charnokite gneiss rock exists as the main bed rock type on this investigated area. Existing bed rock is moderately weathered. Biotite rich internal rock band could be seen on this rock. Bed rock Strike is 170°N/W. Dip angle is 10°N. Moderately developed joint system could be seen.

Overburden Deposits

Overburden deposits of this area mainly consist of Residual type soil. Its' thickness can be observed as about 4-5 meters. Very thick soil overburden can be seen.

Geomorphology of area

Site is situated in a scarp slope of a mountain ridge. The slide is situated on the South West slope of the ridge. Slope angle varies from place to place. The average slope angle of this area varies between 20-45 degrees.

Hydrological Features

Water paths, springs and seepages are prominent in the area. Water springs could be seen in several places. Rather large water paths flow down through the investigated slope area. Seepage of this area is very high. Ten dug wells can be seen in the down slope area. Those wells are fed by spring water.

Land use practices

Upper most area of the mountain slope is covered by a small forest. Well grown rubber plantation can be seen on either side of the landslide area. Mixed vegetation, home garden found in the down slope area.

Human Settlement and Human activities

Three small houses have been existed in this area and they have Sevier damage from debris flow. Those houses have been built in the unstable slope area. House owners have made a flat area on the slope with using vertical cut slop for build their houses. In present three new houses existed near the land slide foot area.

Bedrock Geology

Charnokite gneiss rock is existed as a main bed rock type on this investigated area. Bed rock strike direction is 155° N/S. Dip angle and direction is 55°N. Well developed joint system can be seen. It is existed 260 degrees vertically. One of joint system is developed parallel to valley area of the mountain.

Overburden Deposits

Colluvium soil exists as the main soil type in the overburden deposit. Its' thickness is about 2-3 meters. There is no high thickness in overburden deposits.

Geomorphology the area

Investigated land is situated on the North Western slope of the mountain ridge which is trending North East-South West direction. Morphologically this land can be divided in to major 3 parts. They are upper most part, middle part and lower part. In the upper most part, the slope angle is between 20-30 degrees. Middle part does not have a high slope angle, and only ranges between 5-10 degrees. Lower part is considerably steep with a slope angle range between 40-45 degrees. This area is an escarpment slope area.

Hydrological Features

No special hydrological features could be observed in this area.

Land use practices

Investigated area is covered by a rubber plantation. This area is situated within Halagolla rubber estate. So this area has been covered by rubber trees for a long period.

Human Settlement and Human activities

Lower part of this area had been occupied by a few estate houses and had totally been destroyed as a result of heavy mass movement. These houses had been permanently built houses. One small house can be seen in the steep area. But people do not live in that house presently. Estate rode also had severely been damaged due to the mass movement. Tension crack can be seen, presently, near the human settlement area. Natural drainage system has been blocked by human settlement.

3.3.9. Landslide of Dehiowita

Location

Site is located behind the proposed two storied building of the Dehiowita Pradeshiya Sabhawa in Dehiowita. This has been determined as an area prone to Landslide by NBRO.
GPS Location of the site is N 06^0 58.063^1 and E 080^0 16.049^1

Bedrock Geology

Biotite gneiss rock is the existing bed rock type on this investigated area. Highly fractured Quartzite layer can also be seen. Its thickness is about 0.3 meters. Dip angle of bed rock varies.

Overburden Deposits

Residual soil is the existing overburden deposits. Its thickness is about 2-3 meters. There is no high thickness in overburden deposits.

Geomorphology of the area

The problem had been associated with a 12 meters high vertical cut which has been made on the mountain slope. This mountains' slope angle is about 25-30 degrees. Major tension crack can be observed immediately above the vertical cut. Length of this major crack is about 30m, width is 0.3m, and depth is about 1.2m. Uprooted or slanted trees have moved downward.

Hydrological Features

Springs and seepage are prominent in this area. Water springs can be seen on the vertical soil cut and other slopes in this land. Seepage is very high in this investigated area. The soil is very wet and clayey.

Land use practices

There is no any cultivated crop in this area. This area is covered by bushes and large trees like jack and mahogany.

Human Settlement and Human activities

The investigated area is very close to Dehiowita town. So this area consists with medium concentration of residential, non residential, and public or private buildings. The area is very close to proposed pradeshiya sabha playground. Play ground is situated down slope area of this mountain. Currently, Pradeshiya sabha building is used for human rights office. But this building is not safe for any human activity. Because some tension cracks can be seen on the building walls also.

3.3.10 Landslide on Awissawella Hatton road

Location

The landslide is located between 36+340 km and 36+440 km LHS on Awissaella – Hatton road. The GPS Location is N 06^{0} 59.931^{1} and E 080^{0} 23.762^{1}

Bedrock Geology

Major Rock Type in the investigated area is Charnokite gneiss. Feldspathic gneiss rock also exists in this area.

Strike and joints vary and could not be identified clearly. Foliation is sub horizontal and the joint system is vertical and widely spread.

Overburden Deposits

Colluvium soil is the major overburden soil deposit. Its thickness is very high between 2-6 meters.

Geomorphology of the area

The problem is associated with road cut of Awissawella Hatton road. This mountain slope angle is about 30-40 degrees. Road located on upper part of slope.Kelani river located lower part of slope area. Highly weathered bed rock out crop can be seen at place adjacent to the road.

Hydrological Features

Water paths, springs and seepage are very prominent in this area. Several small water paths flow down through the hill slope to Kelani River. Water seepage is very high in this area. Water seeping even from the sub surface can be seen. Seeping water is muddy.

Land use practices

Investigated area is heavily covered by rubber plantations. Rubber trees exist on both above and below the Awissawella Hatton road. No other cultivation could be seen during the period of investigation.

Human Settlement and Human activities

Any permanent human settlement could not be observed in the investigated area. But small houses could be seen further upslope. Very high and long rod cut could be seen in this area. This rod cut has been made during the construction of Awissawella Hatton road and has disturbed the original stability of the investigated slope area.

3.3.11 Landslide of Ranwala in Kegalle

Location

GPS Location of the location is N 07^0 15.011^1 and E 080^0 20.033^1

Bedrock Geology

Biotite gneiss rock is the major rock type on this investigated area. This bed rock is highly weathered. Strike direction and Dip angle is not clear.

Overburden Deposits

Residual soil is the existing overburden deposit. Its thickness varies between 1-5 meters. Some places have high thickness overburden equal to 5 meters.

Geomorphology of the area

Investigated area is situated on a concave slope of the mountain. Slope angle of investigated site varies between 35-40 degrees. Bed rock exposures can be seen in upper part of the slope and is vertical with about 20-25 meters height. A dry valley could be seen in the middle part of the mountain slope.

Hydrological Features

Water paths and springs can be seen. Seepage is very high in this area. A small water path flows through the middle area of the slope. This water path belongs to the Ranwala Tributary. During the rainy season the capacity of the water path increases. During the time of investigation, a muddy spring was observed in this area. Overburden soil is highly saturated with spring water.

Land use practices

The area had been used as a home garden before the landslide occurred. At present, it is a bear land.

Human Settlement and human activities

Investigated area is very close to the Kegalle town, and therefore, urban residential places could bee seen. Colombo Kandy main road runs adjacent to the down slope. Somewhat larger buildings can be seen in the surrounding area of the landslide. Investigated land had been proposed to seal as a separate piece of land before the landslide occurred. The well constructed rode that was located in the area has totally been destroyed as a result of the mass movement.

3.3.12. Landslide of Uduvilla in Dehiovita

Location

The GPS Location is N 06^0 59.291^1 and E 080^0 13.621^1

Bedrock Geology

Charnokit gneiss rock exists as the major rock type on this investigated area. Biotite rich layer and Quartzite rich layer also can be observed. Strike of Charnokit gneiss rock is 270°N/S. Dip angle of dipping plane is 45°W. Different joint systems can be seen on the bed rock. Bed rock is separated into blocks as a result of dense joint systems and poliation plane.

Overburden Deposits

Residual soil is the major overburden soil deposit. Its thickness varies between 4-5 meters range. Investigated area is covered by a thick soil overburden.

Geomorphology of the area

Investigated site was located in the Western slope of the mountain ridge. This mountain spreads along the North South direction. Landslide has occurred in a steep hill slope. Its slope angle varies between 35-40 degrees.

Hydrological Features

Special hydrological features can not be seen in the investigated area.

Land use practices

Investigated area is covered by a rubber plantation. New rubber plantation is existing in the landslide occurred areas. There is a small home garden near the down slope area.

Human Settlement and human activities

At present, small cottages can be seen on this area. All the houses that had been built in the unstable slope has been destroyed as a result of the landslide. Stability of natural slope area is being decreasing due to human activities. Vertical cut slopes were observed in association with construction of houses in high slope areas.

3.3.13. Landslide of Purukgoda village in Pahala Parussale in Yatiyanthota

Location

The slide is located in an area that has been identified as an area prone to Landslide by NBRO. The GPS Location is N 07^0 01.460^1 and E 080^0 24.432^1

Bedrock Geology

Charnokit gneiss is the major rock type underlain in this investigated area. Strike of Charnokit gneiss rock is 160°N/W. Dip angle of bed rock is 60°W. Main three joint systems were observed as follows.

- 070/ vertical about 3 meters long
- 230/ 60 North West about 3 meters
- 300/ vertical about 3 meters

Overburden Deposits

Residual soil is the major overburden soil deposit. Its thickness varies between 1-2 meters range.

Geomorphology of the area

Investigated site is located in a steep slope. Slope angle of area varies from place to place. Slope angle changes between 30-40 degrees. Landslide threat has been occurred on the uppermost area of the hill. In some places bed rock is exposed, especially near the two small houses which are built on hill slope.

Hydrological Features

There is a small tributary in the upper most area of the investigated hill. Water spring is occurring in cut slope area behind the existing houses.

Land use practices

Investigated area is mainly used for tea plantation. These plantations are carried out at small scale. Small home garden also can be seen in the surrounding area of houses which exists on the left side of the landslide. Small woodlet could also be observed hill top area.

Human Settlement and human activities

Four houses are located on the investigated slope. Two are very near to the existing landslide. Others are situated towards the down slope. All the houses have been built on steep slope. These houses are permanent settlement places. Cut slope can be seen in the surrounding area of all the houses. Some cut slopes are 5-7 meters high. Tea plantation is very poorly maintained.

Surface drainage system is unplanned. Small gully erosions are observed in many places in the area.

3.3.14 Landslide of Parawalthana area in Kithulgala

Location

GPS Location of the observed site is N 06^0 59.416^1 and E 080^0 24.432^1

Bedrock Geology

Charnokit gneiss rock is the major rock type in this investigated area. Strike of bed rock is 330°N/W. Dip angle is 25°W. Well developed joint systems could be observed. They are as follows;

- N 30/90
- N 60/90

Overburden Deposits

Colluvium soil is the major overburden soil deposit. Its thickness is very high, about 1-5 meters.

Geomorphology of the area

Investigated site was located in a steep slope. This area has a high slope angle. Its values vary between 20-35 degrees. The bed rock has been exposed in the uppermost part of the slope. A large rock boulder tilted towards the slope could be seen. Middle size tension crack can be seen on the uppermost part of the slope.

Hydrological Features

A small water path flows to the down slope area of this investigated slope. This water path connects to the Kelani River. Water springs can be seen in the down slope area. Seepage is very high in the down slope area. Soil is very wet in this area.

Land use practices

Small tea plantation can be seen in the investigated area. This plantation spreads all over the hill slope. Uppermost part of the hill is covered by a small woody area.

Human Settlement and human activities

There are seven houses located on this slope. Village temple is situated very close to and on the slope. Houses which are located down slope have a high risk due to potential landslides, because tension cracks could be seen in the surrounding area of houses.

Tea plantation is poorly maintained. No proper drainage system is used for tea plantation. Lot of rock boulders can be seen spread over the slope area. Eroded gullies can also be seen. Unsuitable very high slope cuts have been made in for building houses.

3.3.15. Landslide of Palagala Watte area in Galigamuwa in Kegalle

Location

GPS Location is N 07^0 14.583^1 and E 080^0 18.567^1

Bedrock Geology

Charnokit gneiss rock is the major rock type on this investigated area. Rock is highly weathered. Strike of bed rock is not clear. Dip angle is 65°W. Vertical joint system could be observed.

Overburden Deposits

Residual soil is the major overburden soil deposit. Its thickness varies between 2 to 3 meters.

Geomorphology of the area

Investigated area has been spread over about 1250 m^2. This area is a steep slope area. Its angle varies between 20-32 degrees. Rock boulders could be seen all over the investigated area. They are somewhat large boulders.

Hydrological Features of Investigated Area

Water springs can be seen in the Northern corner of the upper slope area. They have high water capacity in rainy season. Seepage of this area is very high.

Land use practices

There is a home garden in the investigated area. No other special cultivations can be seen.

Human Settlement and human activities

There had being four small houses located on this slope. Two houses had been totally damaged as a result of the landslide. Houses have been built in the very high slope area. Unsuitable cuts on the slope can be seen. Human activities are very high.

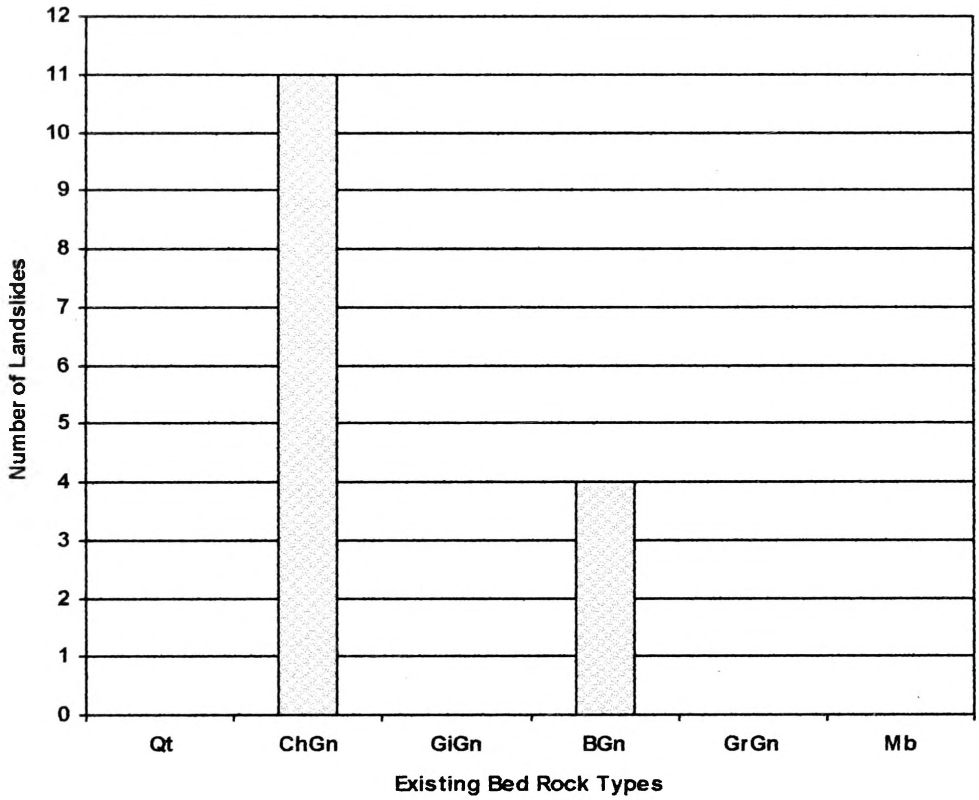
CHAPTER 4

RESULT AND DISCUSSION

4.1 DATA ANALYSIS

The collected data as described in Para 3.3 in the previous chapter were then analysed to evaluate the impact of various factor attributes such as Bedrock Geology, Soil Overburden, Slope Angle Range, Land Use etc. The results of this analysis is discussed in this chapter.

4.2. Effect of Bead rock geology



Qt -Quartzite	**ChGn** -Carnokite Gneiss
GiGn -Granitic Gneiss	**BGn** -Biotite Gneiss
GrGn -Granualitic Gneiss	**Mb** -Marble

Fig.4.1.The Graph of Number of Landslides VS Existing Bed Rock Types

Kegalle district is entirely underlain by pre Cambrian metamorphic rock of highland series. Charnokite gneisses, Biotite gneisses, Hornbland –Biotite and Metasediments are a characteristic lithology of the highland series. (Corey, 1984) During the investigated period, this lithology was identified on the basis of its characteristics in outcrops and using hand specimens only.

Fig.4.1 Show the relationship between different bed rock lithologies VS number of investigated landslides in Kegalle District. It is clearly shown that, prominent bed rock lithology of investigated areas is Charnokite gneisses rock. Eleven landslides out of the fifteen investigated within the district is underlain by the rock identified as Charnokite gneiss. Biotite gneisses is associated with four investigated landslides. Other rock types were not found in association with investigated landslides. Quartzite is found in some investigated area in small quantities as small intrusion in major Charnokite and Biotite Gneisses rock.

Well developed joint system and foliation plain are prominent features of Charnokite gneiss rock surfaces. Investigated results specially provide evidences for, Charnokite bedrock lithology consisting a well developed joints systems in some investigation locations.

Gneiss rock also consists two or three well developed joint patterns. This is the main cause contributing to mass movement, because during rainy periods, infiltration of rain water into the bed rock is facilitated by joint and foliation joints. It causes development of high water pressure inside the joint system and widens the joints. Finally, bed rock separates from the rock cliff, causing slope instability and massive mass movements that occur suddenly. This is the main way in which Charnokite bed rock lithology is involved in mass movement in the district of Kegall. Biotite gneiss is a highly weathered rock type and forms a high clayey soil as a major weathering product. This forms a high overburden deposit in the slope area. But according to investigation results, Biotite gneiss is not the prominentlitho associated with landslides occurred in Kegall District.

4.3. EFFECT OF THE SLOPE ANGLES

The slope angles of landslide occurred hill slopes were measured. These slope angles varie along the mountain from the bottom to the top. The investigated results graphically representated in Fig.4.2. It shows the relationship between number of landslides existing in Kegall district and the degree of slope angles. It is evident that, great majority of landslides occur in intermediate slope angle.30° to 40° which are the angles highly prone to landslides. As per the literature survey, this result is further confirmed as the most vulnerable slope angle for landslides in Sri Lanka has found as 15 to 40° (Bandara, Haridharan and Cruckshank 1994).

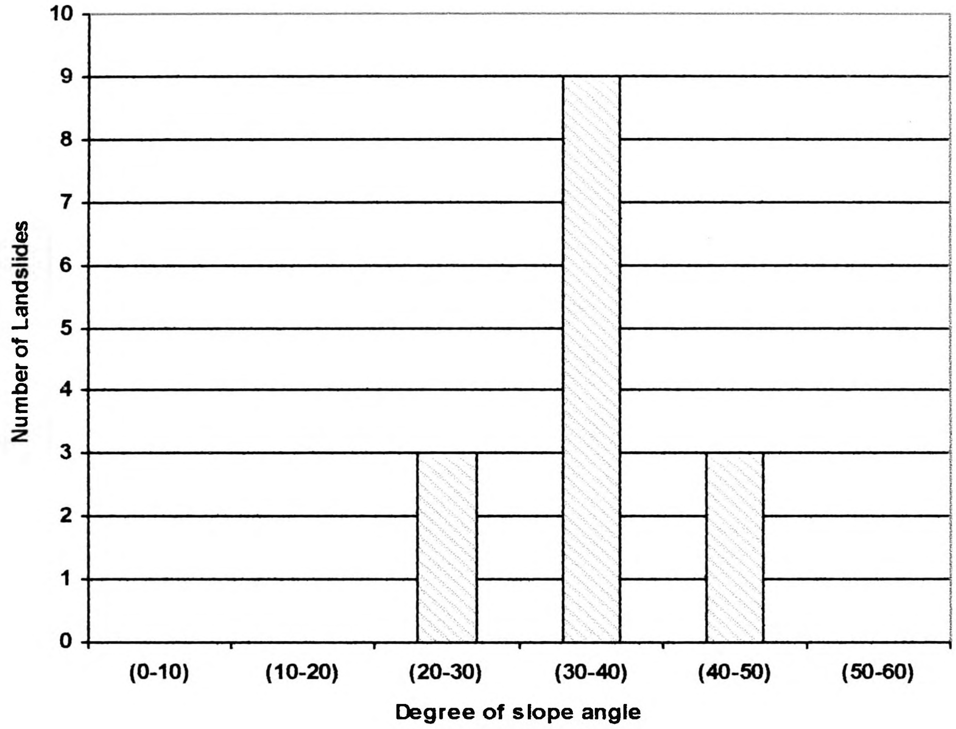


Fig.4.2.The Graph of Number of Landslides VS Degree of Slope Angle

Non of the investigated landslides exists above 50° angle slope area, it reflects that the overburden deposit is very low in thickness on slopes steeper than 50°, because the overburden soil washed away with the rain water and always undergo small soil movements. Also investigation result show that, investigated landslides are not existing in very gentle slopes, because their overburden stability is very high and do not easily subjected to mass movement.

4.4. EFFECT OF OVERBURDEN DEPOSIT

There are few broad categories of overburden called residual soil, Colluvium soil and talus of which the location and thickness are related to the geomorphology and the bed rock lithology of the area. Residual soil is a result of weathered underlying bed rock. Colluvium is loosely deposited within transported soil. Colluvium and Residual soil types are the only overburden type found in investigated areas. Overburden deposit thicknesses is directly related to mass movement in hill slopes. Therefore, within the investigated area, overburden type and their thicknesses were measured. The results are graphically represented in Fig.4.3. It shows the relationship between the overburden deposit and associated number of landslides observed in Kegall District.

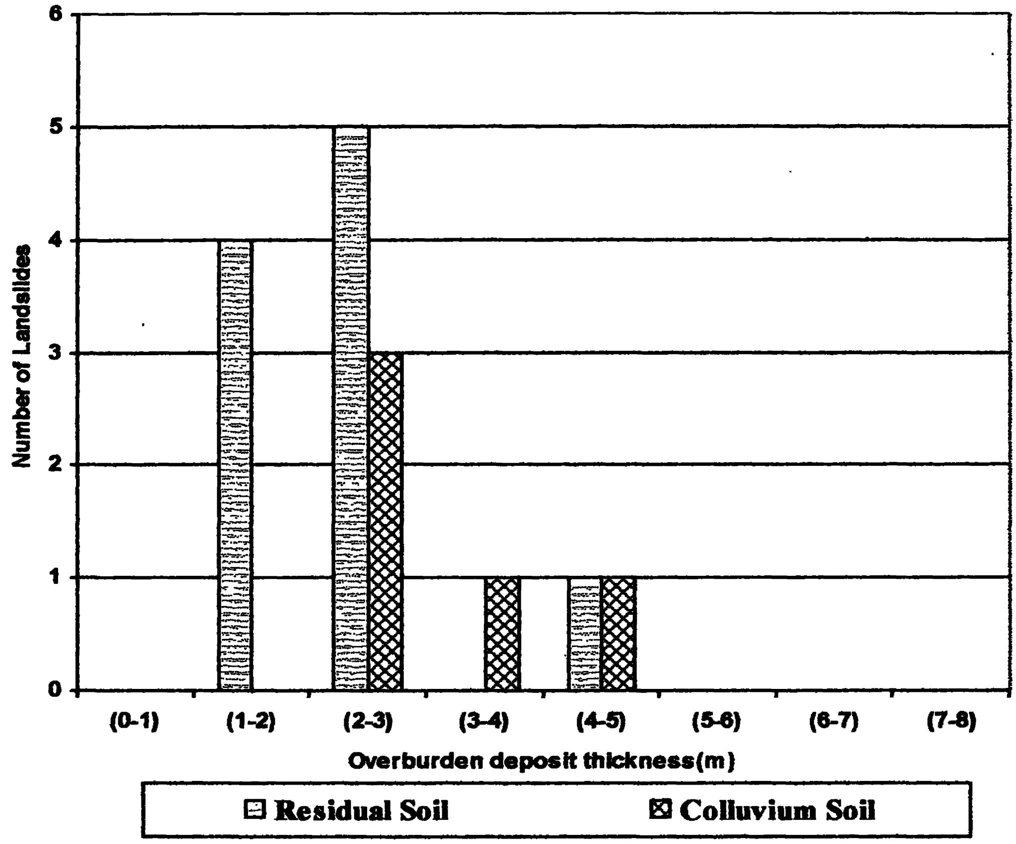


Fig.4.3.The Graph of Number of Landslides VS Thickness of the Overburden Deposited.

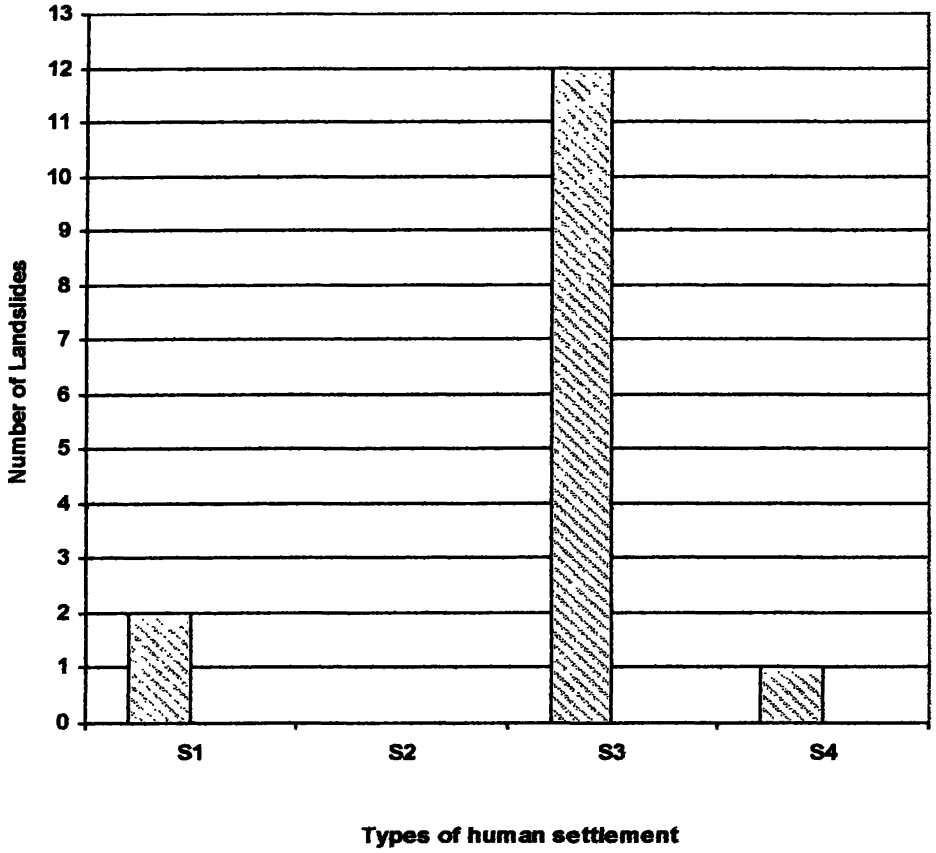
The results show that, the overburden containing moderate thicknesses can most be prone to mass movement. This is because of the following

a) This moderate overburden thickness of soil deposits quickly, in response to the increased pore water pressure, because in heavy rainy seasons, their pore spaces get quickly saturated by infiltrated rain water than in a high overburden thickness of soil deposit. Overburden deposits with high thicknesses need to be exposed to heavy rain for a long period of time in order to increase the pore water pressure. On the other hand, very low thickness of soil overburden deposit does not respond to heavy rain, because in the thin overburden slopes area's water infiltration is very low and most of the water flow over the surfaces without infiltrating. Other cause is thin overburden soil deposits consist very low number of poor spaces than moderate and high thicknesses overburden deposits. This is the cause for not generating enough pore water pressure in very thin overburden deposits.

b) During heavy rain, rain water quickly penetrates into the soil rock interfaces in soils with moderate thicknesses. This causes the development of slip surfaces, immediately.

c) Most landslide locations which were investigated have high slope angles. This mainly causes not to occur very high overburden deposits, because in high relief areas, overburden soil is washed or slid away frequently, so that there is no large accumulation of soil.

4.5 EFFECT OF HUMAN SETTLEMENT



S1 –Urban Settlement	S2-Non Residential Land
S3-Hill Housing	S4-Estate Settlement and Housing

Fig.4.4.The Graph of Number of Landslides VS Types of Human Settlement

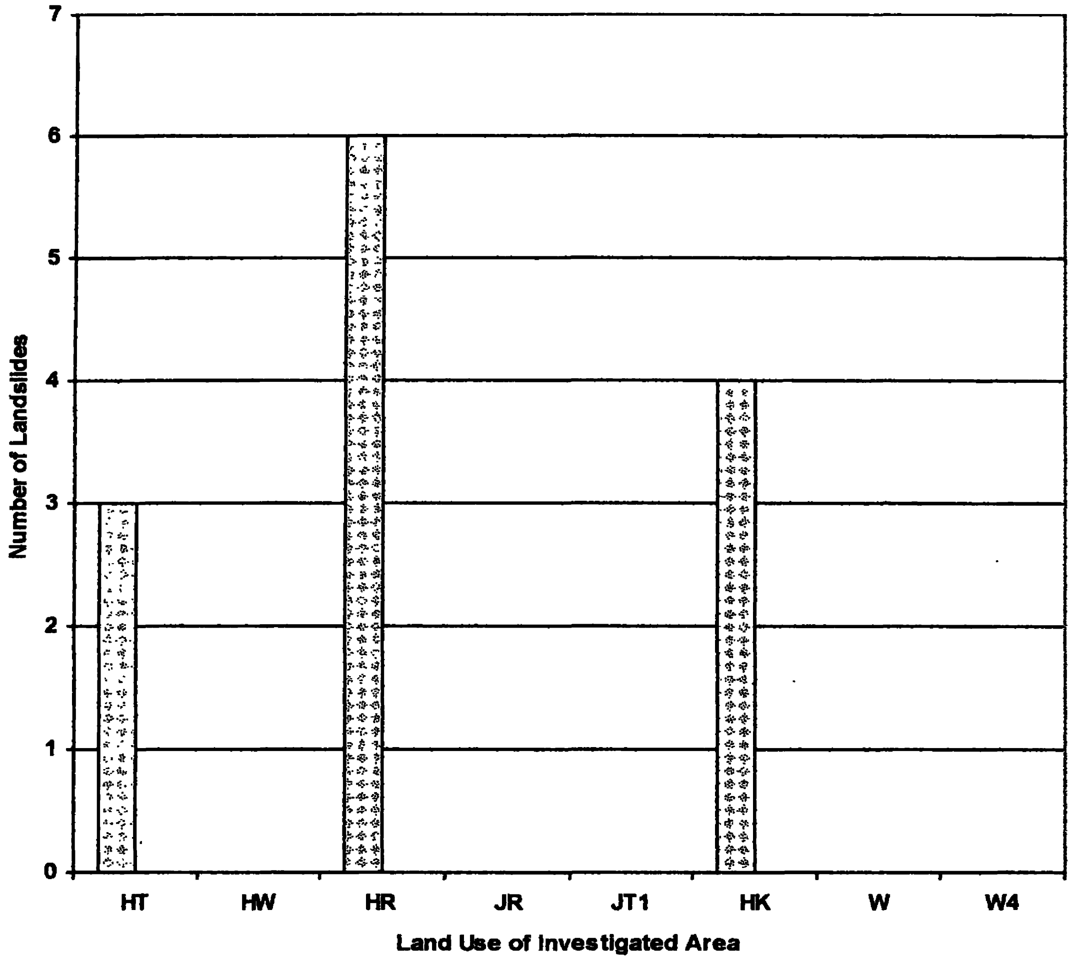
Fig.4.4 shows the graphical representation of the relationship of human settlement types VS the number of landslides occured in the district of Kegalle. The highest rate of landslides has been recorded in the areas where hill houses exists. This is the characteristic feature, which is found from investigation, because every investigated hill slope area could be seen with human settlements. On some slopes, well built houses existed and on other places small cottages could be observed. But urban settlements were record only in two investigated places. The results shown in figure 4.4 can be attributed to following factors

a. The inappropriate building construction practices is the common cause for a slope to fail and to cause mass movement in a hill slope area. In Most of the hill housing areas high vertical cuts could be seen behind the houses and buildings. This leads to reduce the support for the upper part of the slope. Such cut slopes become unstable causing severe damages to human lives and their properties. This is the very prominent cause in the district of Kegalle. The vulnerable slope is severely disturbed by cutting, filling and excavating during the construction process.

b. Poor construction methods applied for construction of infrastructure. Most of the roads construction in hill slopes of the district of Kegalle, are comed out without performing a detailed geological study. Some road cuts have been made in places where rock layer is inclined forward to the slope. Such cut slopes become unstable causing severe damages to human lives and their properties.

c. Other cause is that extremely unsuitable high slopes areas are used for construction of houses. This is directly prone to mass movement of Kegalle district. This type of construction could be found in all investigated areas.

4.6. EFFECT OF LAND USE PRACTICES



HT-Tea, Small Holder Managed
HW-Village Woodlots
HR –Rubber Small Holder Managed
JR-Rubber State, Well Managed
JT1-Tea State, Well Managed
HK-Home Garden
W-Natural Woodlands
G3-Bear Land Escarpment

Fig.4.5.The Graph of Number of Landslides VS Types of Land use Practices

Fig.4.5. graphically represents the main land use practices in Kegalle district VS number of landslides that area has undergone. The highest rates were recorded in association with small holder managed rubber cultivation. Secondly, home gardens and small tea cultivated areas had undergone a certain number of landslides. Considering the investigated area a lot of mass movements have occurred in rubber and tea cultivated hill slopes. Following factors cause the increase in vulnerability of rubber and tea cultivation on slopes in Kegall district.

(a) Inappropriate cultivation practices. Loosening of top soil layer by sudden removal of rubber plantations is commonly observed during logging and changing of the crop type. Heavy mechanical techniques like hydraulic jacking use of, caterpillar etc. are used to uproot rubber cultivation causing damage to stability of soil overburden. These factors increase the rainwater infiltration and soil erosion.

(b)Small tea and rubber cultivations could be observed on unsuitable steep slopes. Before starting tea and rubber cultivation, those slope areas were covered by small bushes and forest area. As a result of starting rubber and tea cultivation this natural forest cover was totally removed for land preparation, leading the rain water infiltration and increase of soil erosion.

(c)Absence of adequate surface drainage systems for those cultivated areas and inappropriate cultivation practices that cause blocking of existing surface drainage systems, especially the natural water paths. Poor surface drainage causes rain water to flow over the slopes causing gully erosion, and unnecessary water infiltration due to stagnation making slip surfaces between soil and rock surface. Poor drainage systems were observed in some investigated areas.

CHAPTER 5

CONCLUSION

The following conclusions were made by analysing the results of the investigated landslides in the District of Kegalle.

i. Most mass movements occur in residual soil or colluvium soil overburden. Mass movements occur in fresh bed rock is very rare.

ii. Charnokite is the major bed rock lithology of the area. Most of the landslides investigated during the study are associated with Charnokite gneiss. Charnokite lithology has a high impact for a landslide to occur.

iii. Landslides occur in low, moderate and high slope areas. But in moderate slope angles with scarp slopes a high frequency of landslides were observed. Also qualitatively most large landslides have occured in moderate slope areas. Most landslides occur in slope angle ranges of 30 to 40°.

iv. Small or large scale rubber cultivation has a high tendency for a landslide to occur.

v. In highly landslide prone slopes, human settlements also are high. Those hill slopes has high vulnerability to landslides.

vi. Most of the landslides in the Kegalle District occur during south west monsoon season on moderate hill slopes with human settlements and tea or rubber cultivated lands.

Due to the limitations in accessibility to landslides and the time duration for this study, the number of sites investigated was limited to fifteen. However, it is advisable to study a larger number of landslides, in order to strengthen the outcome of this study further.

CHAPTER 6

RECOMMENDATIONS

Based on the literature review, field investigations, and analysis of this research, the following recommendations can be made in order to minimize the impact of landslides on life and property in the district of Kegalle.

- Landslides occur in low, moderate and high slope areas. Steeper slopes should not be used for human settlements and cultivation of seasonal crops. Financial support for cultivation in steeper slopes should not be recommended and such slopes should be kept as forest reserves wherever possible.
- When the extent of land is limited, moderate slopes can be utilized for human activities with appropriate planning. Experts' opinion should always need to be obtained and adhered to, when moderate slopes are used for human activities.
- Gentle slopes can be used for human activities. However, extreme care should be taken not to block natural drainage paths.
- The land should be covered with vegetation to control erosion. Drains on steep slopes also should be lined with impermeable material such as concrete, to minimize infiltration and erosion.
- When the slopes are cut to level the land for building purposes, such cuts should not be higher than 3 m. A suitable retaining structure should be introduced under the consultation of an Engineer to support the cut slope.
- Guidelines for construction on landslide prone areas are available in NBRO and in most local authorities in the mountainous areas. These guidelines should be followed to minimize the destabilization of slopes.

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APPENDIX

LEGEND FOR AIR PHOTO INTERPRETATION OF LAND USE & MANAGEMENT CATEGORIES ACCORDING TO THEIR STABILITY PARAMETERS-CLU T/2B			
LAND USE/MANAGMENT		STABILITY	
Map Unit Code	Land Use Map unit	Attribute (LUMSG)	Group (LUMSG)
JT1	Tea Estate, Well Managed (70-90% Cover)	J	1
JT2	Tea Estate, Poorly Managed (20-70% Cove)	J-Y%	2
JR	Rubber Estate (Seasonal Leaf Fall)	J-X%	2
JC	Coconut Estate, Well Managed	J	1
JQ	Farms, Nurseries Greenhouses etc.	J	1
JWB	Forest Plantations (Broadleaf Varieties)	J	1
JWP	Forest Plantations (Pinus Varieties)	J-Y%	2
HP	Terraced Paddy	H	2
HK	Mixed, Agro-Forestry/Home-Gardens	H	2
HA	Annual Crops (Shifting Cultivation,	H-Y%	3
	Tobacco)	H-X%	2
HM	Market Gardens (Potato, Vegetable Crops)	H-X%	2
HT	Tea, Small Holder Managed	H	2
HW	Village Woodlots	H	3
HR	Rubber Small Holding		
		W	1
W1	Dense ,Mixed, Evergreen Natural Forests	W-Y%	2
W2	Degraded Natural Forests(50-70% Cover)	W-Y%	2
W3	Secondary Forest/Scrubland	W-Y%	2
W4	Gullies & Stream Reservation, Vegetation		
		G	3
G1	Natural Grasslands (Periodically Burnt)	G-V%	3
G2	Open Country /Miscellaneous uses	G?*	2
G3	Barren Lands Escarpments/Erosional Remnants		3
G4	Marsh Land	S	1
		S-X%	2
S1	Urban Settlements/Built up areas	S-Y%	3
S2	Non Residential Land/Non Agricultural Uses	S-X%	2
S3	Rural Settlements/Village/Hill Housing		
S4	Estate Settlements and Housing	N	3
		N	3
N1	Natural Rivers Streams & Water Ways	N-X%	3
N2	Natural Lakes & Ponds	N-X%	3
N3	Artificial Lakes & Ponds		
N4	Artesian Springs, Wells & Cavities		

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