CHAPTER ONE

1.0 INTRODUCTION

1.1 Slope stability

The stability of a slope is always discussed in terms of its susceptibility to failure and is a topic of serious concern to geologists all over the world. Kliche (1999) defined slope stability as the resistance of any inclined surface, as the wall of an open pit or cut, to failure by sliding or collapsing. Any ground surface that stands at an angle to the horizontal is termed an unrestrained slope and can be of natural origin or man-made. As the ground surface is not horizontal, there will always be the tangential component of gravity that tends to move the slope-forming materials down-slope. If the tangential component of gravity is very large, and the internal shear strength of the slope-forming materials rather low, a slope failure can occur (Terzaghi and Peck, 1967). Both natural and man-made slopes can be stable or unstable and several methods of analyses of their stability have evolved from simple to more sophisticated ones.

Nelson (2007) has pointed out that on any slope, the gravitational attraction of the earth can be resolved into two components; one acting perpendicular to the slope face, and the other acting tangentially to the slope. In Fig. 1.1, the component acting perpendicular to the slope face (gp), acts to hold objects in place on the slope, while the tangential component (gt) results in a shear stress acting parallel to the slope and tends to pull the objects down-slope. On a steep slope, the tangential component of gravity (gt) increases, whilst the perpendicular or normal component of gravity (gp) decreases.

Forces resisting movement down the slope are grouped under the term "shear strength" and include frictional resistance and cohesion amongst the particles of the slope-forming materials. When the shear stress acting parallel to the slope is greater than the combination of the forces holding the slope-forming materials, there can be failure of the slope and movement of the slope-forming materials down-slope. Down-slope movements are thus favored by steep slope angles which increase the shear stress as well as all factors that reduce the shear strength such as lowering the cohesion or friction within the slope-forming materials (Fig. 1.2). The relationship between the shear stress (τ) and the shear strength (τ_f) is usually expressed in terms of the factor of safety (Fs), i.e. $Fs = \tau_f / \tau$.

Whenever the factor of safety of a slope is less than 1.0, its failure can be anticipated. Slope failures can be detected in an area by several features such as the titling or inclination of telephone poles and retaining walls as well as cracked house foundations, sidewalks, driveways and roads, broken pipelines and underground wiring, curved tree trunks, windows and doors that stick, and so on. The appearance of, and increased, ground subsidence or upheaval is also a good indication of impending slope failure.

Slope failures show several variable characteristics such as the area and volume involved, perimeter and flow path length, width, slope angle, vegetation cover and type of slope forming materials. The causes and effects of slope failures, as well as their appropriate remedial measures, have been analyzed and studied in detail in recent times. It must, however, be noted that these failures show very variable features and any attempt at their classification is often only approximate and incomplete. Slope failures furthermore, have had tremendous impacts on man and his environment and have resulted in considerable loss of life, damage to structures and properties, as well as economic hardships.

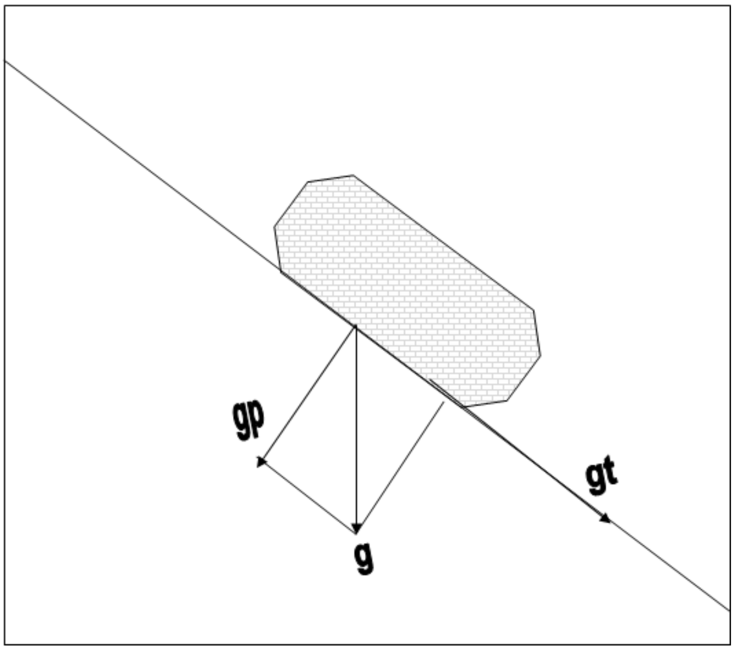


Fig. 1.1: Schematic diagram of a steeper slope.

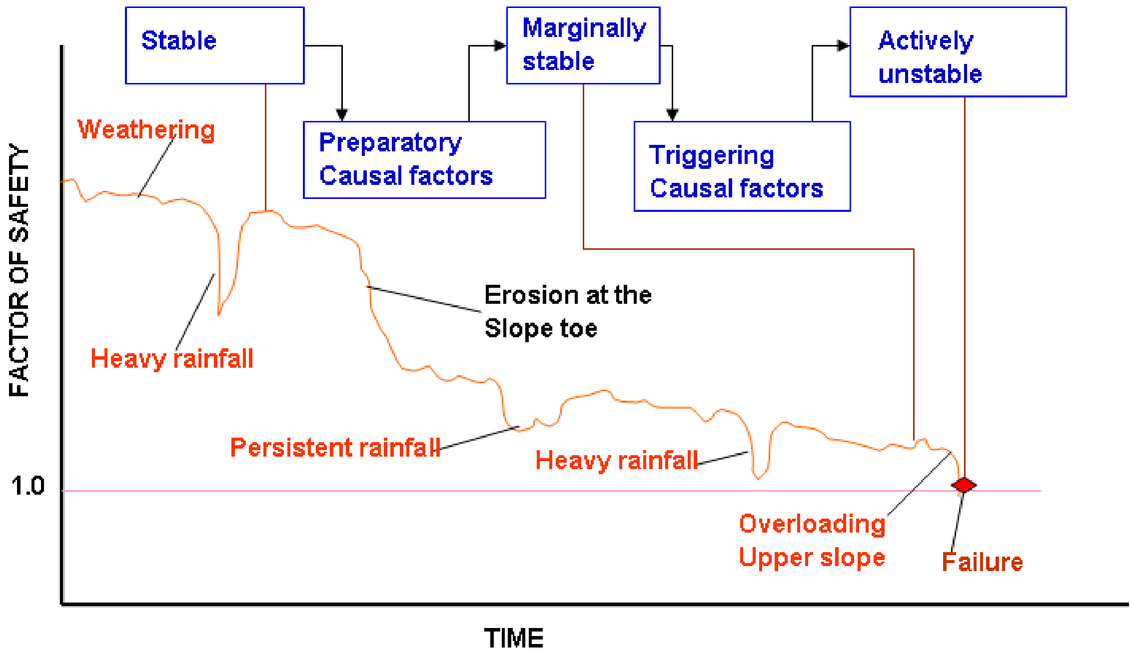


Fig 1.2.: Schematic diagram showing influence of different factors on instability.

1.2 Slope failures

1.2.1 Classification of slope failures

Earth materials with sloping ground surfaces, either natural or man-made are subject to gravitational and other forces as seepage which lead to instability and ultimately failure. Resistance to failure is mainly derived from a combination of the slope geometry and inherent shear strength of the soil or rock mass involved. Slope failures occur in many forms and there is a wide range in their predictability, rapidity of occurrence and movement, and ground area affected, all of which relate directly to the consequences of failure (Hunt 2005). There are various classifications of slope failures, but the most useful classifications are those that employ as their primary criteria the type of movement and the type of slope forming materials involved, with secondary considerations of velocity and the amount and phase of water. Table 1.1 shows one of the simplest methods of classification as proposed by Varnes in 1978, where six types of failures are recognized:

a. Falls
b. Topples
c. Slides
d. Lateral spreads
e. Flows
f. Complex

<table>
<tr><th colspan="2" rowspan="3">Type of Movement</th><th colspan="3">Type of Material</th></tr>
<tr><th rowspan="2">Bedrock</th><th colspan="2">Engineering Soils</th></tr>
<tr><th>Predominantly Coarse</th><th>Predominantly Fine</th></tr>
<tr><td rowspan="2"></td><td>FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td>TOPPLES</td><td>Rock topple</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td rowspan="2">SLIDES</td><td>ROTATIONAL</td><td rowspan="2">Rock slide</td><td rowspan="2">Debris slide</td><td rowspan="2">Earth slide</td></tr>
<tr><td>TRANSLATIONAL</td></tr>
<tr><td rowspan="4"></td><td>LATERAL SPREADS</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td rowspan="2">FLOWS</td><td rowspan="2">Rock flow
(deep creep)</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td colspan="2">(soil creep)</td></tr>
<tr><td>COMPLEX</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

Table. 1.1: Types of landslides. Abbreviated version of Varnes' classification of slope movements . (Varnes, 1978).

1.2.1a Falls

Falls are those down-slope movements where the mass in motion mostly travels through air, (Fig.1.3). Falls include free fall, movements by leaps and bounds, and rolling of fragments of bedrock or soil. Rockfall (free fall of rock) is an extremely rapid process and occurs without warning. Rockfall is typically the result of frost wedging. Frost wedging is a process where water enters cracks in rocks, freezes, expands, and breaks the rock apart. Frost wedging results in a fan-shaped pile of rock fragments at the base of the slope. The rock fragments are called talus and the slope is referred to as a talus slope. The presence of a talus slope is a warning sign itself.

Cutbanks are the result of stream erosion. A stream undercuts the outer bend, which results in the remaining overlying stream bank falling, dropping into the moving water. This is an example of soilfall. Another example of soilfall is produced by ocean waves undercutting cliff faces. The end result is loss of support. This type of undercutting can also result in slumping.

1.2.1b Topples

The down-slope movements as a result of forces that cause an overturning moment about a pivot point below the center of gravity of the unit are topples (Fig. 1.4). If topples are unchecked, falls or slides may result.

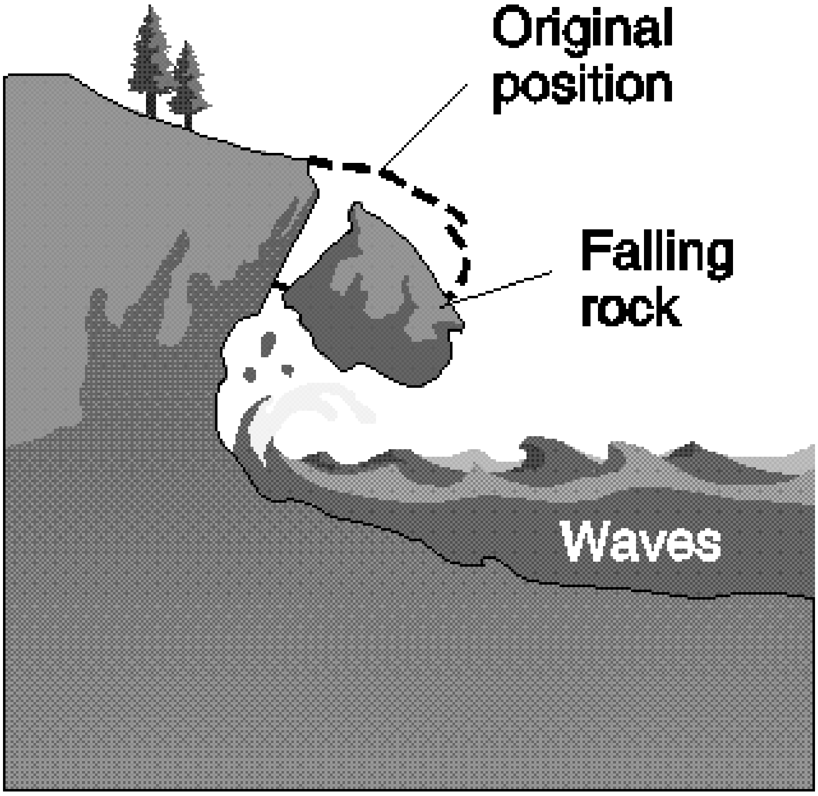


Fig.1.3: Fall - material free fall.

Fig. 1.4. Topples - the end-over-end motion of rock down a slope.

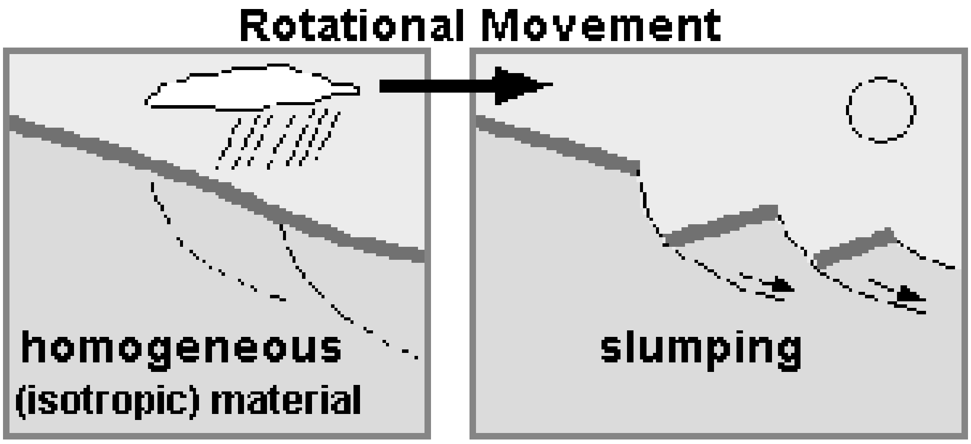
1.2.1c Slides

Slides may occur in almost every conceivable manner, slowly and suddenly, and with or without any apparent provocation. Usually, slides are due to excavation or undercutting the foot of an existing slope. However, in some instances, they are caused by gradual disintegration of the structure of the soil, starting at hair cracks which subdivide the soil into angular fragments . In others, they are caused by an increase of the pore-water pressure in a few exceptionally permeable layers, or by a shock that liquefies the soil beneath the slope (Terzaghi and Peck, 1967).

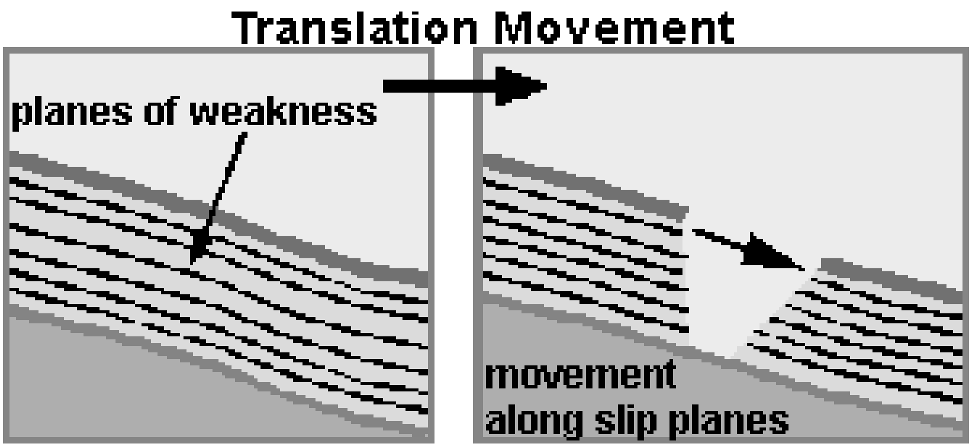
Slides can be separated into rotational and translational types. In Fig. 1.5, the behavior of the slides depends mostly on the type of material and whether that material is:

(i) homogeneous (isotropic) material (similar properties in all directions), or

(ii) inhomogeneous (anisotropic) material with planes of weakness.



Caused by slope failure of homogeneous (isotropic) materials (similar properties in all directions).



Caused by slope failure of inhomogeneous (anisotropic) material with planes of weakness.

Fig. 1.5: Graphic diagram of rotational and translational movements.

According to the Geological Survey of the United States (USGS, 2004), a rotational slide is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide (Fig. 1.6). In a translational slide (as shown in Fig. 1.7), the landmass moves along a roughly planar surface with little rotation or backward tilting. Fig. 1.8 shows a schematic diagram of a block slide. This is a translational slide in which the moving mass consists of a single unit or a few closely related coherent masses.

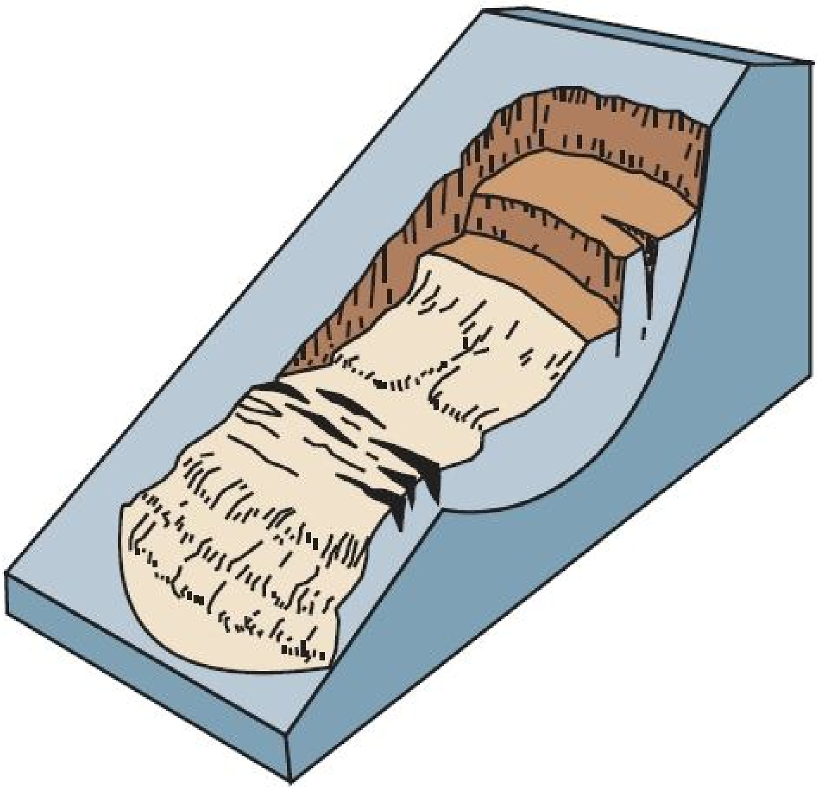


Fig. 1.6: Schematic diagram of a rotational slide. (USGS, 2004).

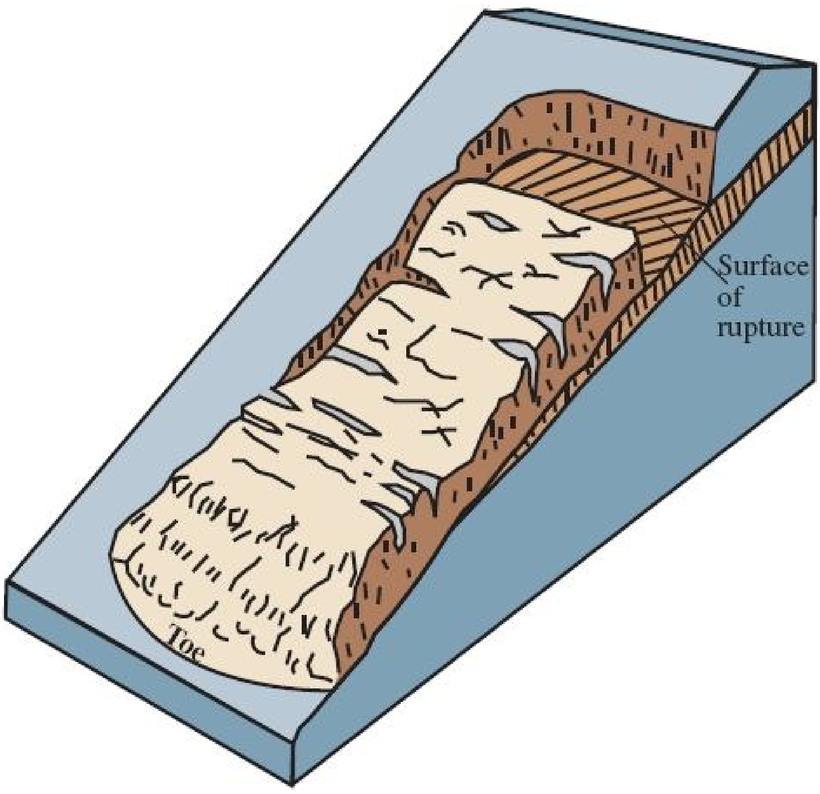


Fig. 1.7: Schematic diagram of a translational slide. (USGS, 2004).

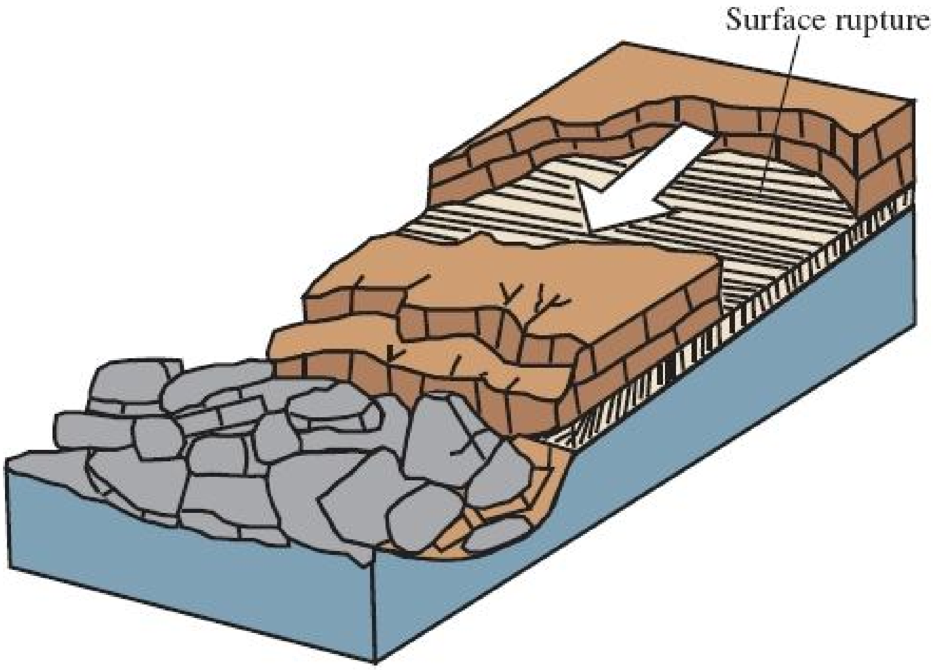


Fig. 1.8: Schematic diagram of a block slide. (USGS, 2004).

1.2.1d Lateral spreads

Lateral spreads are disturbed lateral extensional movements in a fractured mass. They involve the lateral displacement of large, surficial blocks of soil as a result of liquefaction of a subsurface layer (Fig. 1.9). Displacement occurs in response to the combination of gravitational forces and inertial forces generated by an earthquake (Youd, 1992).

Two subgroups of lateral spreads are often identified;

(i) where the spread is without a well-defined controlling basal shear surface or zone of plastic flow, and

(ii) in which extension of rock or soil results from liquefaction or plastic flow of subjacent material. The process whereby saturated, loose, cohesionless sediments (usually sands and silts) are transformed from a solid into a liquefied state.

Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain. Failure is usually triggered by rapid ground motion, such as that experienced during an earthquake, but can also be artificially induced. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often the initial failure is a slump, but in some materials movement occurs for no apparent reason (USGS, 2004). Lateral spreads, like other types of failures, exhibit fairly specific topographic signatures that are easily identified (Fig. 1.10).

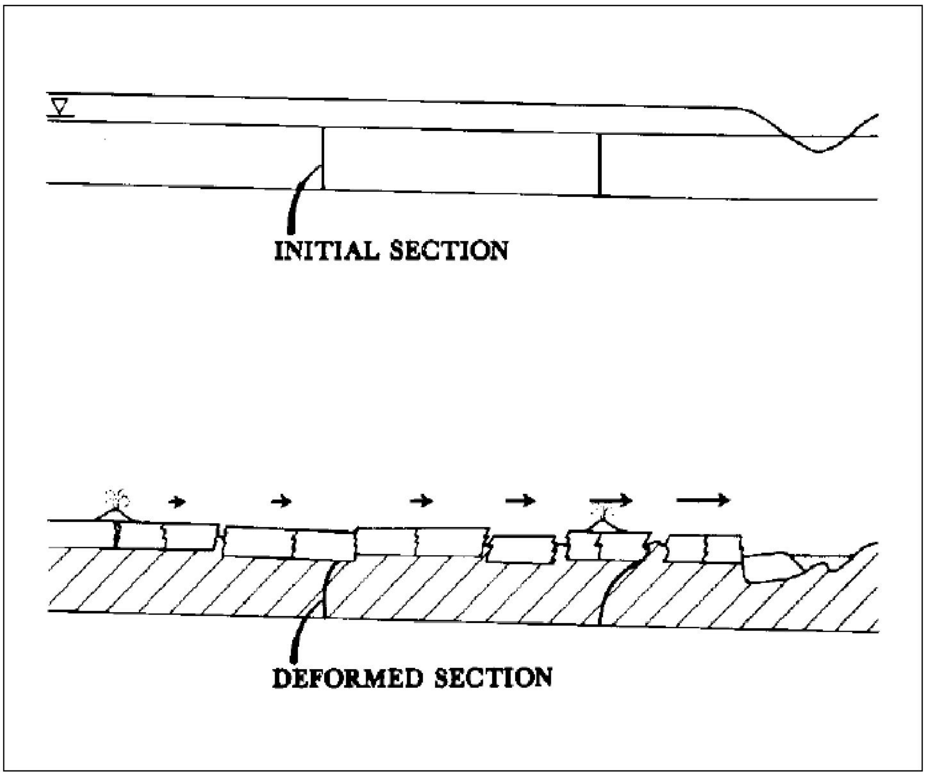


Fig. 1.9: Schematic diagram of a lateral spread (Youd, 1992).

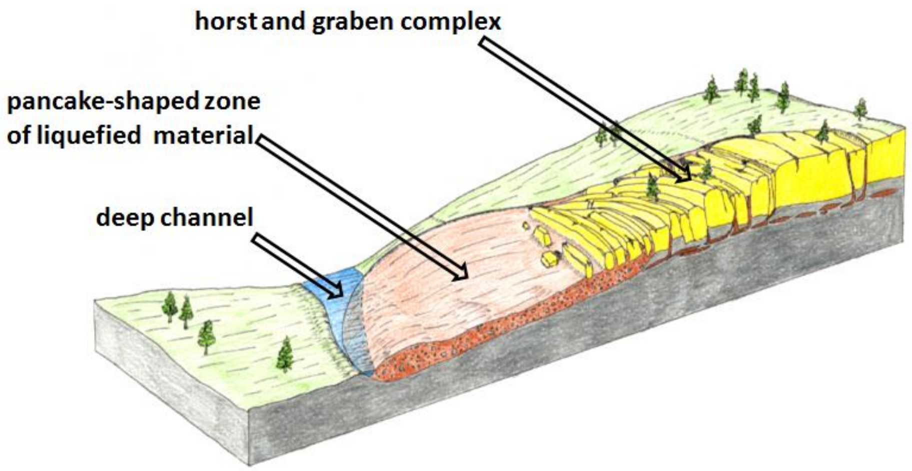


Fig. 1.10: Classic features of a lateral spread. (Redrawn from Rogers and Doyle, 2003).

1.2.1e Flow.

Flows occur when sufficient force is applied to rocks and regolith that they begin to flow down slope (Fig. 1.11). A sediment flow is a mixture of rock and/or regolith with some water or air which can occur in bedrock or soils. In bedrock, flows include spatially continuous deformation, and superficial as well as deep creep and extremely slow and generally non-accelerating differential movements among relatively intact units. The movements may:

i . be along shear surfaces that are apparently not connected,

ii . result in folding, bending or bulging, or

iii. roughly simulate those viscous fluids in distribution of velocities.

In soils, the movement within the displaced mass is such that the form taken by moving material, or the apparent distribution of velocities and displacements, resemble those of viscous fluids. The slip surfaces within the moving material are usually not visible or are short-lived. The boundary between the moving mass and material may be a sharp surface or differential movement or a zone of distributed shear. Movement ranges from extremely rapid to extremely slow.

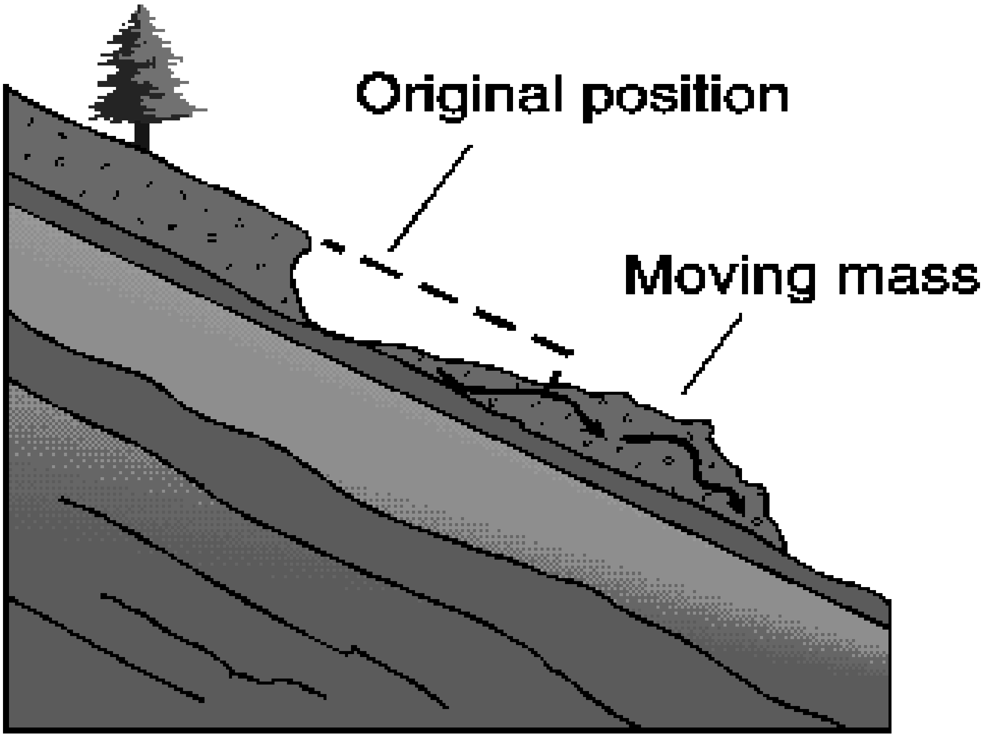


Fig. 1.11: Flow. Viscous to fluid-like motion of debris.

Depending on the amount of water present in the sediment, Flows can be subdivided into slurry flows and granular flows (Fig 1.12). Slurry flows are sediment flows that contain between about 20% and 40% of water. As the water content increases above some 40%, slurry flows grade into streams. Slurry flows are considered water-saturated flows. Granular flows on the other hand are sediment flows that contain between about 0% and 20% water. This flow is possible with little or no water. Fluid-like behavior is given these flows by mixing with air. Granular flows are not saturated with water (Nelson, 2005).

Slurry flows can further be subdivided into :

- Solifluction - with flowage rates measured on the order of centimeters per year of regolith containing water. Solifluction produces distinctive lodes on hill slopes. These occur in areas where the soil remains saturated with water for long periods of time.

- Debris flows - occur at higher velocities than solifluction, with velocities between 1 meter/year and 100 meters/hr, and often result from heavy rains causing saturation of the soil and regolith with water. They sometimes start with slumps and then flow down hill forming lobes with an irregular surface consisting of ridges and furrows.

- Mud flows - are highly fluid, high velocity mixture of sediment and water that has a consistency ranging between soup-like and wet concrete. They move at velocities greater than 1 km/hr and tend to travel along valley floors. These usually result from heavy rains in areas where there is abundance of unconsolidated sediment that can be picked up by streams. Thus after heavy rainfall, streams can turn into mud flows as they pick up more and more loose sediments. Mud flows can travel for a long distance because of their high velocities and are potentially dangerous.

On the other hand, Granular flows can be divided into:

- Creep - which is a very slow, usually continuous movement of regolith down slope.
- Earth flows - are usually associated with heavy rains and move at velocities between several cm/year and 100 of m/day. They usually tend to be narrow tongue-like features that begin at a scarp or small cliff.
- Grain flows - usually form in relatively dry material, such as a sand dune on a steep slope. A small disturbance sends the dry unconsolidated grains moving rapidly down the slope.
- Debris Avalanches - which are very high velocity flows of large volume mixtures of rock and regolith that result from collapse of a mountainous slope. They move down slope and then can travel for a considerable distances along relatively gentle slopes. These are often triggered by mature events such as earthquakes and volcanic eruptions.

1.2.1f Complex failures

Complex movements are those involving a combination of one or more of the other five principal types of movements. These mechanisms are often complex and act at depth, making the investigation and characterization of contributing factors difficult. This poses a problem in the analysis stage of the investigation as uncertainties arise concerning the analysis technique to be employed and what input data is required (Eberhardt, 2003).

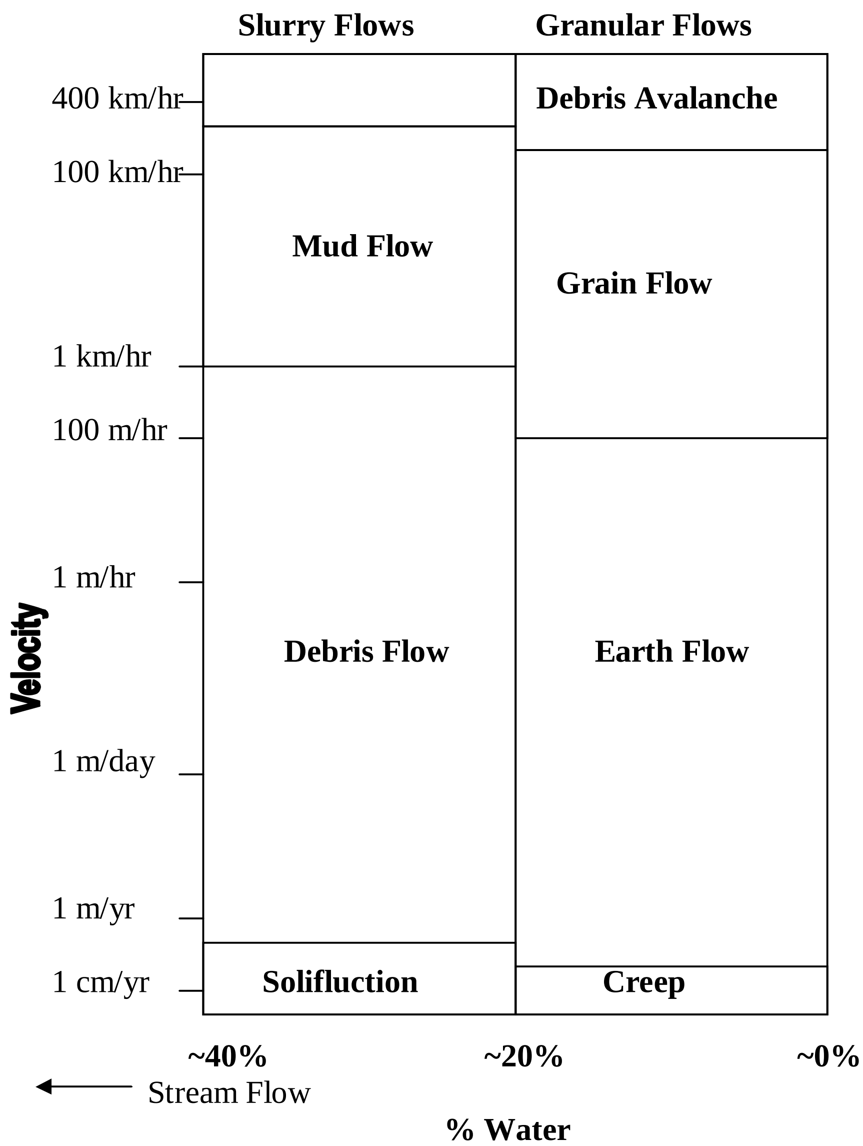


Fig. 1.12:. Sketch of subdivisions of slurry flows and granular flows based on water saturation and velocity.
(Redrawn from Nelson, 2005).

1.2.2 Causes of slope failures

It may be useful to visualize slopes as existing in one of the following three stages:

Stable: The margin of stability is sufficiently high to withstand all destabilizing forces.

Marginally Stable: Likely to fail at some time in response to destabilizing forces reaching a certain level of activity.

Actively Unstable: Slopes where destabilizing forces produce continuous or intermittent movements.

These three stages thus provide a useful framework for understanding the causal factors of instability and classifying them into preparatory causal factors and triggering causal factors. The preparatory causal factors are those which make the slope susceptible to movement without actually initiating it and thereby tending to place the slope in a marginally stable state. Ground cracks are the surface manifestation of a variety of mass movements. In plan, they are commonly concentric or parallel, and have widths of a few centimeters and lengths of several meters which distinguish them from the much shorter desiccation cracks. The formation of cracks and any increase in their rate of widening is a common measure of impending slope failure. The appearance of, and increases in ground subsidence or upheaval are also a good measure of impending failure.

Triggering causal factors are those which initiate movement. These causal factors shift the slope from a marginally stable state to an actively unstable state. Beginning with the general definition of factor of safety (F_s) given by the ratio of resisting stresses (τ_f) to shearing stresses (τ), i.e. ($F_s = \tau_f / \tau$), Terzaghi (1950) identified several external causes of slope instability that lead to an increase in shearing stress as well as several internal causes that result in a decrease of the shear resistance. There are however, some causes that affect both terms in the definition of the factor of safety. The influence of the different contributory factors on the factor of safety of a slope also varies in time due to a variety of factors. Different analyses have shown that short-term variations in factor of safety may occur due to seasonal variations in groundwater levels, while longer term trends may reflect the influences of weathering or longer term changes in groundwater conditions. This approach is useful in emphasizing that slope instability in general may not be attributable to a single causal factor.

Slope failure is a natural process which can be induced, accelerated or retarded by human actions. Many causes are involved, including:

a. Removal of lateral support through the erosive power of streams, glaciers, waves, and longshore and tidal currents; through weathering and wetting, drying and freeze-thaw cycles in surficial materials; through land subsidence or faulting that create new slopes; and through human actions such as cutting slopes for roads and other structures, quarrying, removal of retaining walls, and lowering of reservoirs.
b. Adding weight naturally to slopes by rain, hail, snow and water from springs, by accumulation of talus or volcanic debris, and by human actions such as landfills, stockpiles of ore or rock, waste piles, construction of heavy buildings and other structures, and water leaking from pipelines, sewers, canals, and reservoirs.
c. Earthquakes, thunder, or vibrations from nearby slope failures, and human activities such as vibrations from explosives, machinery, road and air traffic.
d. Regional tilting that increases slope angles.
e. Decrease of underlying support by removal of granular and soluble materials, mining, loss of strength or failure and/or freezing out of underlying material.
f. Lateral pressure from water in cracks, freezing of water in cracks, hydration of minerals, and mobilization of residual stress.

g. Volcanic processes that modify ground and rock stresses, such as inflation or deflation of magma chambers, fluctuations in lava-lake levels, and increase in ground tremors.

1.3 Aims of study

Failures of natural slopes and cut slopes are of a common occurrence in Malaysia, especially during the Northeast Monsoon from November to March when heavy rainfall is received in most parts of the country. There are, however, only a few studies on the stability of natural slopes and cut slopes in the country. For instance, slope stability analyses have been carried out by various authors including Fauziah, et al, (2002), Jasmi, (2003). They attempted to use GIS for slope stability prediction, to map landslide hazard zones, and to assess slope failure risks. Raj, (1985 & 1998) studied the cut slopes in porphyritic biotite granite in relation to the morphological zonation of their weathering profile. The study of the failures in granitic bedrock of Malaysia streamlining guidelines to their prevention, and prevention of slope failure related disasters in these areas was also carried out by Raj (2003). Several internal and external factors that influence failures at slope cuts in clastic sedimentary bedrock in Malaysia were also studied by Raj (2004a). A hazard assessment of a granite cut slope in a hillside development off Jalan Kuari Cheras, Selangor was also carried out by Mustapha and Tajul, (2006). Their method of analysis evaluates the orientations of the slopes as well as the discontinuities and the internal angle of friction of the rock.

The main objective of this research project is to investigate the stability of cut slopes in the Ukay Perdana area of Selangor Darul Ehsan in Malaysia through the study of the inherent geological features as well as past slope failures and shear strength along structural discontinuity.

The study of slope stability clearly describes the deformation of the earth's crust, the forces producing such deformations, and the geologic and structural features involved. Hence this research project will focus on the causal factors, and severity of these deformations to man and his environment, and the possible approaches to reduce the destructive effects. An intensive and meticulous review of published and unpublished accounts of failures and the geology of the study area was thus undertaken in the course of this research project. These accounts formed an integral platform for this research work to avert the impediments encountered by previous researchers and analysts. There are catalogues of slope failures in Malaysia, however, the disparity of these slope failures are in their damage effects, area of occurrences, types, causes, and the earth movements triggered by these failures.

Through the study of rock distributions in the area, their physical properties and analyses, and tilt tests, this research project aims to classify and determine the shear strength of the rocks, and thus causes of the slope failures that have occurred in this area. Though natural and cut slopes abound in this area, much attention was focused on the cut slopes. The causal factors of the slope failures were determined through field mapping and related studies, samples collection and laboratory analyses. This enabled a comprehensive study of the geologic setting of the area. Hence the preventive measures are outlined to avert future slope failures and to reduce environmental and economic ravages.

1.4 Method of study

The research project was carried out in various phases which involved in the first phase, a search for literature on the general topic of slope stability. During this phase, background information on the study area was ascertained as well as other places in Malaysia. In the second phase, field mapping was carried out in the study area observing various structures in the field and giving their adequate interpretations.

Instruments used for the field work include:

(i) The base map of the area

(ii) Hammers (sledge and small)

(iii) Tape for tying and labeling of weathered rock samples)

(iv) Marker pens (for labeling of unweathered rock samples)

(v) Clinometer for measuring attitudes and bearings

(vi) A field mapping notebook

(vii) Digital camera

(viii) Measuring tape

(ix) Lead and coloured pencils

(x) A 30cm ruler

(xi) Binoculars

(xii) Schmidt hammer

In the third phase, laboratory study of thin sections and tests to determine the physical and mechanical properties of rock samples were carried out. Fieldwork and mapping were carried out for the analyses of geological structures and for evaluation of the mechanical properties of the Dinding schist using the Schmidt Hammer. Monitoring of possible failures during the peak rainfall seasons and in areas of building and other construction works were also carried out at intervals. In the final phase, information was collated and interpretations carried out, considering possible mitigation methods for slope failures.