LECTURE OBJECTIVES

1. Discuss the mechanisms of mass movement.
2. Compare the different types of mass movement.
3. Discuss the factors affecting mass movement.

Introduction

Most of Earth's surface is not perfectly horizontal; sloping surfaces are everywhere. On Earth, most slopes are formed by stream erosion and are related to the walls of stream valleys. Some, however, are the result of tectonic activity such as faulting; others result from wave erosion, extrusion of lava, glaciation, and even impact of meteorites. Regardless of a slope's origin, gravity has a universal tendency to pull materials on it to a lower gravitational potential. Consequently, the downslope transfer of material through the direct action of gravity - mass movement - is extremely common.


Left: Landslide and Right: Mudflow

Mass movement processes can be classified into 4 categories:

1. Fall
2. Slide
3. Flow
4. Creep (move by heave mechanism)

They can be compared based on:

1. Mechanism of movement
2. Conditions required for occurrence
3. Trigger
4. Coherence of material
5. Speed
6. Level of water content
7. Effects on slope

(A) WHAT IS MASS MOVEMENT?

Mass movement is the downslope movement of slope material such as soil and rock by direct action of gravity and does not involve a flowing transporting medium such as water, wind and ice.

(B) WHAT ARE THE MECHANISMS OF MASS MOVEMENT?

Mass movement occurs when shear stress exceeds shear strength (Fig. 1).

Shear stress is the force which causes downward movement of the body parallel to the slope.

a. Shear stress has a positive relationship to the (a) weight of the body and the (b) slope angle.

b. The greater the weight of the body and the steeper the slope, the greater the shear stress and hence the greater the potential for shear stress to exceed shear strength and for mass movement to occur.

Shear strength is the internal resistance of the body to movement.

a. Shear strength has a positive relationship to frictional resistance, cohesion between particles and the binding action of plant roots.

b. The greater the frictional resistance between the mass and the slip plane, the cohesion between particles and the binding action of plant roots, the greater the shear strength and hence the lesser the potential for mass movement to occur.

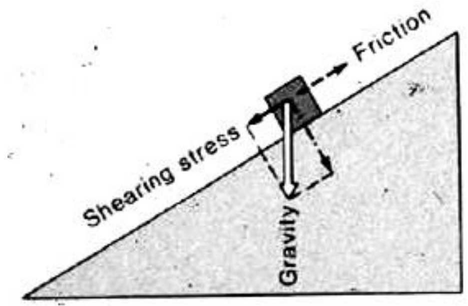

Fig. 1: Shear stress and shear strength (represented by friction between the body and the slope surface).
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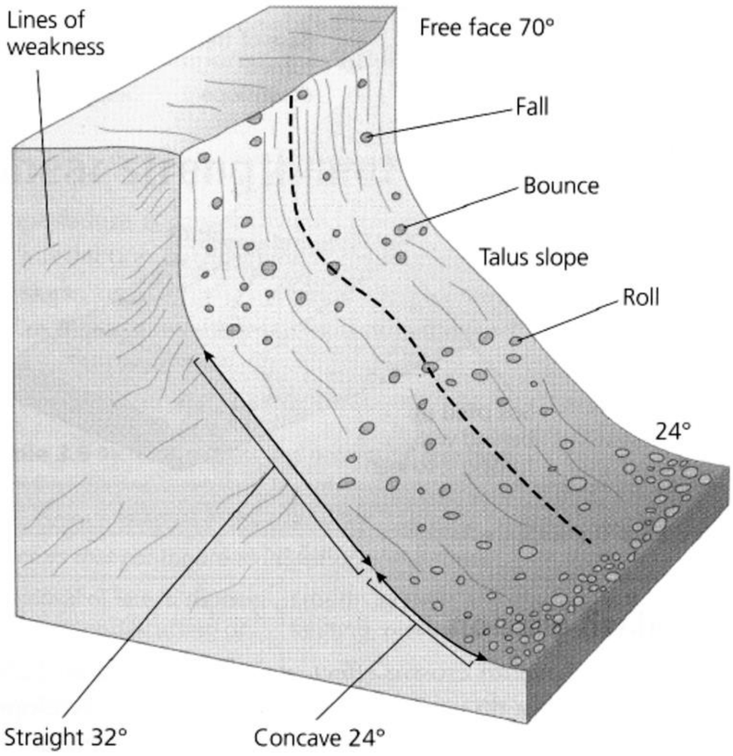

Fig. 2: Diagram of a fall
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Mechanism of Movement
Falls are the free-falling of detached bodies of bedrock from a cliff or steep slope (Fig. 2).

Conditions for Occurrence
Falls generally occur on steep slopes (greater than 70^o) which have bare rock faces where joints are exposed.

Trigger
Falls are triggered when erosion or weathering processes such as freeze-thaw action prise open lines of weakness and reduce the shear strength of the slope. When shear stress exceeds shear strength, the rocks become detached and fall under the influence of gravity.

Falls are also triggered by earthquakes which generate tremors that prise open lines of weakness and reduce shear strength of the slope. When shear stress exceeds shear strength, the rocks become detached and fall under the influence of gravity.

Characteristics
Falls display coherence of material, are very fast in speed, and have negligible water content.

Effects on Slope

Falls result in the retreat of steep rock faces and also form scree (also known as talus)[1] slopes at the base of the original slope.

Type of Fall - Rockfall

A type of fall is rockfall (Fig. 3).

A rockfall occurred in Cairo, Egypt in 2008 when 8 boulders weighing more than 50 tons each split from the edge of the Muqattam mountain and destroyed 40 houses and killed more than 100 people.

Fig. 3: Photograph of rockfall with talus slope at the base of the slope

[1] Scree is a collection of broken rock fragments at the base of crags, mountain cliffs, volcanoes or valley shoulders that has accumulated through periodic rockfall from adjacent cliff faces.

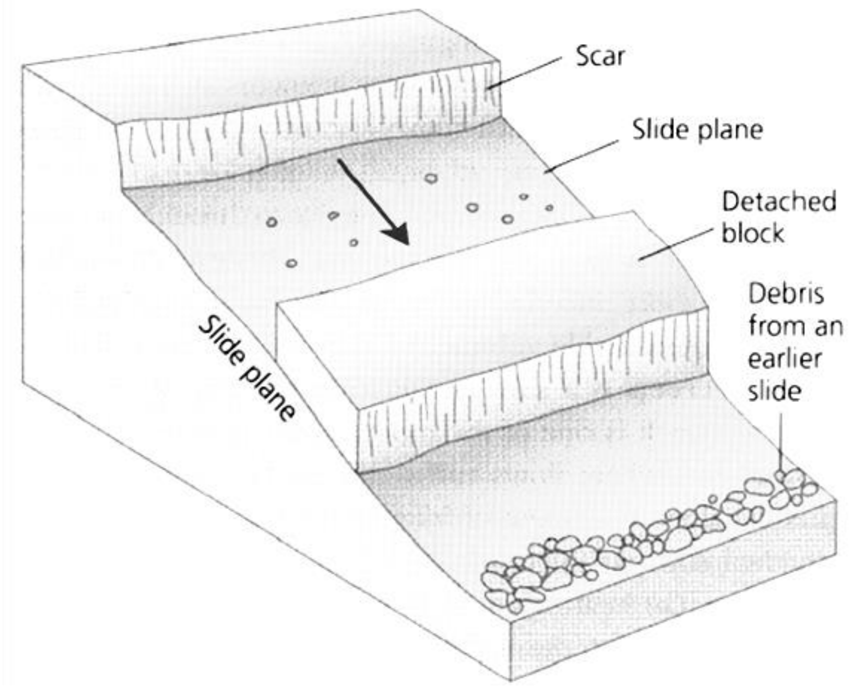

Fig. 4: Diagram of a slide
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Mechanism of Movement
Slides are the downslope movement of detached masses of material which moves *en masse* (as a coherent mass without any internal shearing or deformation of the material) along a clearly defined inclined surface known as a slip plane (Fig. 4).

Conditions for Occurrence
Slides generally occur in areas where there has been undercutting of the base of a slope by building a road or coastal erosion, causing the slope to steepen and increasing shear stress.

Trigger
Slides may be triggered after periods of heavy rain when the topmost layer of surface material becomes saturated and extremely heavy which increases shear stress, and where water has lubricated the slip plane and reducing friction between the slope and rock / soil, decreasing shear strength. Slides may then occur when shear stress exceeds the shear strength.

Slides may also be triggered by earthquakes and volcanic eruptions, as the shaking of the ground can reduce friction between the slope and soil / rock, thus decreasing shear strength. Slides may then occur when shear stress exceeds the shear strength.

Characteristics
Slides display coherence of material as it moves en masse, are fast in speed and the velocity is similar at all depths of the slide (Fig. 5) as the slide moves en masse, and have relatively high water content as water acts as a lubricating agent between slip plane and rocks.

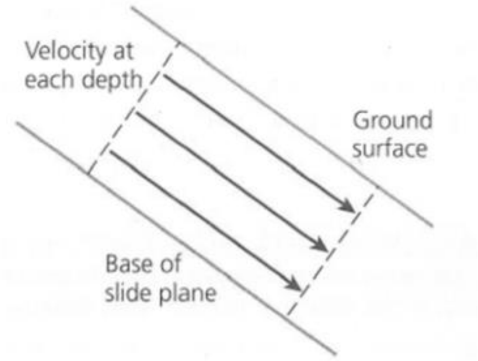

Fig. 5: Velocity Profile of a Slide
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Effects on Slope
Slides result in the formation of a scar[2] on the slope and a toe bulge[3] at the base of the slope.

Type of Slide - Rotational Slide (Slump)
A type of slide is a rotational slide (also known as a slump) (Figs 6-7).

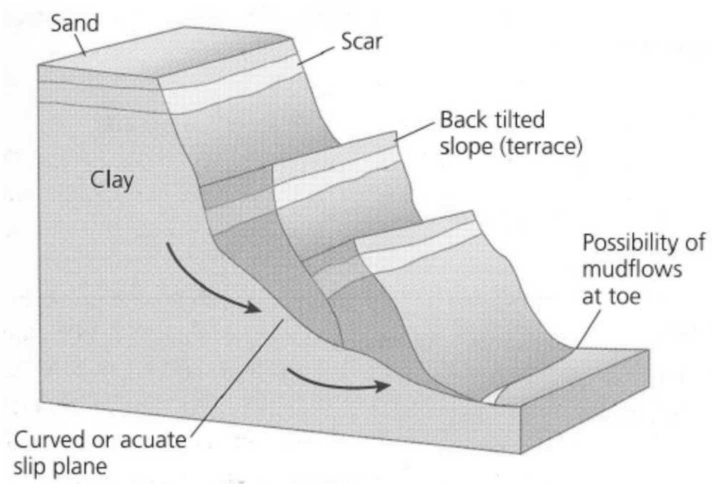

Fig. 6: Diagram of a slump
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[2] Barren surface that forms after a slide occurs
[3] Rock fragments that accumulate at the base of the steep slope.

Fig. 7: Photograph of a slump (rotational slide)

Mechanism of Movement

A slump is a downward and outward rotational movement of rock or regolith which occurs along a curved concave slip plane.

Effects on Slope

Similar to slides, slumps result in the formation of a scar on the slope and a toe bulge at the base of the slope.

However, slumps will also produce reverse slopes, as the top of the displaced block is usually tilted backward as slumps occur along a concave sliding surface causing some backward rotation.

Type of Slide - Landslide and Rockslide

Other types of slide include landslide (Fig. 8) and rockslide.

For example, the Cherry Hills Landslide occurred in Antipolo City (Philippines) in 1999. Heavy rainfall due to Tropical Cyclone Ising intensified the normal monsoon rainfall, triggering a disastrous landslide. Many houses were destroyed and some 58 people lost their lives.

Fig. 8: A landslide?? in Hong Kong in 1972

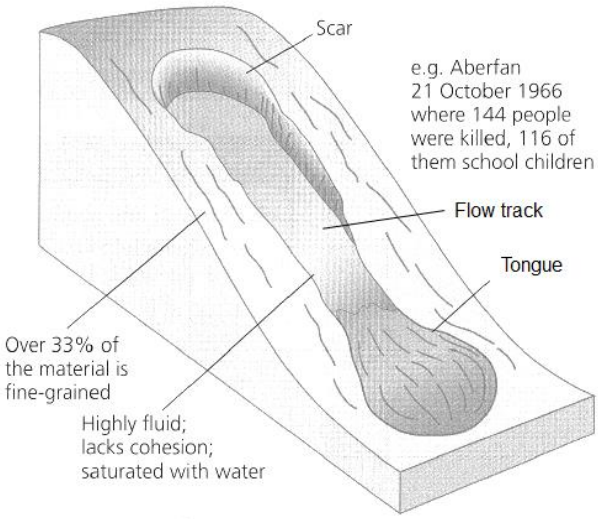

Fig. 9: Diagram of a flow
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Mechanism of Movement

Flows are the downward movement of regolith whereby the moving regolith mass undergoes internal deformation due to liquefaction of slope material.

Conditions for Occurrence

Flows generally occur in places where there is abundant loose and unconsolidated material such as ash and debris, and where torrential rainfall occurs.

Trigger

Flows are triggered usually as a result of heavy rainfall when the ground is saturated and pore water pressure between particles of the regolith is high. This causes particles within the regolith to shear relative to each other and cause liquefaction[4] to occur. Thus, the great reduction in shear strength causes flow to occur.

Characteristics

Flows have no coherence of material as internal shearing of slope material has occurred.

Flows are also fast. Furthermore, the velocity profile of a flow is not similar at different depths of the flow as internal deformation occurs. Velocity at the base of the flow is lowest due to friction with the ground (Fig. 10).

[4] The regolith behaves like a fluid rather than a solid.

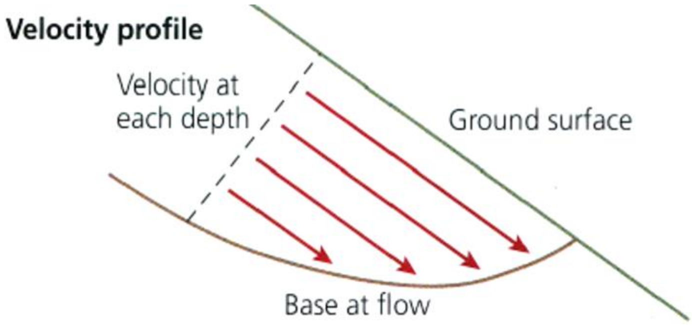

Fig. 10: Velocity Profile of a Flow
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Flows also have very high water content.

Effects on Slope
Flows will form scar, flow track and a tongue.

Type of Flow - Mudflow and Debris Flow
A type of flow is mudflow, which consist mostly of small silt and clay-sized particles. (Fig. 11)

Another type of flow is debris flow, which consists of mixtures of rock fragments and mud. If the debris flow is formed due to a volcanic eruption it is more commonly known as a lahar.
For example, the Venezuela debris flows occurred in 1999, due to a combination of deforestation and extreme rainfall events. Up to 30,000 people lost their lives, and more than 400,000 were made homeless as 90,000 homes were destroyed, washed away or buried by several metres of mud.


Fig. 11: Mudflow

Creep (via the heave mechanism)

Mechanism of Movement

Heaves are the progressive steplike movement of regolith downslope due to the expansion and contraction of the slope.

Materials are moved by the heave mechanism where particles are lifted perpendicularly from the ground and are replaced perpendicularly to the horizontal, resulting in a net downslope movement for the particle (Fig. 12).

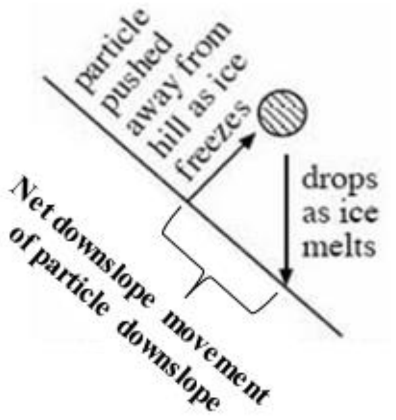

Fig. 12: Diagram of heave mechanism for soil creep
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Conditions for Occurrence

Heave generally occur in areas where there are variations in temperature or moisture levels to allow for the expansion and contraction of the ground.

Trigger

There is no trigger for heave, as it will occur as long as the conditions for occurrence are fulfilled.

Characteristics

Heaves have no coherence of material as particles move individually depending on the level of expansion and contraction of the ground.

Heaves are very slow, usually moving less than 1cm (mainly for soil creep) – 30cm (mainly for solifluction) a year.

Heaves have variable water content, as more water is required for solifluction to occur compared to soil creep.

Effects on Slope

Soil creep will form terracettes, while solifluction will form solifluction lobes.

Type of Heave - Soil Creep

One type of heave is soil creep.

Soil creep occurs in two different ways:

Wet-dry periods: During times of heavy rainfall, moisture increases the volume and weight of the soil, causing expansion. In a subsequent dry period, the soil will dry out and then contract, resulting in a net downslope movement.

Freeze-thaw: When the regolith freezes, the presence of ice crystals increases the volume of the soil by 9%. As the soil expands, particles are lifted at right-angles to the slope in a process called heave. When the ground later thaws and the regolith contracts, these particles fall back vertically under the influence of gravity and there is a net downslope movement.

The effects of soil creep can be seen in the small terraces formed on hillsides known as terracettes (Fig. 12) and others such as cracks in the road (Fig. 13).


Fig. 12: Soil creep forming terracettes

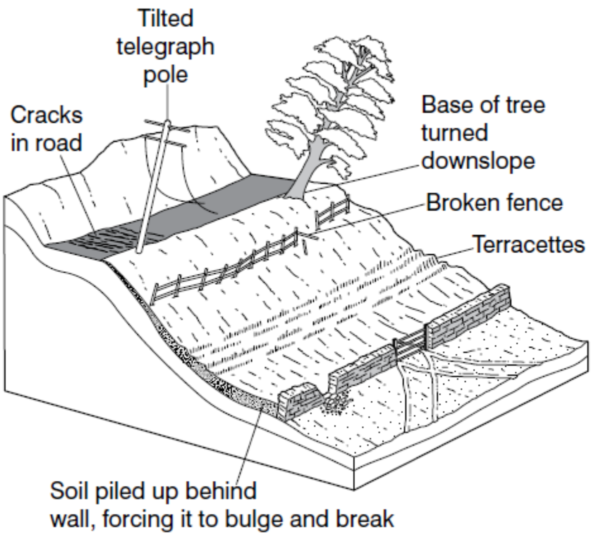
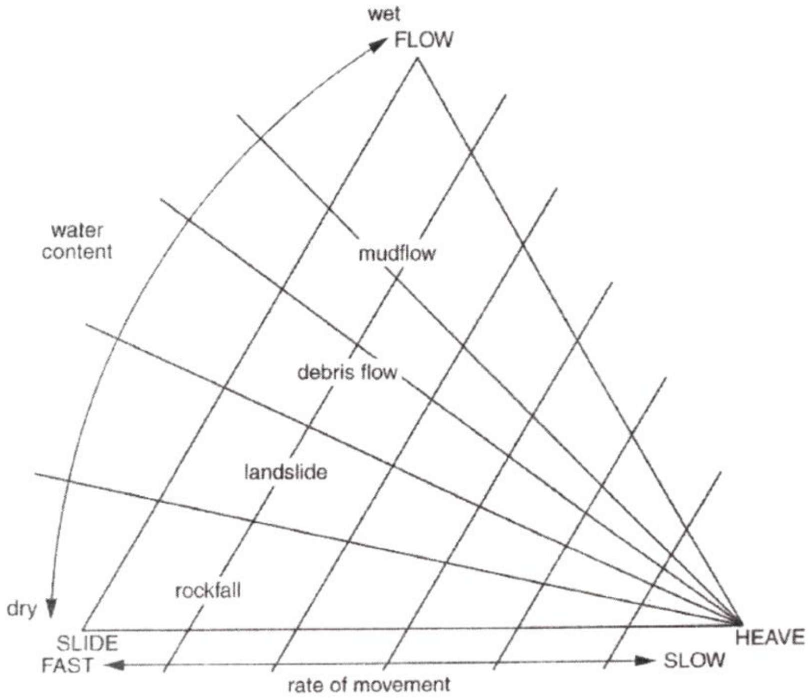


Fig. 13: Diagram of evidence of occurrence of soil creep

Carson and Kirkby's Diagram

When Carson and Kirkby (1972) attempted to group mass movements, they used the speed of movement and the amount of moisture present as a basis for distinguishing between the various types. (Qn: Where would you place (i) soil creep, (ii) solifluction in the diagram?)



(D) WHAT ARE THE FACTORS AFFECTING MASS MOVEMENT PROCESSES?

The factors that can influence mass movement processes are factors that can increase or reduce shear strength or shear stress.

These factors can be further divided into two categories: natural factors as well as anthropogenic (human) factors.

It has to be noted that while these factors can increase or decrease shear strength and shear stress, there must be a trigger in order for the equilibrium between shear strength and shear stress to be disrupted and causing mass movement to occur.

The natural factors that affect mass movement are:

1. Slope angle
2. Climate
3. Geology (Rock Type)
4. Geology (Rock Structure)
5. Slope Undercutting
6. Seismic Activity

The human factors that affect mass movement are:

1. Slope Undercutting

2. Modifying Land Use
3. Building on Slopes
4. Management of Slopes

Slope Angle

The steeper a slope, the greater will be the shear stress and effectiveness of the downward pull of gravity, making mass movements more likely to occur.

Climate

Climate influences that amount of water present in an area. Water has a major role influencing slope stability as it both increases the weight of the slope, which increases shear stress and reduces the friction between rock or soil particles which decreases shear strength so that mass movements are more likely to occur.

Saturated ground may also lead to liquefaction occurring causing flows to occur. Environments subjected to periods of intense rainfall, for example cyclones or monsoons, are particularly vulnerable to mass movement. The majority of mass movements can be linked to the presence of water in a slope. **Thus, climate may serve as a trigger for mass movements to occur, especially heavy rainfall events.**

For example, the influence of climate could be seen in the case of Cherry Hills Landslide in Antipolo City (Philippines) in 1999. Heavy rainfall due to Tropical Cyclone Ising intensified the normal monsoon rainfall, triggering a disastrous landslide. Many houses were destroyed and some 58 people lost their lives.

Geology (Rock Type)

Rocks that are loose and unconsolidated have less shear strength and are much more prone to collapse. For example, granite and limestone will hold a vertical slope without collapsing whereas sands and clays are only stable if the slope is at a low angle.

Geology (Rock Structure)

Heavily jointed rocks will be more prone to weathering processes such as frost shattering. This reduces the shear strength of the slope, making them vulnerable to collapse.

Rock juxtaposition such as weaker rocks on top of stronger rocks such as clay lying on top of more resistant rocks such as granite create a natural slip plane for slides to occur, reducing the shear strength of the slope.

For example, the influence of geology could also be seen in the case of Cherry Hills Landslide in Antipolo City (Philippines) in 1999. The Cherry Hills development comprised of low-cost housing units constructed on steep slopes (up to 25 degrees) on the edges of the city. The slope comprised of heavily fractured sedimentary rocks (siltstones, sandstones and clays), with varying degrees of permeability and shear strength. This creates inherent planes of weakness in the bedrock beneath the slope. When heavy rainfall due to Tropical Cyclone Ising intensified the normal monsoon rainfall, it triggered a disastrous landslide. Many houses were destroyed and some 58 people lost their lives.

Slope Undercutting

Undercutting of slopes reduces shear strength. Natural undercutting is caused by streams eroding their banks, or by waves cutting cliffs on a shoreline causing cliffs to overhang.

Seismic Activity

Seismic activity such as earthquakes and volcanic eruptions may reduce shear strength as they generate tremors in the earth that can break the bonds that hold pieces of rock together.

For example, the Los Colinas mudslide (El Salvador) in 2001 was triggered by a massive 7.6 earthquake that occurred in the Pacific Ocean. Many hundreds of people lost their lives and several thousand were injured.

Human Factors

Slope Undercutting

Humans may cause undercutting of slopes to occur, when home and road construction undercut natural slopes, increasing shear stress on the slope.

Modifying Land Use

Humans may modify the land use and remove vegetation for the development of infrastructure. Vegetation, particularly trees, increases shear strength of the slope and reduces the likelihood of mass movement because it intercepts rainfall and stops soils from getting too saturated and their roots helps to bind soil and rock particles together. If vegetation is removed, shear strength of the slope decreases.

Building on Slopes

Humans can construct buildings or dump waste material on slopes which increase shear stress on the slope.

An example of a mass movement event mainly caused by human activity was the Venezuela debris flows in 1999. In recent decades, large tracts of land had been cleared of forest to make way for urban development, in particular shanty towns. The absence of trees to intercept rainfall and hold together soil significantly reduced the shear strength of the slope. Extreme rainfall events in December 1999 resulted in debris flows and up to 30,000 people lost their lives, and more than 400,000 were made homeless as 90,000 homes were destroyed, washed away or buried by several metres of mud.

Management of Slopes

Humans can also reduce the likelihood of occurrence of mass movements. This can be done via structural engineering methods, such as the use of steel pins, wire cages, gabion walls and netting to increase the shear strength of the slope.

An example of this is the Hoar Edge slope stabilisation in Northern England. During the construction of the Trans Pennine motorway, shallow landslides occurred one of the newly cut slopes. A combination of structural measures was subsequently employed to stabilise the slope. The angle of the profile was lowered to reduce the likelihood of further mass movement taking place. Also, a rock buttress was constructed to act as a wall at the base or toe of the slope. Lastly, the top of the wall was held in place by 41 cable anchors that were attached to a layer of stable sandstone below the ground surface. There has been no movement since these measures were employed.

(E) WHAT ARE THE EFFECTS OF MASS MOVEMENT?

Mass movements impact both the physical and the human environment.

In terms of the physical environment, mass movements serve to:

1. Alter slope form
2. Create slope features

In terms of the human environment, mass movements may:

1. Damage infrastructure and homes
2. Cause death and injury

Alter Slope Form

Besides making the resulting slope have a gentler gradient, different mass movements may alter the form of the slope in different ways.

For example, slides, slumps and flows tend to create concave slope profiles, while falls and heaves tend to create convex slopes.

Create Slope Features

Different mass movements also result in specific features formed on the slope. For example, flows will result in scar, flow track and tongue.

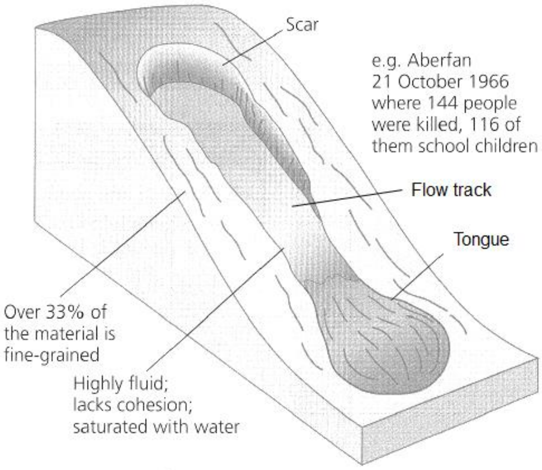


Fig. 15: Diagram of a flow

Damage Infrastructure and Homes

Earthquake-triggered landslides can damage infrastructure and homes.

Cause Death and Injury

Death and injury may also result due to mass movements.

For example, the Cherry Hills Landslide in Antipolo City (Philippines) in 1999 was caused by heavy rainfall due to Tropical Cyclone Ising intensified the normal monsoon rainfall, triggering a disastrous landslide. Many houses were destroyed and some 58 people lost their lives

In this lecture, we will tackle the guiding question, **how else do materials move down slope <u>If its not by mass movement</u>.**

Well, in the humid and arid tropics, there will still be some rainfall, thus there can be erosion of slope materials by water on the slope.

In this lecture, we shall examine **three specific processes**

- **Splash Erosion**
- **Rainwash**
- **Rillwash**

It will be helpful to think of them as a sequence – meaning that one can only occur after another.

<u>Splash Erosion (Rain Drop Impact)</u>

- Results from raindrop detachment of soil material causing movement of particles from its original position.
- Caused by intense rain with large raindrops splashing on bare or near bare ground
- Occurs as a combination of raindrop detachment and transport, either by direct ejection of particles or by entrainment in droplets that rebound from surface. The particles can subsequently be transported by unconcentrated surface flows
- Is a diffusive process that moves sediments in all directions (lateral, both upslope and downslope)
- Is the primary cause of soil detachment and soil disintegration: Rain drops behave as little bombs when falling on exposed or bare soil, displacing soil particles and destroying soil structure. Studies in America have shown that splashed particles may rise as high as 0.6 metres above the ground and move up to 1.5 metres horizontally.
    - Dependent on particle size & density, slope angle, soil cohesion etc

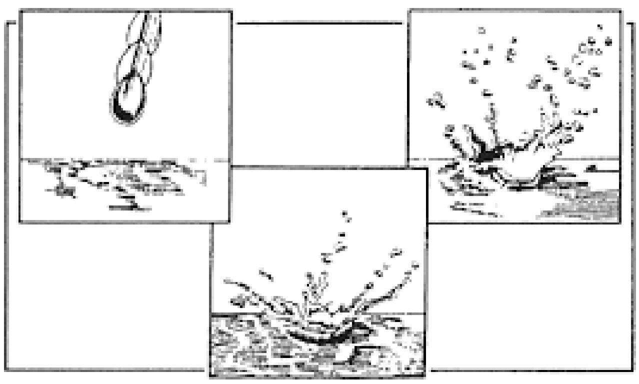


Fig 1: Splash Erosion

- Resettled sediment tends to blocks soil pores resulting in surface crusting and lower infiltration.

Rainwash (Sheet erosion, sheetwash, sheetflood)

- Refers to the unconcentrated movement of eroded materials downslope along the ground surface in the form of overland flow, its movement downslope gathers momentum and represents an erosive force of high potential.
- Is the second stage in the erosion process that follows rainsplash impact
- Is a major process in the denudation of land surfaces.
- Is DIFFERENT from *gully erosion* or rillwash and stream erosion.
- On rough surfaces, rainwash may give way to rillwash instead whereby unconcetrated flows begin to concentrate in smaller, narrower streams and erosion continues in this concentrated manner

Rillwash (Rill erosion)

- Refers to the concentrated movement of eroded materials downslope along the ground surface
- Results in the development of very small channels (less than 30cm deep).
- Involves concentration of the surface water flow in surface channels, developing rills, which over time, enlarge and develop into gullies. These gullies may eventually result in development of streams.

Rills are small channels <30cm deep and wide

Gullies are enlarged rills >30cm deep and wide.

Fig 2a and Fig. 2b below shows the development of the various water erosion processes on a hillslope

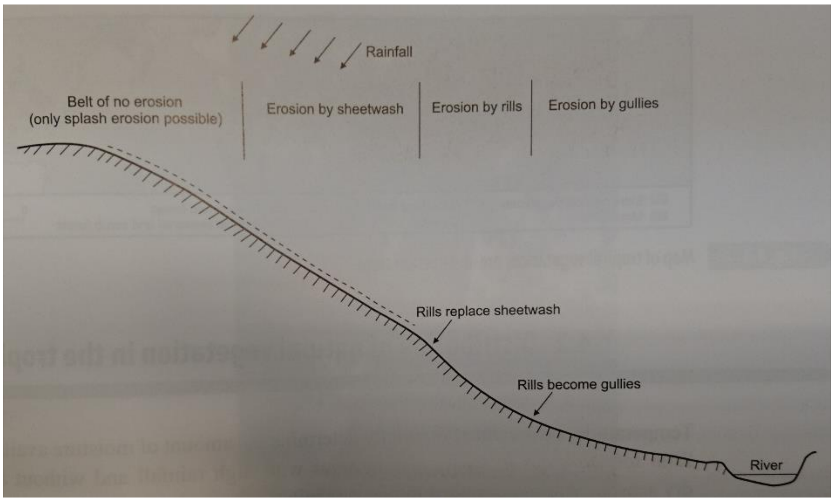


Fig. 2a Rainfall resulting in erosion on hillslope

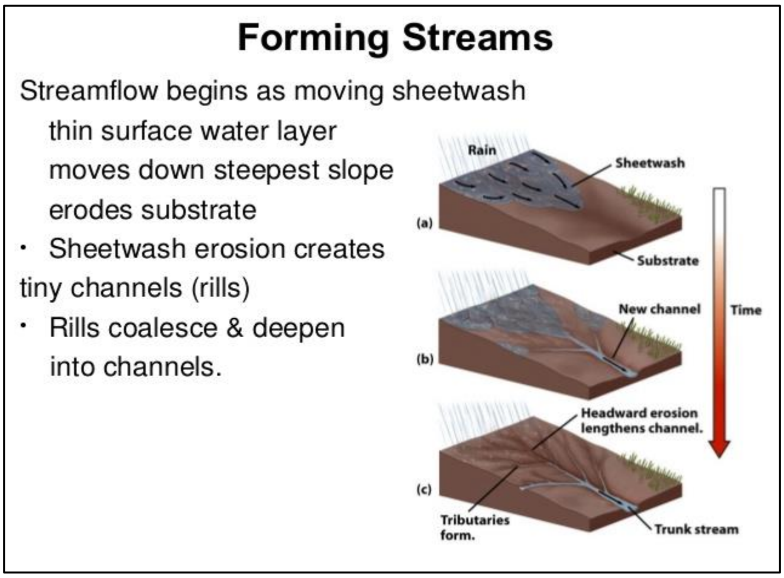


Fig. 2b: Development and formation of streams on hillslope

(D) WHAT ARE THE FACTORS AFFECTING WATER EROSION PROCESSES?

The nature of specific locations such as rainfall intensity and amount, topography (e.g. gradient of slope), soil properties, vegetation) determines which types of erosion would be more effective at a particular location.

Sample Explanation: How is the landform in the figure below formed?

The landforms shown above are rills and gullies on a rather bare slope. It is formed by different fluvial erosion processes.

- These fluvial erosions are likely to be caused by repeated precipitation over a prolonged period of time or streamflow
- The first possible process that could have led to the formation of the landform would be splash erosion caused by rainfall. Splash erosion is erosion caused by raindrop impact and splash on the soil surface → this could have worked to detach and loosen the sediments on the slope surface in resource 4
- The second process that occur would be unconcentrated surface overland flow erosion or **sheet erosion. This process** occurs when rainfall accumulates in sheets as a thin layer of moving water that erodes by detaching and moving some soil surface down the slope.
- Subsequently as the precipitations becomes more prolonged or intense, **concentrated overland-flow erosion** can occur which can lead to the formation of rills which are tiny hillside channels a few centimeters wide and deep.
- Rainwash/Unconcentrated overland flow erosion can also occur between the rills to remove sediments and soil particles (this is known as inter-rill flows)
- The concentrated flow erosion can also accumulate and occur within the rills as rill flow.
- Flow energy can accumulate and increase within the rills
- Over time, as more erosion occurs and the rill enlarges, the rills can grade into gullies. Gullies are channels more larger than rills.