



ACBA6014

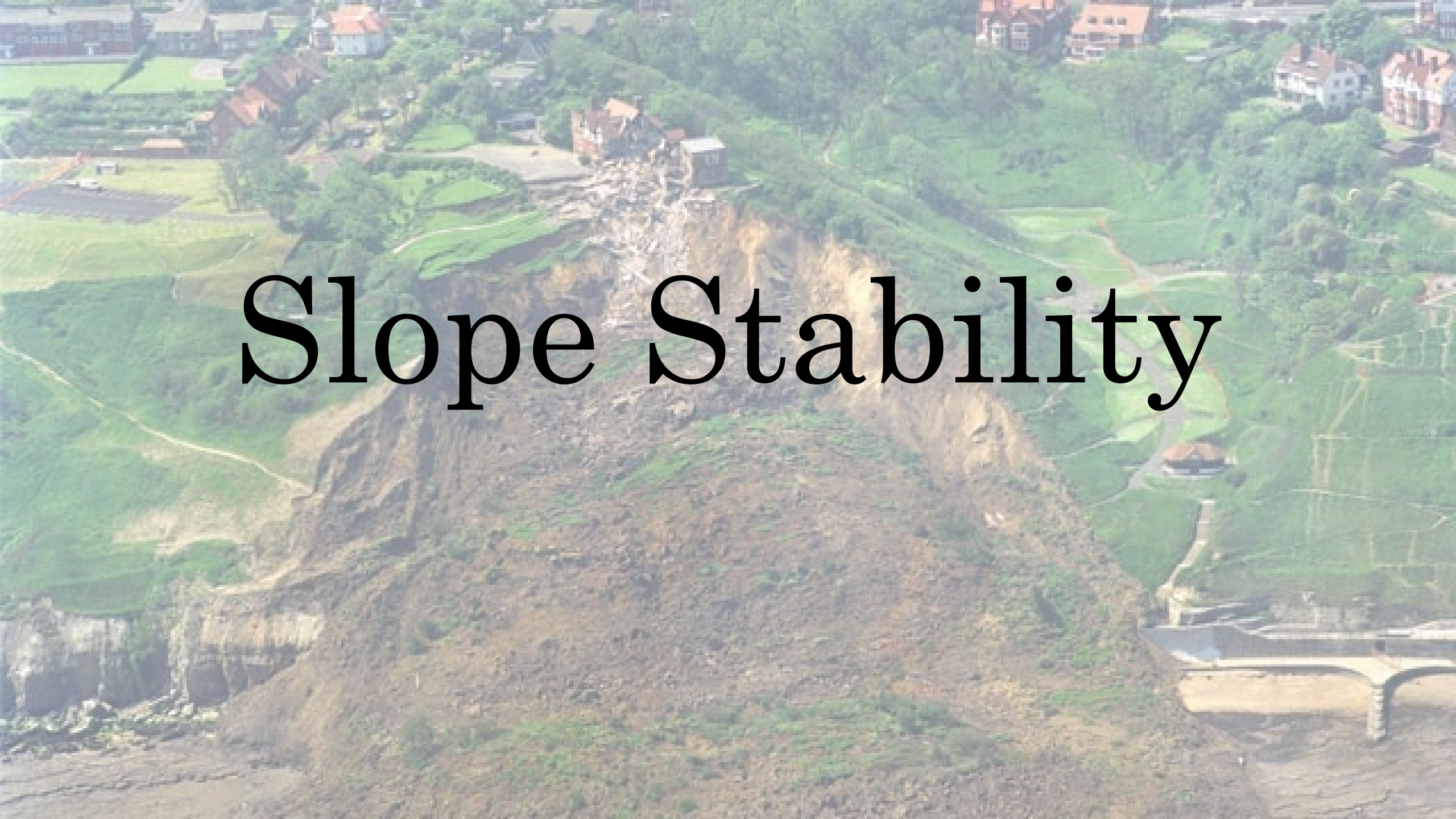
Geotechnical and Environmental Engineering

Module Aim

- To equip students with the ability to be able to analyse engineering solutions to environmental issues.



Slope Stability

An aerial photograph showing a massive landslide on a hillside. The landslide area is a large, exposed, brownish-grey mass of earth and rock, contrasting sharply with the surrounding green grass and trees. At the top of the slope, several houses are visible, some of which appear to be at the edge of the unstable ground. In the lower right corner, a concrete bridge with multiple arches spans a body of water. The overall scene illustrates a significant geotechnical hazard in a residential and developed area.

What is slope stability?

- Slope stability refers to the ability of a slope (natural or man-made) to remain intact without undergoing failure, such as landslides or collapses.



What is slope stability?

- Slope stability refers to the ability of a slope (natural or man-made) to remain intact without undergoing failure, such as landslides or collapses.
 - For an engineer, it involves analysing the forces acting on the slope, the material properties, and the conditions that may lead to slope failure.
- 

What is slope stability?

- Slope stability refers to the ability of a slope (natural or man-made) to remain intact without undergoing failure, such as landslides or collapses.
 - For an engineer, it involves analysing the forces acting on the slope, the material properties, and the conditions that may lead to slope failure.
 - Stability is assessed by evaluating the balance between driving forces and resisting forces.
- 

Natural Slopes

- These are formed through natural processes such as erosion, weathering, and tectonic activity.
- They evolve over time and can vary in stability depending on their geology, vegetation, and environmental factors.

Natural Slopes - Formation

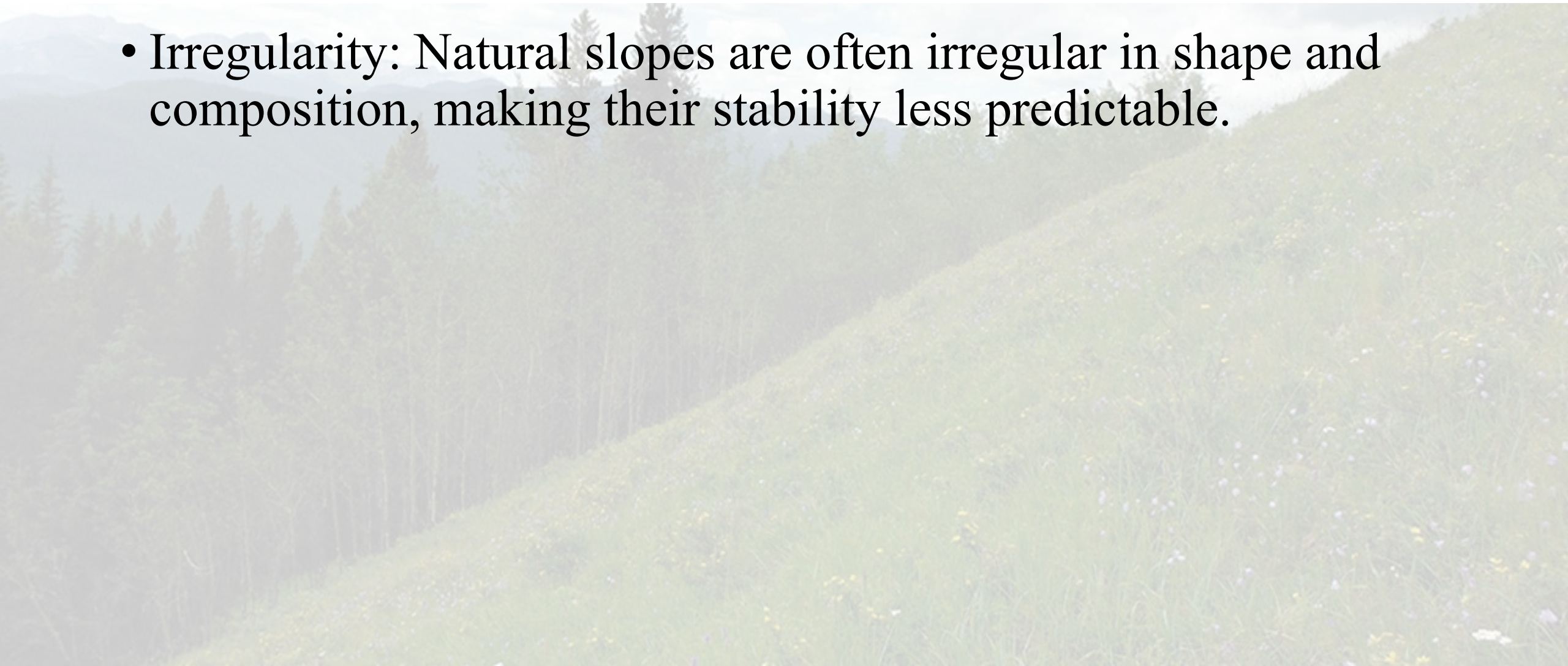
- Natural slopes develop through geological processes like erosion by wind or water, sediment deposition, landslides, or tectonic uplift.

Natural Slopes - Formation

- Natural slopes develop through geological processes like erosion by wind or water, sediment deposition, landslides, or tectonic uplift.
- They tend to reach a state of relative equilibrium based on the local climate, vegetation, and the type of material present.

Natural Slopes - Characteristics

- Irregularity: Natural slopes are often irregular in shape and composition, making their stability less predictable.



Natural Slopes - Characteristics

- Irregularity: Natural slopes are often irregular in shape and composition, making their stability less predictable.
- Vegetation: They may be covered with vegetation, which can provide some reinforcement and affect stability through root systems.

Natural Slopes - Characteristics

- Irregularity: Natural slopes are often irregular in shape and composition, making their stability less predictable.
- Vegetation: They may be covered with vegetation, which can provide some reinforcement and affect stability through root systems.
- Weathering: Natural slopes are affected by long-term processes like weathering, which can reduce material strength over time

Natural Slopes - Examples

- Hill Slopes: These are slopes that occur on the sides of hills and mountains. Stability is affected by rock composition, weathering, and water flow.



Natural Slopes - Examples

- Riverbanks and Coastal Cliffs:
Slopes that form
along rivers and
coasts due to erosion
by water currents or
waves.



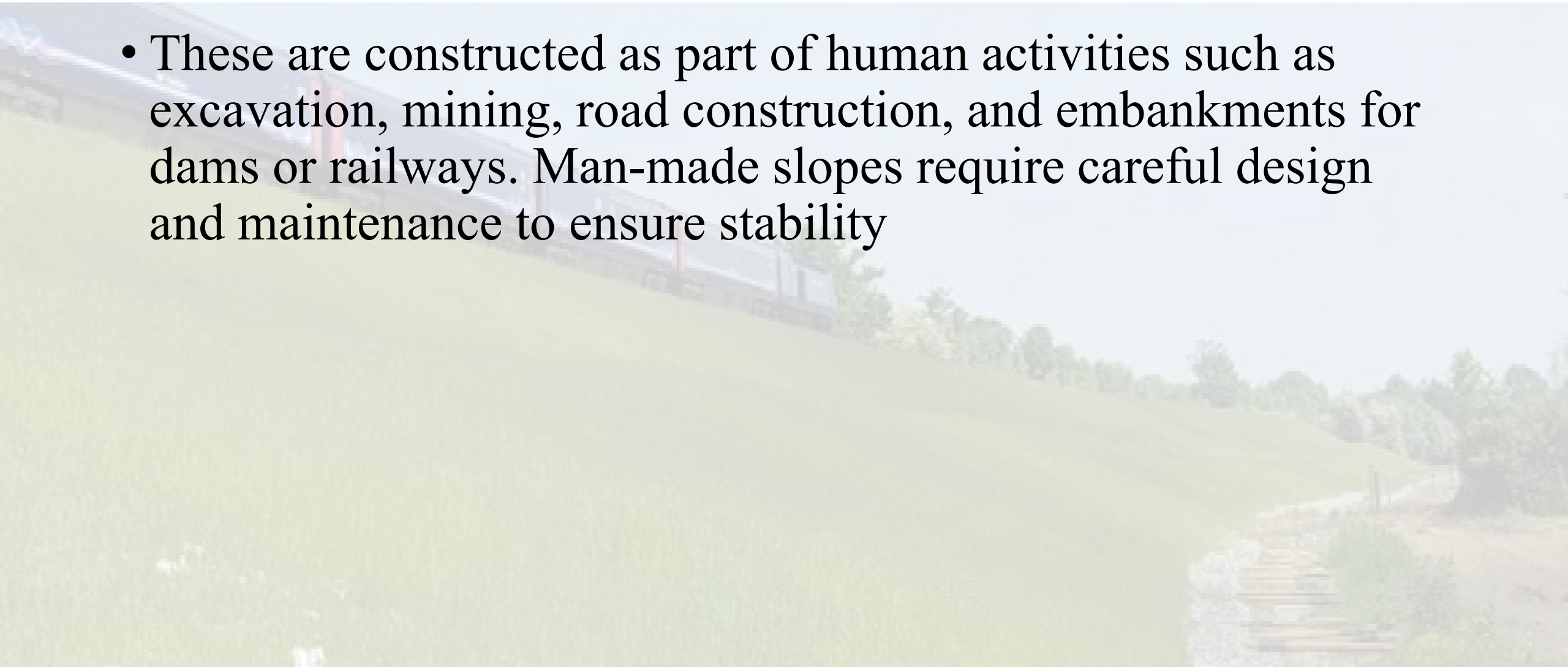
Natural Slopes - Examples

- Mountain Slopes:
Often steep and
composed of rock.



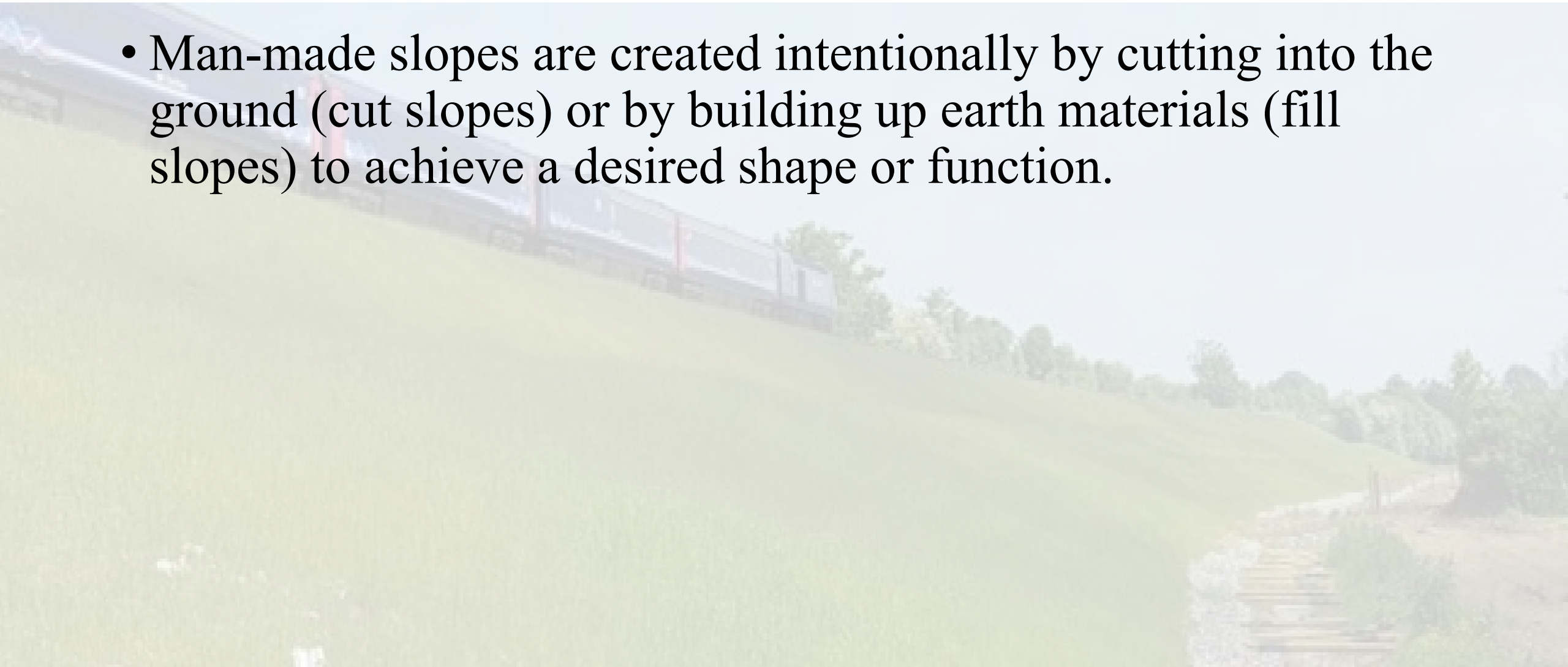
Engineered Slopes

- These are constructed as part of human activities such as excavation, mining, road construction, and embankments for dams or railways. Man-made slopes require careful design and maintenance to ensure stability



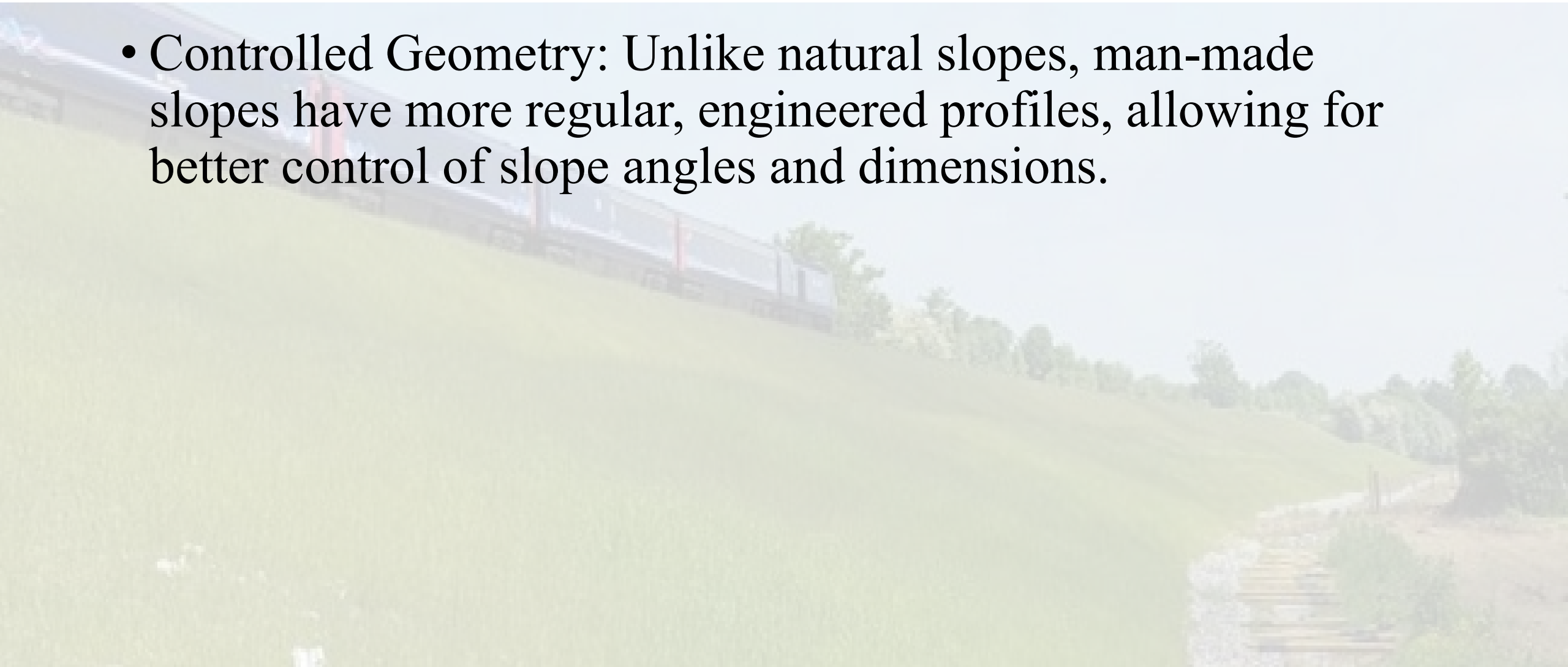
Engineered Slopes - Formation

- Man-made slopes are created intentionally by cutting into the ground (cut slopes) or by building up earth materials (fill slopes) to achieve a desired shape or function.



Engineered Slopes - Characteristics

- Controlled Geometry: Unlike natural slopes, man-made slopes have more regular, engineered profiles, allowing for better control of slope angles and dimensions.



Engineered Slopes - Characteristics

- **Controlled Geometry:** Unlike natural slopes, man-made slopes have more regular, engineered profiles, allowing for better control of slope angles and dimensions.
- **Reinforcement:** Engineers often reinforce man-made slopes with structures such as retaining walls, soil nails, or geosynthetics to improve stability.

Engineered Slopes - Characteristics

- **Controlled Geometry:** Unlike natural slopes, man-made slopes have more regular, engineered profiles, allowing for better control of slope angles and dimensions.
- **Reinforcement:** Engineers often reinforce man-made slopes with structures such as retaining walls, soil nails, or geosynthetics to improve stability.
- **Designed Drainage:** Drainage systems are typically incorporated to manage water flow and reduce the risk of slope failure.

Engineered Slopes - Examples

- Cut Slopes: These are slopes formed by excavating into natural terrain to create space for infrastructure, such as roads, tunnels, or building foundations.



Engineered Slopes - Examples

- Embankments: These are built-up slopes made from compacted soil or rock, commonly used in the construction of highways, railways, and dams.



Engineered Slopes - Examples

- Retaining Walls: These are structures designed to support the soil behind them, preventing the soil from collapsing onto roads or other infrastructure.



Engineered Slopes - Examples

- Coal Tip: These slopes are created from compacted waste material from coal extraction.



Comparison

	Natural	Engineered
Geometry	Irregular Profile	Specific Angles and Geometries
Stability Factor	Material Properties, Weathering, Vegetation, Groundwater	Reinforcement Techniques, Drainage, Precise Calculations
Risk of Failure	Weather Events, Natural Degradation	Poor Drainage, Over-steep, Inadequate Reinforcement

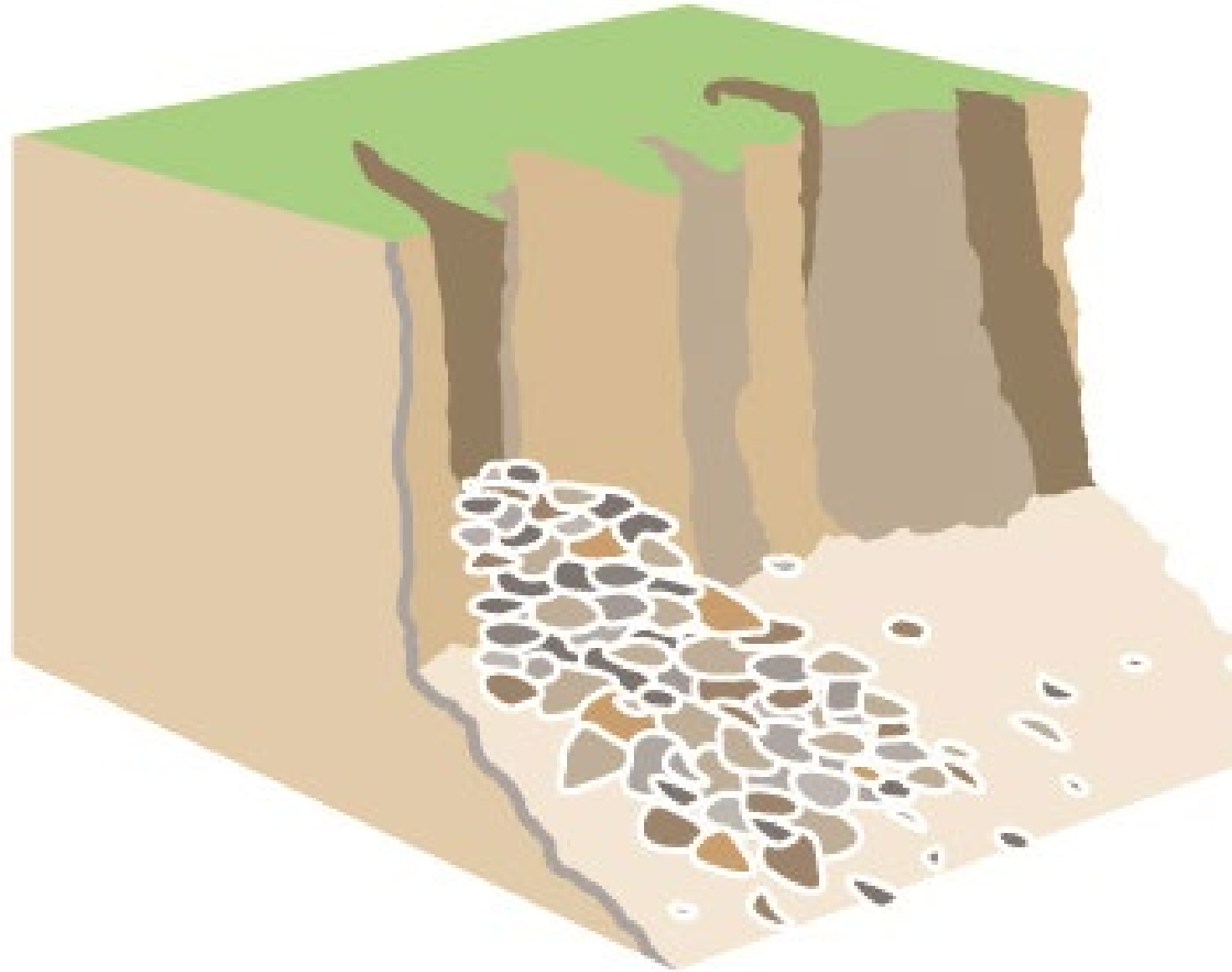
Slope Failure

Landslides are classified by their type of movement. The four main types of movement are:

Slope Failure

Landslides are classified by their type of movement. The four main types of movement are:

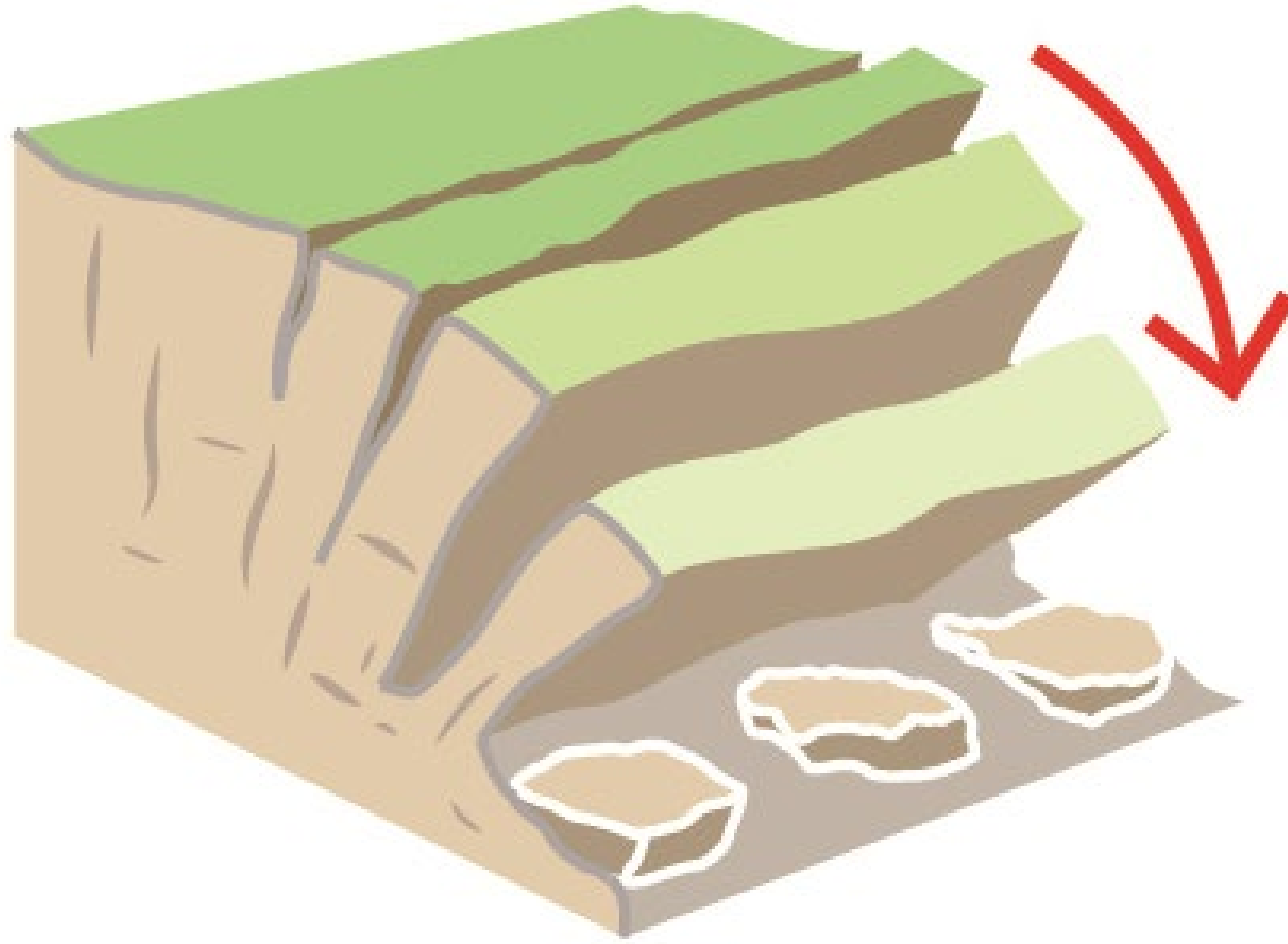
- Falls



Slope Failure

Landslides are classified by their type of movement. The four main types of movement are:

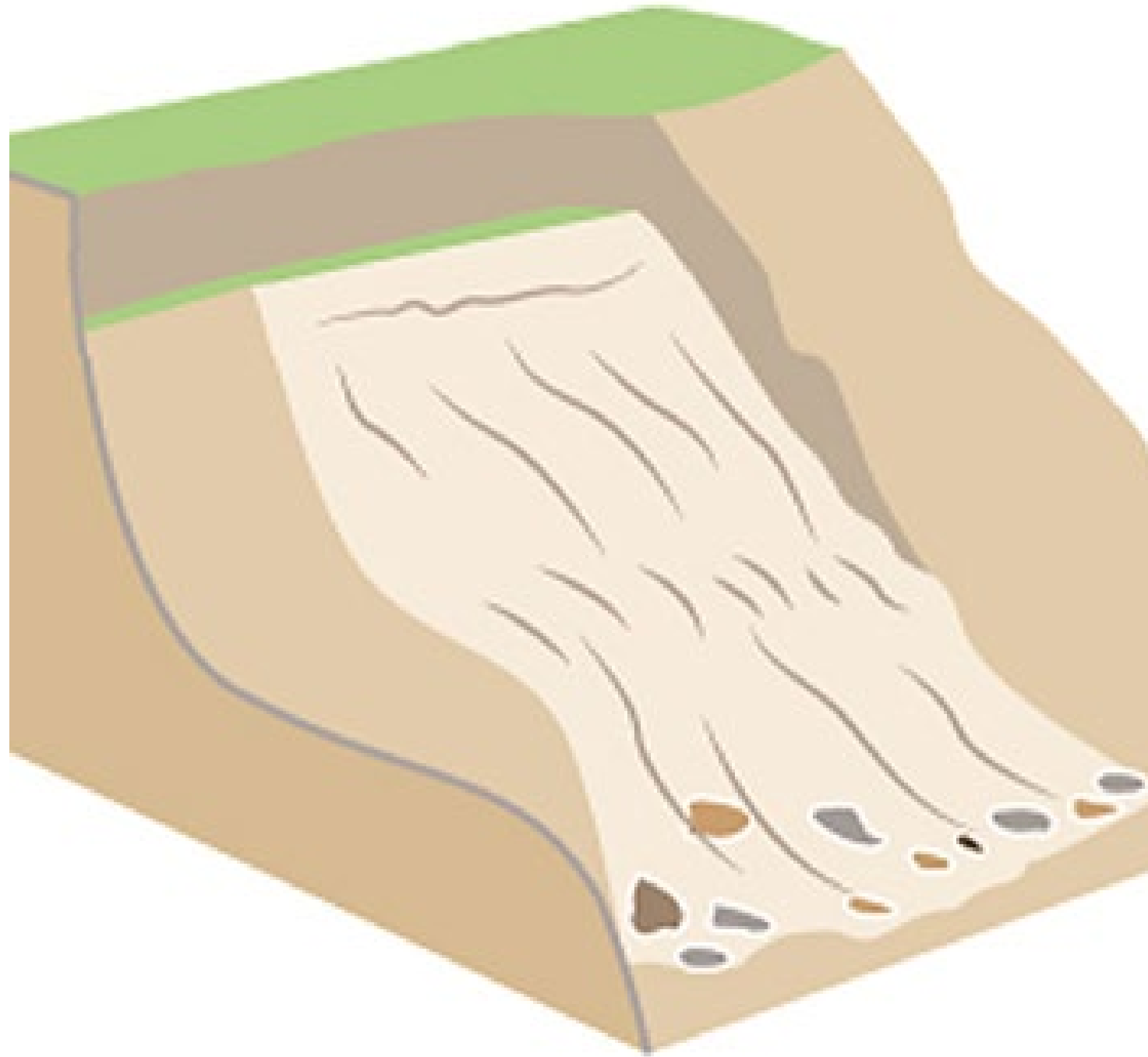
- Falls
- Topples



Slope Failure

Landslides are classified by their type of movement. The four main types of movement are:

- Falls
- Topples
- Slides



Slope Failure

Landslides are classified by their type of movement. The four main types of movement are:

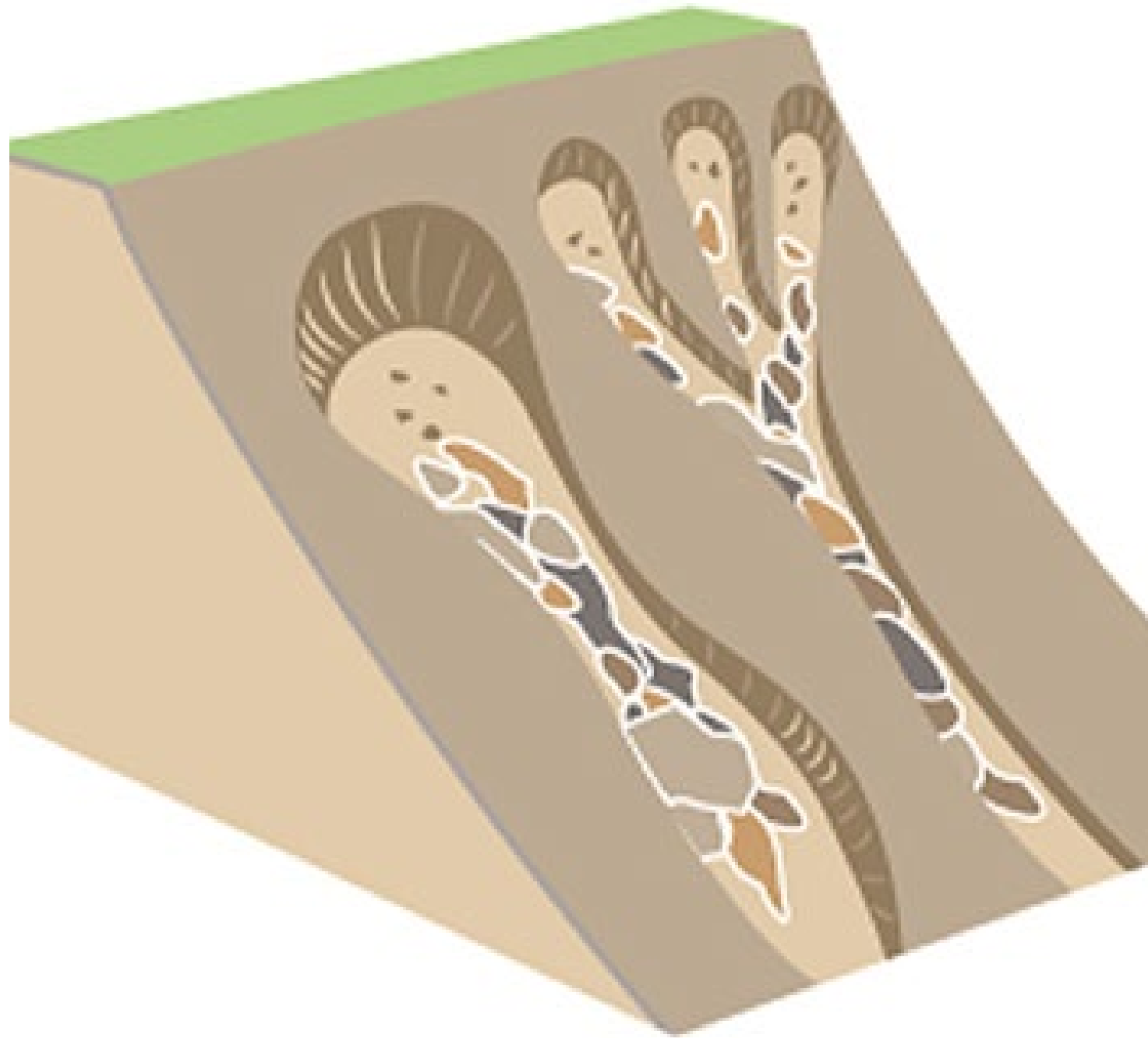
- Falls
- Topples
- Slides



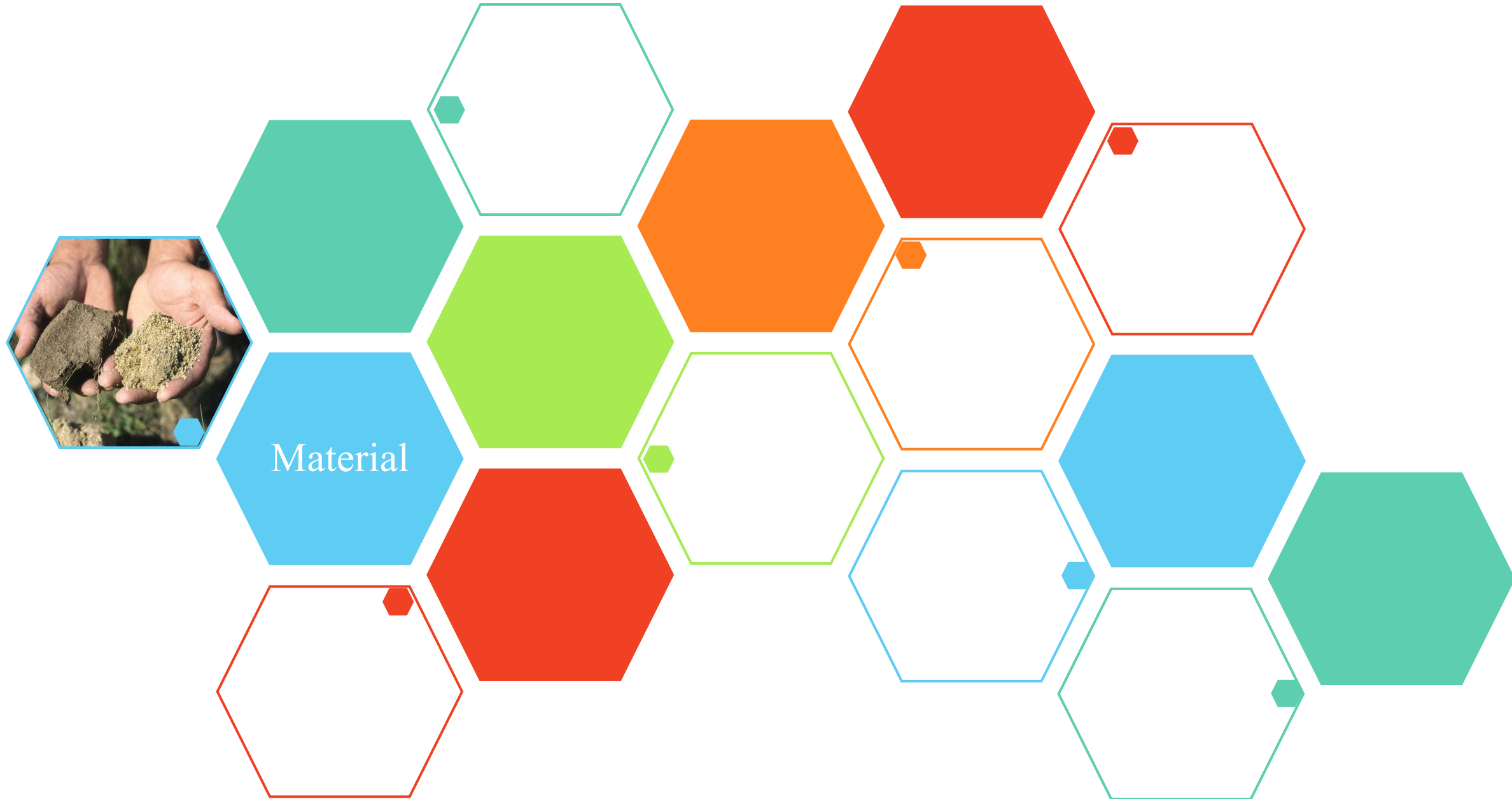
Slope Failure

Landslides are classified by their type of movement. The four main types of movement are:

- Falls
- Topples
- Slides
- Flows



Factors affecting slope stability



Factors affecting slope stability



Factors affecting slope stability



Factors affecting slope stability



Factors affecting slope stability



Factors affecting slope stability



Factors affecting slope stability



Mechanisms of Slope Failure

The stability of a slope depends on the balance between the driving forces that cause movement and the resisting forces that oppose it.

Understanding these forces is critical in assessing whether a slope is stable or at risk of failure.

Mechanisms of Slope Failure

Driving Forces: Primarily the gravitational force acting on the mass of the slope material. This force is increased by factors such as steep slope angles, water saturation, and external loads.

Mechanisms of Slope Failure

- **Driving Forces:** Primarily the gravitational force acting on the mass of the slope material. This force is increased by factors such as steep slope angles, water saturation, and external loads.
- **Resisting Forces:** These include the shear strength of the slope material, which is influenced by cohesion, internal friction, and effective stress. Vegetation, soil reinforcement, and drainage also contribute to resisting forces.

Factor of Safety

The Factor of Safety (FOS) is defined as the ratio between these components:

Factor of Safety

The Factor of Safety (FOS) is defined as the ratio between these components:

$$FoS = \frac{\textit{Resisting Forces}}{\textit{Driving Forces}}$$

Factor of Safety

If the FoS of a slope is >1 the slope is...

Factor of Safety

If the FoS of a slope is >1 the slope is...

STABLE

Factor of Safety

If the FoS of a slope is <1 the slope is...

Factor of Safety

If the FoS of a slope is <1 the slope is...

UNSTABLE

Factor of Safety

If the FoS of a slope is $=1$ the slope is...

Factor of Safety

If the FoS of a slope is $=1$ the slope is...

CRITICAL

Factor of Safety

In practical design, engineers aim for a $\text{FoS} = 1.3\text{-}1.5$ for typical slopes to provide a safety margin.



Driving Forces

- The driving forces in slope stability are the forces that act to destabilize or cause downslope movement of materials.

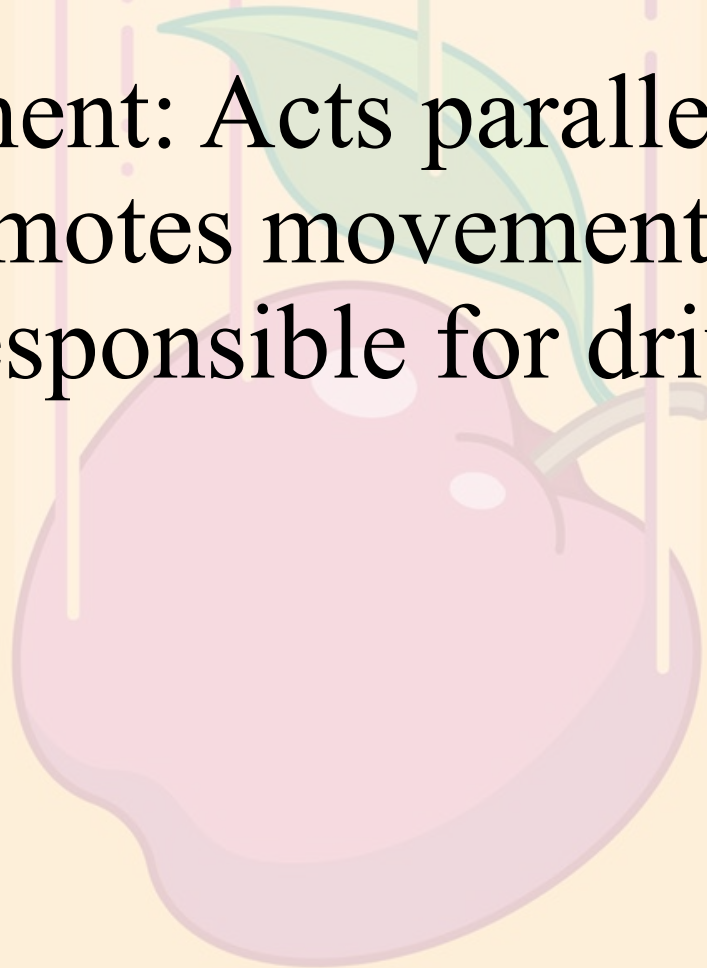


Driving Forces

- The driving forces in slope stability are the forces that act to destabilize or cause downslope movement of materials.
- These forces promote the potential failure of a slope by overcoming the resisting forces that hold the material in place.

Driving Forces - Gravity

- Parallel component: Acts parallel to the slope surface and promotes movement downslope. This component is responsible for driving slope failure.

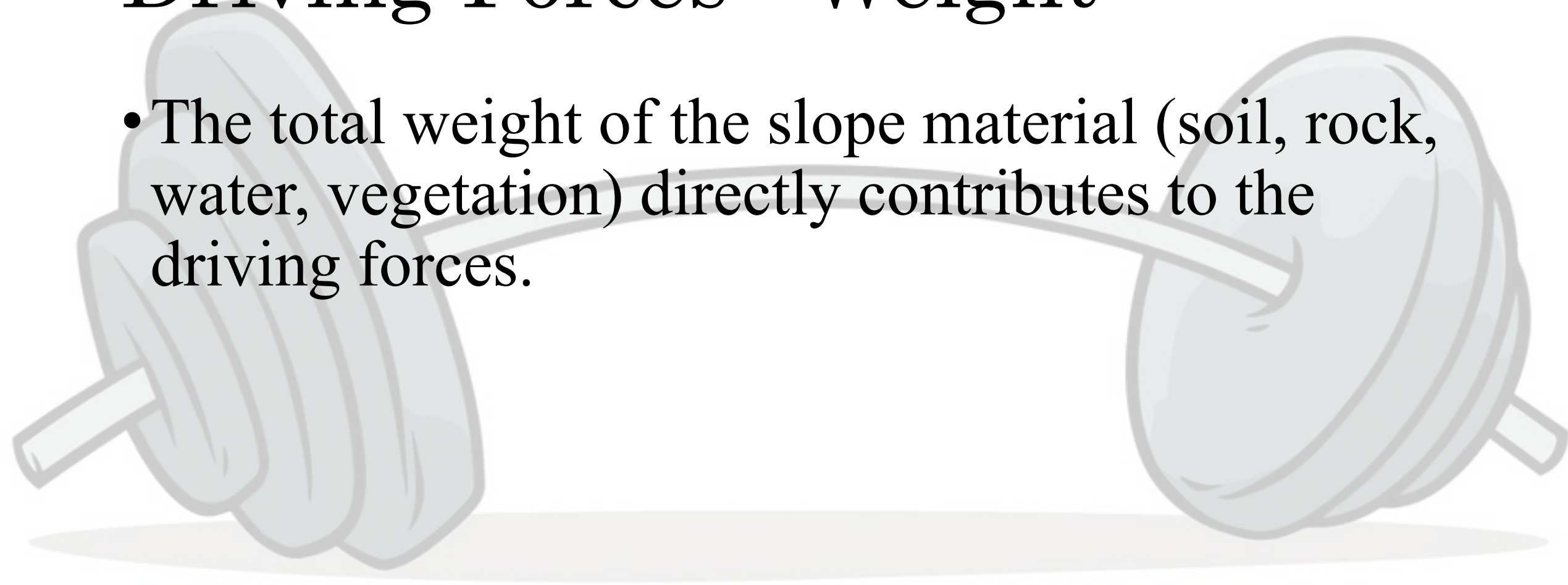


Driving Forces - Gravity

- Parallel component: Acts parallel to the slope surface and promotes movement downslope. This component is responsible for driving slope failure.
- As the slope angle increases, the downslope component of gravity becomes larger, making it easier for the material to slide.

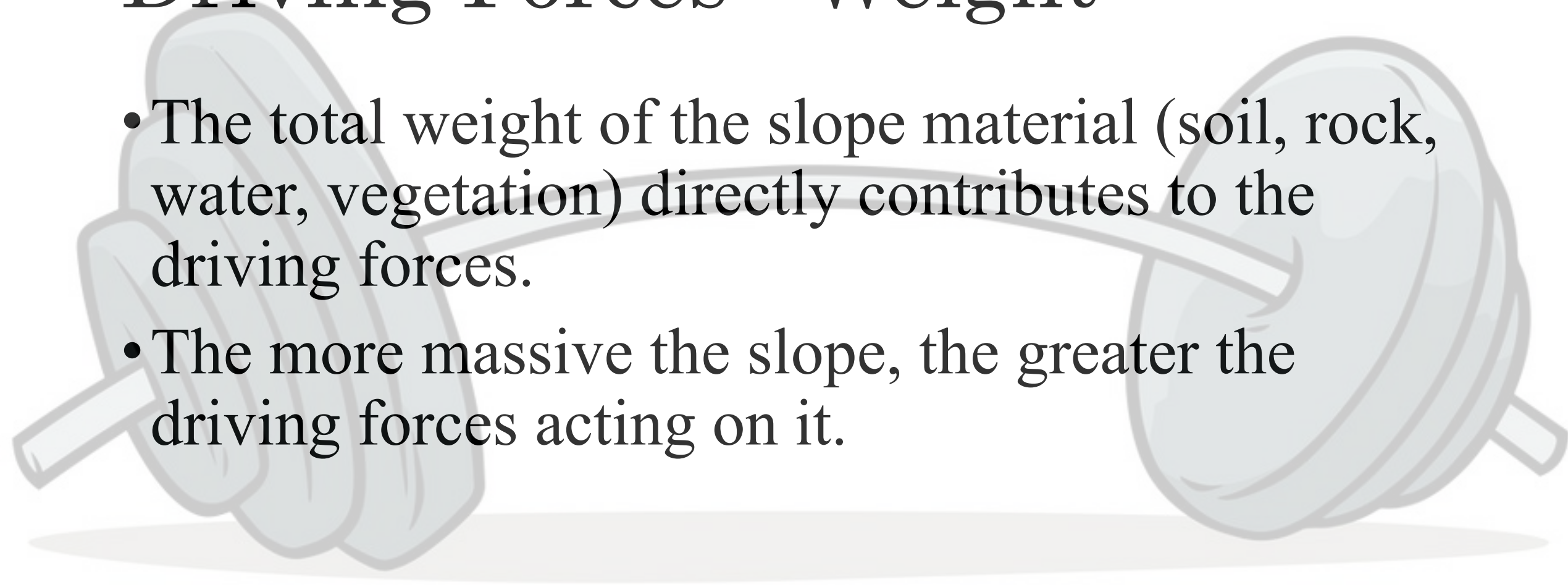
Driving Forces - Weight

- The total weight of the slope material (soil, rock, water, vegetation) directly contributes to the driving forces.



Driving Forces - Weight

- The total weight of the slope material (soil, rock, water, vegetation) directly contributes to the driving forces.
- The more massive the slope, the greater the driving forces acting on it.



Driving Forces – Pore Water Pressure

- Pore water pressure refers to the pressure exerted by water within the pores of the soil. When soil becomes saturated with water, the pore water pressure increases, reducing the effective stress that helps hold the soil particles together.

Driving Forces – Pore Water Pressure

- Pore water pressure refers to the pressure exerted by water within the pores of the soil. When soil becomes saturated with water, the pore water pressure increases, reducing the effective stress that helps hold the soil particles together.
- High pore water pressure reduces the shear strength of the soil and increases the likelihood of slope failure.

Driving Forces

- External Loads



Driving Forces

- External Loads
- Seismic



Driving Forces

- External Loads
- Seismic
- Erosion / Weathering



Driving Forces

- External Loads
- Seismic
- Erosion
- Weathering

Driving Forces

- External Loads
- Seismic
- Erosion
- Weathering
- Removal of Vegetation





Resisting Forces

- Resisting forces are those that act to maintain the stability of a slope by counteracting the driving forces that cause movement.



Resisting Forces

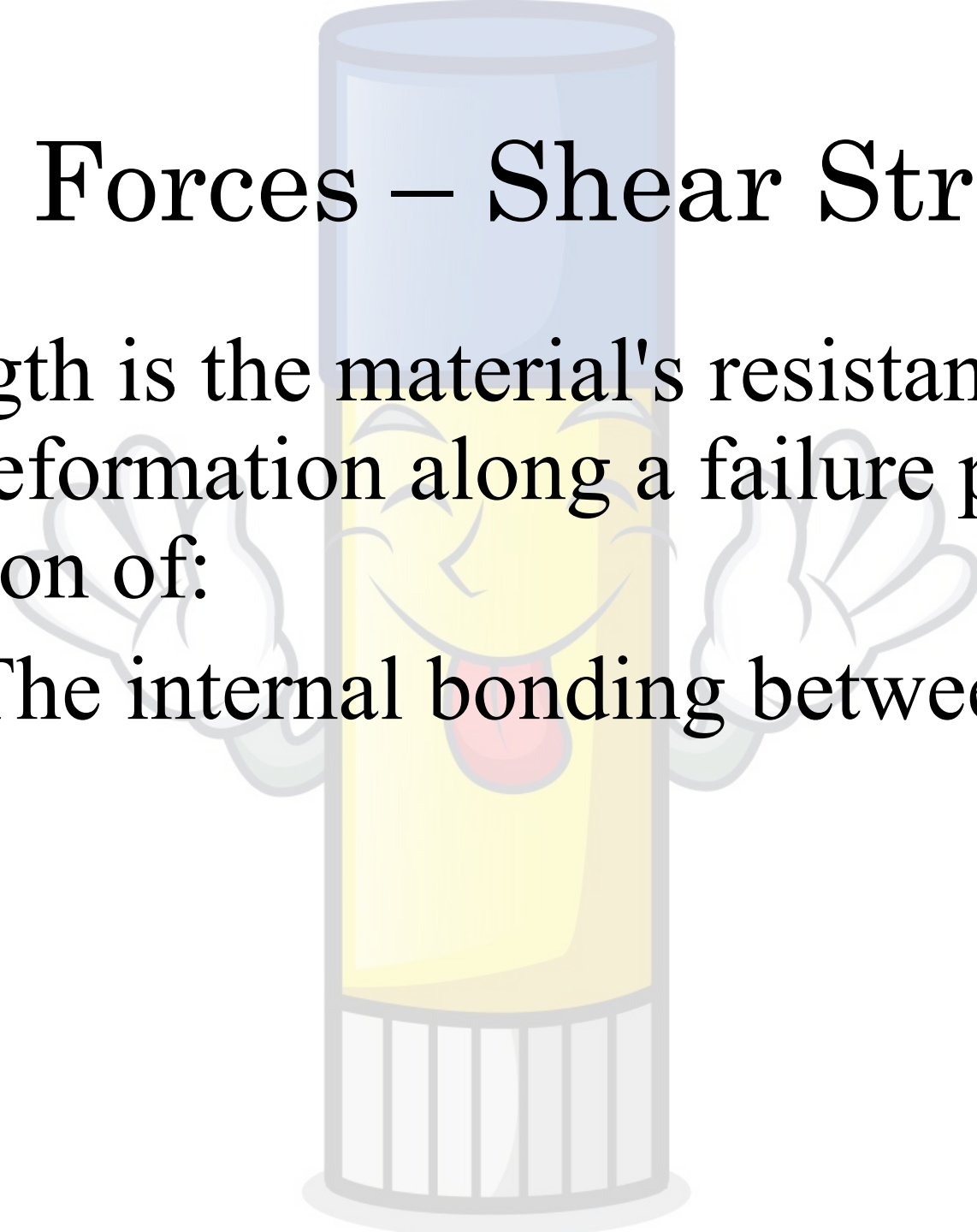
- Resisting forces are those that act to maintain the stability of a slope by counteracting the driving forces that cause movement.
- These forces primarily stem from the shear strength of the slope material, including factors like cohesion, friction, normal stress, and external support like vegetation or engineering structures.

Resisting Forces – Shear Strength

- Shear strength is the material's resistance to sliding or deformation along a failure plane. It is a combination of:

Resisting Forces – Shear Strength

- Shear strength is the material's resistance to sliding or deformation along a failure plane. It is a combination of:
- Cohesion: The internal bonding between particles.

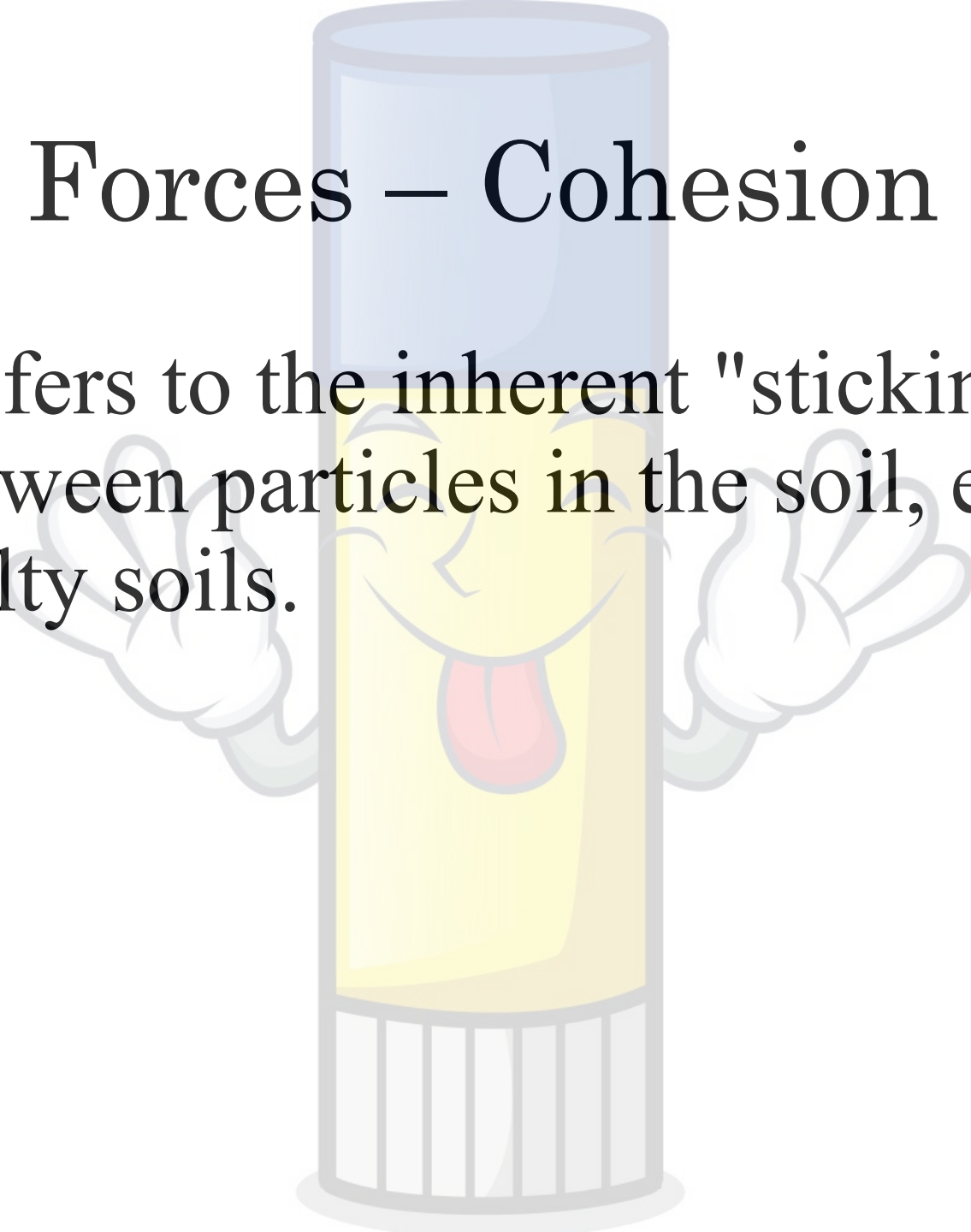


Resisting Forces – Shear Strength

- Shear strength is the material's resistance to sliding or deformation along a failure plane. It is a combination of:
- Cohesion: The internal bonding between particles.
- Frictional resistance: Resistance between particles when they try to move past each other.

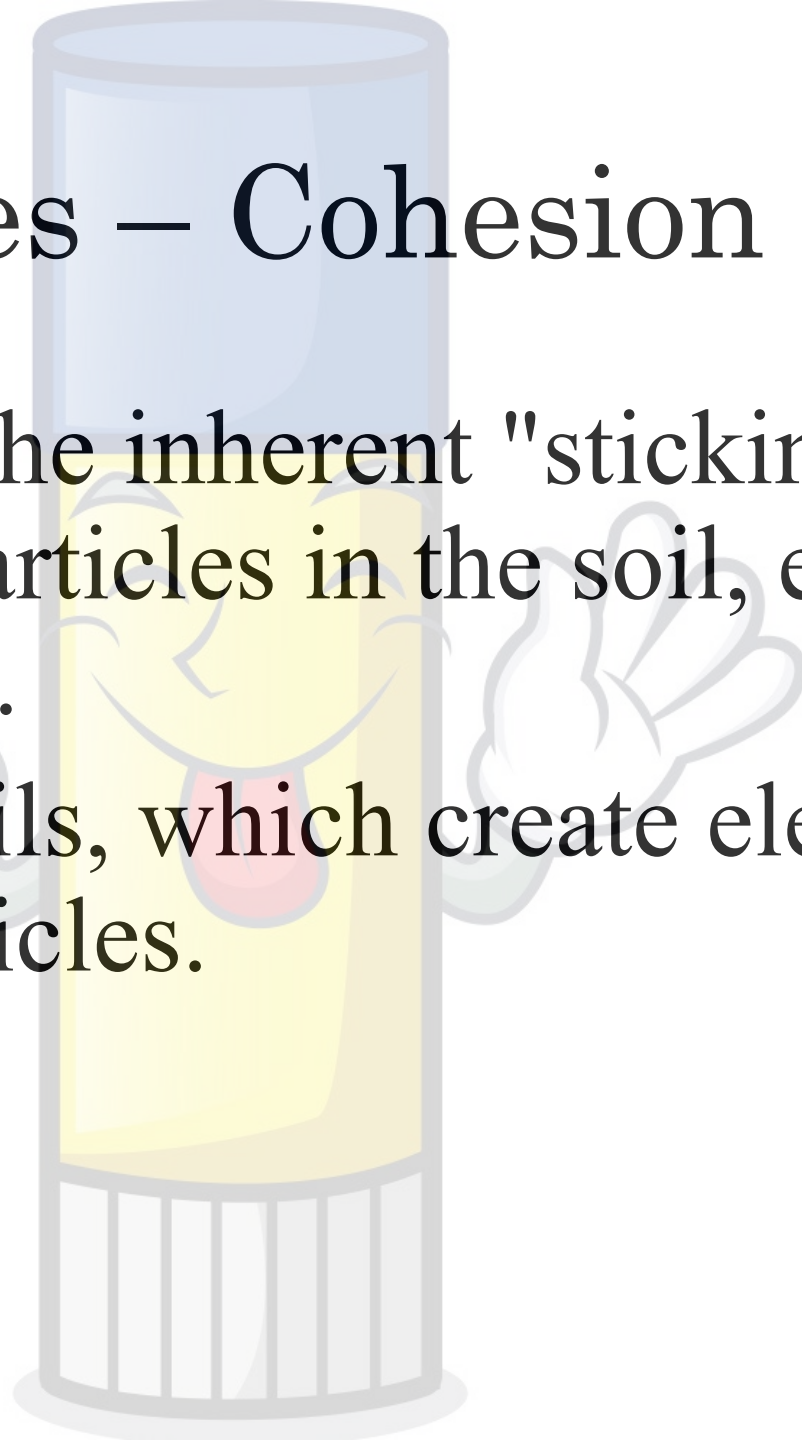
Resisting Forces – Cohesion

- Cohesion refers to the inherent "stickiness" or bonding between particles in the soil, especially in clay or silty soils.



Resisting Forces – Cohesion

- Cohesion refers to the inherent "stickiness" or bonding between particles in the soil, especially in clay or silty soils.
- Clay minerals in soils, which create electrostatic bonds between particles.

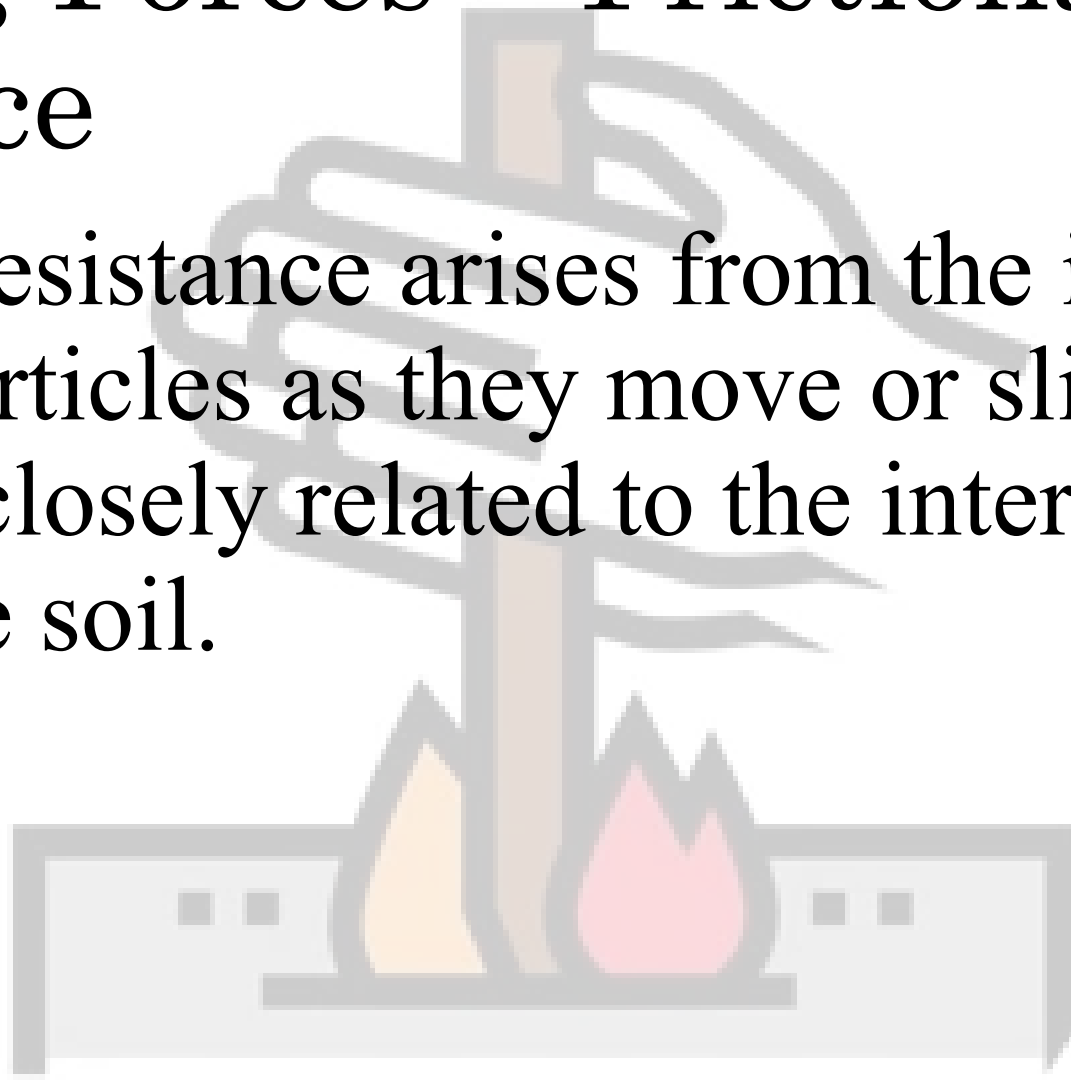


Resisting Forces – Cohesion

- Cohesion refers to the inherent "stickiness" or bonding between particles in the soil, especially in clay or silty soils.
- Clay minerals in soils, which create electrostatic bonds between particles.
- Cementation in soils or rocks, where mineral deposits (like calcite or silica) naturally bond particles together.

Resisting Forces – Frictional Resistance

- Frictional resistance arises from the interaction between particles as they move or slide past each other. It is closely related to the internal friction angle of the soil.



Resisting Forces – Normal Stress

- Normal stress is the stress exerted perpendicular to the slope surface, primarily due to the weight of the material above.

Resisting Forces

- Negative Pore Water Pressure

Resisting Forces

- Negative Pore Water Pressure
- Vegetation and Root Reinforcement

Resisting Forces

- Negative Pore Water Pressure
- Vegetation and Root Reinforcement
- Man-made Structures

Resisting Forces

- Negative Pore Water Pressure
- Vegetation and Root Reinforcement
- Man-made Structures
- Groundwater and Drainage Control

Angle of Repose

- The steepest angle at which rock and soil material is stable and will not move downslope is called the angle of repose.



Angle of Repose

- The angle of repose is measured relative from the horizontal.



Angle of Repose

- When a slope is at the angle of repose, the shear force is in equilibrium with the normal force.

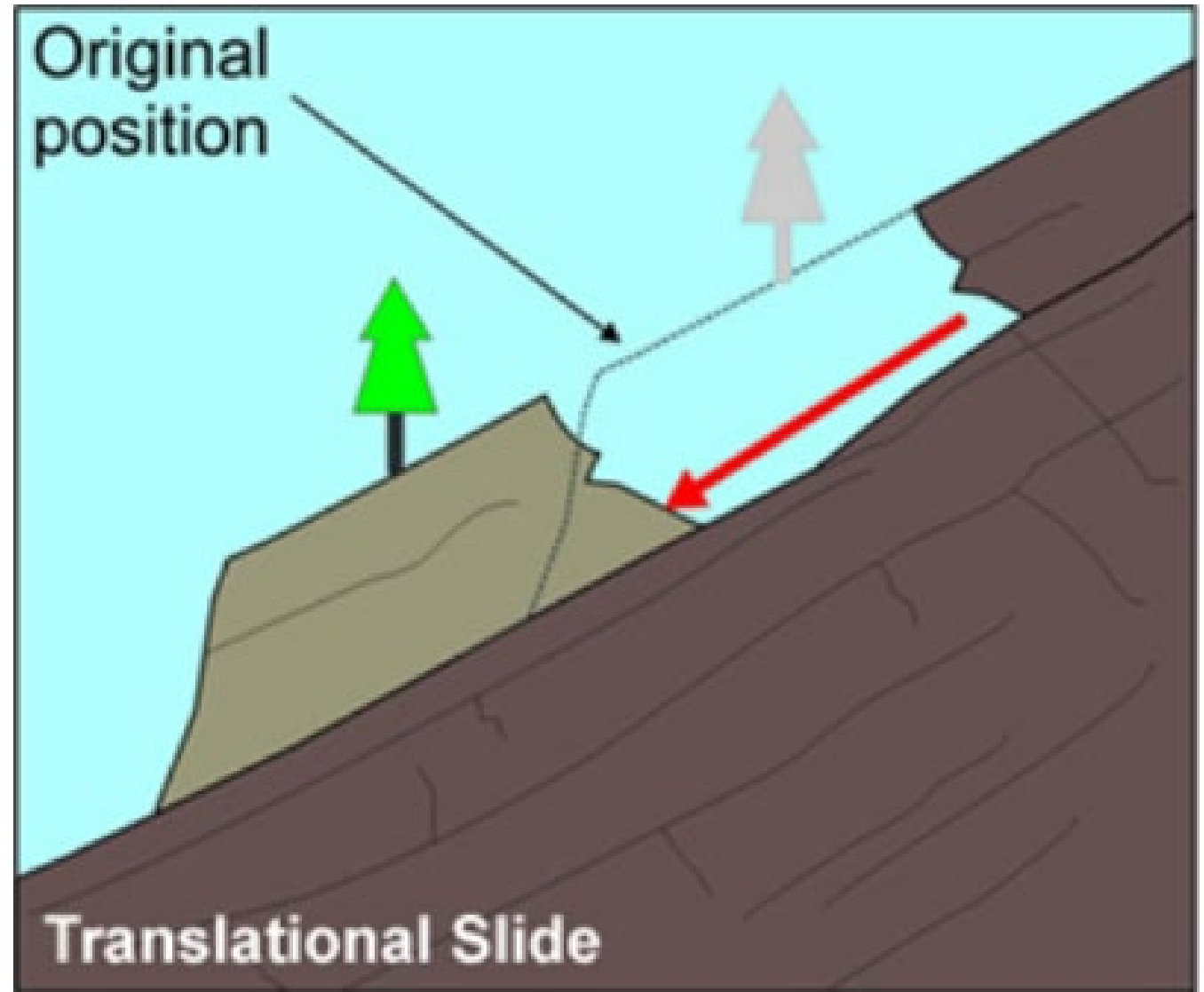


Angle of Repose



Types of Slope Failure – Plane / Translational

- Occurs when a block of material slides down a slope along a relatively flat, inclined surface.



Types of Slope Failure – Plane / Translational

- The failure plane is approximately parallel to the slope surface.

Types of Slope Failure – Plane / Translational

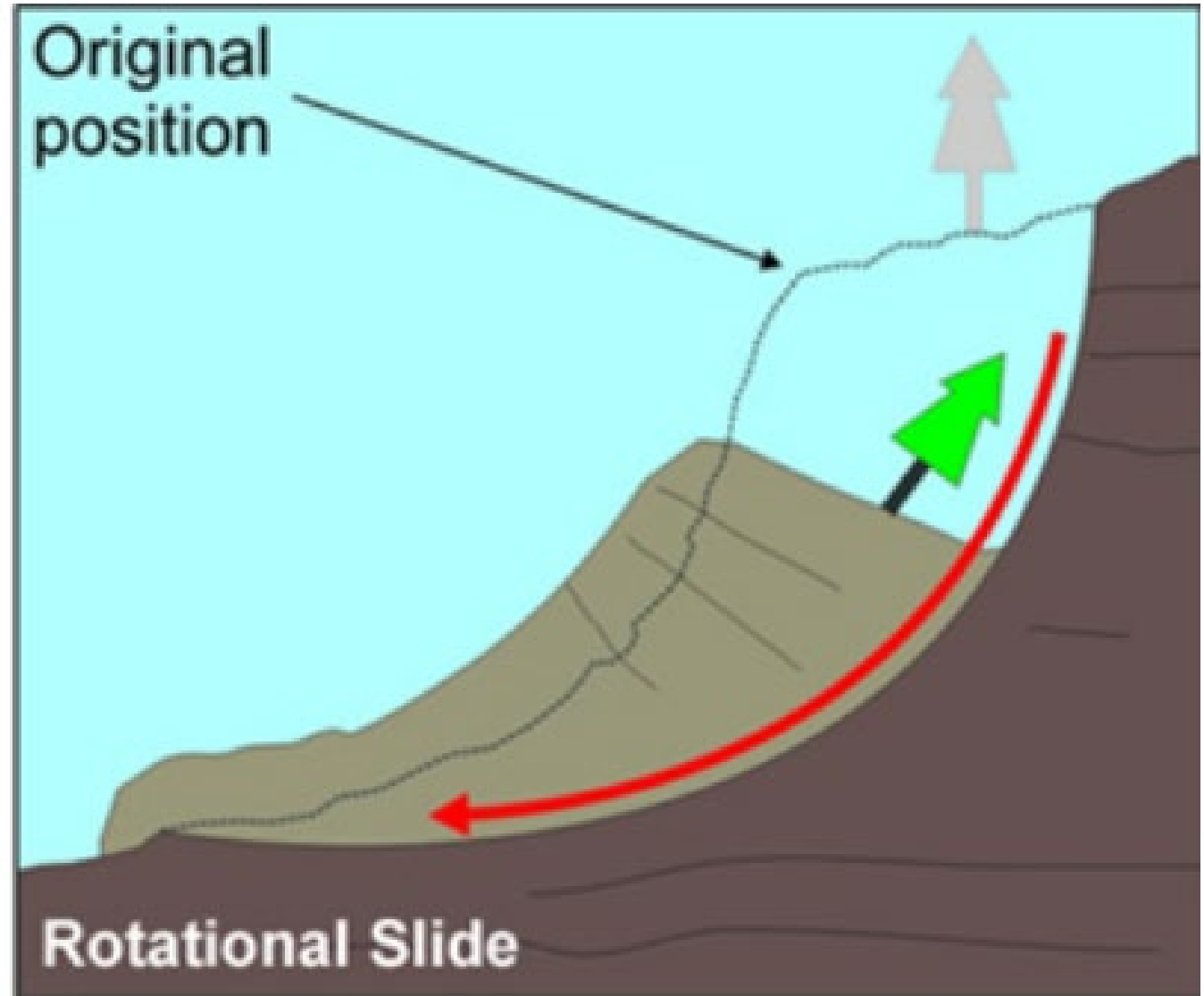
- The failure plane is approximately parallel to the slope surface.
- The sliding occurs in a straight line with little to no rotation or deformation of the material.

Types of Slope Failure – Plane / Translational

- The failure plane is approximately parallel to the slope surface.
- The sliding occurs in a straight line with little to no rotation or deformation of the material.
- Common in rock slopes where there is a distinct weak layer with lower shear strength, often found in sedimentary rocks with bedding planes, or in slopes with pre-existing fractures.

Types of Slope Failure – Rotational

- Rotational failure involves the movement of soil or rock along a curved, concave failure surface.



Types of Slope Failure – Rotational

- The failure surface is curved, typically forming a circular or near-circular arc.

Types of Slope Failure – Rotational

- The failure surface is curved, typically forming a circular or near-circular arc.
- The failure mass rotates and moves downward, often resulting in a bulging toe at the base and a concave depression at the top.

Types of Slope Failure – Rotational

- The failure surface is curved, typically forming a circular or near-circular arc.
- The failure mass rotates and moves downward, often resulting in a bulging toe at the base and a concave depression at the top.
- Common in homogeneous slopes, embankments, and cohesive soils like clay.

Next Week

SLOPE ANALYSIS