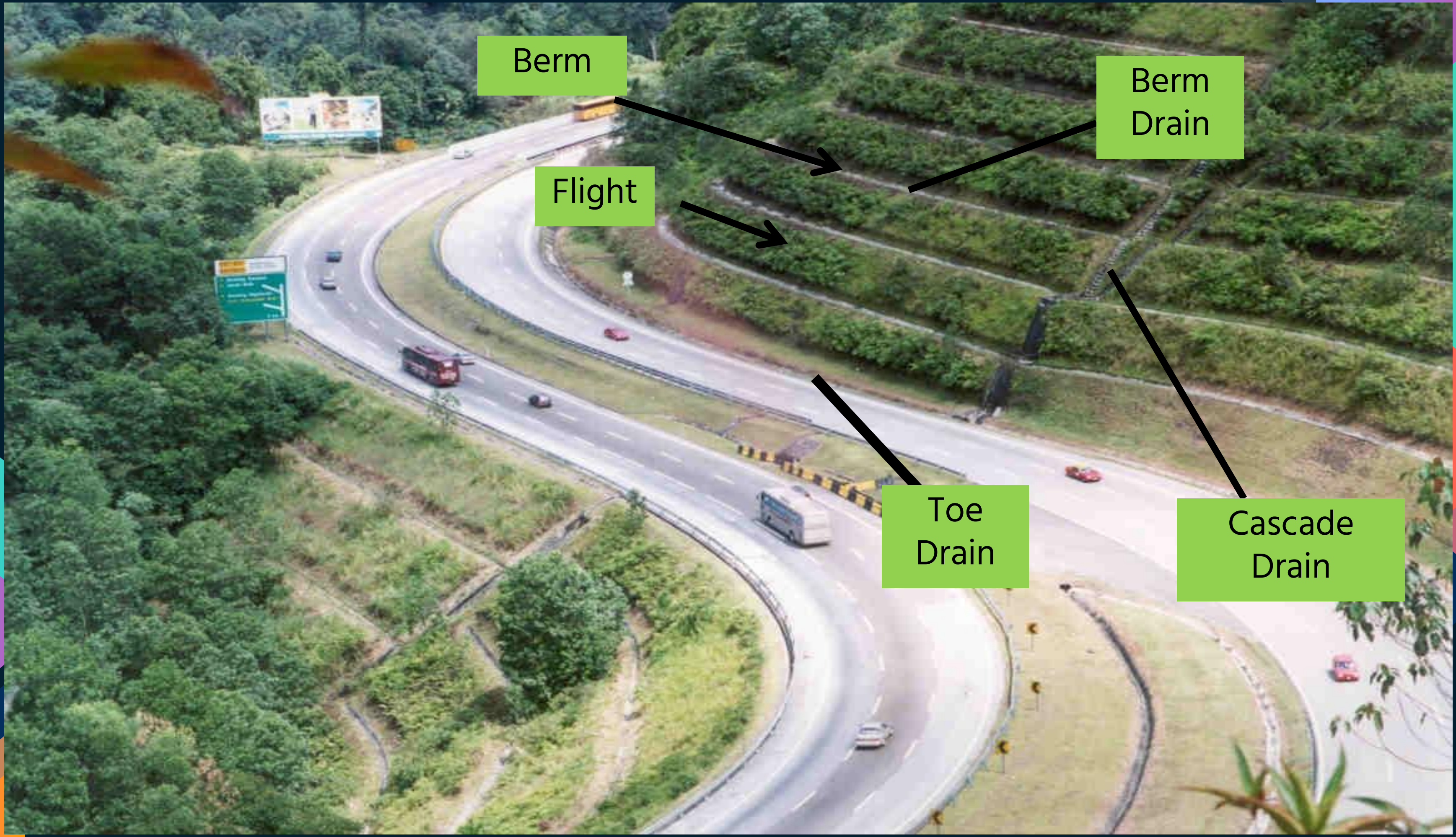
INTRODUCTION TO SLOPE

DATE : 16 MAC 2020
VENUE : CREATE, MELAKA
PRESENTER : IR NOR'AISHAH BINTI MD ALI

PRESENTATION OUTLINES

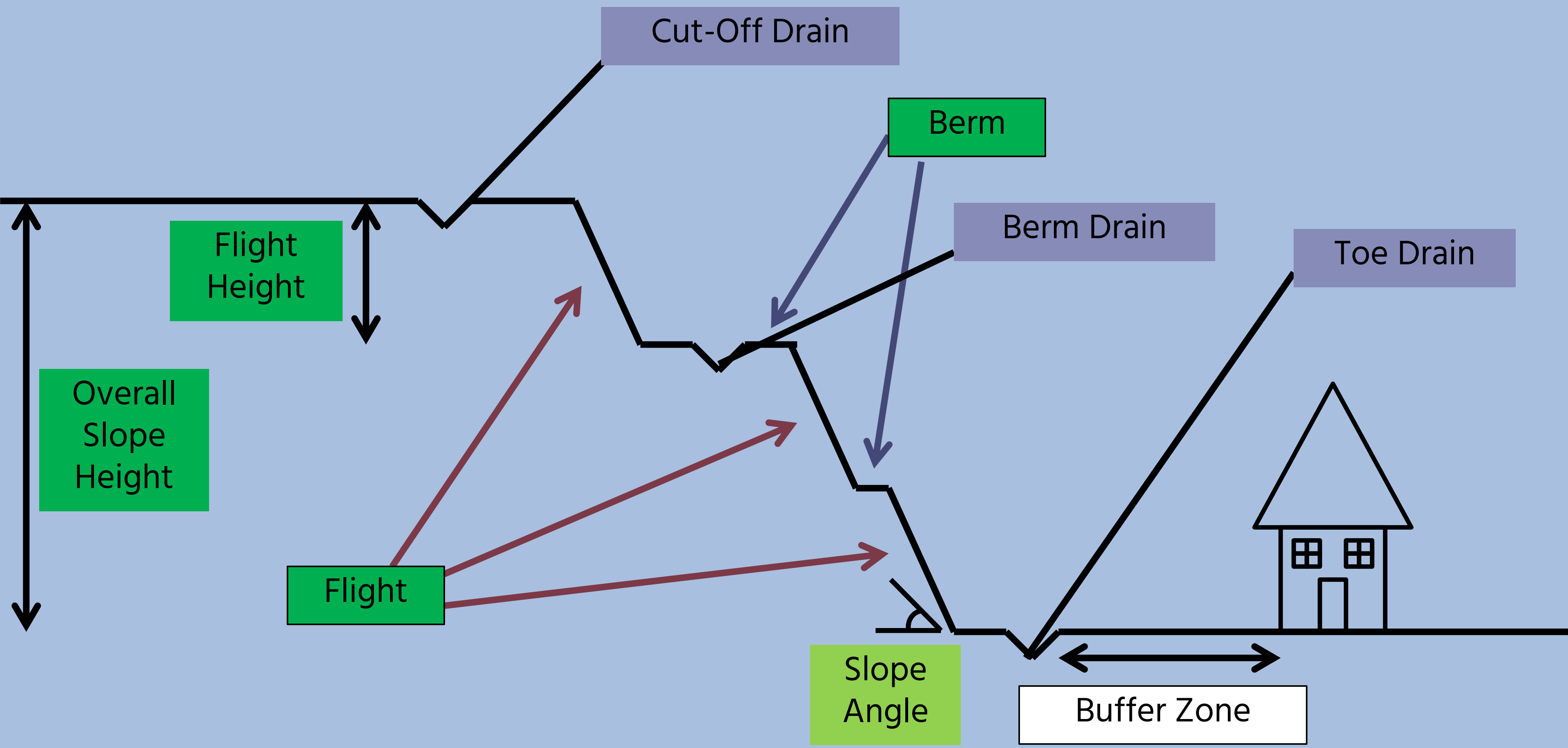
- SLOPE TERMINOLOGY
- TYPES OF SLOPE
- TYPES OF SLOPE FAILURE
- FUNDAMENTAL AND CONCEPT OF SLOPE STABILITY
- IMPORTANT FACTOR OF SLOPE STABILITY
- SLOPE ANALYSIS
- FACTOR OF SLOPE INSTABILITY

SLOPE TERMINOLOGY



SLOPE TERMINOLOGY

Berm, Flight, Drainage, Buffer Zone and Height



TYPES OF SLOPE

NATURAL ROCK SLOPES

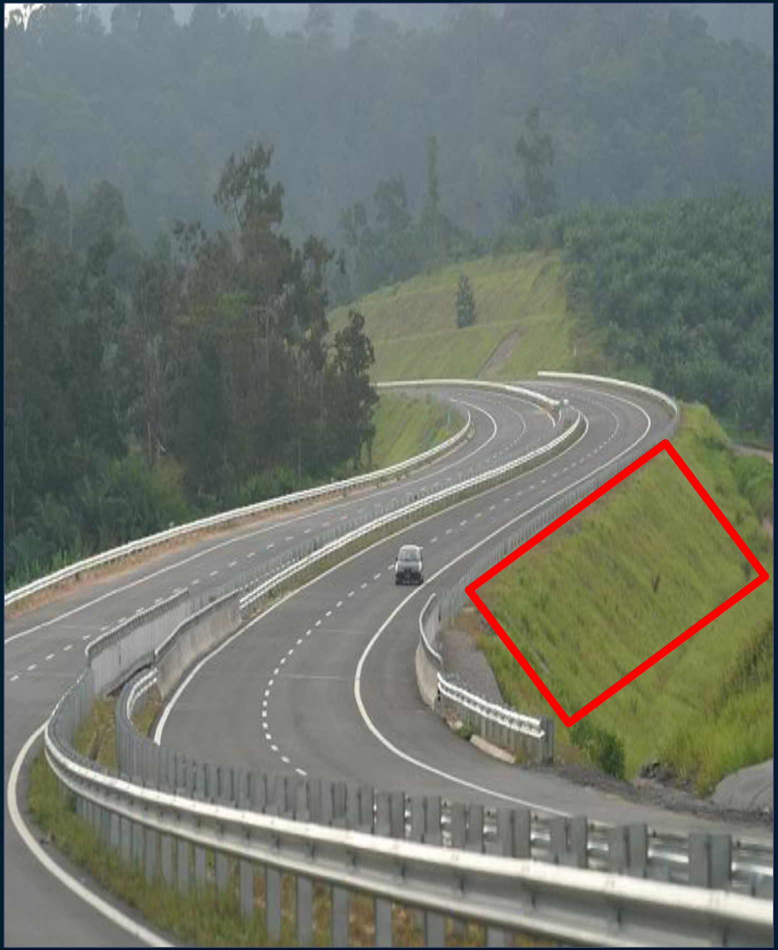
MAN-MADE

- **EMBANKMENT**
- **CUT SLOPE**
- **FILL SLOPE**

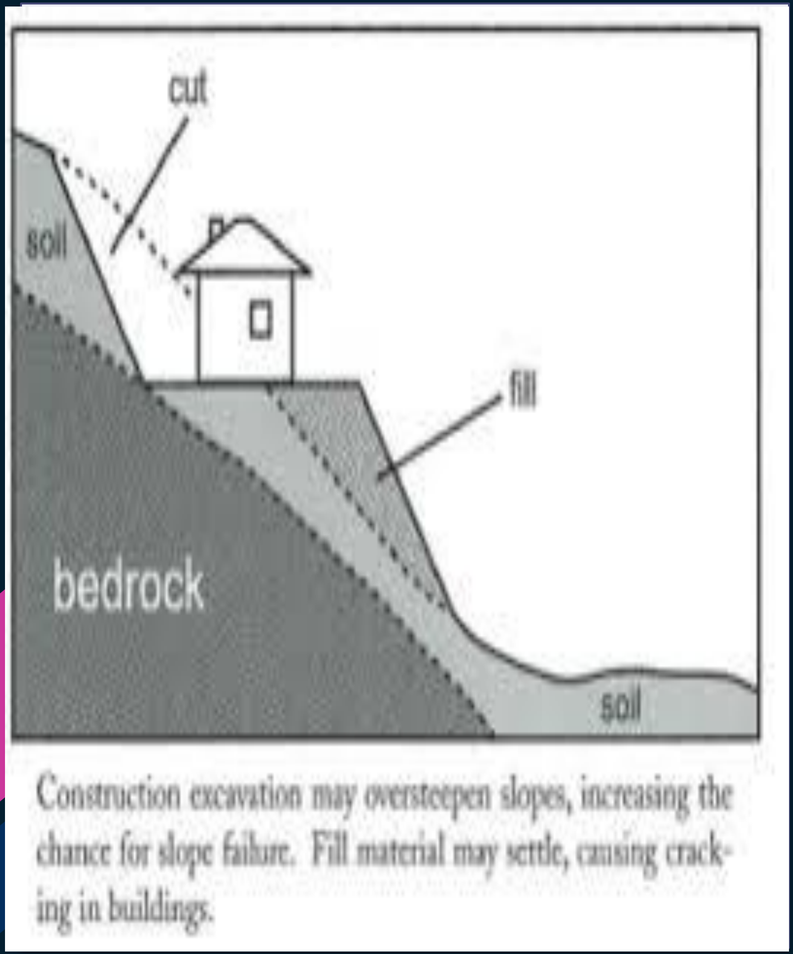
ROCK SLOPE

NATURAL SLOPE

EMBANKMENT



CUT AND FILL SLOPE




Perak

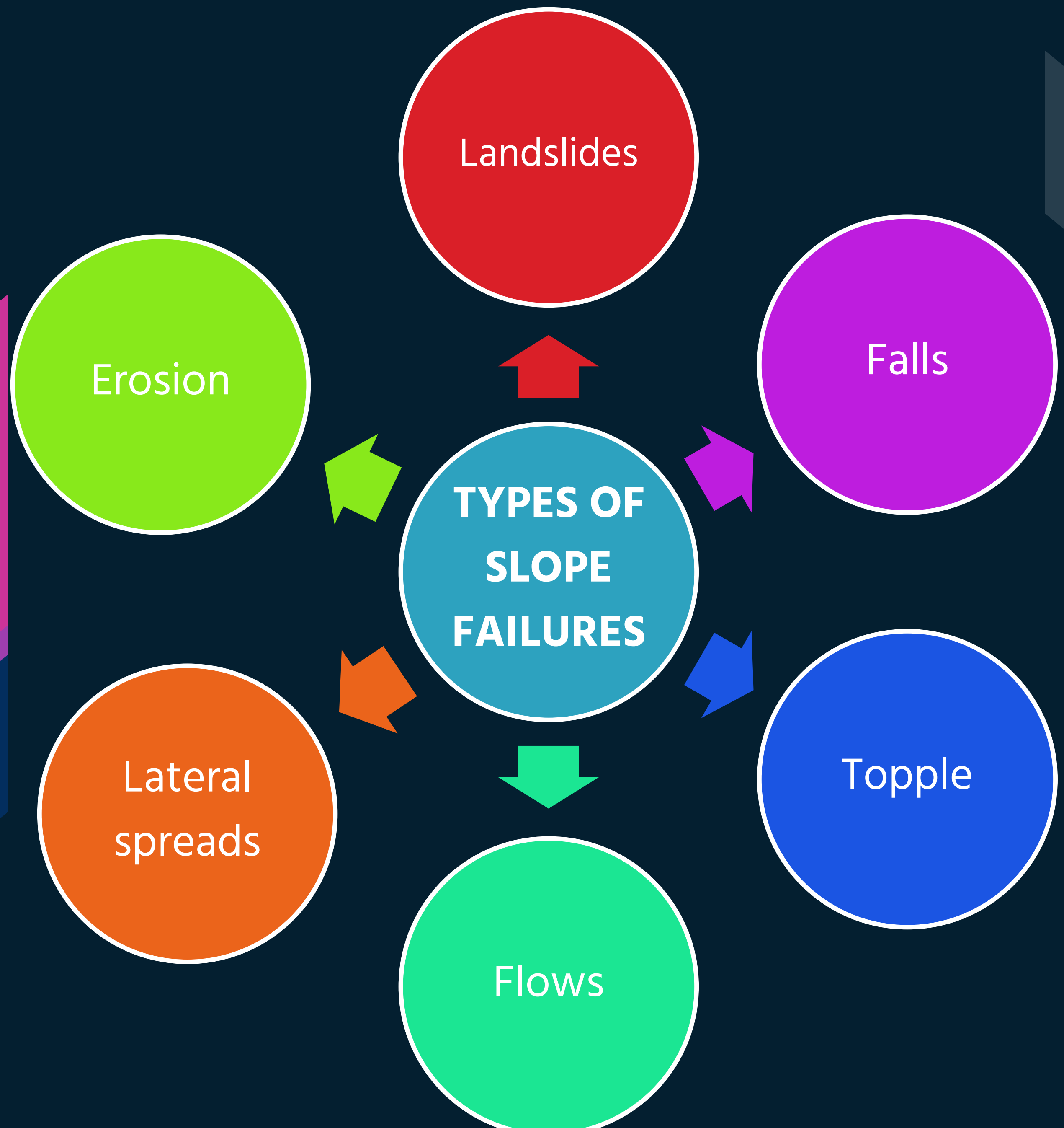

Karak Highway


Bentong-Gombak

SLOPE FAILURES IN MALAYSIA


Kundasang,Sabah


Kenyir,Terengganu


TYPES OF SLOPE FAILURES
Landslides
Falls
Topple
Flows
Lateral spreads
Erosion

LANDSLIDES

The movement of a mass of rock, debris or earth flowing down a slope

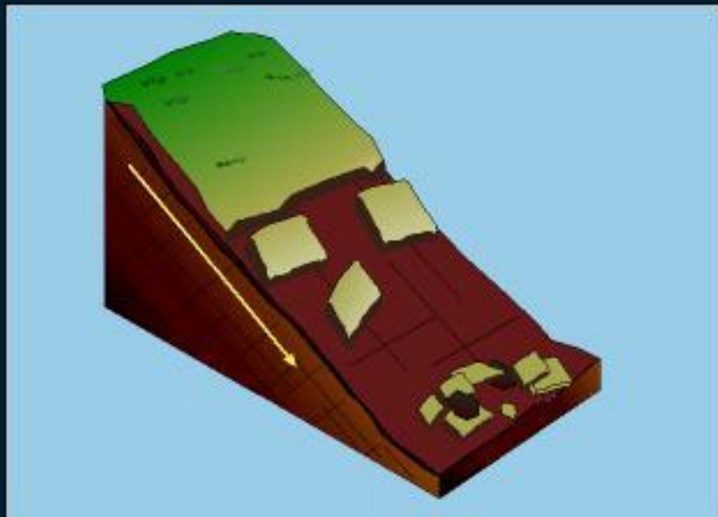
(Cruden 1991)

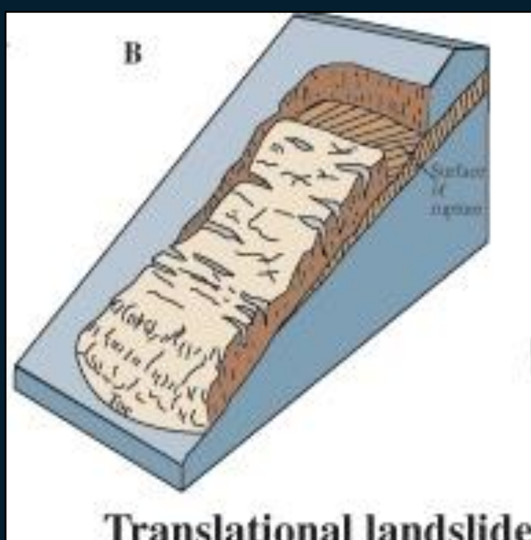
There are TWO types of landslide movement:

1. TRANSLATIONAL landslide

2. ROTATIONAL landslide

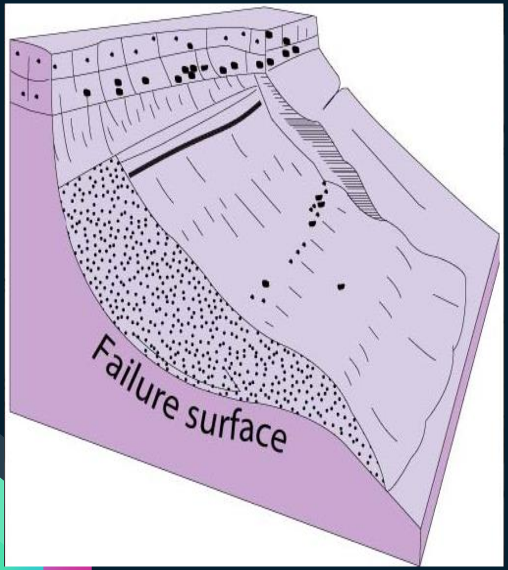
TRANSLATIONAL SLIDE



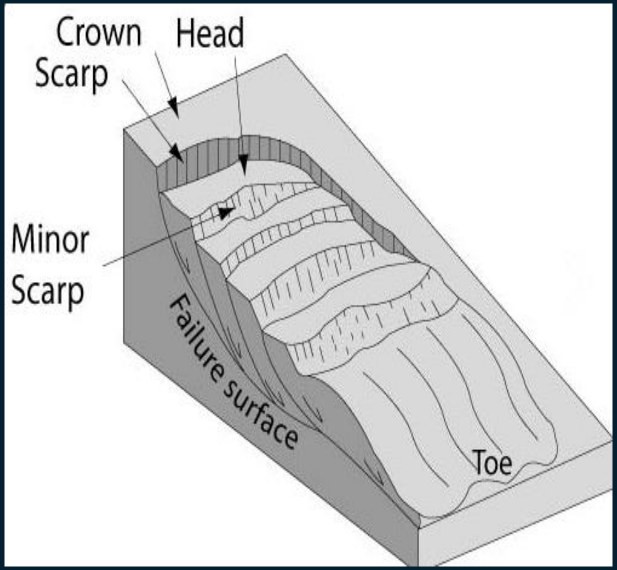


The material displaces along a planar surface, sliding out over the original ground surface.

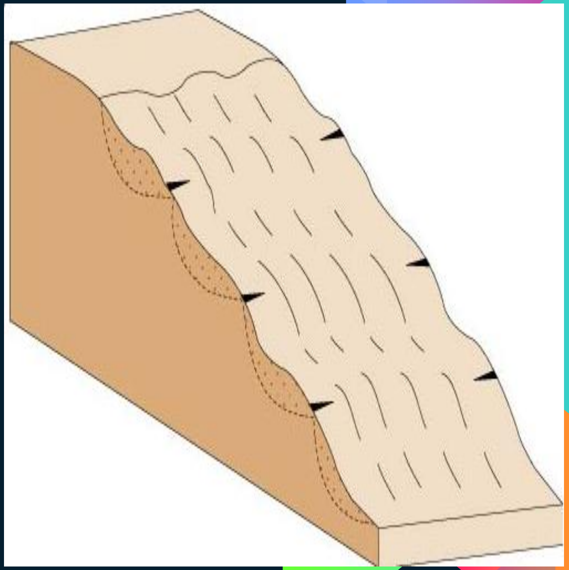
ROTATIONAL SLIDE



Single Rotational Landslide



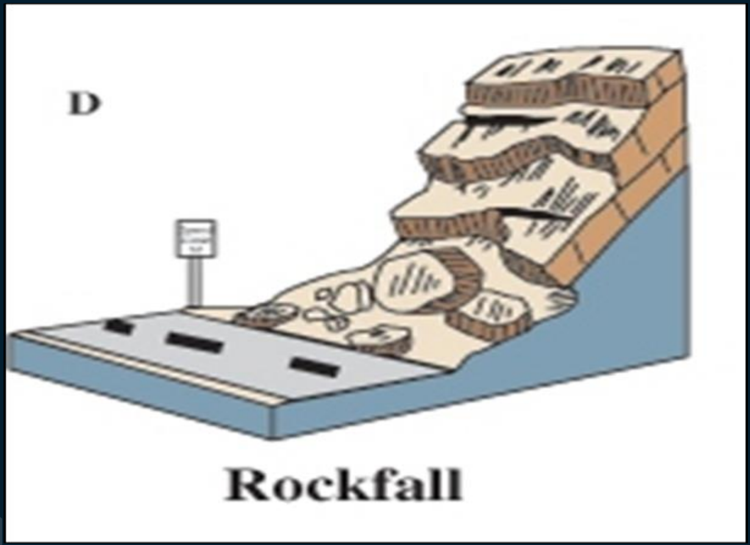
Multiple Rotational Landslide



Successive Rotational Landslide

Rotational movement, about an axis that is parallel to the slope contours

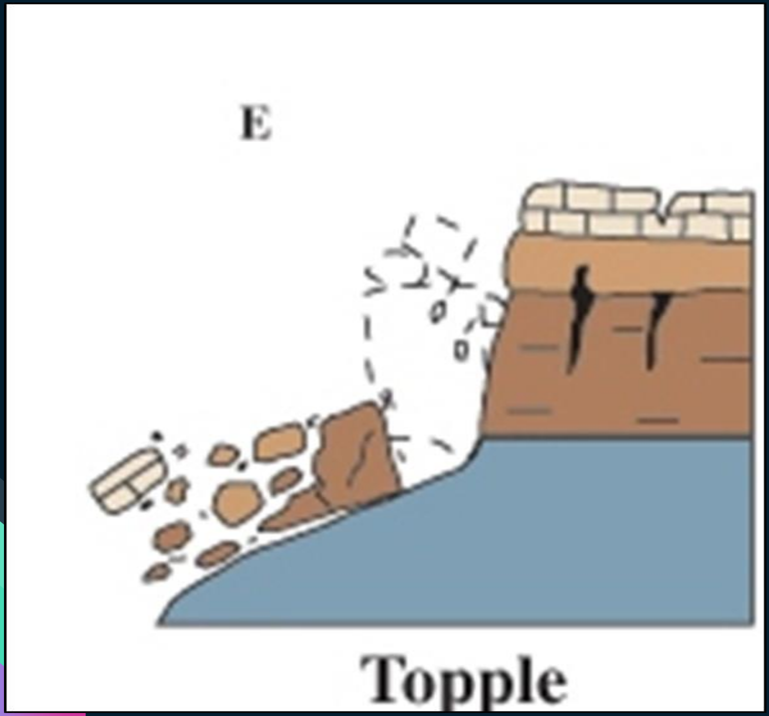
ROCK FALLS



Rockfall at Bukit Lanjan 28th November 2003

A fall starts with the detachment of material from a steep slope

ROCK TOPPLE



A slope movement that occurs due to forces that cause an over- turning moment about a pivot point below the center of gravity of the slope.

FLOWS

Downslope movement of unconsolidated material. Particles move around and mix with the mass.

There are few types of flows such as:

1. CREEP

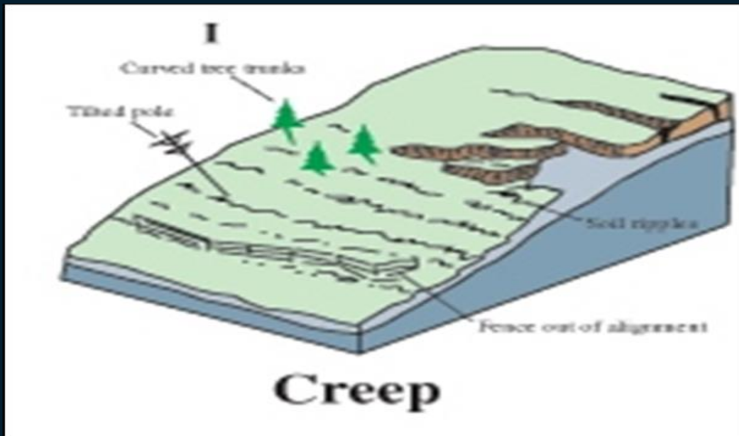
2. EARTHFLOW

3. MUDFLOW

4. DEBRIS FLOW

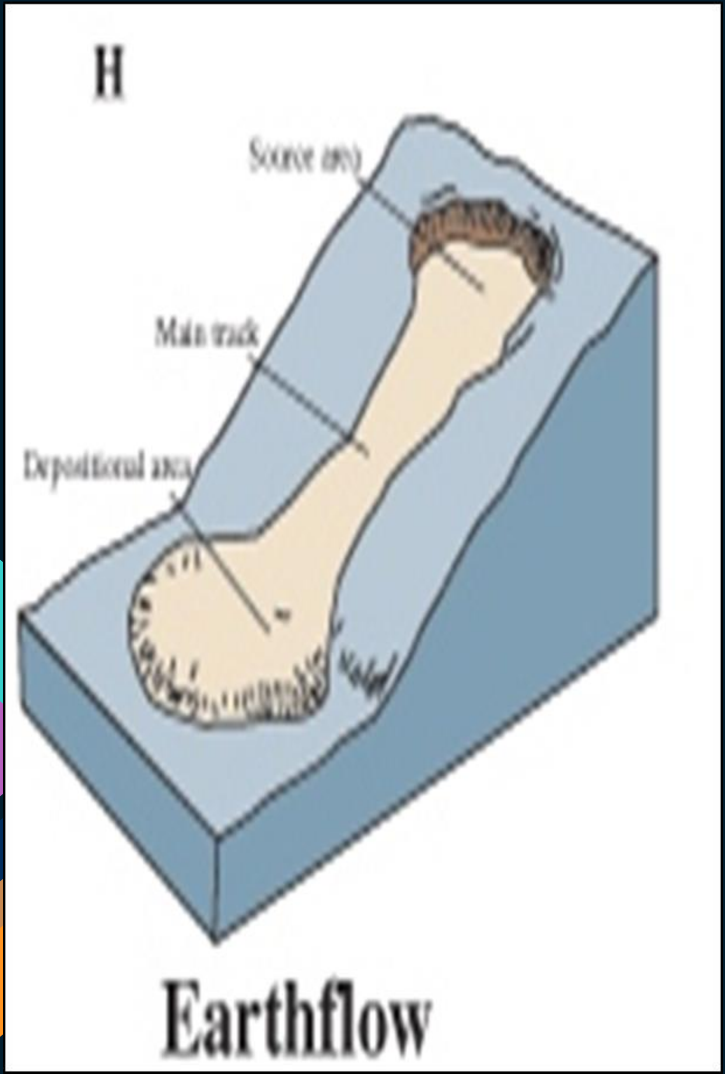
5. DEBRIS AVALANCHE

CREEP



A group of trees on a slope where the base of each tree bows outward in the downslope direction

EARTHFLOW



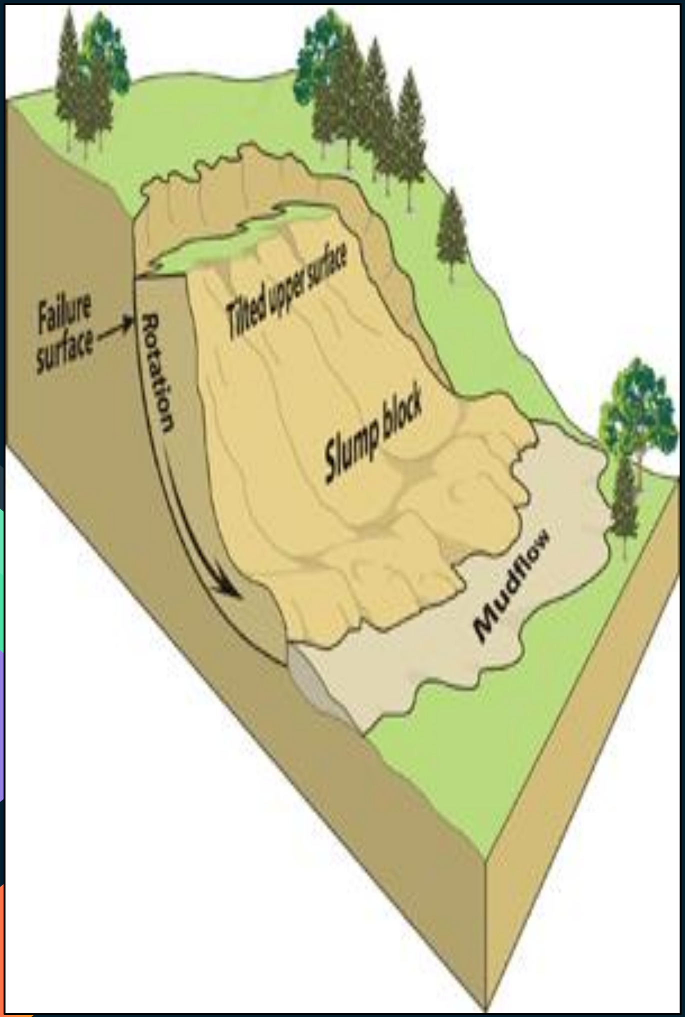
Earthflow video at Quebec,Canada

CHARACTERISTIC:

a. Moderate-to-slope.

b. Movement may be slow-to-rapid.

MUDFLOW



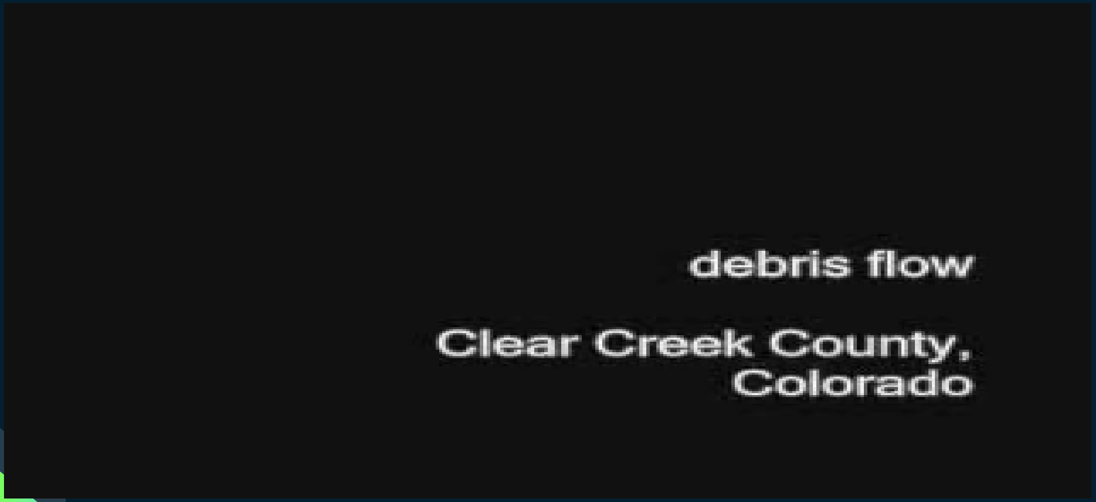
CHARACTERISTIC:

a. Occur on moderate-to-steep slopes.

b. Typically flows down slopes or follows drainage channels

c. Movement is generally rapid

DEBRIS FLOW



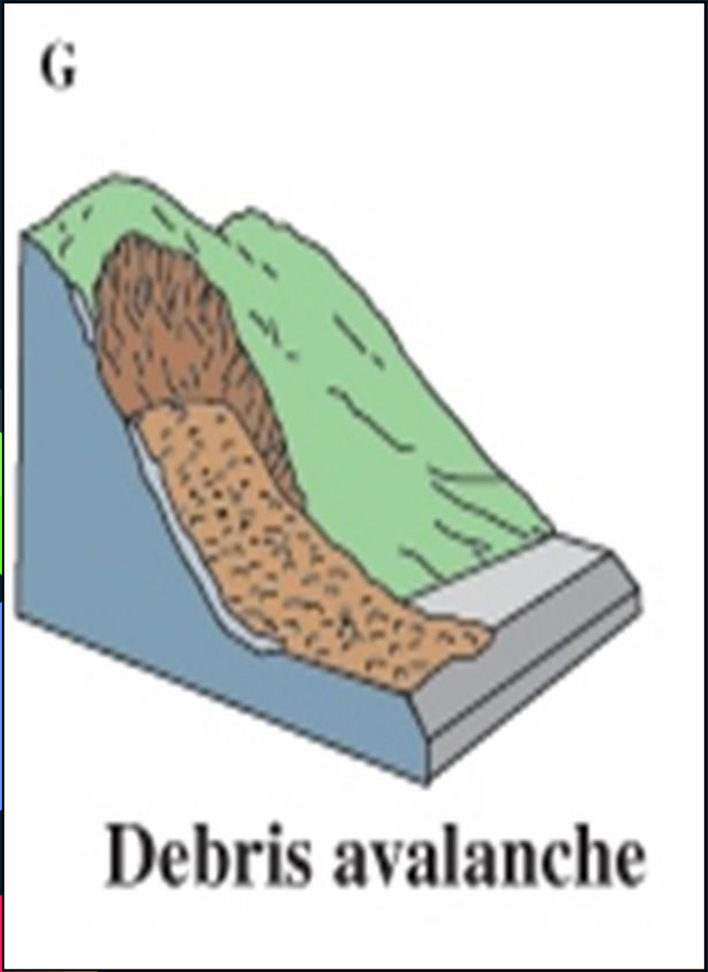
CHARACTERISTIC:

a. Movement very slow to very rapid.

b. Consists of coarse material (more than 50% is sand-sized particles or larger).

c. Often follows drainage systems downslope.

DEBRIS AVALANCHE



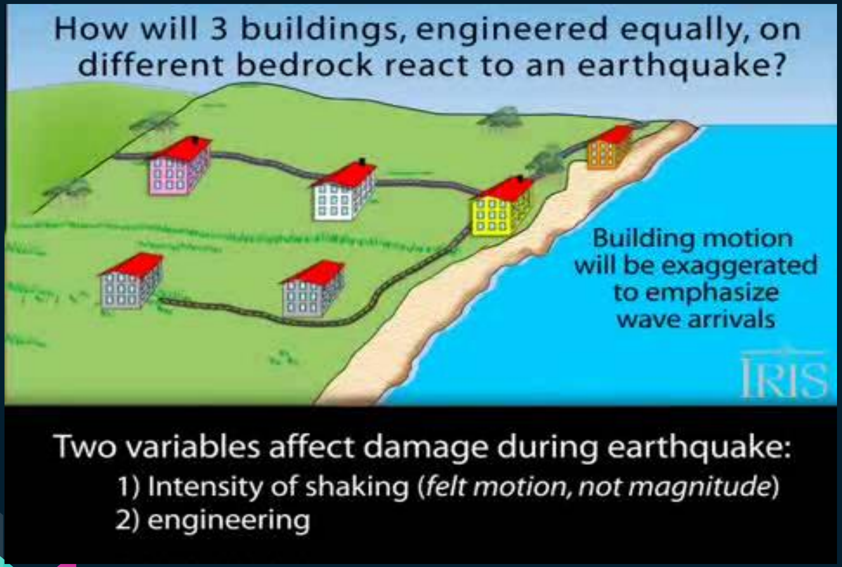
CHARACTERISTIC:

a. Occur on very steep slopes.

b. Movement a combination of fall, flow, and slide.

c. Material consists of a mixture of rock, soil, and organic debris (trees, shrubs).

LATERAL SPREAD



CHARACTERISTIC:

1. Lateral spreads are distinctive usually occur on very gentle slopes or flat terrain.

2.Usually caused by earthquakes

SLOPE EROSION


Slope Erosion
Water Erosion
Sheet Erosion
Rill Erosion
Ephemeral Erosion
Gully Erosion
Stream-Bank Erosion
Wind Erosion
Creep
Saltation
Suspension

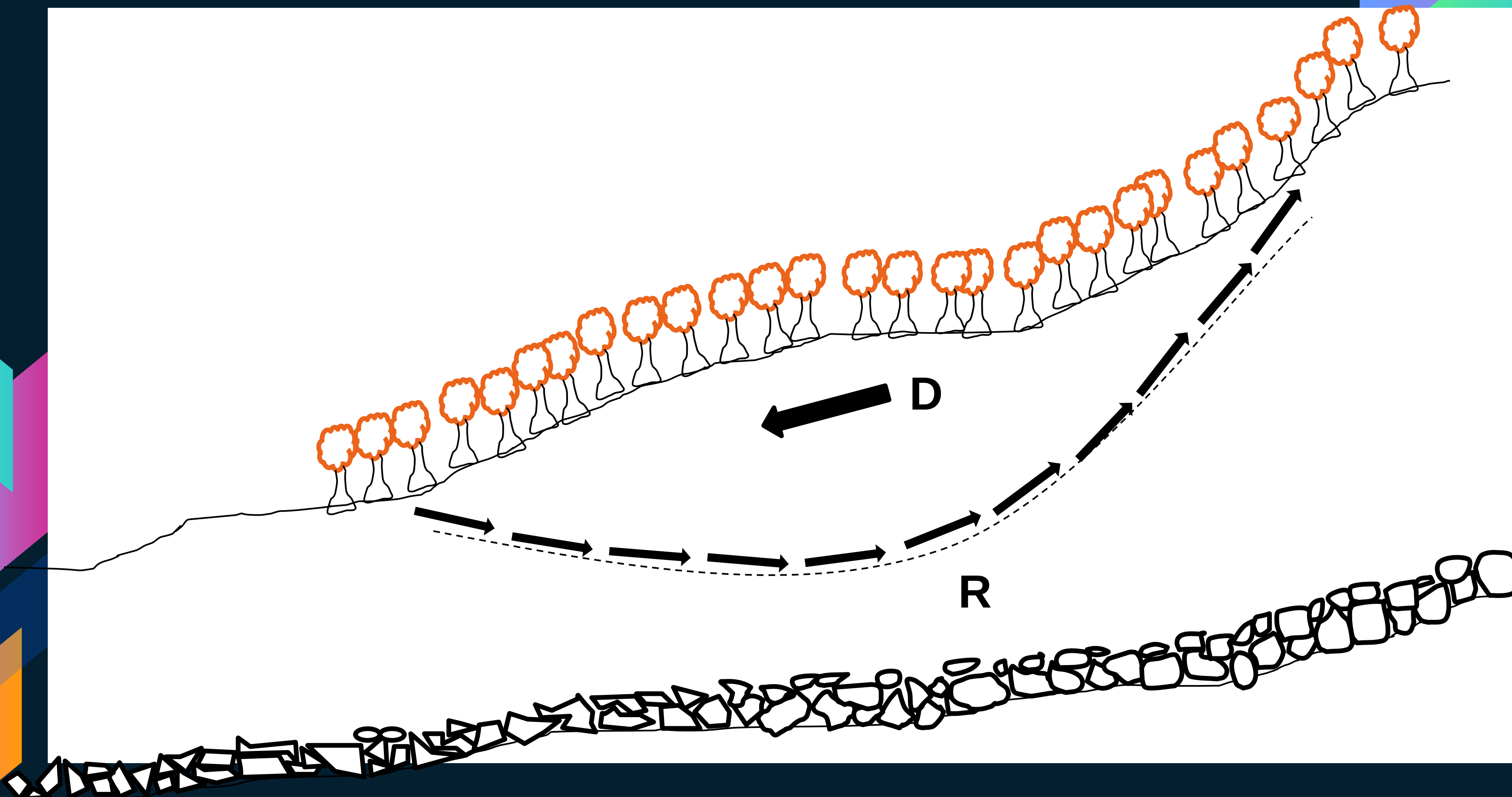
WIND EROSION VIDEO

WATER EROSION VIDEO

FUNDAMENTAL AND CONCEPT OF SLOPE STABILITY

What is the factor of Slope Stability?

Slope stability is based on the interplay between two types of forces , driving and resisting forces.



SLOPE STABILITY

Factor of Safety(FOS) is equals to the ratio of resisting forces to driving forces.

$$FOS = \frac{RESISTING\ FORCE(N)}{DRIVING\ FORCE(D)}$$

If FOS > 1 then SAFE

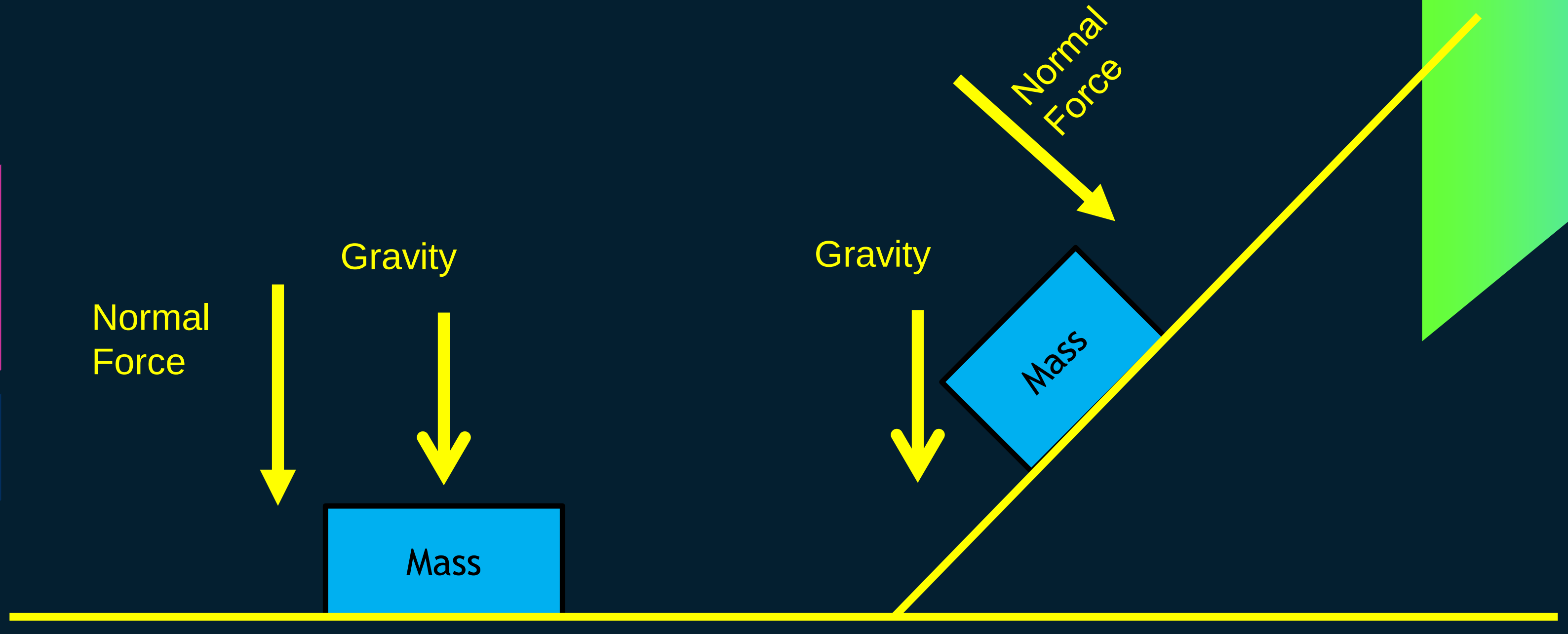
If FOS < 1 UNSAFE

(Refering to JKR Guidelines 2010 FOS> 1.3 for natural slopes, FOS >1.5 for man-made slopes)

The main driving force in most land movements is gravity

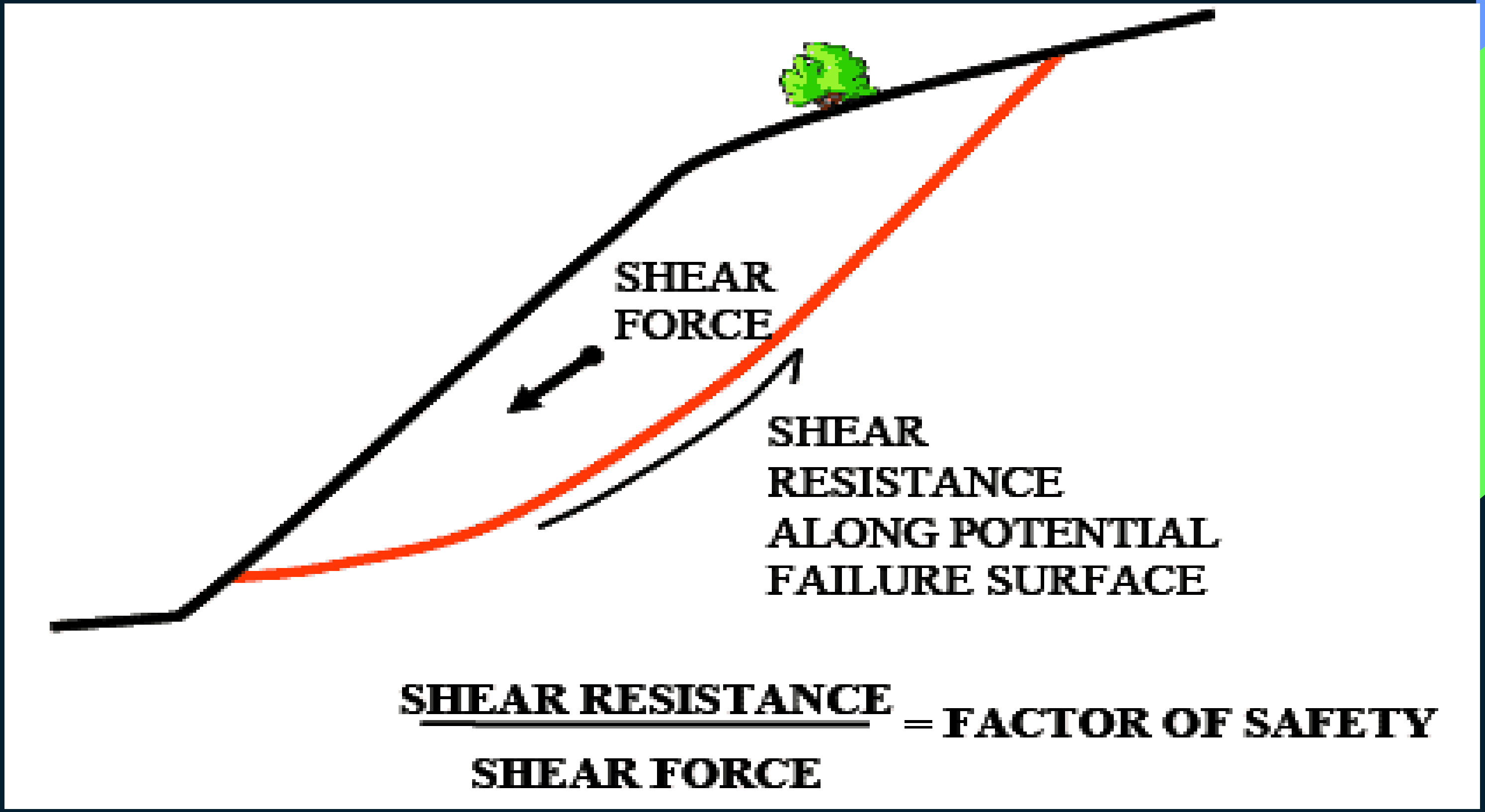
Slope angle,climate,slope material,and water contribute to the effect of gravity

Driving forces promote downslope movement of material



The main resisting force is the material's shear strength

Resisting forces deter movement

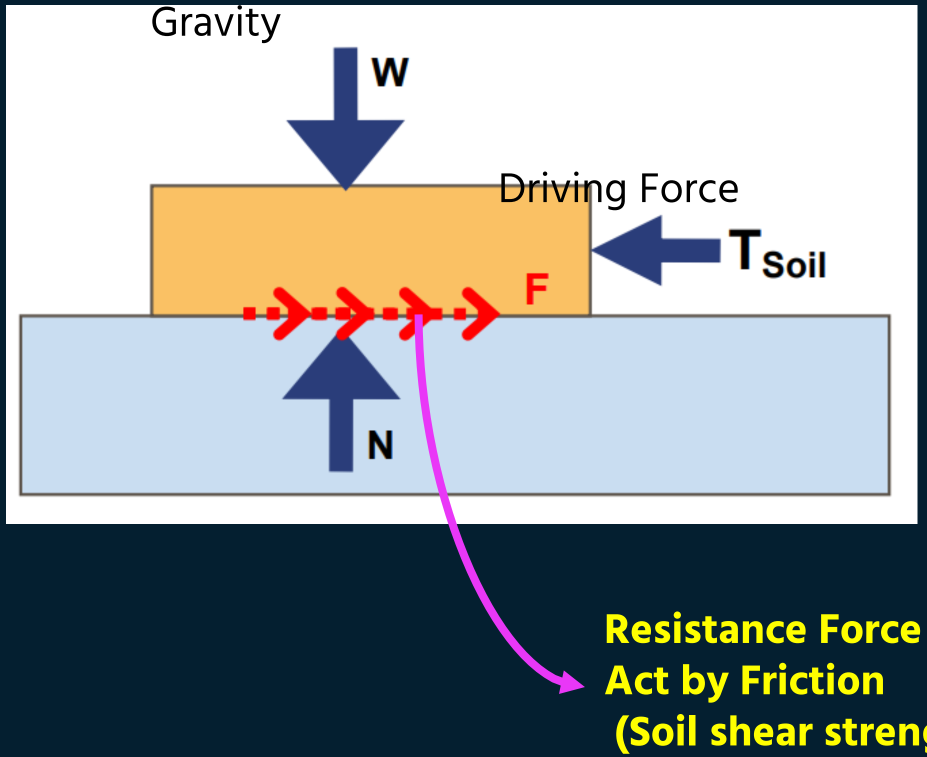


IMPORTANT SLOPE STABILITY FACTORS

1. Soil Properties

- The main properties of soil is **SHEAR STRENGTH PROPERTIES** - Soil Unit Weight (γ), Effective Cohesion (c′) and Effective Friction Angle (Ø′)

CONCEPT OF FRICTION

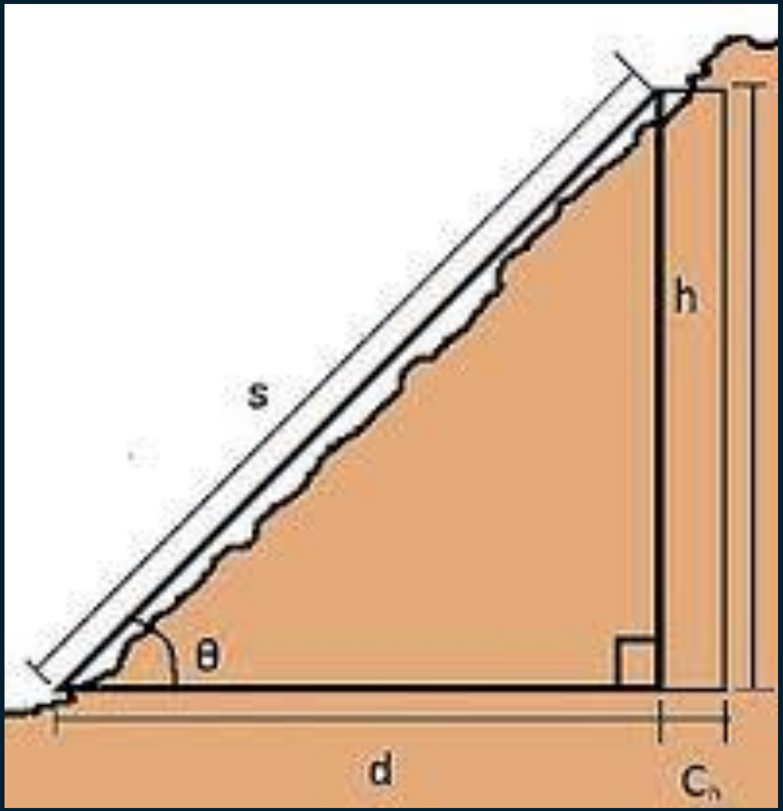


2. Geometric Factors

1. SLOPE HEIGHT

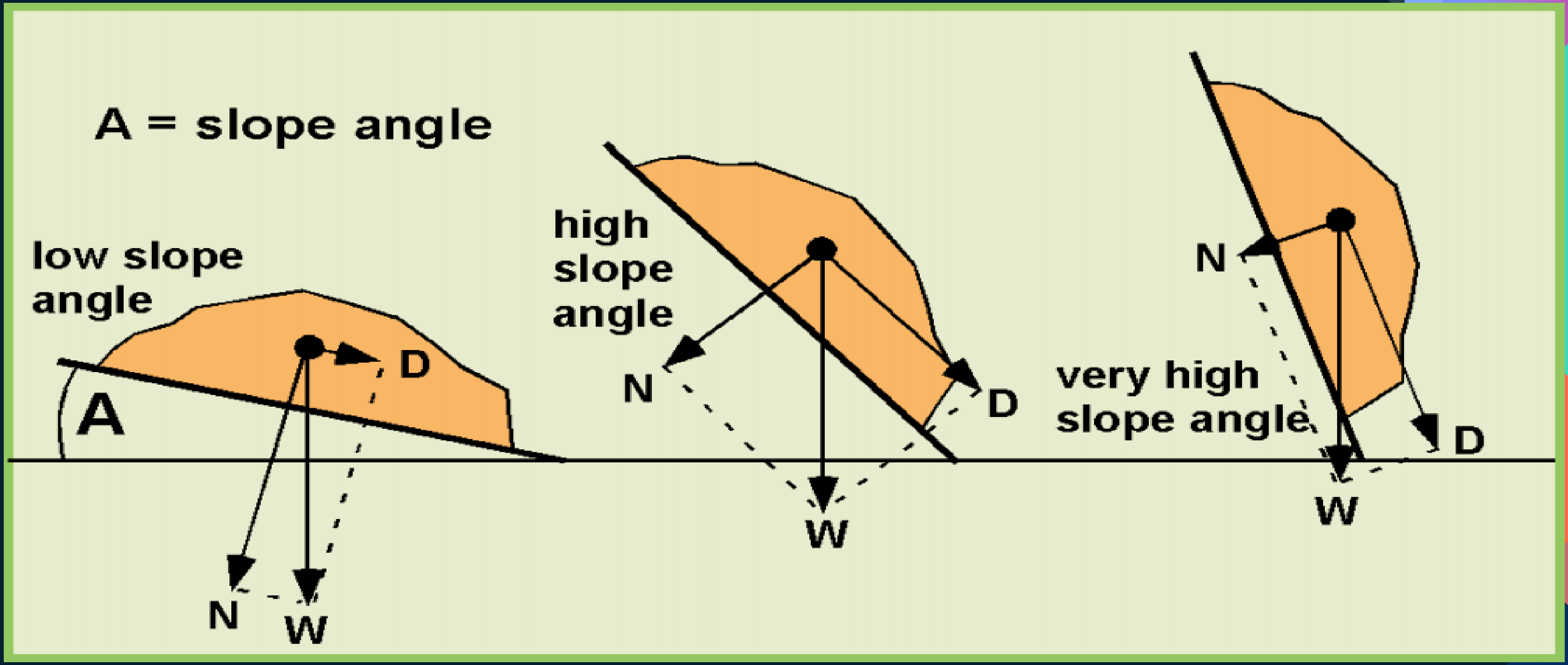
The higher the height of the slope, the greater the shear stress of the slope.

Thus, reducing the Factor of Safety of the slope.



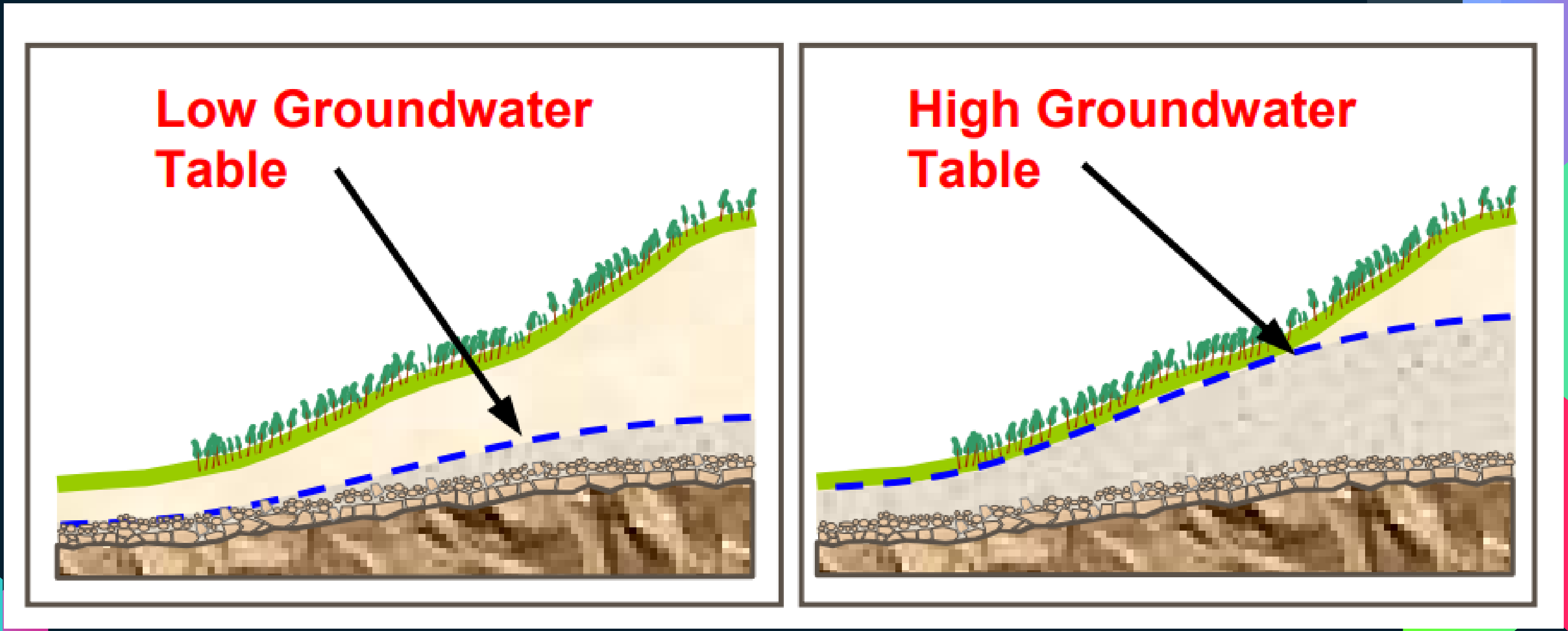
2. Geometric Factors

2. SLOPE ANGLE AND FORCES



W = Weight of total mass of earth material (at center of mass).
D = Vector component of W parallel to potential movement.
N = Vector component of W normal to slip plane.

3. Ground Water Profile



Water plays a key role in producing slope failure.

Water also increase the driving force by adding the total mass that is subjected to gravity

4. Slope Maintenance

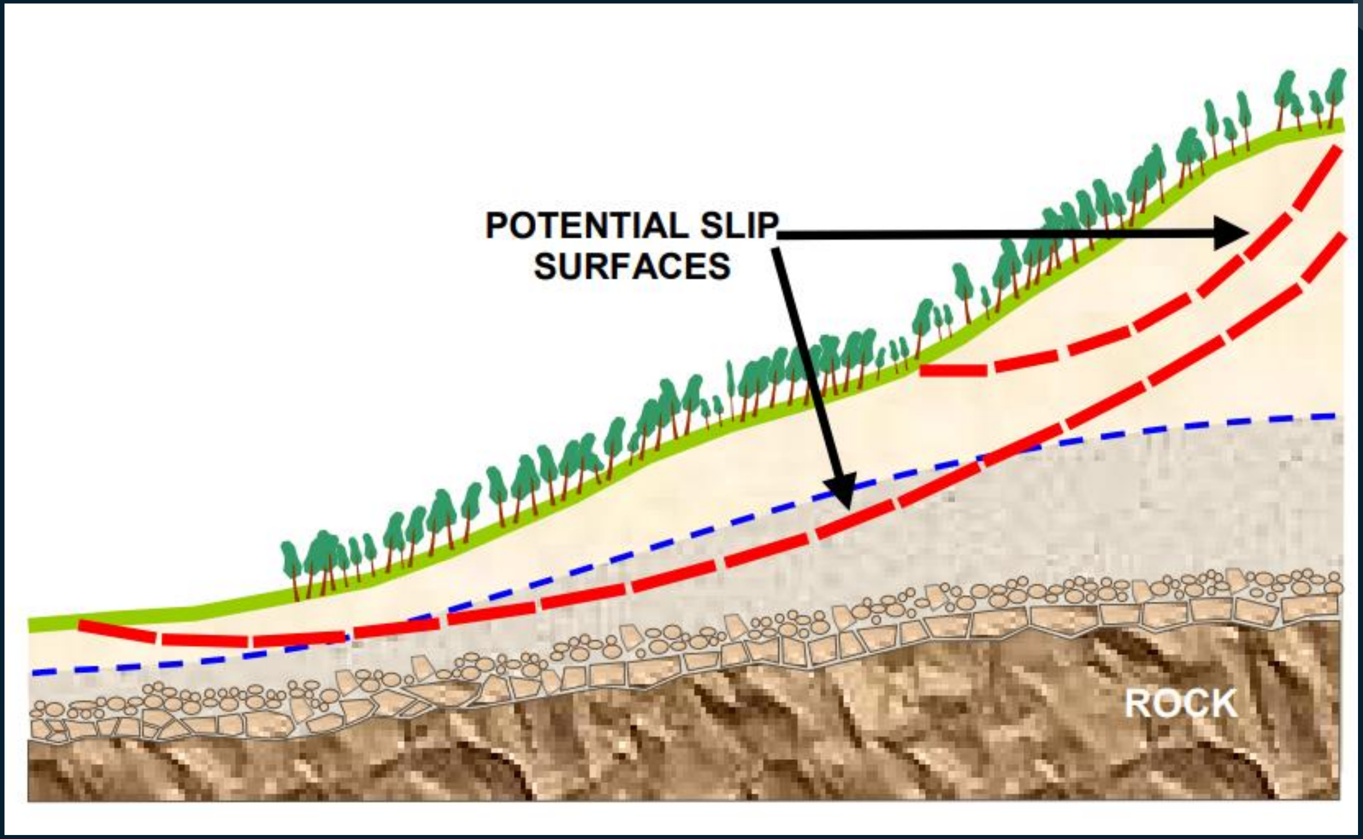
- Poor maintenance can lead to slope failure.
  - Improper drainage
  - Inadequate surface erosion control
  - Damaged/cracked drainage

5. Un-engineered Works at toe of slope

- Disturbance to the stability of slope

SLOPE ANALYSIS

Potential Slip Surface

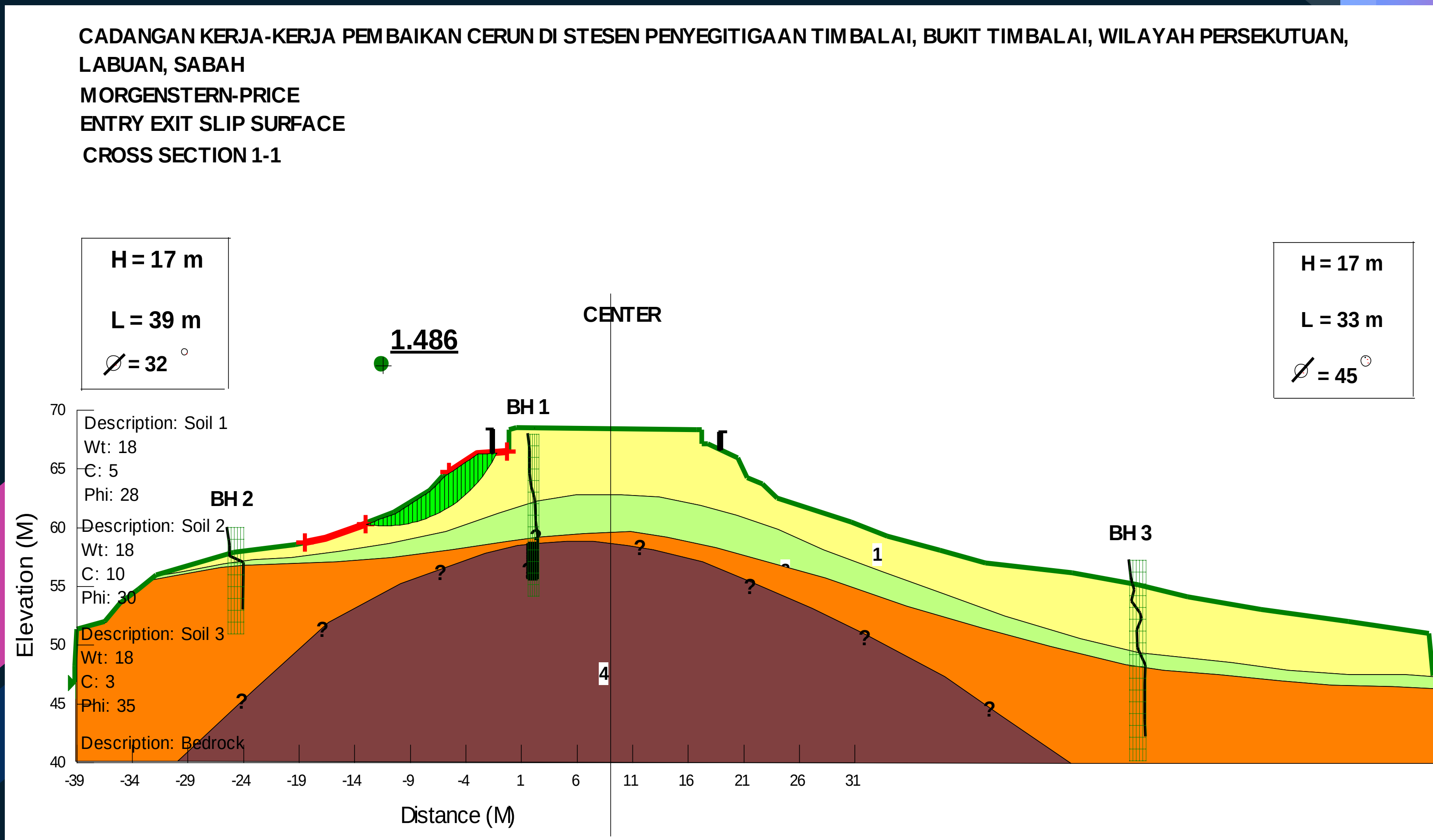


To determine whether the slope is SAFE, potential slip surfaces are to be analyzed using slope analysis in terms of Total Driving Forces and Total Driving Force.

Slope Stability Analysis

- To assess the stability of slopes under short-term (often during construction) and long-term conditions.
- To assess the possibility of slope failure involving natural or existing slopes.
- To determine the factor of safety (FOS) of slope (before failure, during failure and after remedial work applied)

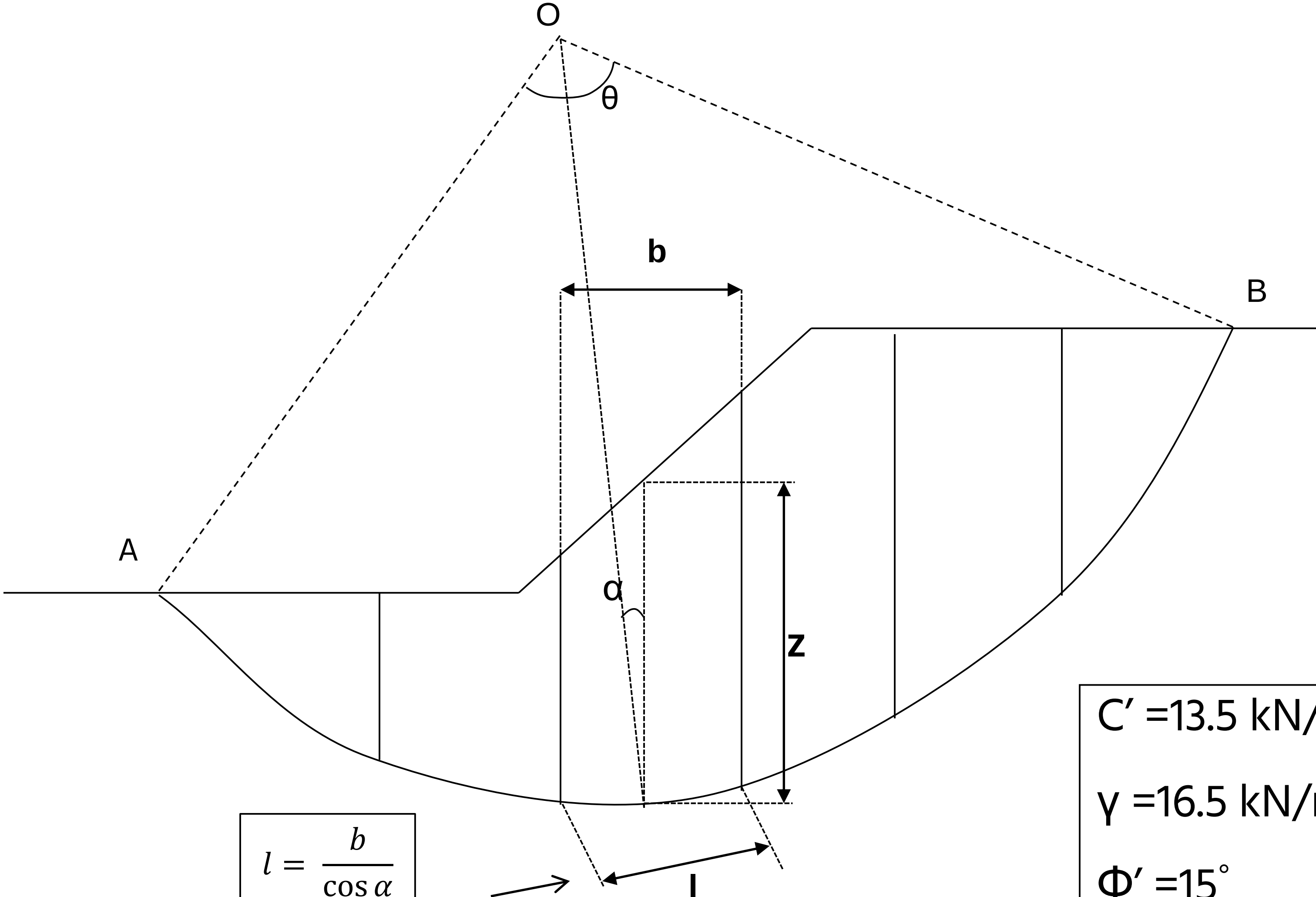
Example of Slope Stability Analysis (Using Slope-W Software)



FOS CALCULATION METHODS

- Ordinary/Fellenius Slices Method
- Simplified or Modified Bishop Methods
- Janbu Method
- Morgenstern-Price’s Method

FELLENIUS SLICES METHOD
Example Calculation



$$l = \frac{b}{\cos \alpha}$$

$C' = 13.5\ kN/m^2$

$\gamma = 16.5\ kN/m^3$

$\Phi' = 15^{\circ}$

Table Of Analysis

$$\text{F.O.S} = \frac{Resisting\ Force}{Driving\ Force} = \frac{\sum C'L + \Sigma W\ \cos\alpha \tan\Phi}{\sum W \sin\alpha}$$

Slice	α	Z (m)	b (m)	W=γbz	W Sinα	W Cosα	l
1	-7	3.4	2.5	140.25	-17.09	139.2	2.52
2	5^0	5.5	2.0	181.5	15.82	180.81	2.01
3	18^0	6.8	2.0	224.4	69.34	213.42	2.10
4	25^0	5.8	2.0	191.4	80.89	173.47	2.21
5	40^0	4.6	2.0	151.8	97.58	116.29	2.61
6	55^0	2.8	2.0	92.4	75.69	53	3.49
				Total	322.2	876.19	14.94

$$\text{F.O.S} = \frac{\textit{Resisting Force}}{\textit{Driving Force}} = \frac{\sum C'L + \Sigma W \cos\alpha \tan\Phi}{\sum W \sin\alpha}$$

$$= \frac{13.5 * 14.94 + 876.19 * \tan 15}{322.2}$$

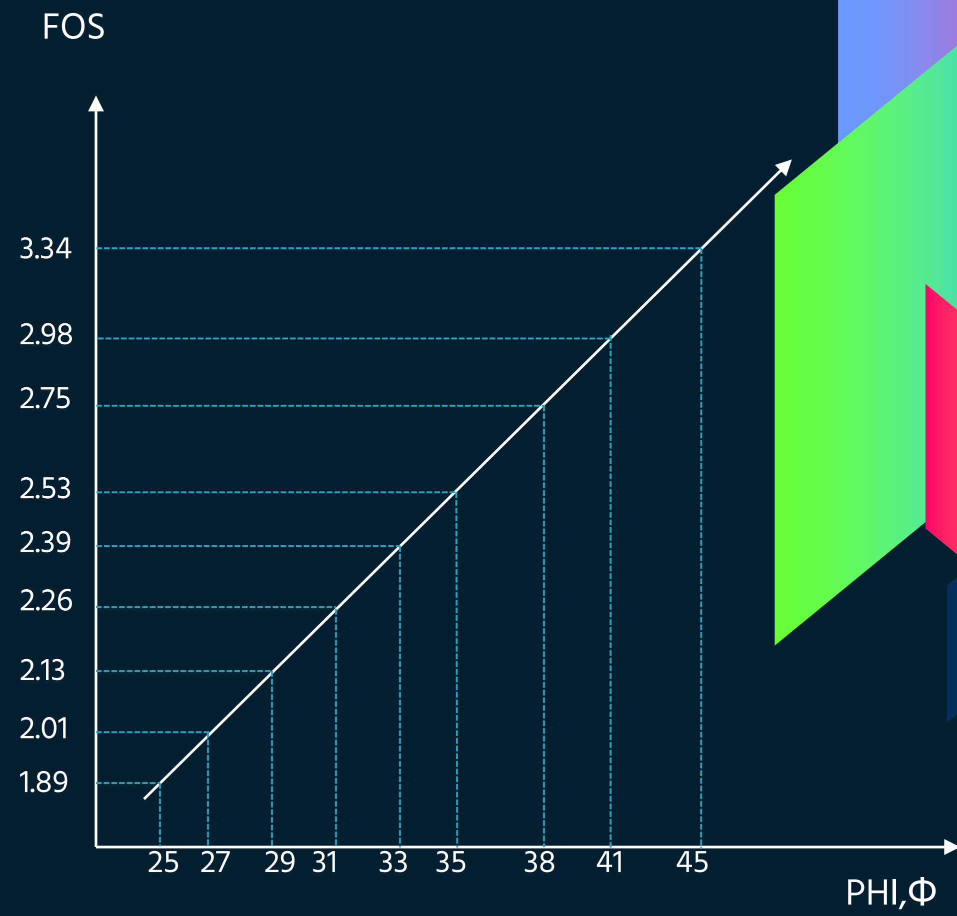
= 1.35 > 1 OK (Slope design is therefore, adequate)

EFFECTS OF SOIL PROPERTIES ON FACTOR OF SAFETY

EFFECTS OF FRICTION ANGLE (PHI, Ø) ON FACTOR OF SAFETY

Unit Weight,γ = 16.5
Cohesion, c′ = 13.5

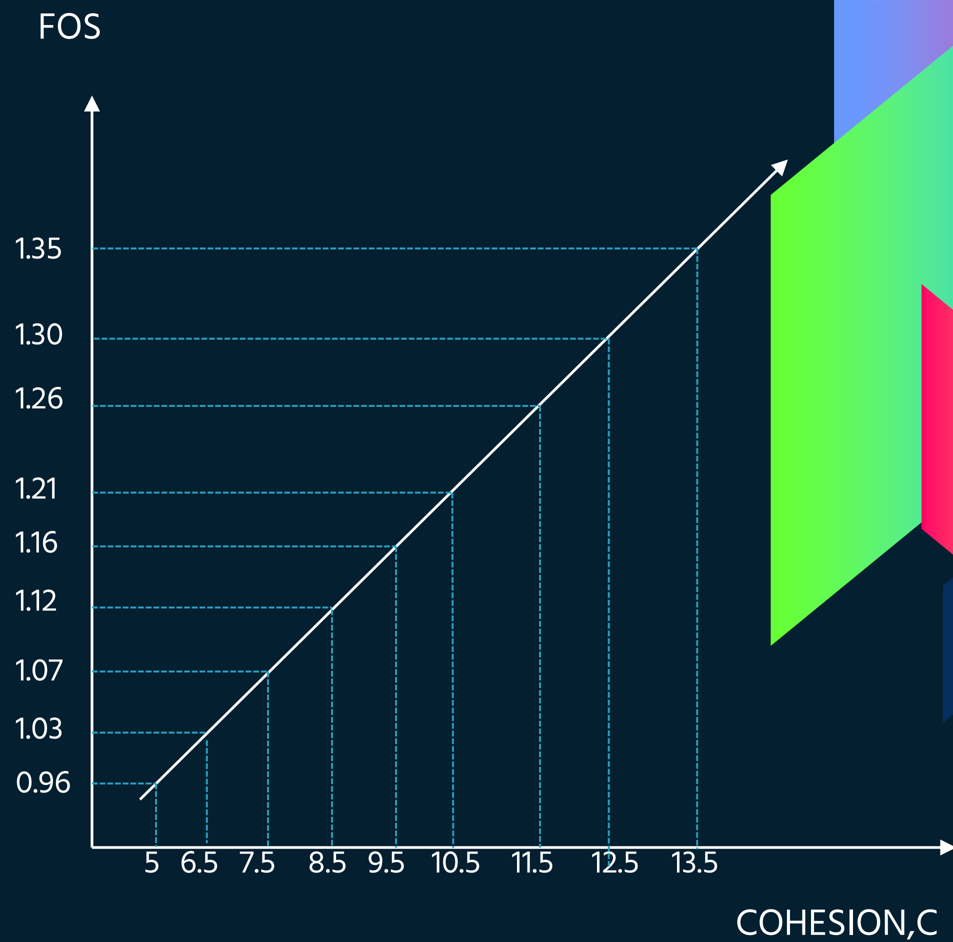
PHI , Φ	F.O.S
45	3.34
41	2.98
38	2.75
35	2.53
33	2.39
31	2.26
29	2.13
27	2.01
25	1.89



EFFECTS OF COHESION (C’) ON FACTOR OF SAFETY

Unit Weight,γ = 16.5
Slope Angle,Φ’= 15

COHESION,C	F.O.S
13.5	1.35
12.5	1.3
11.5	1.26
10.5	1.21
9.5	1.16
8.5	1.12
7.5	1.07
6.5	1.03
5	0.96 (FAIL)



HYPOTESIS

Driving Force (D)

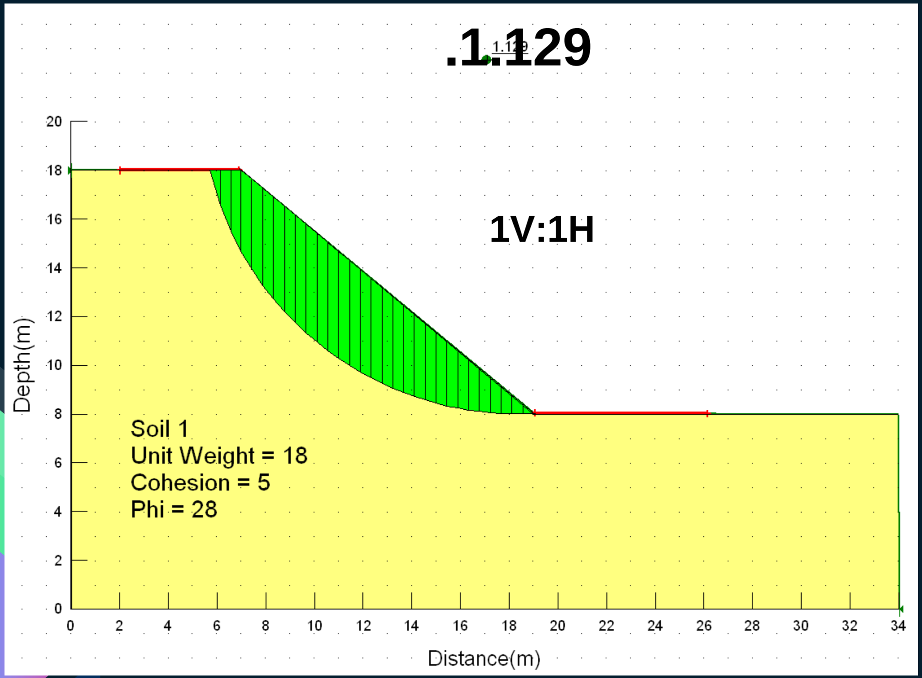
Soil Properties	Value	F.O.S
Unit Weight (γ)	↑	↓
Slope Angle (θ)	↑	↓

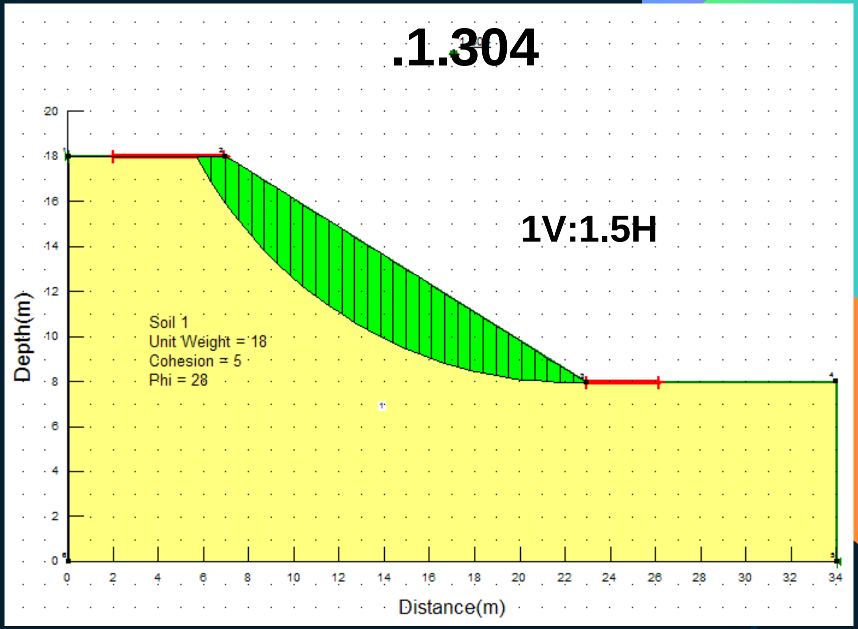
Resisting Force (N)

Soil Properties	Value	F.O.S
Cohesion (C)	↑	↑
Phi (Φ)	↑	↑

EFFECTS OF SLOPE ANGLE ON FACTOR OF SAFETY

EFFECTS OF SLOPE ANGLE ON FACTOR OF SAFETY

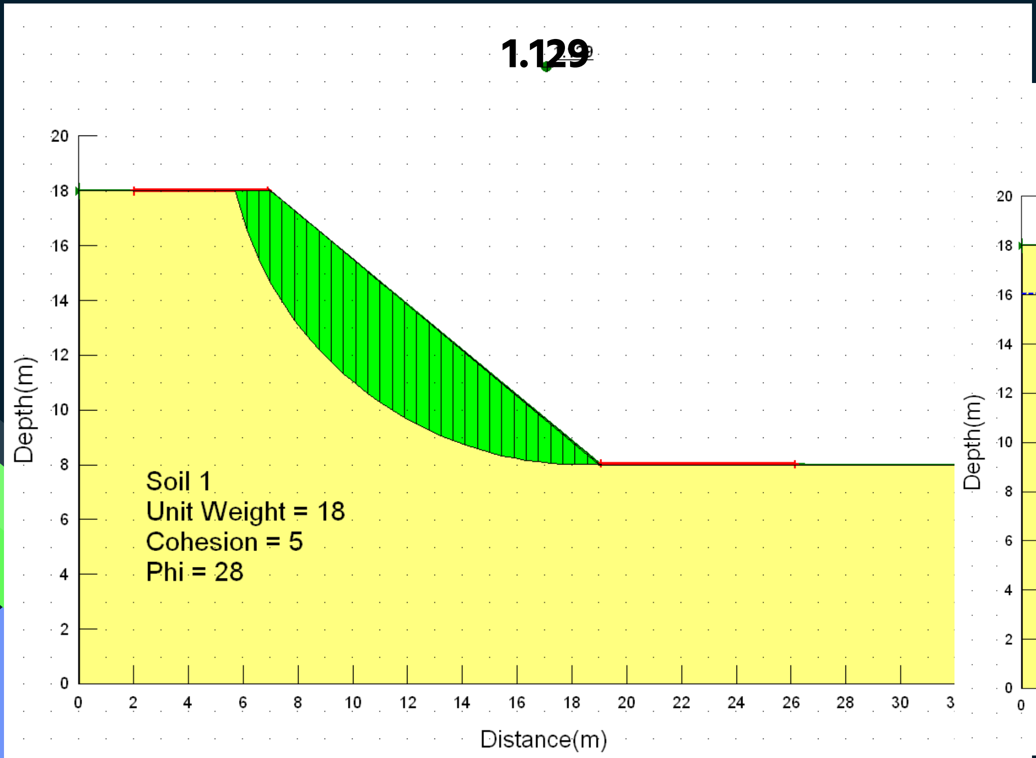


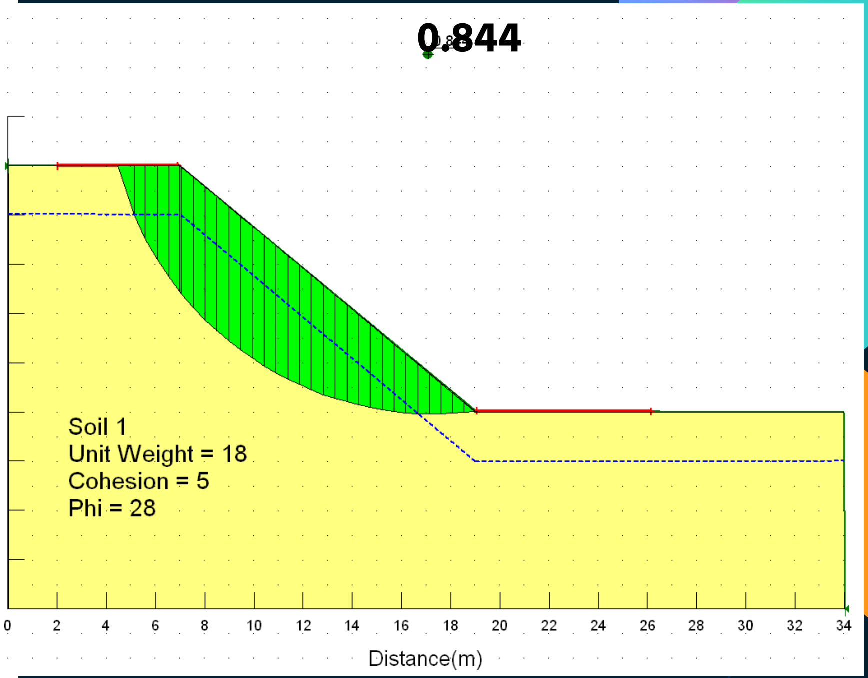


The gentler the slope the higher the Factor of Safety of the slope

EFFECTS OF GROUND WATER TABLE ON FACTOR OF SAFETY

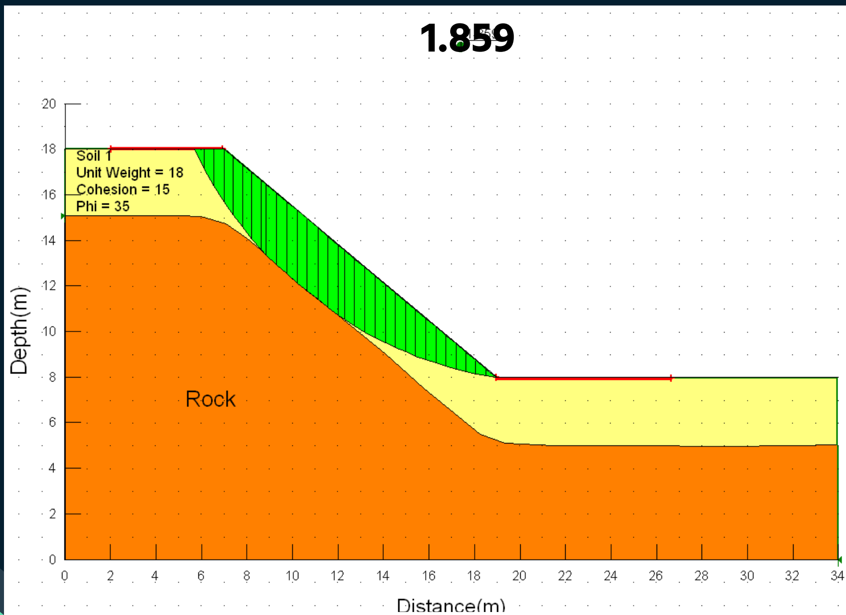
EFFECTS OF GROUND WATER TABLE ON FACTOR OF SAFETY

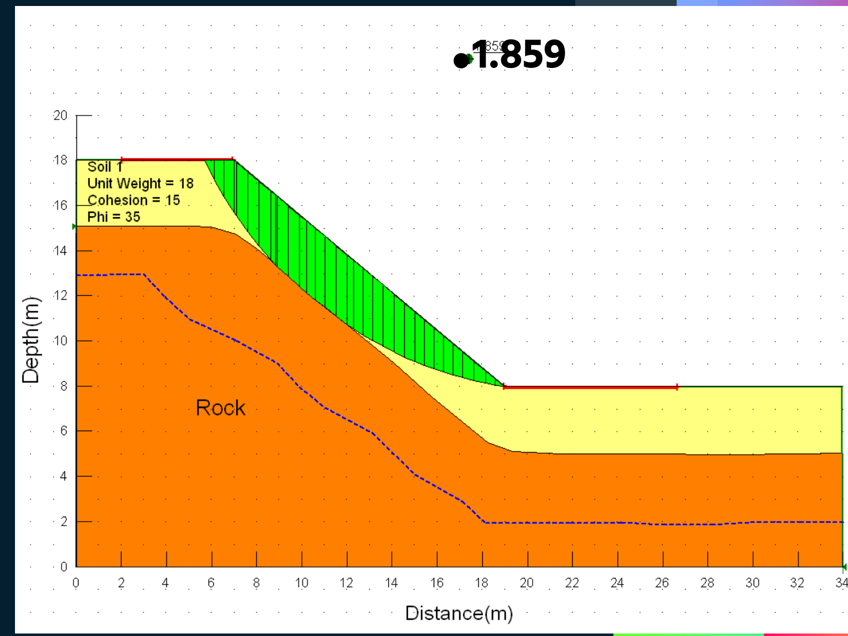


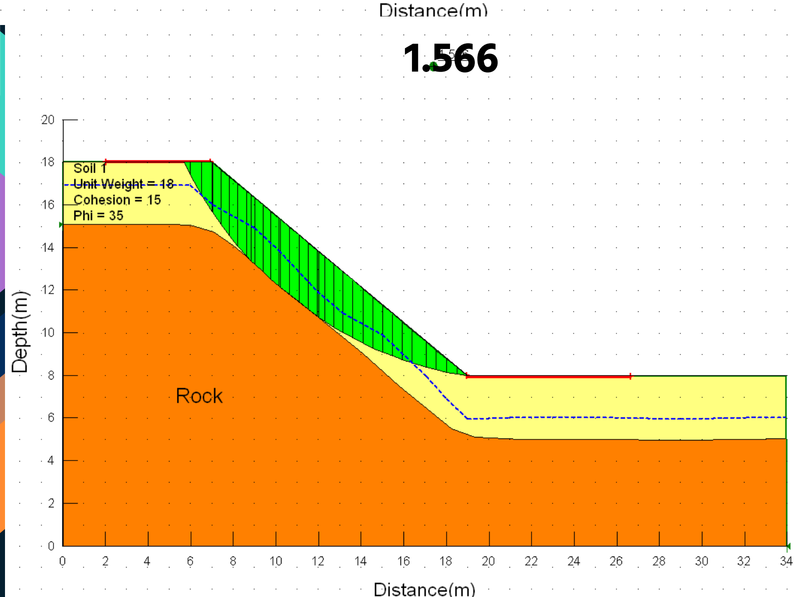


The present of ground water table within the slip plane the lower the Factor of Safety of the slope

EFFECTS OF GROUND WATER TABLE ON FACTOR OF SAFETY





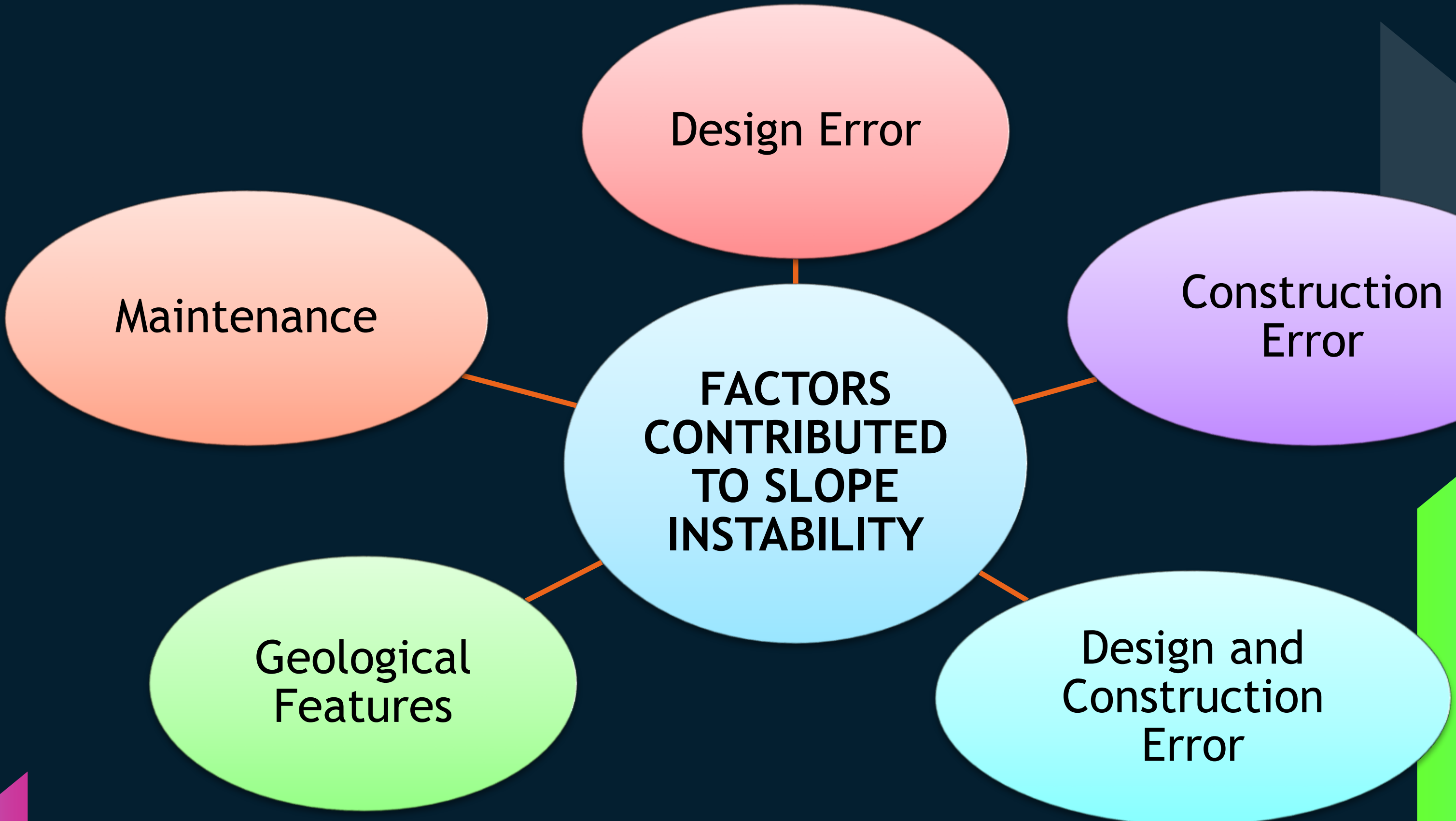


The water level which located below the slip plane would not give any reduction on the Factor of Safety of the slope

WHY DO WE NEED TO ANALYZE SLOPE ?

- To understand the development and form of natural and man made slopes and the processes responsible for different features.
- To analyse slope stability and to understand failure mechanisms and the influence of environmental factors.
- To enable the redesign of failed slopes and the planning of preventive and remedial measures, where necessary.

WHAT IS THE FACTOR TO SLOPE INSTABILITY?



Causes of Landslides	Number of Cases	Percentage (%)
Design Errors	29	60
Construction Errors	4	8
Design and Construction Errors	10	20
Geological Features	3	6
Maintenance	3	6
Total	49	100

REFERENCE: IEM

HUMAN ERRORS INVOLVING SLOPE FAILURE

- According to the landslide forensic statistic data from year 2004 to 2007 of Slope Engineering Branch under the Public Works of Department Malaysia,57% of landslides were due to human factors, whereas only 29% and 14% due to physical and geological factors,and most of the landslides occur at man-made slopes

HUMAN ERRORS INVOLVING SLOPE FAILURE

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Reference: Proceedings of the 3rd International conference on Geotechnical Engineering for Disaster Mitigation and Rehabilitation 2011

DESIGN ERROR

- Abuse of the prescriptive method on the slope gradient (slope angle) to be adopted for cut or fill slopes without proper geotechnical analyses and calculations.
- Rule of thumb

  1V:1H for cut slope and 1V:1.5H for fill slope without proper geotechnical analysis and design.

DESIGN ERROR

- Subsurface investigation (S.I.) and laboratory tests were not carried out to obtain representative soil parameters, subsoil and groundwater profiles for design and analysis of slopes.

DESIGN ERROR

- A lack of good understanding of fundamental soil mechanics so that the most critical condition of cut slopes is in the long term (in the “Drained Condition”).
- it is necessary to adopt effective shear strength parameters for the “Drained Analysis” of the cut slopes in residual soils instead of undrained shear strength (s^u or c^u)

CONSTRUCTION ERROR

- Forming cut slopes by excavating slopes from the bottom instead of the correct practice of cutting from the top downwards.

- This will trigger landslides or potential shear planes extending beyond the proposed cut slope profile.

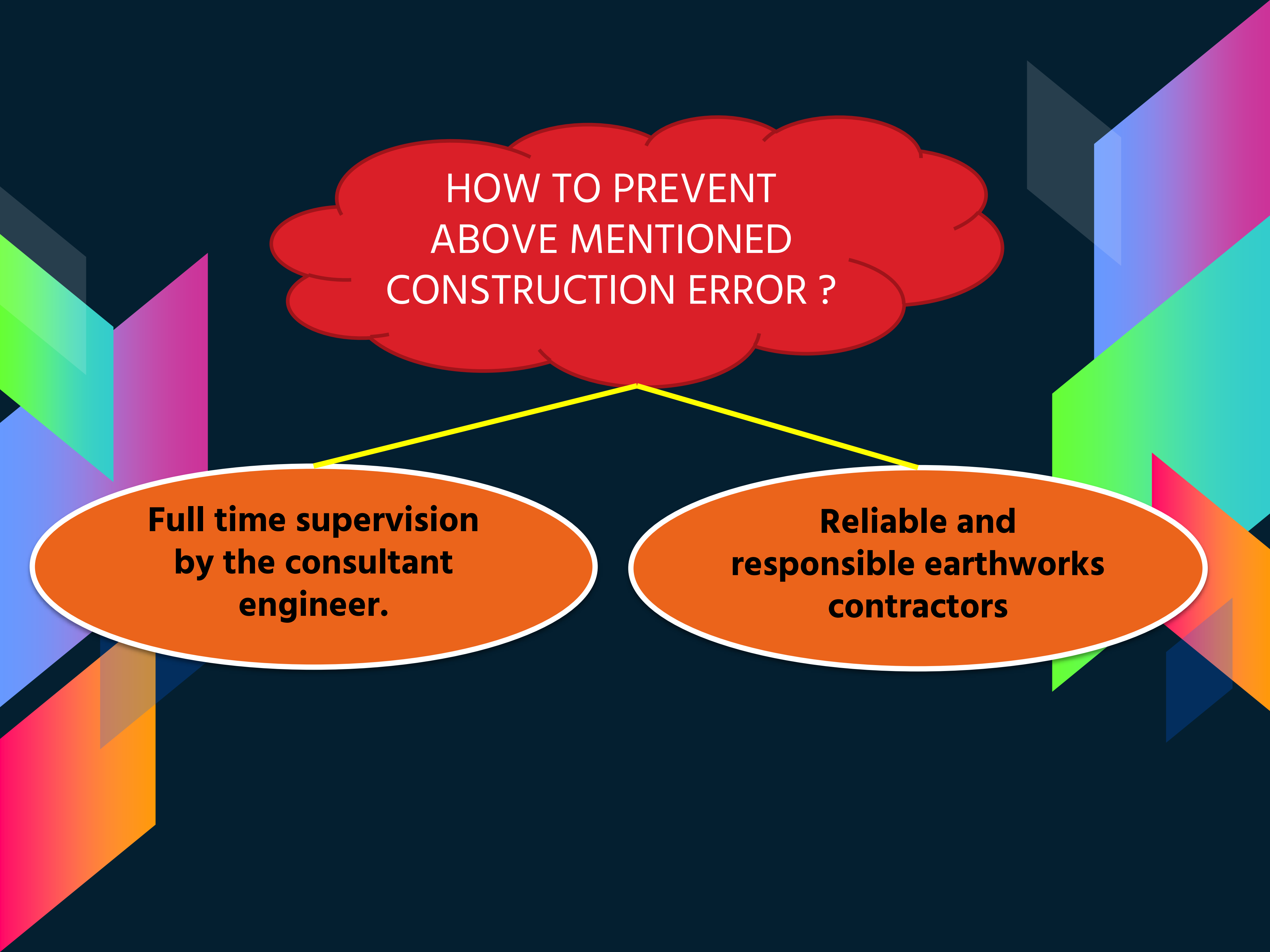
- **Tipping of loose material on slopes to form a filled platform or filled slope**. Why contractor do this at site?

CONSTRUCTION ERROR

- **Not removing the vegetation on the slopes** causing the bio-degradable materials to be trapped beneath the dumped fill, forming a potential slip plane with a very low friction angle of the bio-degradable materials (vegetation).

- The uncompacted fill slopes having a very low Factor of Safety will likely fail in the long term.

- Over-excavation of cut slopes. Contractors unintentionally over-excavate cut slopes and then try to fill back the excavated materials to reform the slope to the required gradient. The un-compacted loose materials will slip down.


HOW TO PREVENT ABOVE MENTIONED CONSTRUCTION ERROR ?
Full time supervision by the consultant engineer.
Reliable and responsible earthworks contractors

GEOLOGICAL FACTOR

Discontinuities in residual soils, especially sedimentary formations, are not usually detectable during the design stage even with extensive subsurface investigation (boreholes, geo-physical method)

MAINTENANCE

- blockage of drains for surface run-off, and erosion.

- Blockage of drains will cause large volumes of water to gush down a slope causing erosion to the slope and the formation of gullies.

- These gullies will further deteriorate into a big scar on the slope and finally lead to a landslide. The blockage of drains could also be due to debris accumulated on cracked drains, the collapse of drains, etc.

THANKS!

Any questions?

You can find me at:
naishah@ikram.com.my