Area 4-1: Unreinforced Slope

1. Landslides in Malaysia
2. Factors Trigger to Landslides
3. Introduction of Unreinforced Slope
4. Properties of Slope Material.
5. Identification Varies of Rock Types
6. General Input on Unreinforced Slope Stability Analysis in Compliance with JKR Need Statement
7. Ground Water Regime Effect
8. Basic of Drainage System
9. Slope Surface Protection Types
10. Construction Sequences
11. Slope Maintenances

1.0 Landslides in Malaysia

Terzaghi (1950) defined landslide as "a rapid displacement of a mass of rock, residual soil, or sediments adjoining a slope, in which the centre of gravity of the moving mass advances in a downward and out- ward direction"

LANDSLIDE

"The movement of a mass of rock, debris or earth flowing down a slope" defined by **Cruden (1991)** is the most widely used definition, and it also adopted by the International Geotechnical Societies UNESCO Working Party on the World Landslide Inventory (2000).


Is their marriage on the rocks?
No, they are worried about rock blasting!
BUKIT PAYA TERUBUNG
M DESA

Genting Sempah Landslide (1995)

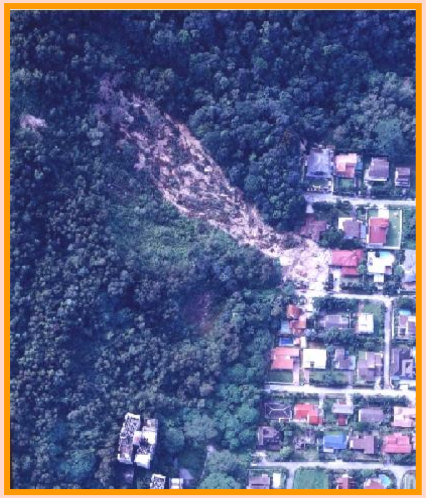
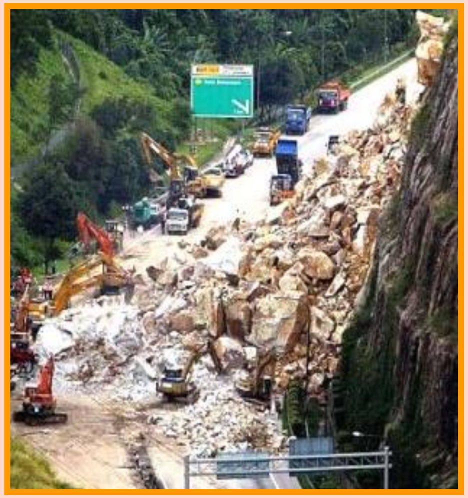
Slip road to Genting Highland
Mudslide brought down a tour bus & killing 20 passengers

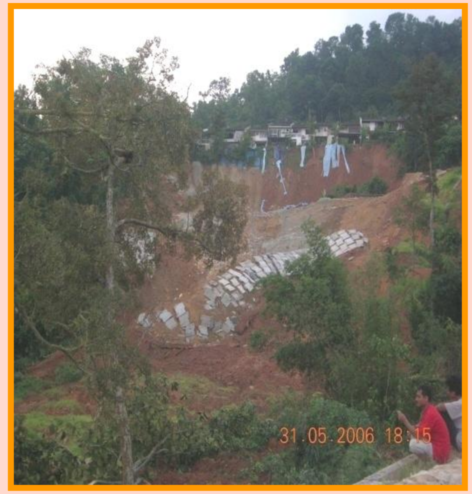
Gua Tempurung 6th Jan 1996

Huge boulder and slide debris along North South Expressway killing a lorry driver

Mud slide at Pos Dipang, Perak (29 Aug 1996)

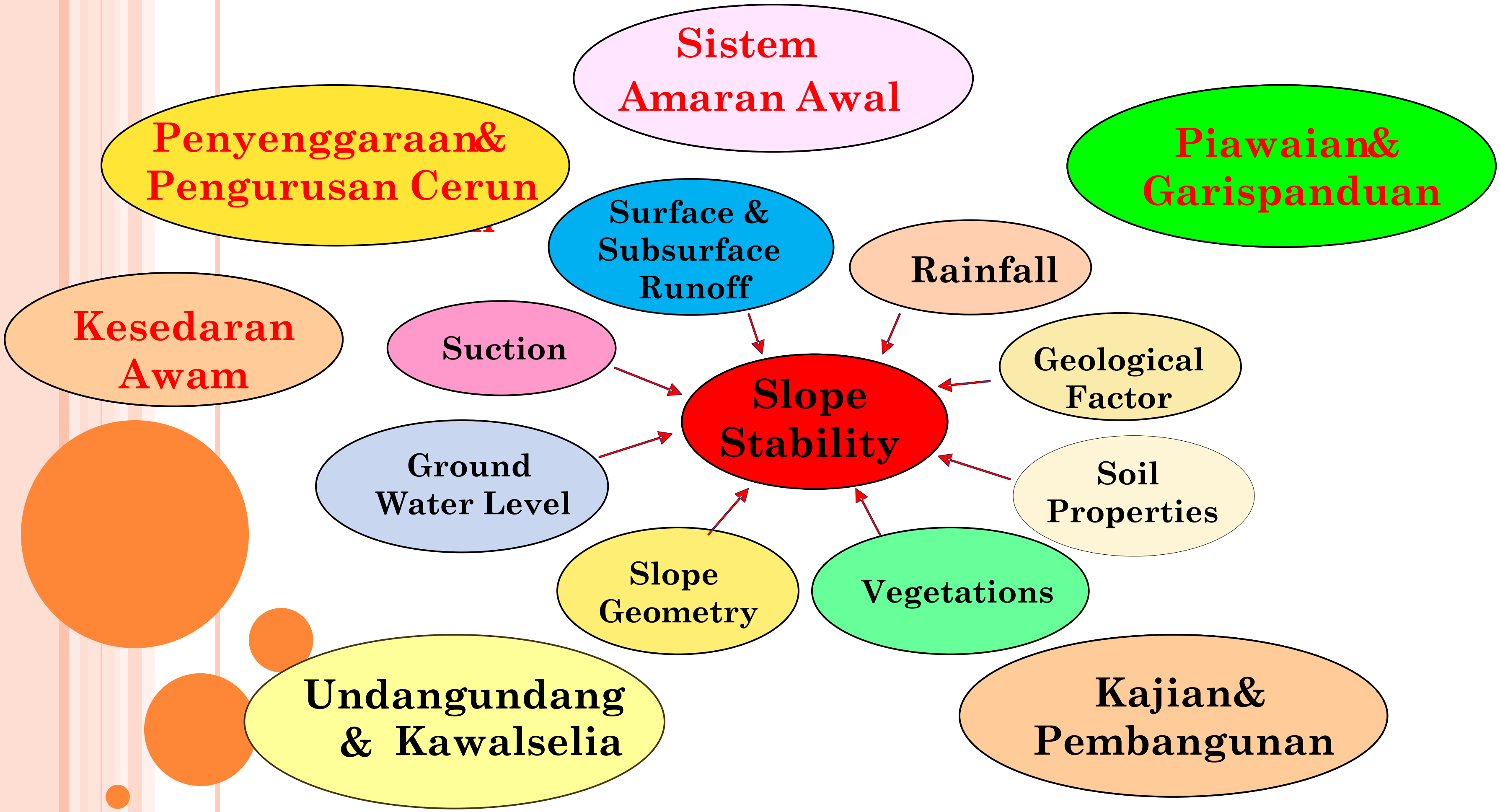
Massive mud slide at the kampung orang asli Pos Dipang with 38 casualties

Landslide Cases	Debris Flow at Hill View (2002) ➢ 8 casualties	ROCK FALL AT BUKIT LANJAN (2003) ➢ Road closure	Cemerlang Height Tmn Harmonis(2004) ➢ 1 casualty
Landslide Photos			
Landslide Causes	➢ Poor filling material without compaction ➢ High GWT ➢ Cohesionless soil ➢ No surface drainage system	➢ Loose rock due to the intersection between two fault zone	➢ Damage of drainages ➢ Leakage of hydrant ➢ Weaken in soil structure due to heavy downpour

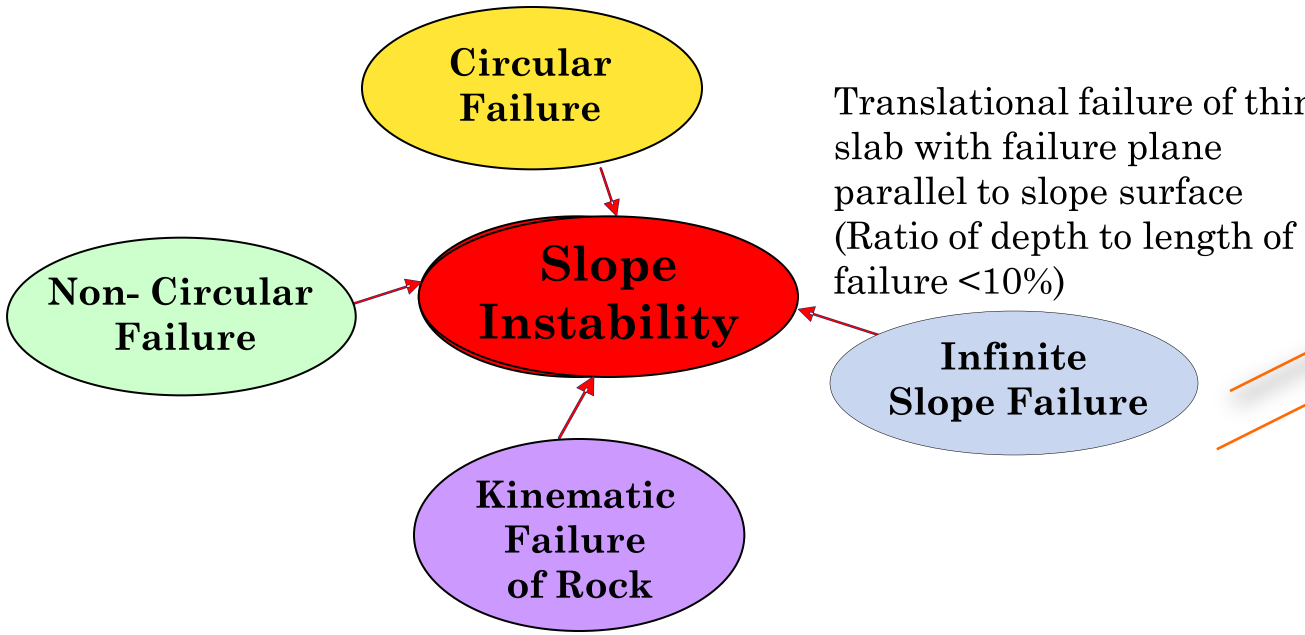
Landslide Cases	Embankment Failure Sec 4.3-5.71, FT270 Kesban Rd (2005) ➢ Road closure	Deep Seated Failure at Kampung Pasir, Ampang (2006) ➢ 4 casualties	Embankment Failure at Sepanggar Rd, Karambunai (2006) ➢ 1 casualty
Landslide Photos			
Landslide Causes	➢ Water infiltration through road cracking lines into steep embankment during rainfall (poor maintenance) ➢ No surface drainage	➢ Improper planning of major housing projects ➢ Pore water pressure at backfill of under construction tie back RE wall	➢ Rainfall ➢ High tide ➢ Excavation works at downslope

Landslide Cases	Deep Seated Failure at Persint 9, Phase II Putrajaya (2007) ➢ Damage 25 cars	Debris Flow at **FT55** Gap-Teranum, Pahang (2008) ➢ Road closure	Landslide at Bkt Antarabangsa (2008) ➢ 5 Casualties, damage 14 Banglos
Landslide Photos			
Landslide Causes	➢ GWT very high due to rainfall ➢ Inadequate on surface drainage system	➢ Water infiltration through road cracking lines into steep embankment during rainfall (poor maintenance) ➢ Poor surface drainage system ➢ Loose boulders	➢ Leakage in active water supply pipes ➢ Poor maintenance on existing surface drainage, crib walls. ➢ Abandoned housing projects ➢ Water ponding due to rainfall

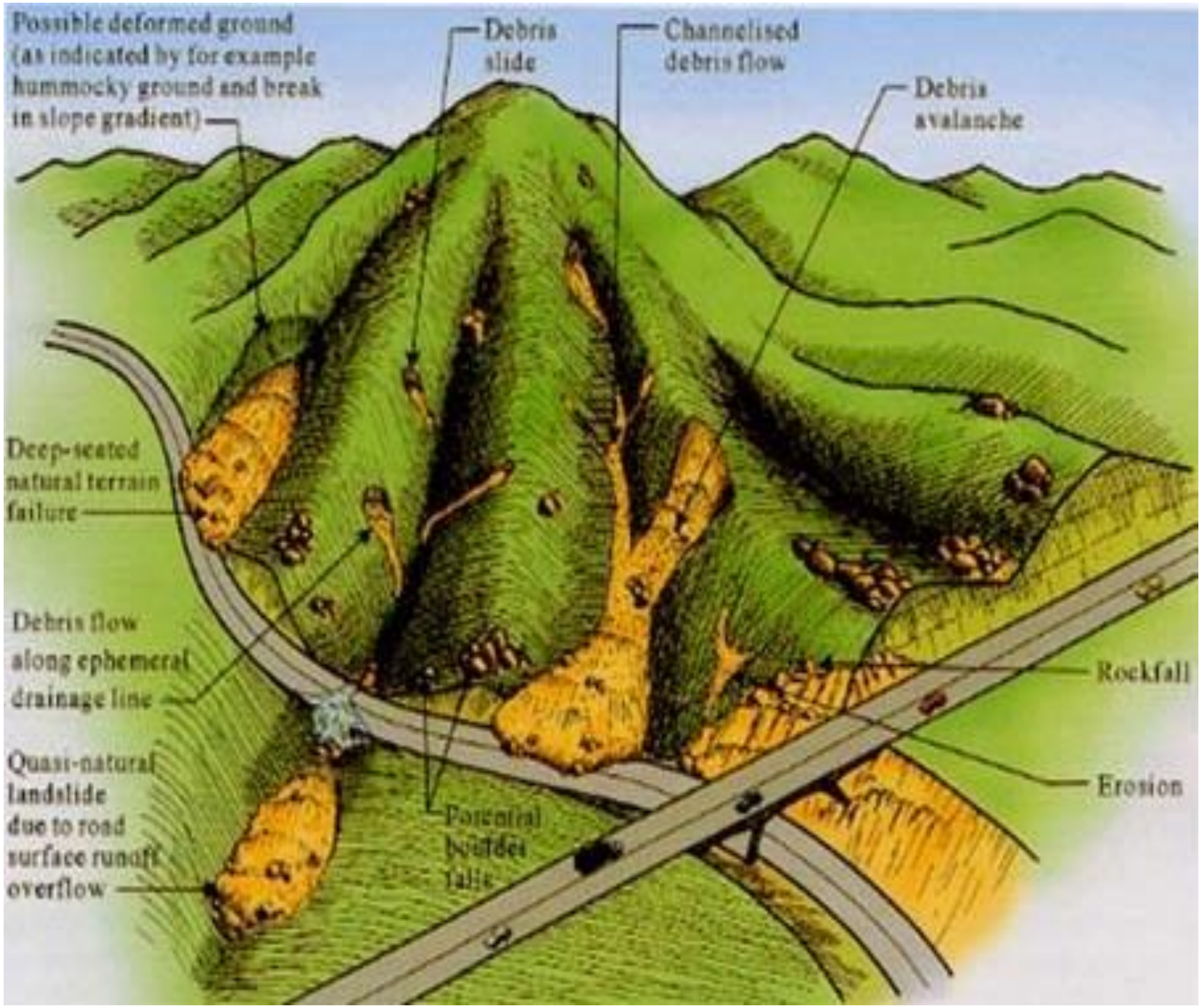
2.0 Factors Trigger to Landslide



Faktor-Faktor Lain :
Gempa Bumi, Gunung Berapi.



- Planar failure (rigid block failure)
- Wedge failure (rigid block failure)
- Toppling failure
- Circular failure



Mode of Failure

EROSION

ROCKFALL

DEBRIS AVALANCHE

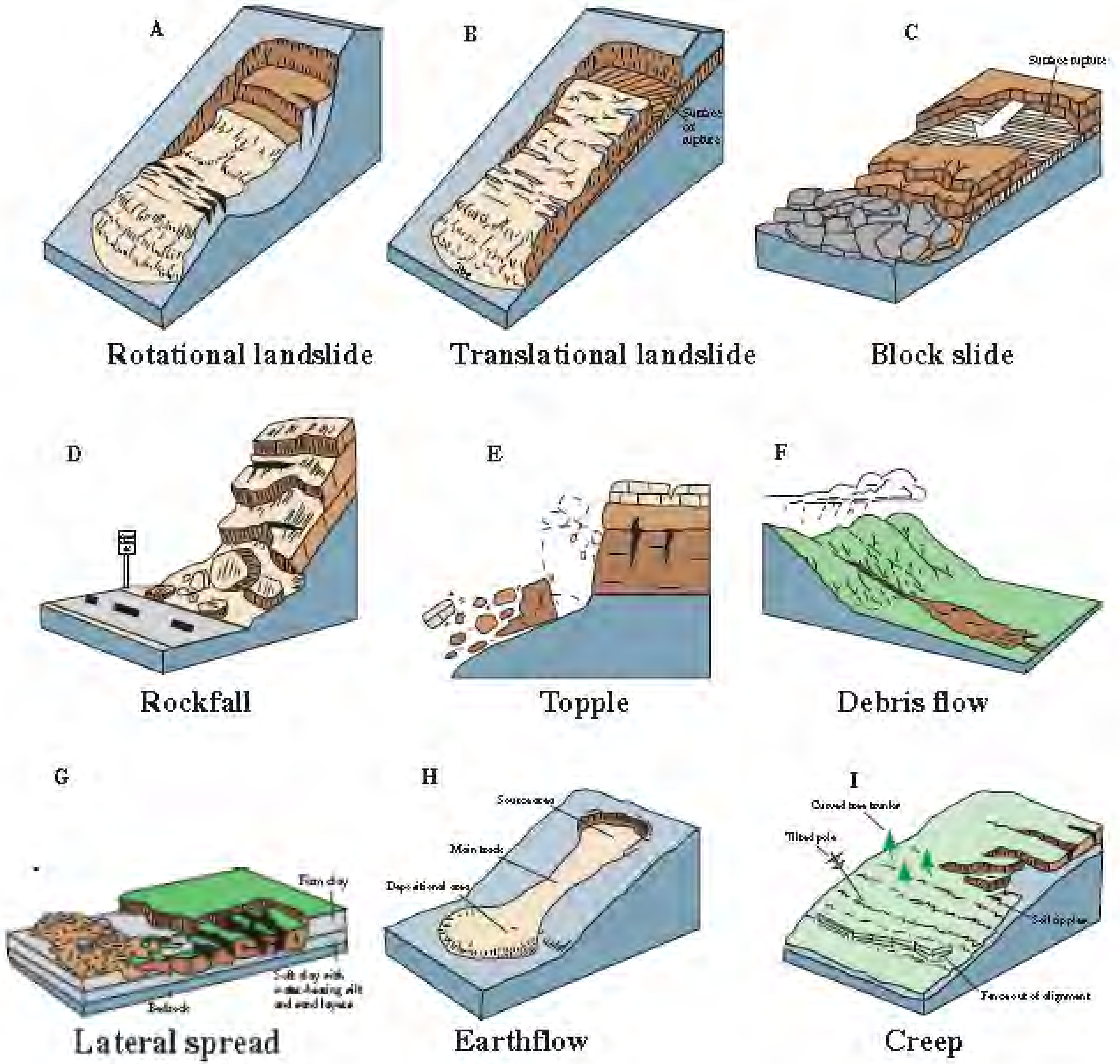
CHANNELISED DEBRIS FLOW

DEBRIS SLIDE

BOULDER FALL

DEFORMED GROUND

DEEP-SEATED FAILURE


A
Rotational landslide
B
Translational landslide
C
Block slide
D
Rockfall
E
Topple
F
Debris flow
G
Firm clay
Lateral spread
H
Depositional area
Earthflow
I
Tilted pole
Creep

Mass Erosion

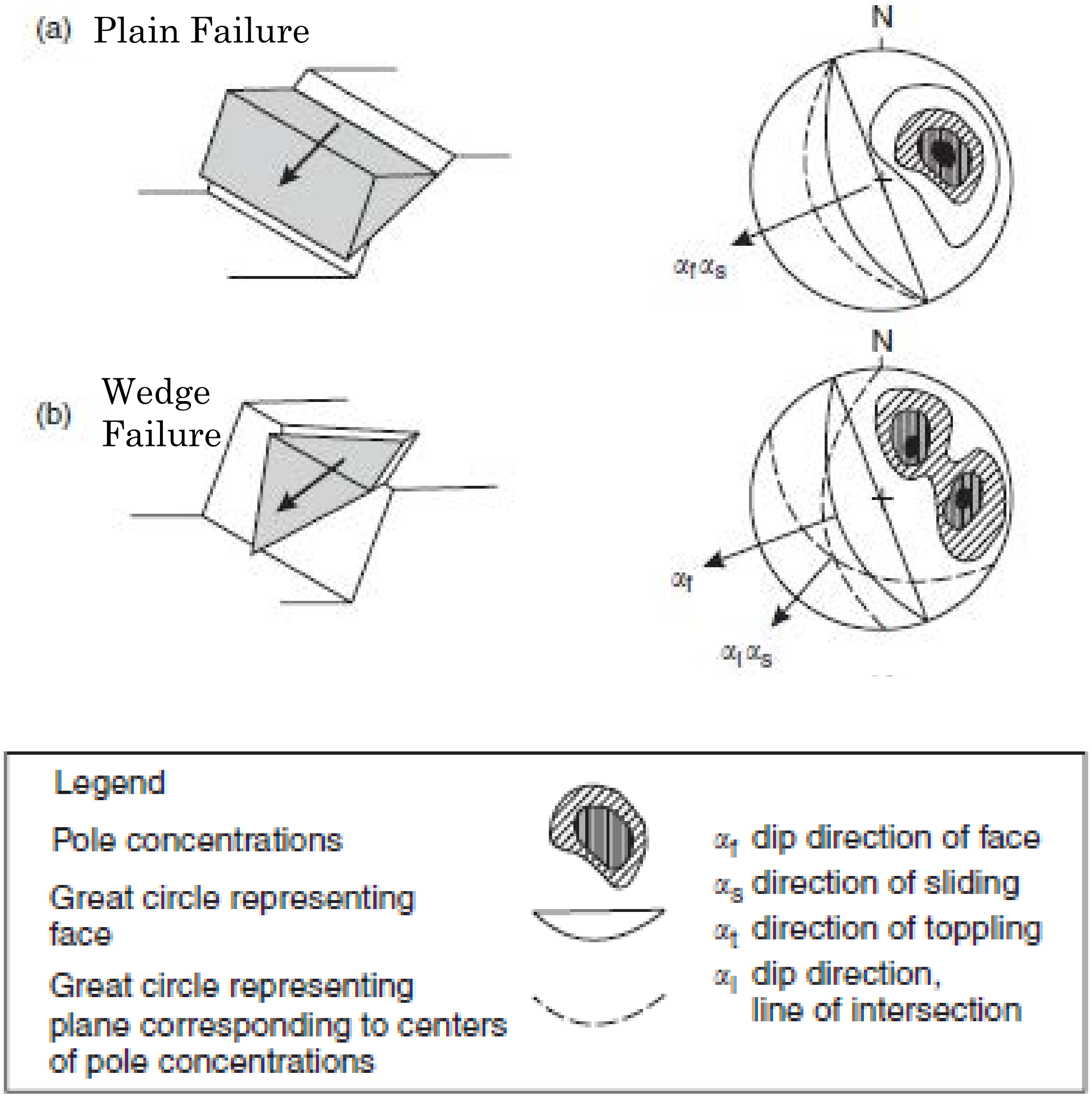
Sheet Erosion

Gully Erosion
(Hakisan Gegeluk)

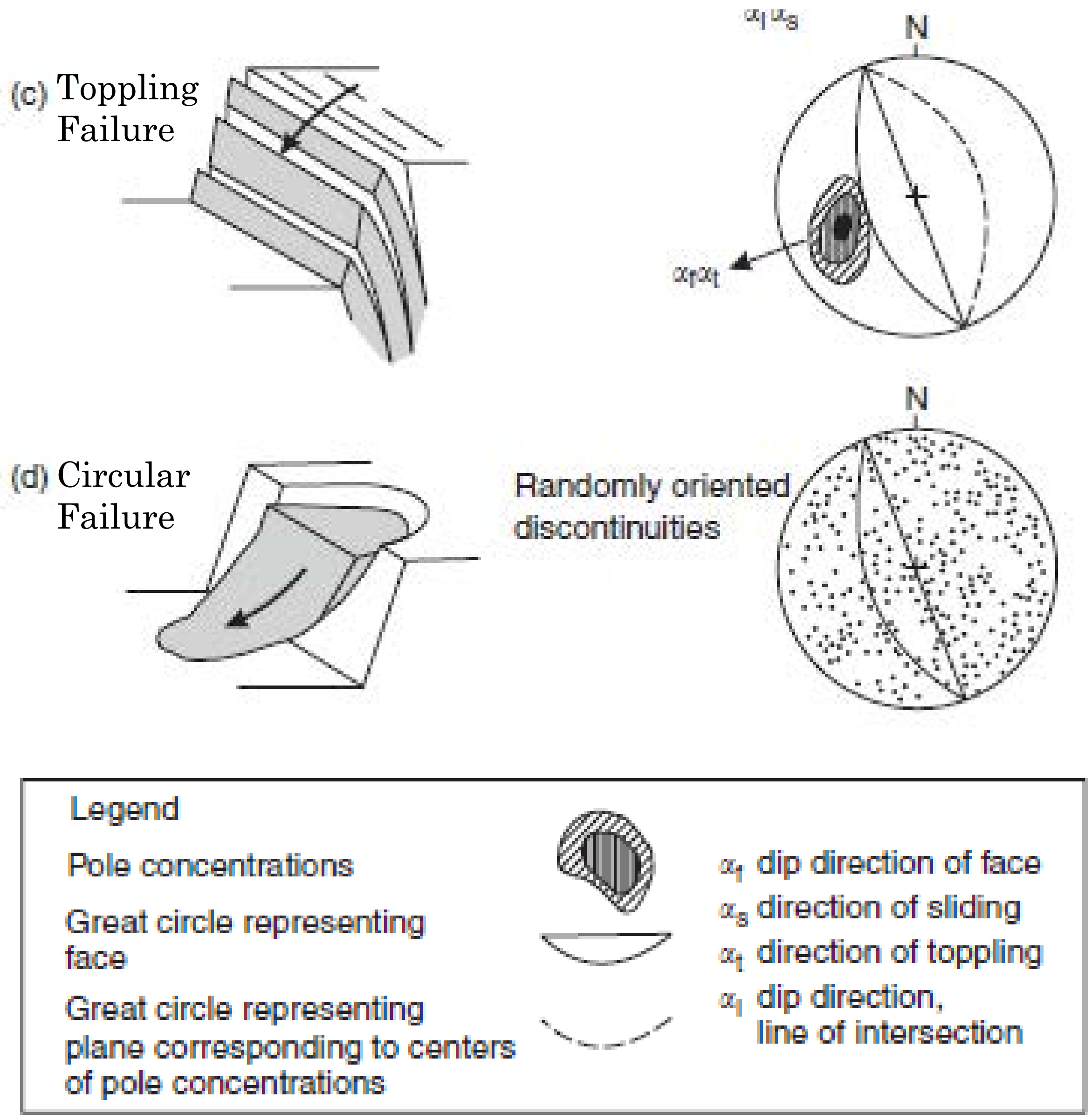
Rill Erosion

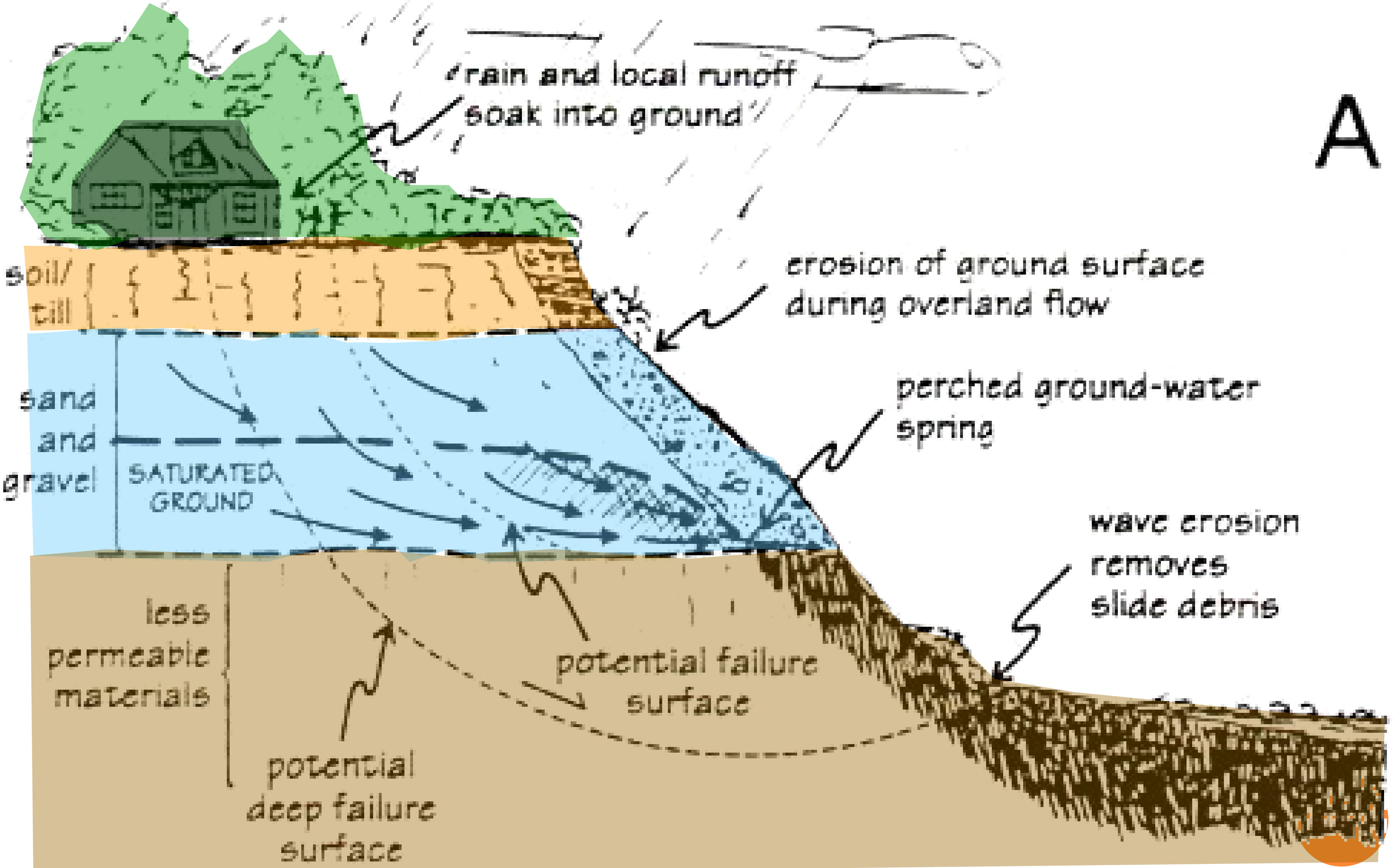
Daylighting

Wedge Landslide

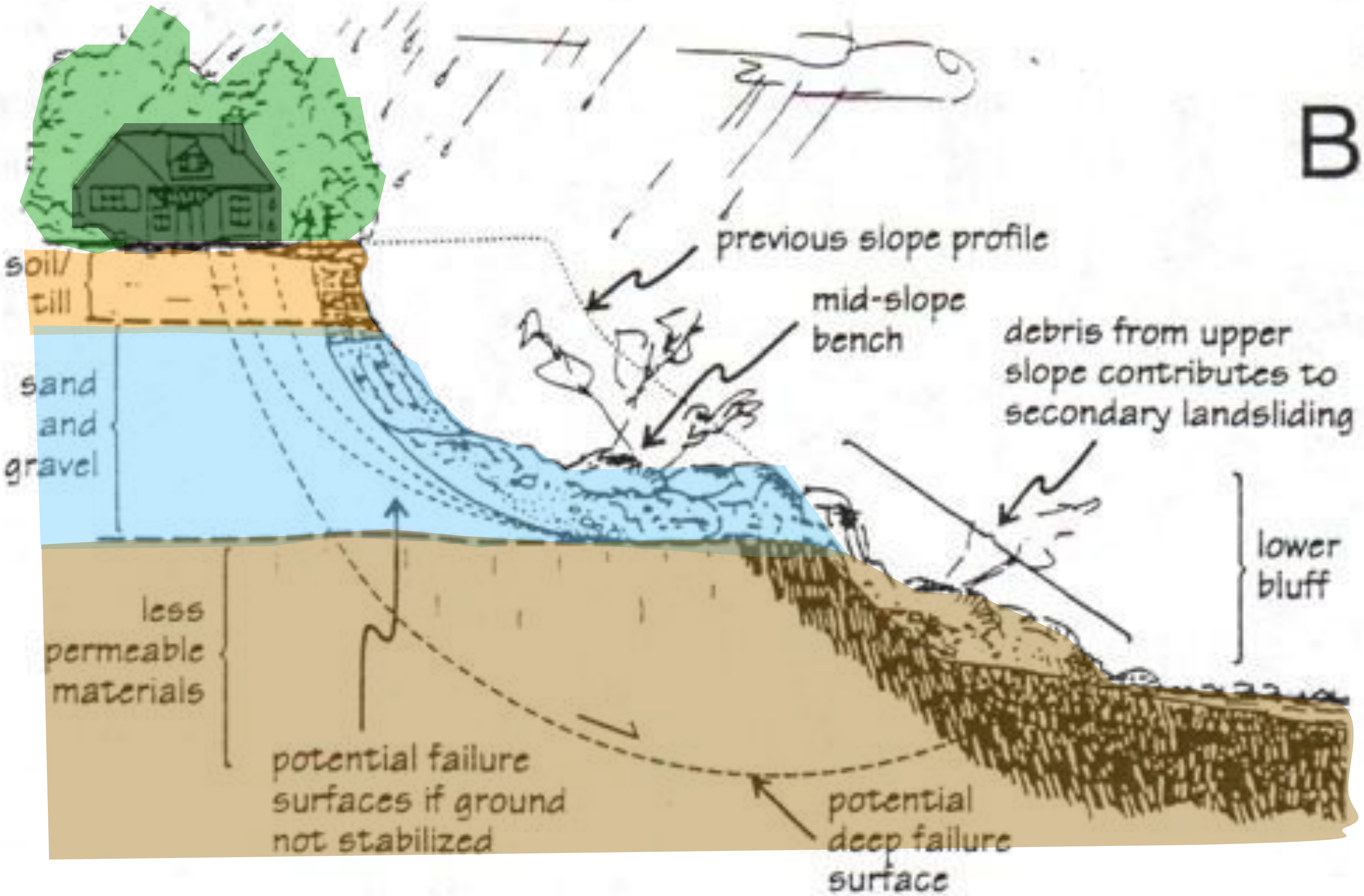


(a) Plain Failure
N
$\alpha_f \alpha_s$
(b) Wedge Failure
N
α_f
$\alpha_i \alpha_s$
Legend
Pole concentrations
Great circle representing face
Great circle representing plane corresponding to centers of pole concentrations
α_f dip direction of face
α_s direction of sliding
α_t direction of toppling
α_i dip direction, line of intersection

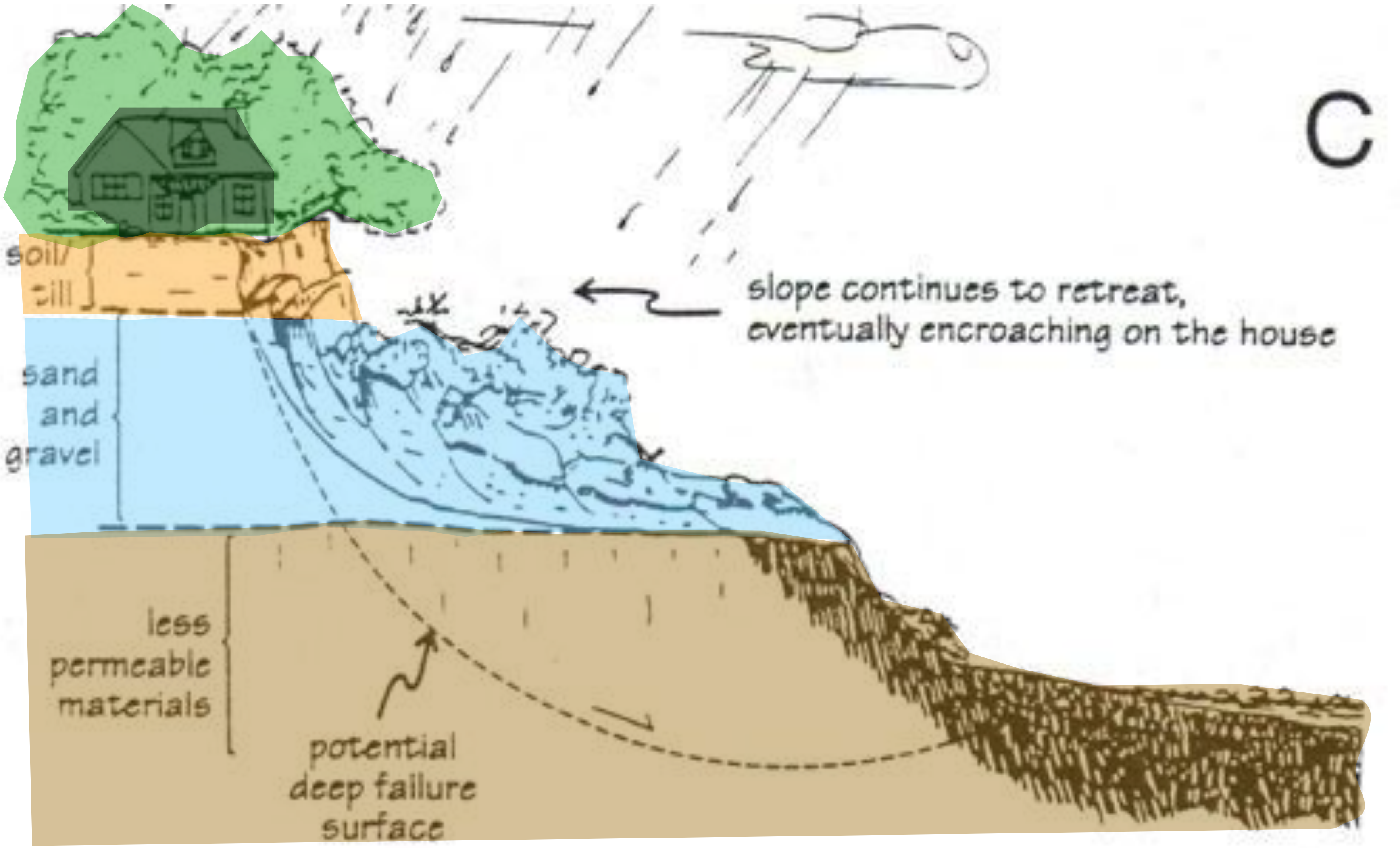

(c) Toppling Failure
N
(d) Circular Failure
Randomly oriented discontinuities
N
Legend
Pole concentrations
Great circle representing face
Great circle representing plane corresponding to centers of pole concentrations
α_f dip direction of face
α_s direction of sliding
α_t direction of toppling
α_i dip direction, line of intersection



Failure Mechanism

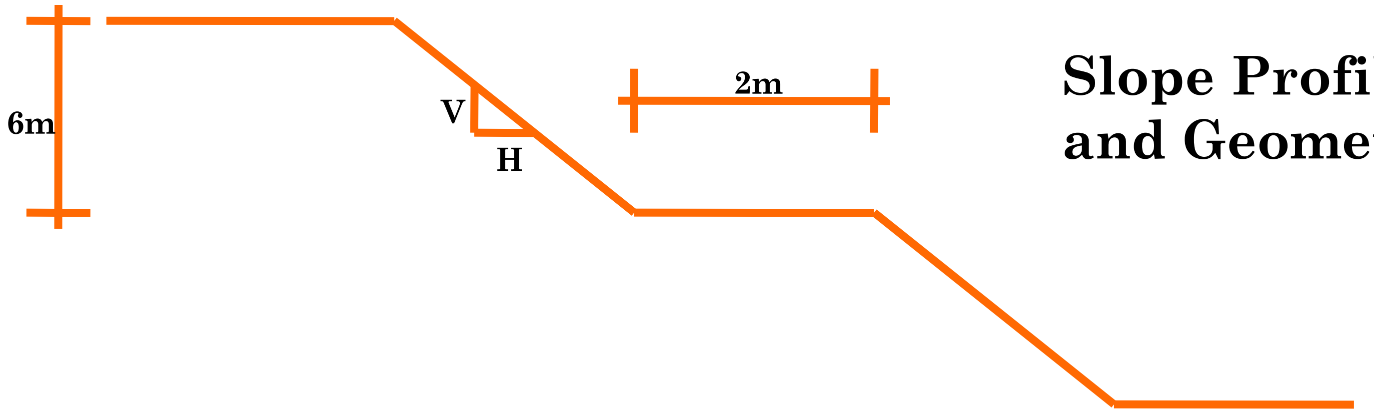


Failure Mechanism



Failure Mechanism

3.0 Introduction of Unreinforced Slope



Slope Profile and Geometry

1) **Fill Slopes and Embankments**
   - Fills slope and embankment gradient - 1V:2H
   - All untreated fill slopes and embankments shall be designed with 2m berm width and 6m berm height.

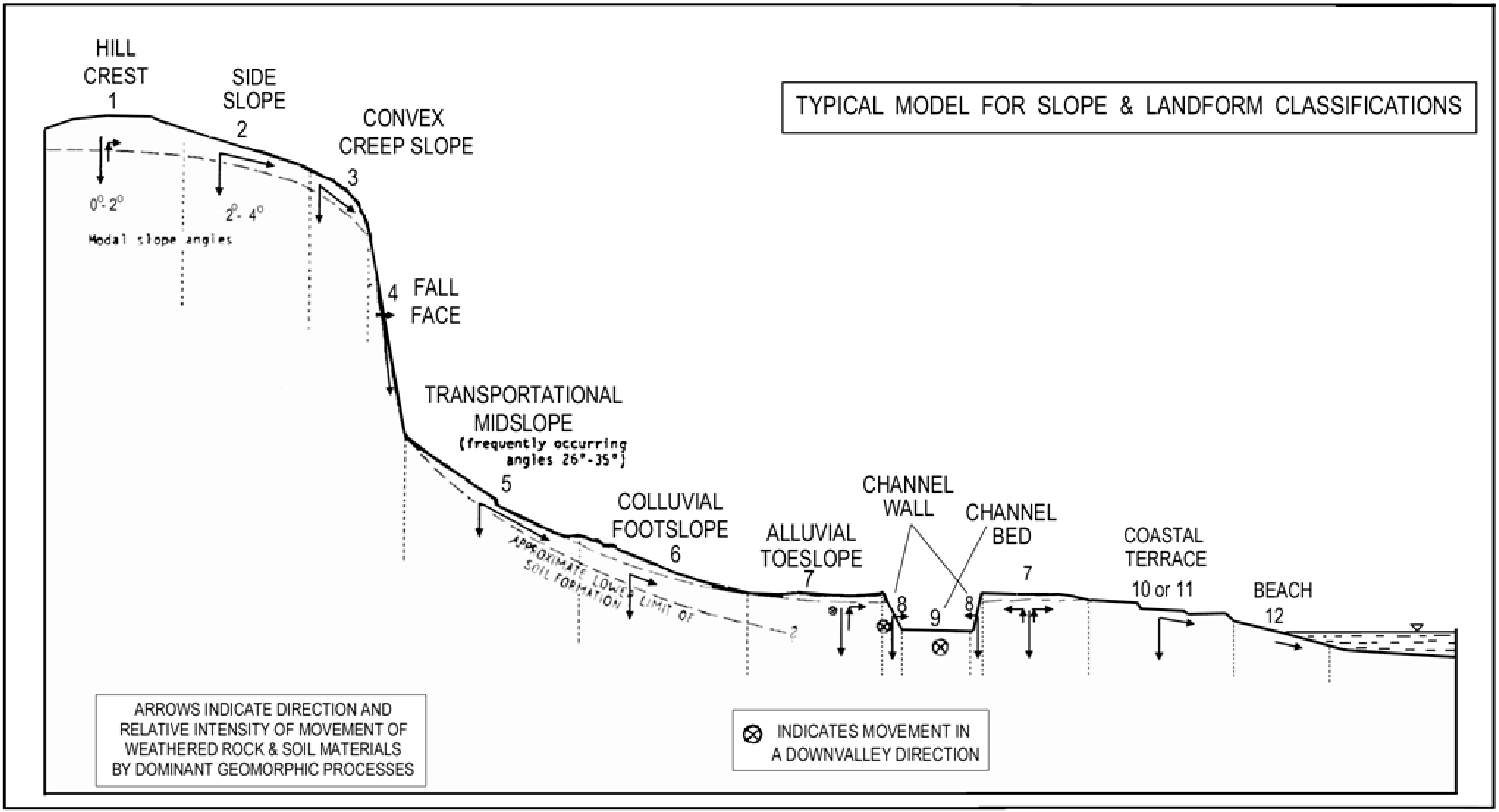
2) **Cut Slope**
   - Cut slope gradient - 1V:1.5H
   - All untreated slopes shall be designed with minimum of 2m berm width and maximum 6m berm height.
   - These include cut slopes in residual soils and in completely decomposed rock.

3) **Rock Slope**
   - All rock slopes shall be analysed and designed.
   - Preliminary consideration can be used using 4V:1H.

4) Base on Case Study

- Fill slope and embankment gradient at the side of stream or on beach shall be 1V:4H to 1V:5H.

5) Slope Geomorphic Units



Class	Total Height (H_T)	Global Angle (α_G)	Localised Height (H_L)	Localised Angle (α_L)
CLASS 1 (Low Risk)	≥ 15 m	< 19°	< 3 m	< 27°
	6 m – 15 m	< 27°	< 3 m	< 30°
	< 6 m	-	-	< 34°
CLASS 2 (Medium Risk)	> 15 m	19° - 27°	-	-
		-	≥ 3 m	27° – 30°
	6 – 15 m	≥ 27°	-	-
		-	≥ 3 m	≥ 30°
	< 6 m	-	≥ 3 m	≥ 34°
CLASS 3 (High Risk)	> 15 m	> 27°	-	-
		-	≥ 3 m	≥ 30°

THE INSTITUTION OF ENGINEERS, MALAYSIA

POSITION PAPER FOR MITIGATING THE RISK OF LANDSLIDE ON HILL-SITE DEVELOPEMENT

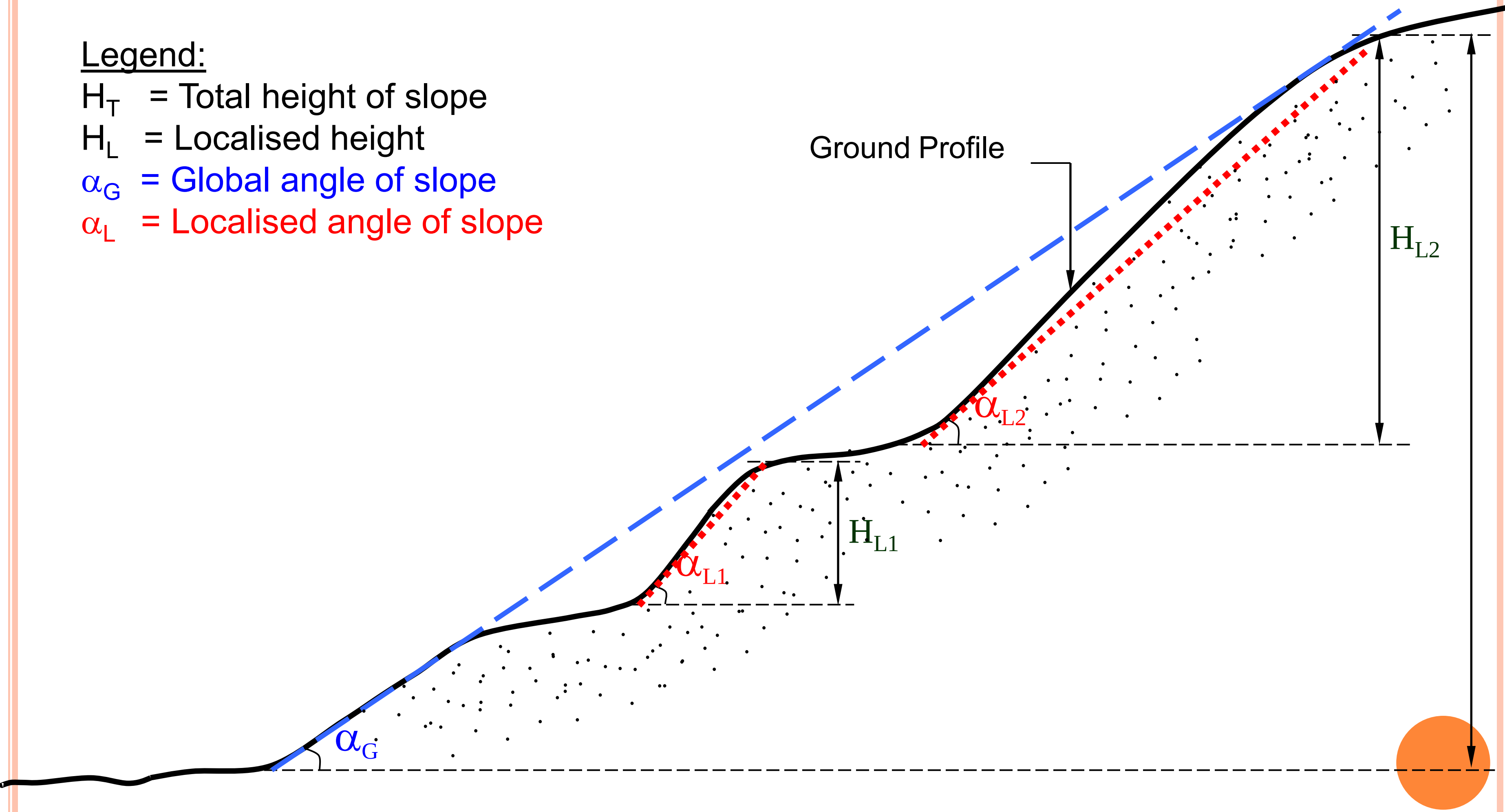
Legend:

H_T = Total height of slope

H_L = Localised height

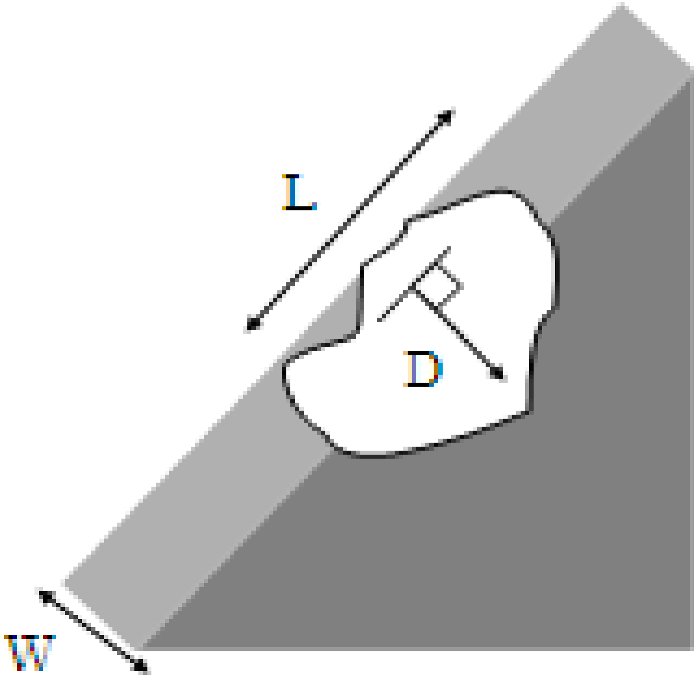
α_G = Global angle of slope

α_L = Localised angle of slope



Failure Details:

L	= Max. Length
W	= Max. Width
D	= Max. Depth



4.0 Properties of Slope Material

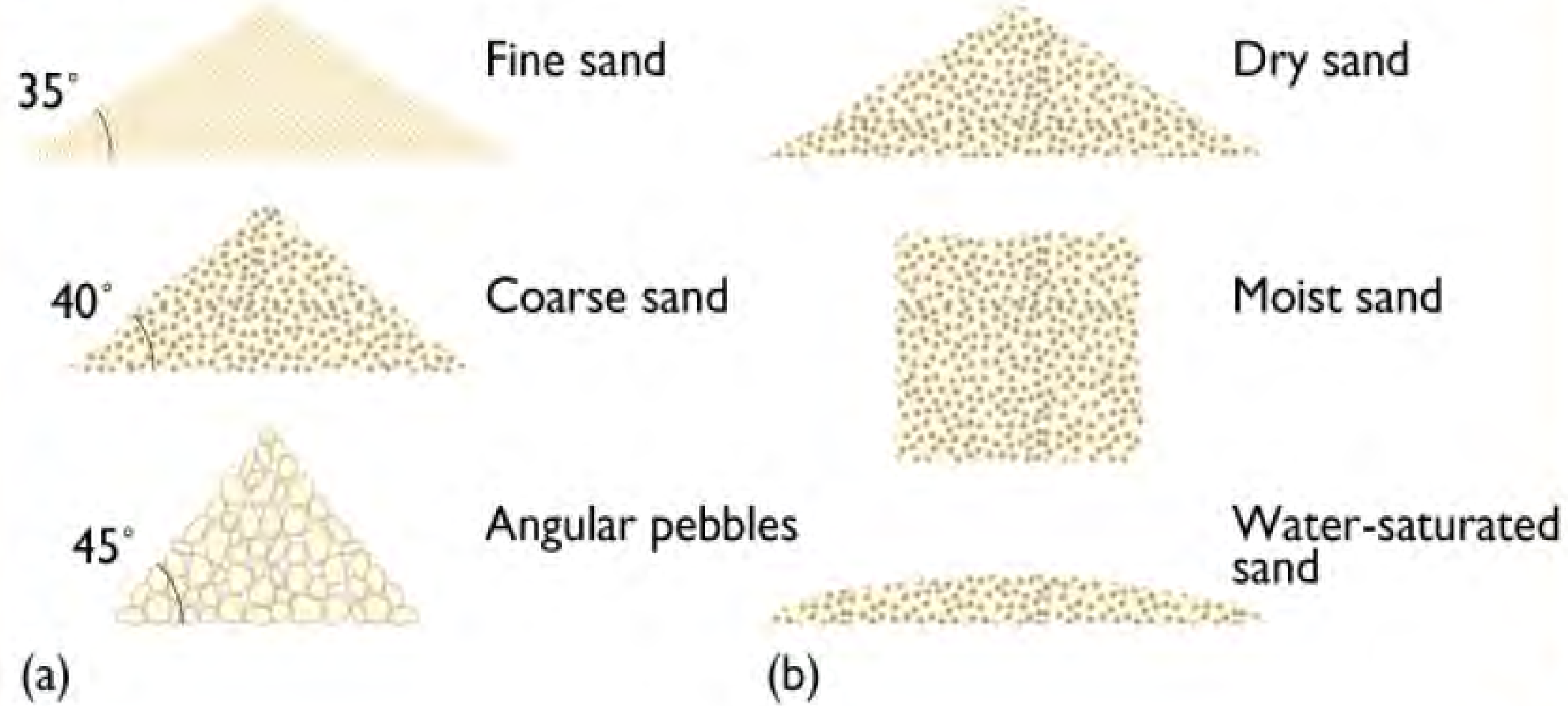
1) Suitable materials shall mean those materials other than:
   i. running silt, peat, logs, stumps, perishable or toxic material, slurry or mud, or
   ii. any material
      - consisting of highly organic clay and silt;
      - which is clay having a liquid limit exceeding 80% and/or a plasticity index exceeding 55%;
      - which is susceptible to spontaneous combustion;
      - which has a loss of weight greater than 2.5% on ignition;
      - containing large amounts of roots, grass and other vegetable matter.

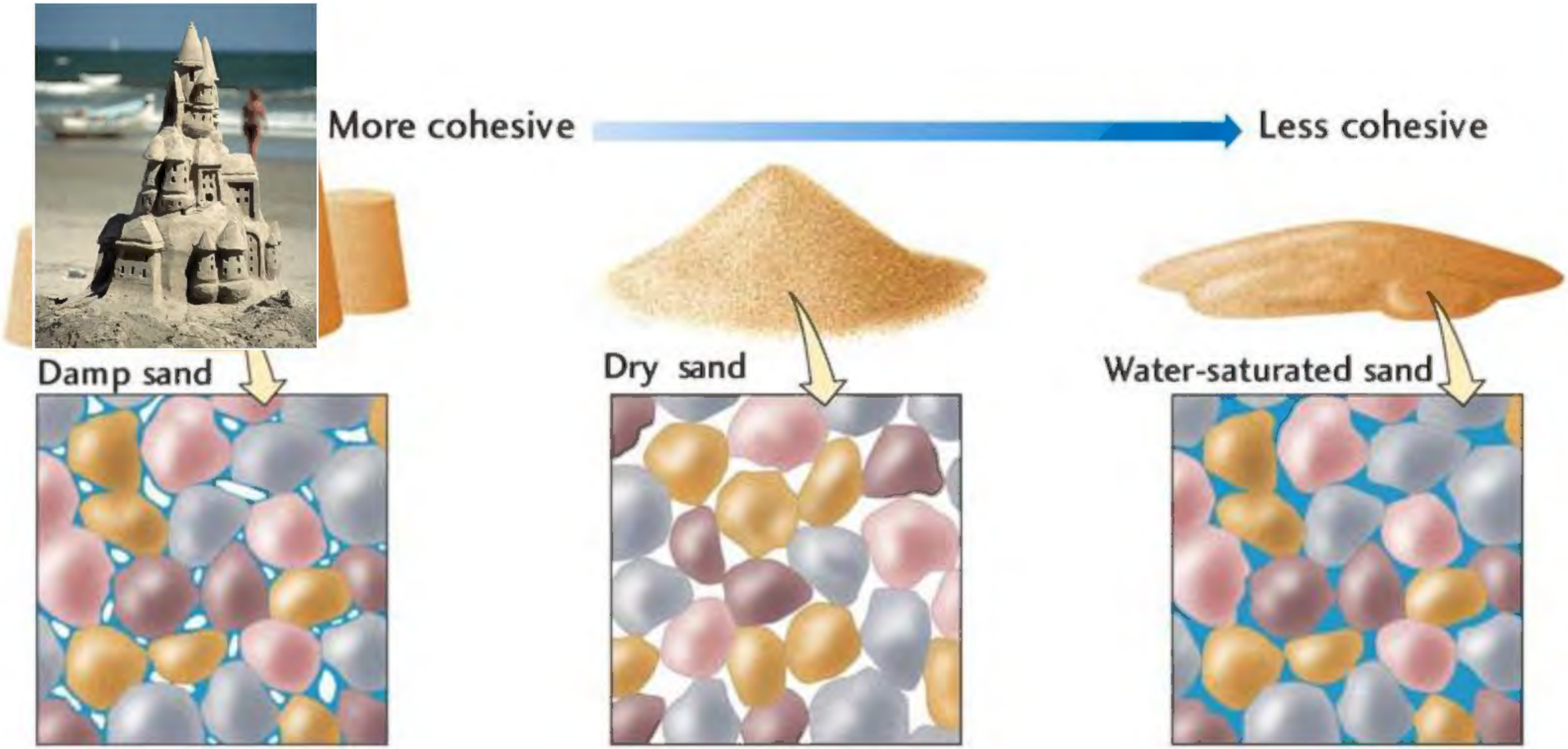
2) Degree of Compaction
   i. Every top of 300 mm shall be compacted to not less than :
      - 90% (for cohesive material – exp: clay)
      - 95% (for non-cohesive material – exp: sand)

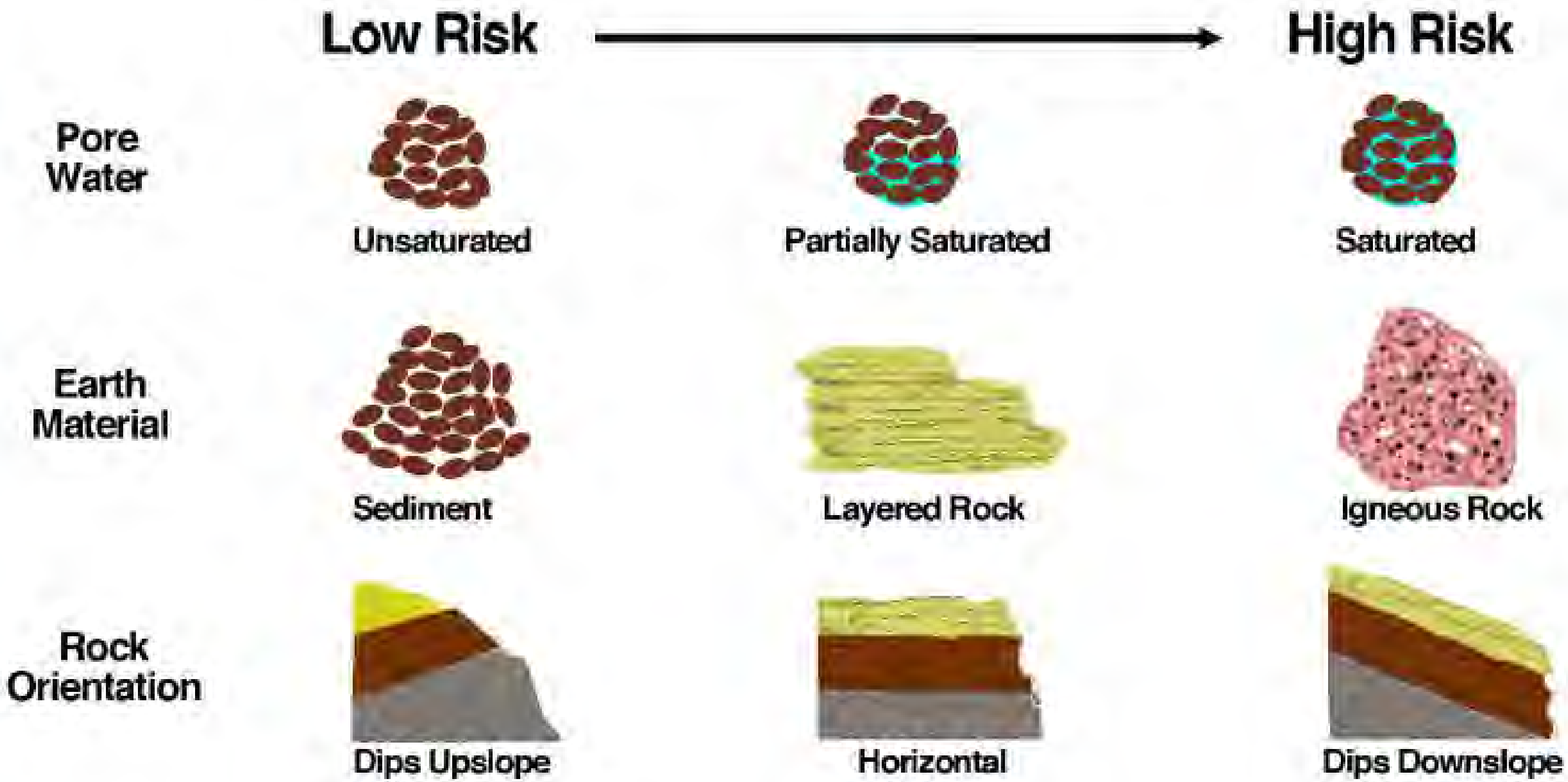
      of the maximum dry density

3) Sources of deriving of soil parameters:
   - Laboratory tests
   - Field test
   - Back-analysed operational ~ mobilised strength parameters by engineer

MASS MOVEMENT DEPENDS ON THE NATURE OF MATERIAL, WATER CONTENT, AND SLOPE STEEPNESS




More cohesive
Less cohesive
Damp sand
Dry sand
Water-saturated sand



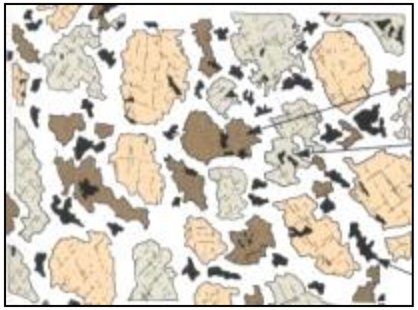
Low Risk
High Risk
Pore Water
Unsaturated
Partially Saturated
Saturated
Earth Material
Sediment
Layered Rock
Igneous Rock
Rock Orientation
Dips Upslope
Horizontal
Dips Downslope

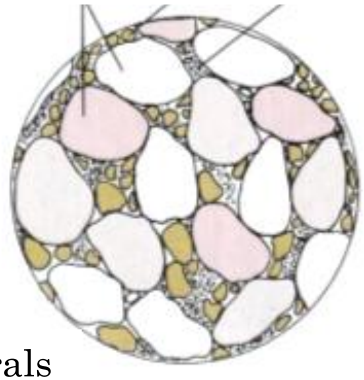
5.0 Identification Varies of Rock Types

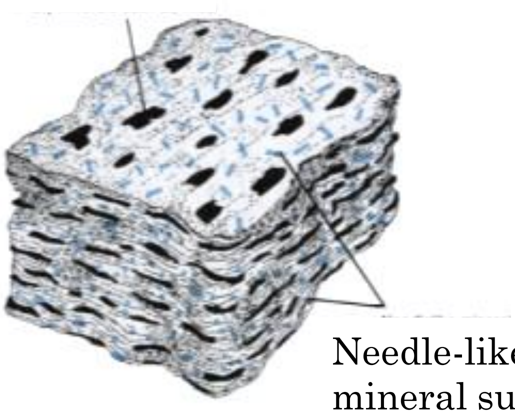
1) **Igneous Rock**
   - Derived from molten material or magma;
   - (eg. granite, syenite, basalt, etc)

2) **Sedimentary**
   - Rock formed from materials derived from pre-existing rocks by processes of denudation; (eg. Sandstone, limestone, mudstone, shale, coal, etc)

3) **Metamorphic**
   - all rocks which have been transformed due to pronounced changes in temperature, pressure and chemical environment during the mountain building processes and/or magma intrusions; (e.g. marble, quartzite, schist, phyllite, slate, hornfels, etc)







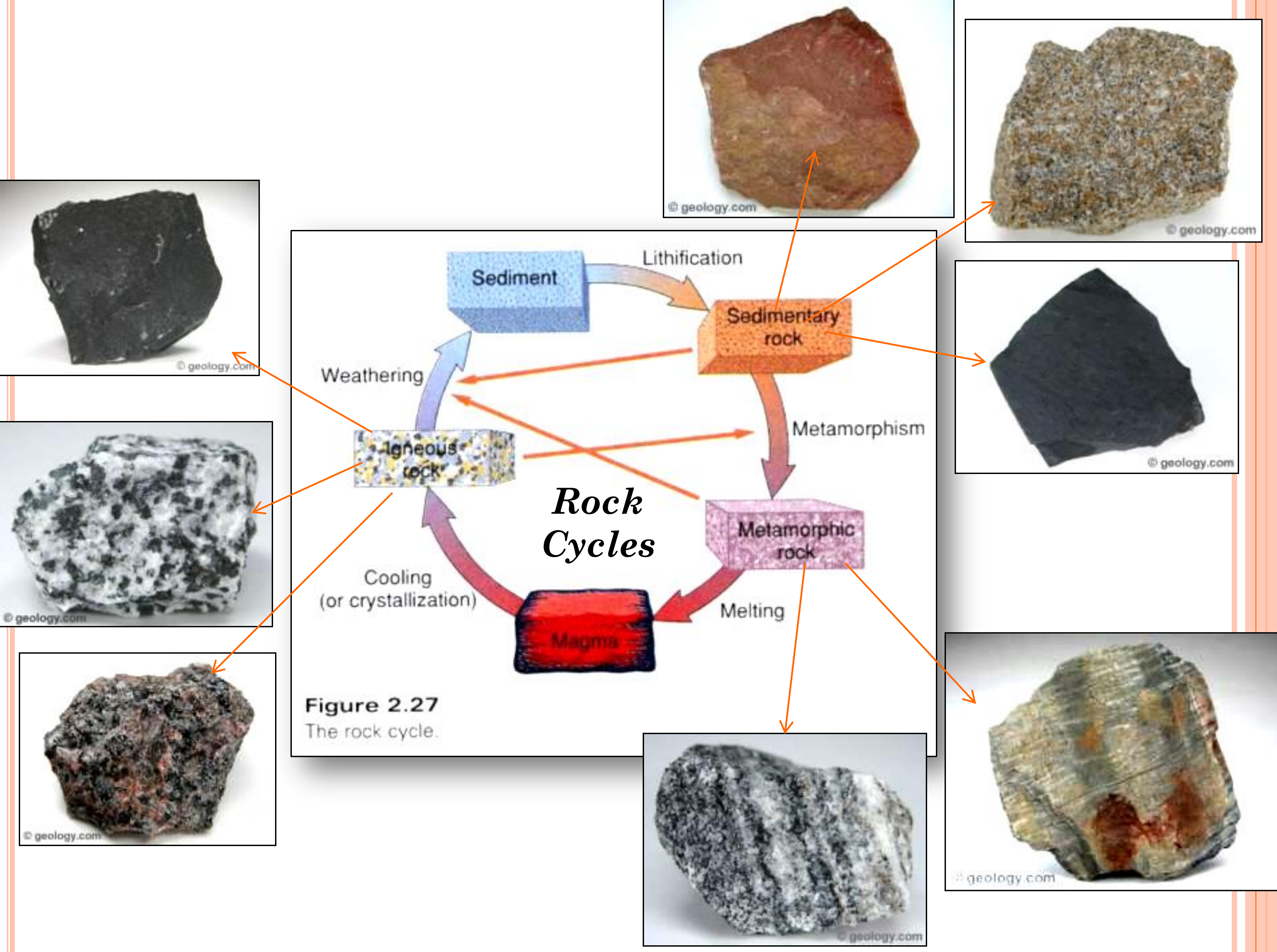
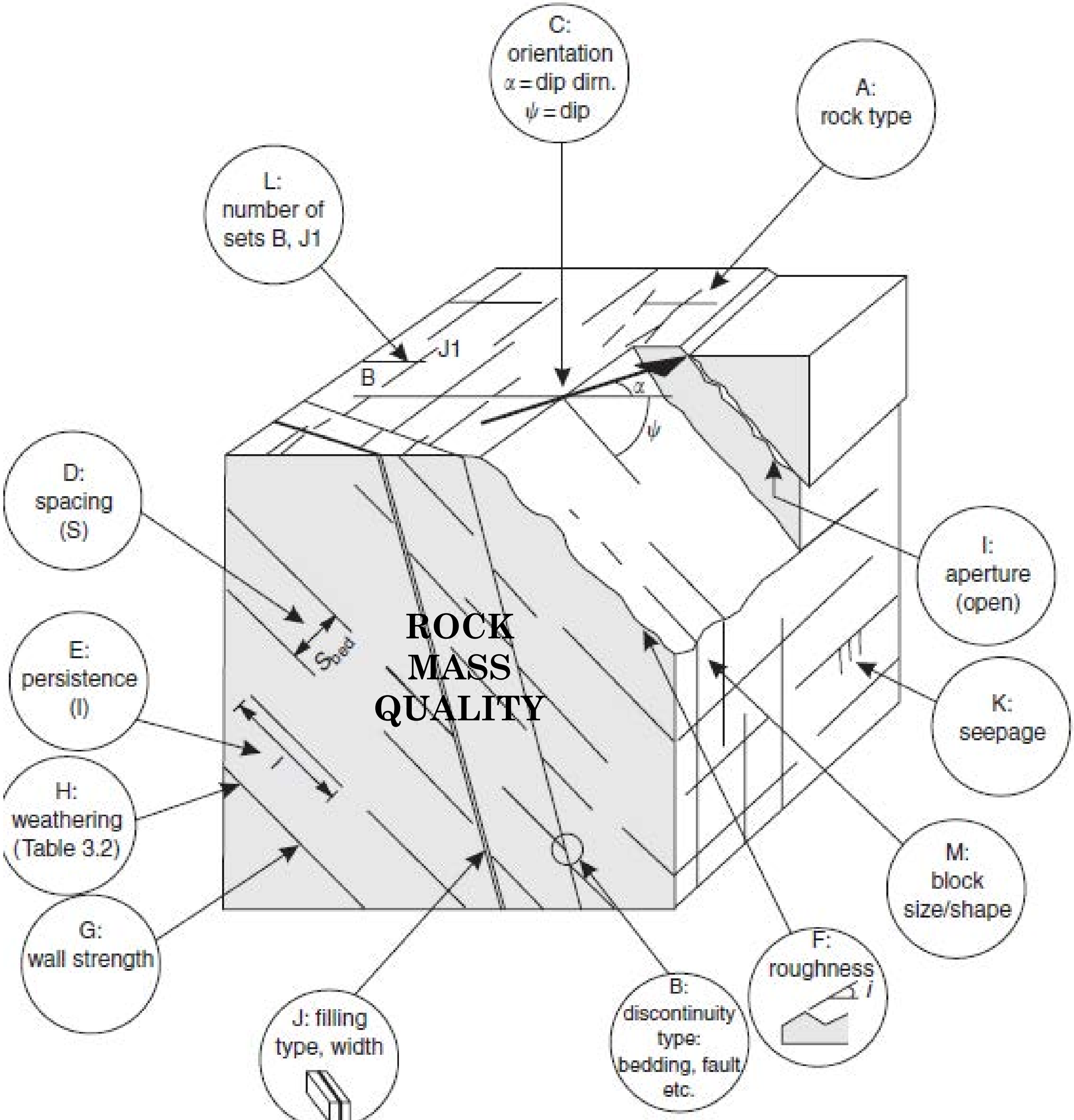
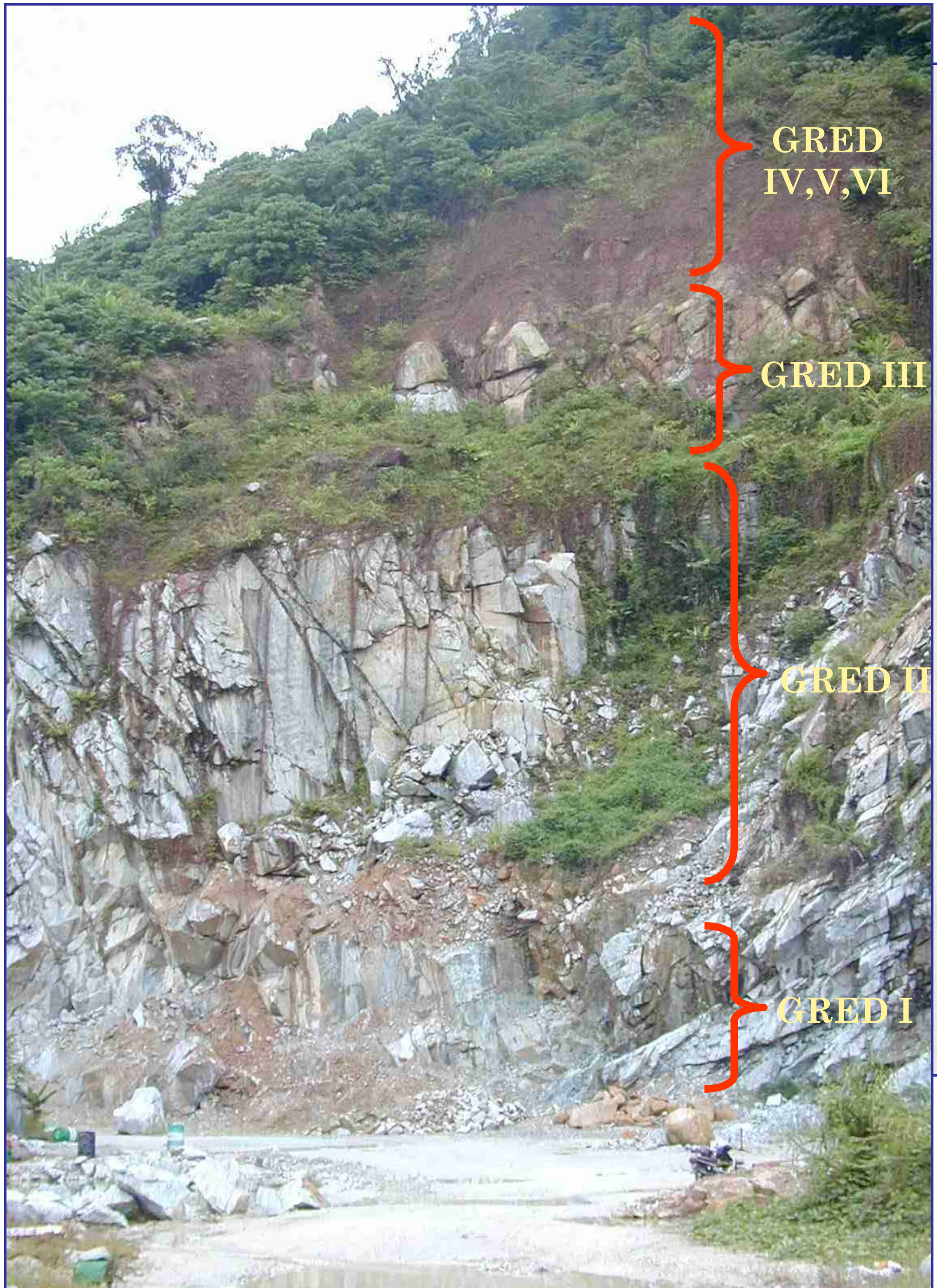
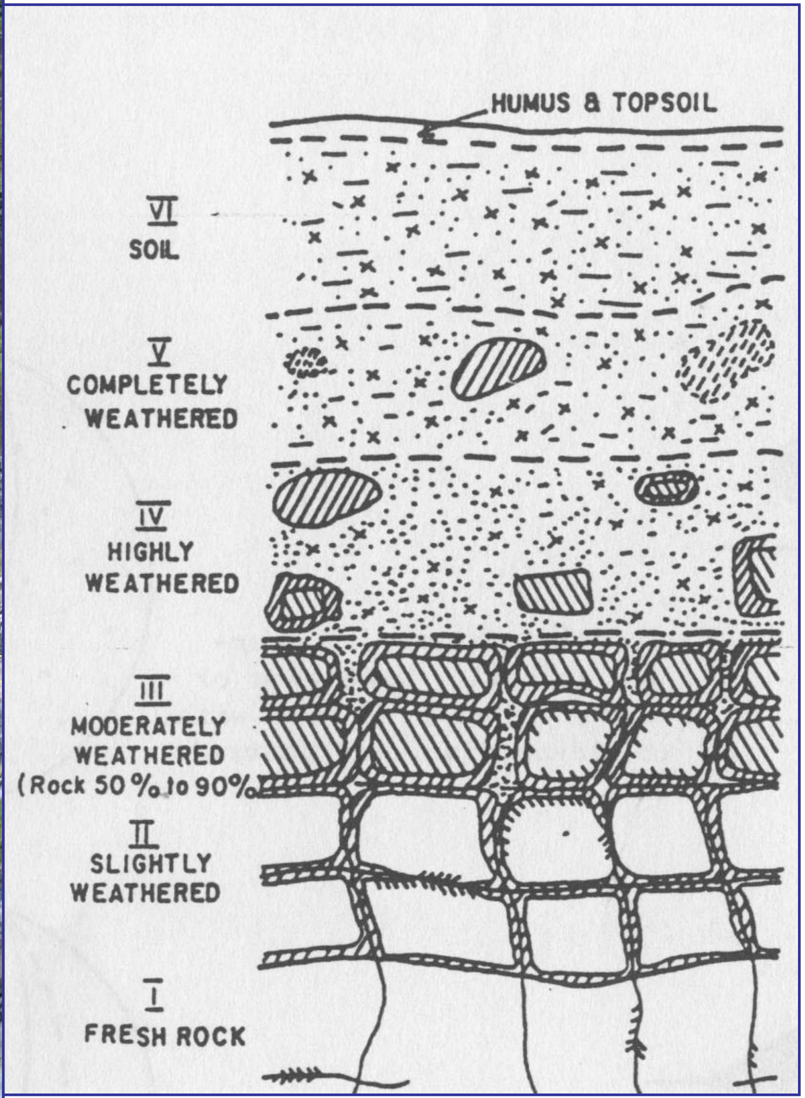


Figure 2.27
The rock cycle.


ROCK MASS QUALITY
C: orientation α = dip dirn. ψ = dip
A: rock type
L: number of sets B, J1
J1
B
α
ψ
D: spacing (S)
S_{bed}
E: persistence (l)
l
H: weathering (Table 3.2)
G: wall strength
J: filling type, width
B: discontinuity type: bedding, fault, etc.
F: roughness
i
M: block size/shape
K: seepage
I: aperture (open)


GRED IV,V,VI
GRED III
GRED II
GRED I


HUMUS & TOPSOIL
VI
SOIL
V
COMPLETELY WEATHERED
IV
HIGHLY WEATHERED
III
MODERATELY WEATHERED
(Rock 50% to 90%)
II
SLIGHTLY WEATHERED
I
FRESH ROCK

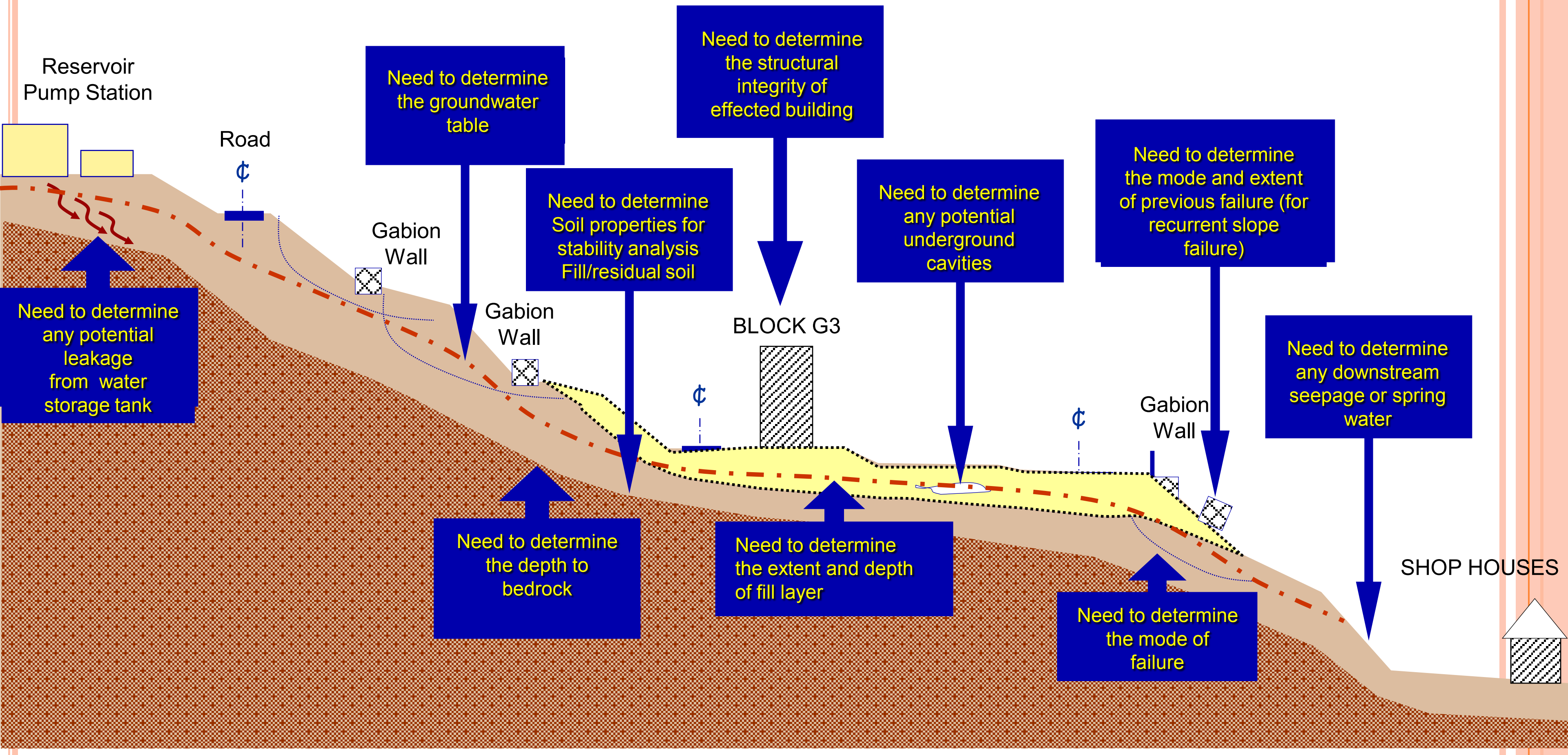
6.0 General Input on Unreinforced Slope Stability Analysis

6.1 Compliance with JKR Need Statement

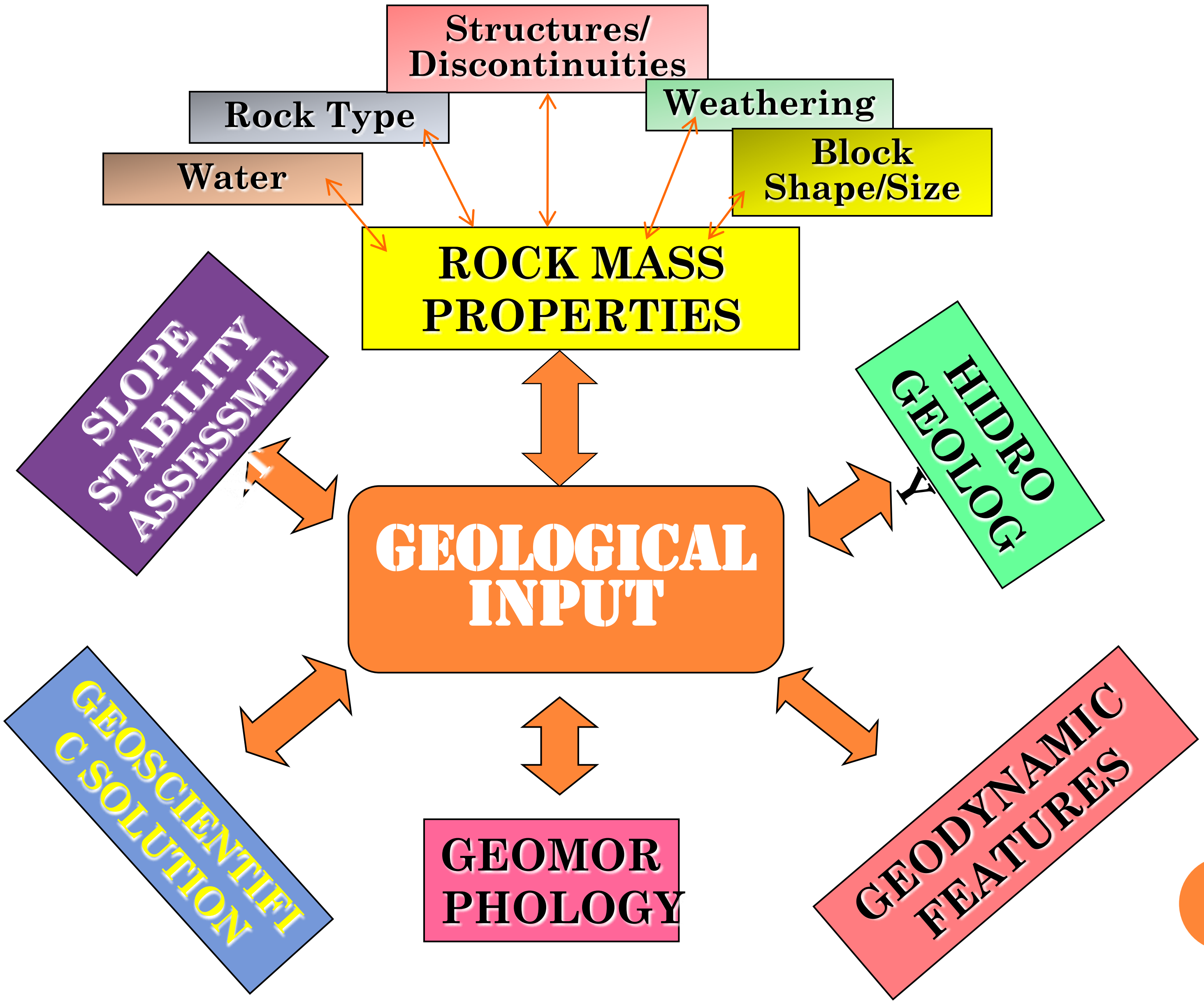
DESIGN COMPONENT		MODE OF FAILURE	MINIMUM FACTOR OF SAFETY	DESIGN LIFE (durability of materials)
1. Slope / Embankment (not on soft ground)	Unreinforced	1.1 Local & Global Stability	1.3	75 yrs
	Reinforced or Treated	1.2 Local & Global Stability	1.5	75 yrs
2. Embankment on Soft Ground		2.1 Bearing (short term) 2.2 Local & global slope stability (short term) 2.3 Local & global slope stability (long term)	1.4 1.2 1.3	75 yrs

TYPICAL SLOPE DESIGN CRITERIA FOR ROAD WORKS

6.2 What To Look For ?



6.3 Geological Input



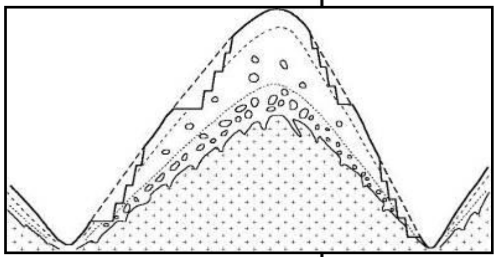
6.4 Consideration on Unreinforced Slope Stability Analysis

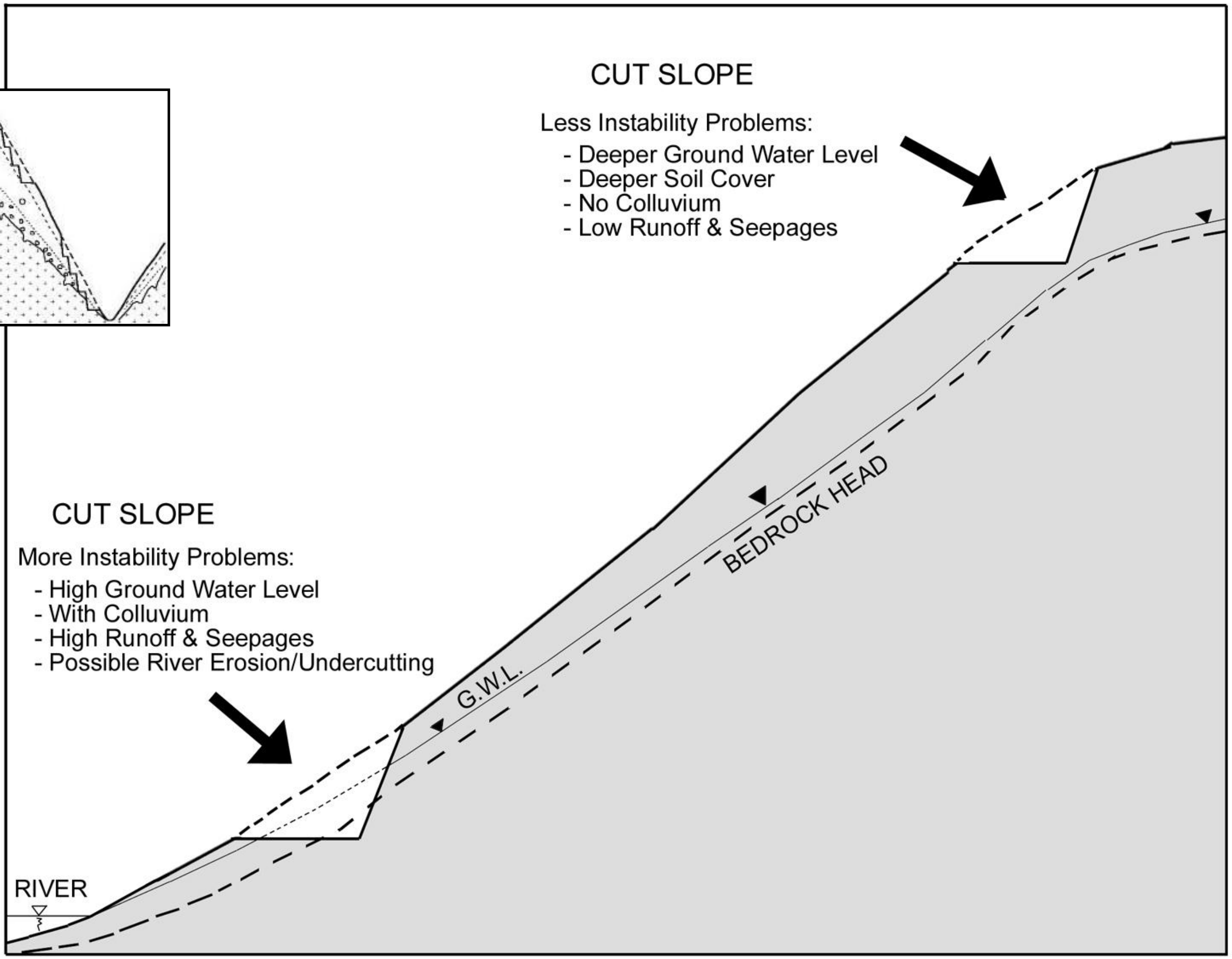
i. Surface Failure?
   - For fill slope, usually circular after saturation.
   - For cut slope, usually shallow translational unless deep saturation or presence of massive relict joints / bedding, foliation, day-lighting, fault lines, etc.

ii. Realistic soil parameter (shear strength)?
   - For fill slope
   - For cut slope

iii. Ground Water Level?

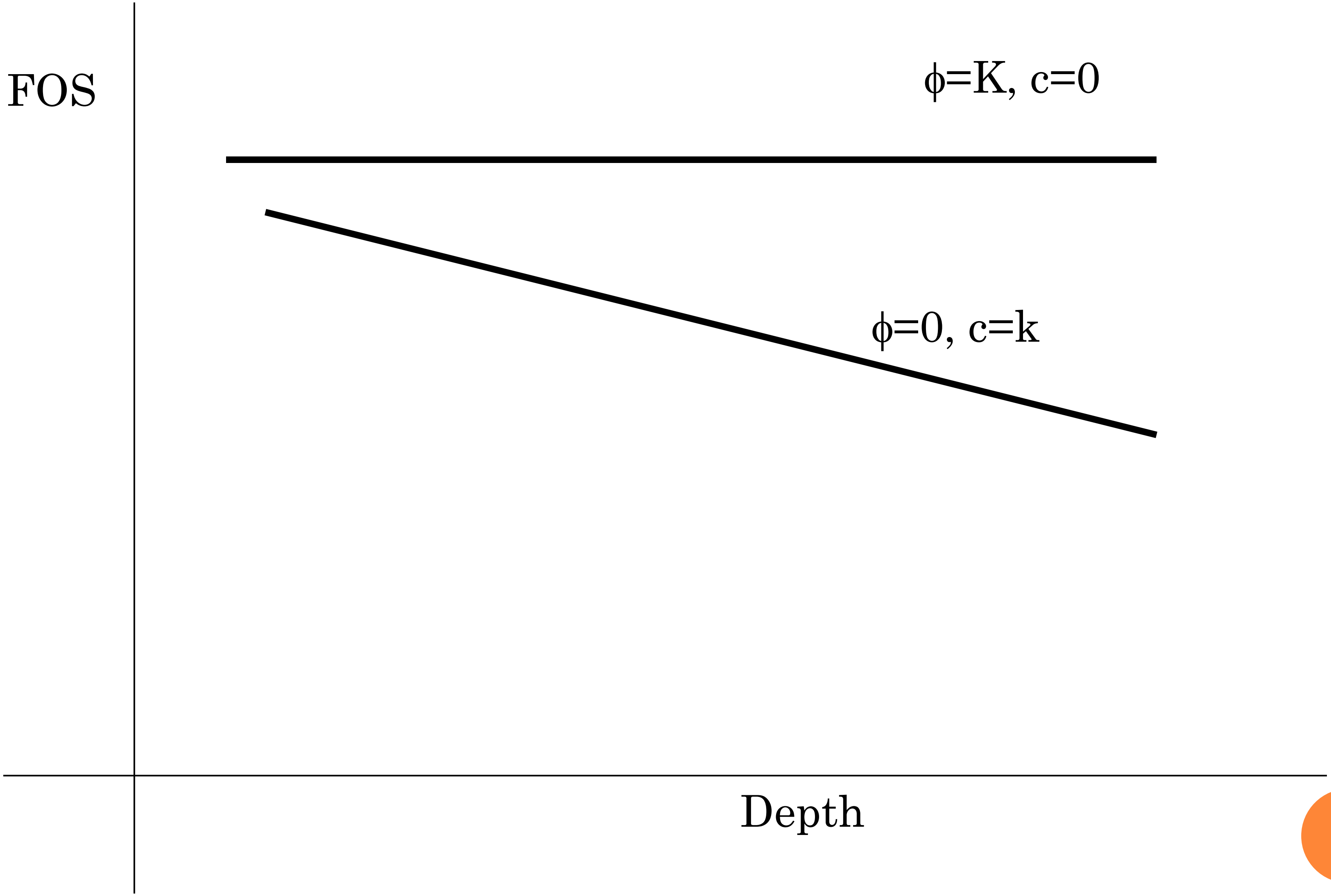
iv. Assumption & Verification of the Design?





v. Cut slope on hillslope morphology and the anticipated geotechnical problems

6.5 ϕ', c', DEPTH and Slope Stability



Civil engineers are expected to make calculations to check the safety of slopes (slope stability analysis), it involves determining and comparing the shear stress developed along the most likely rupture surface with the shear strength of the soil. Generally, the factor of safety is:

$$FOS = \frac{\tau_f}{\tau_d} = \frac{c + \sigma' \tan\phi}{c_d + \sigma' \tan\phi_d}$$

τ_f: *average soil shear strength*

τ_d: *average shear stress along potential failure surface*

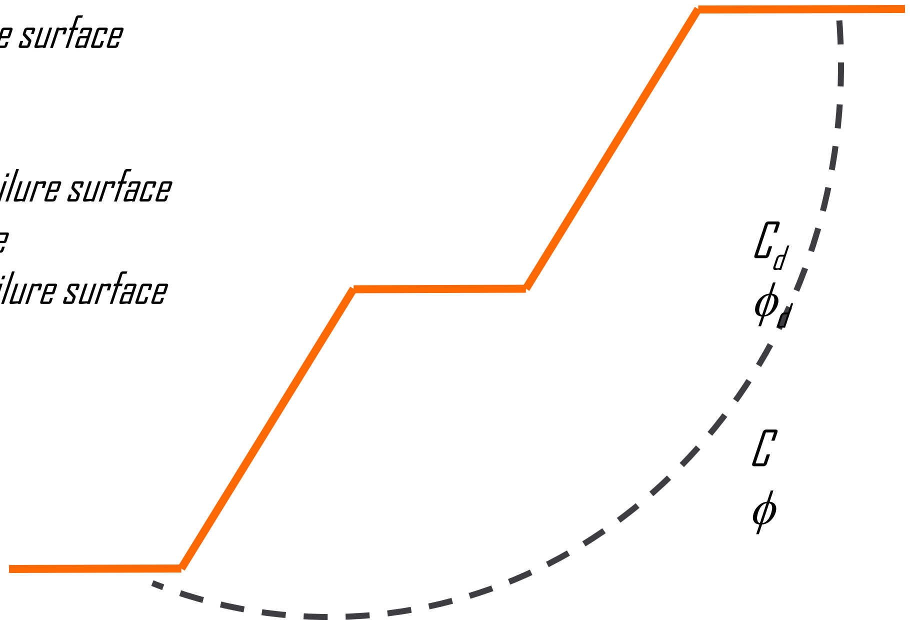
C: cohesion

ϕ: *drained angle of friction*

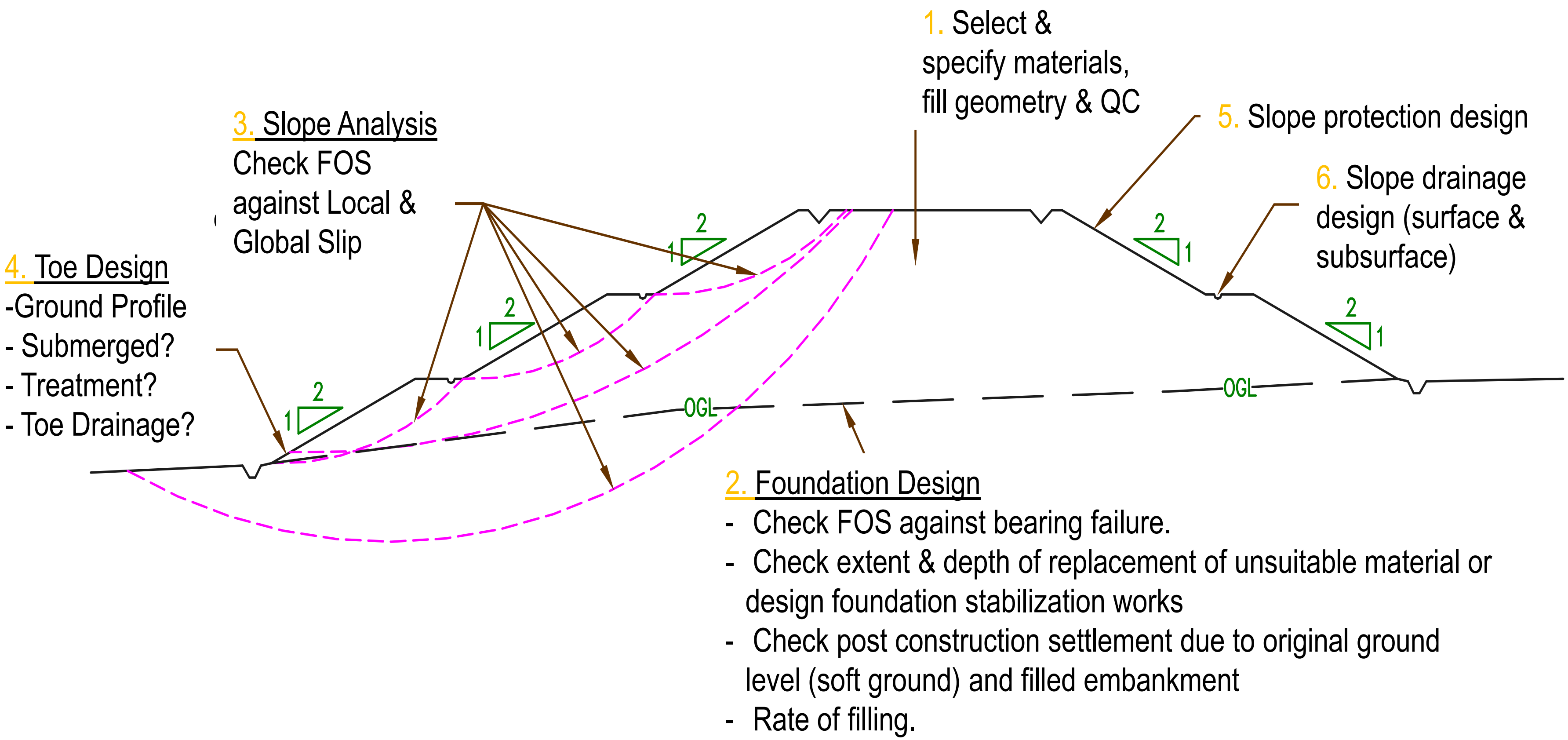
σ' : *effective normal stress on the potential failure surface*

C_d: *cohesion along the potential failure surface*

ϕ_d : *drained angle of friction along potential failure surface*



6.6 Design Procedures



7.0 Ground water regime effect

- Water pressures will encounter if groundwater lowering is not carried out in the long term.
- Bulk density may be increased below the water table.
- Rise in groundwater leading to increase in the load to be supported (accounted in design).
- Construct of drainage system can lowering the groundwater table.
- To reduce or eliminate porewater pressure: construct/install weepholes, horizontal drains, permeable filter blanket, inclined drains, etc.

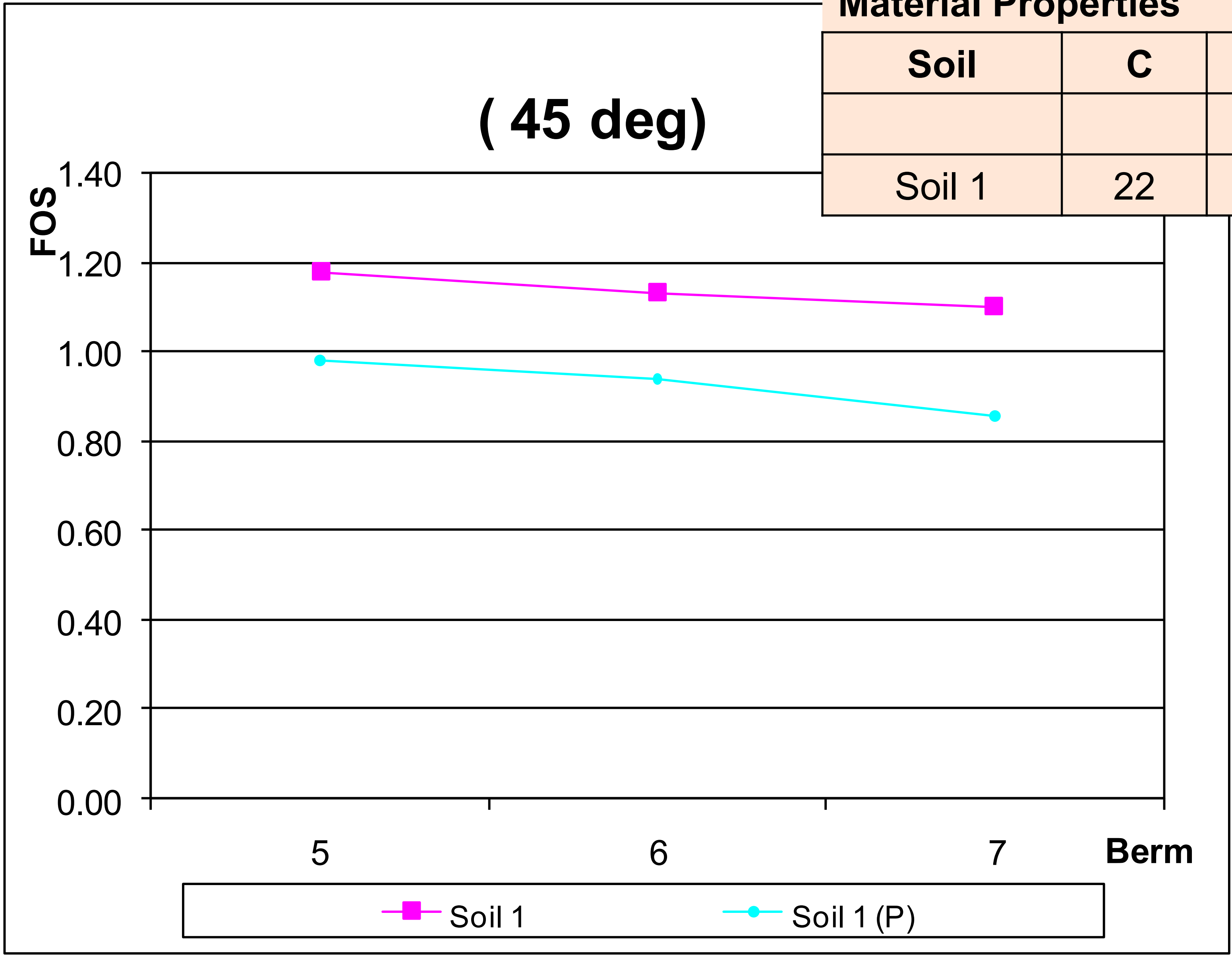
- Flow of water through soil is evaluated on the basis of the Darcy's Law, Q = k.i.A, where

  k : *permeability*   i : *hydraulic gradient*   A : *cross sec. area*
- Stand-pipe or piezometer can be used to measure water level under the ground.

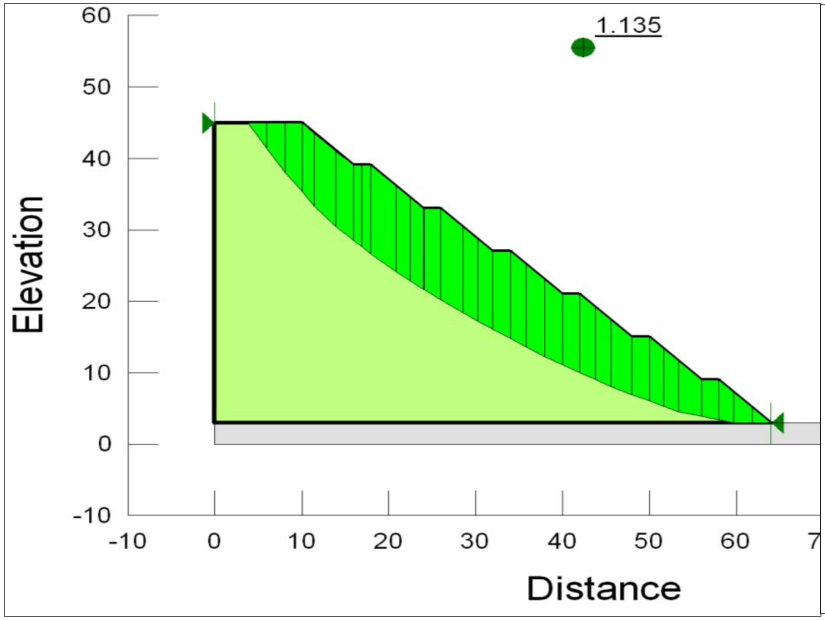
φ', c', PWP, Berm and Slope Stability

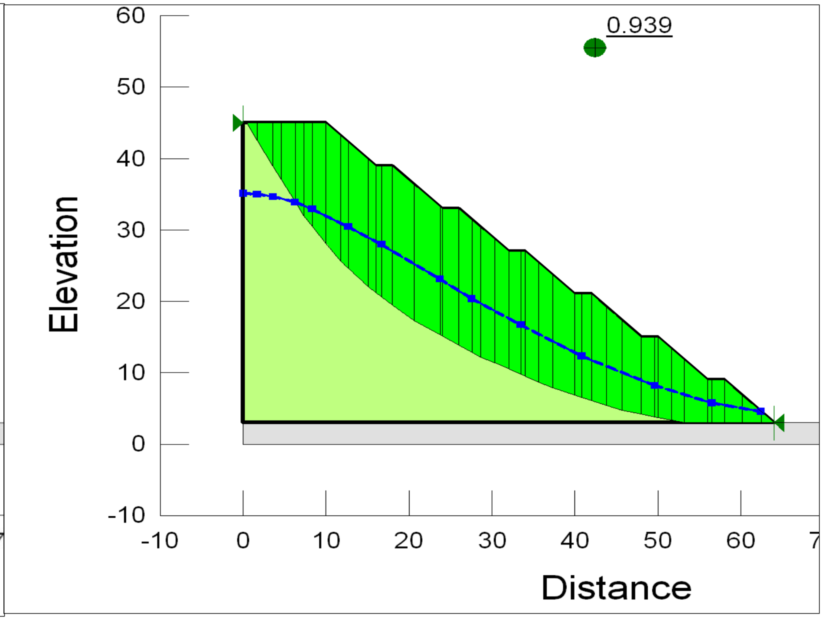
Material Properties

Soil	C	Phi
Soil 1	22	28



Soil 1: Phi=28, c=22

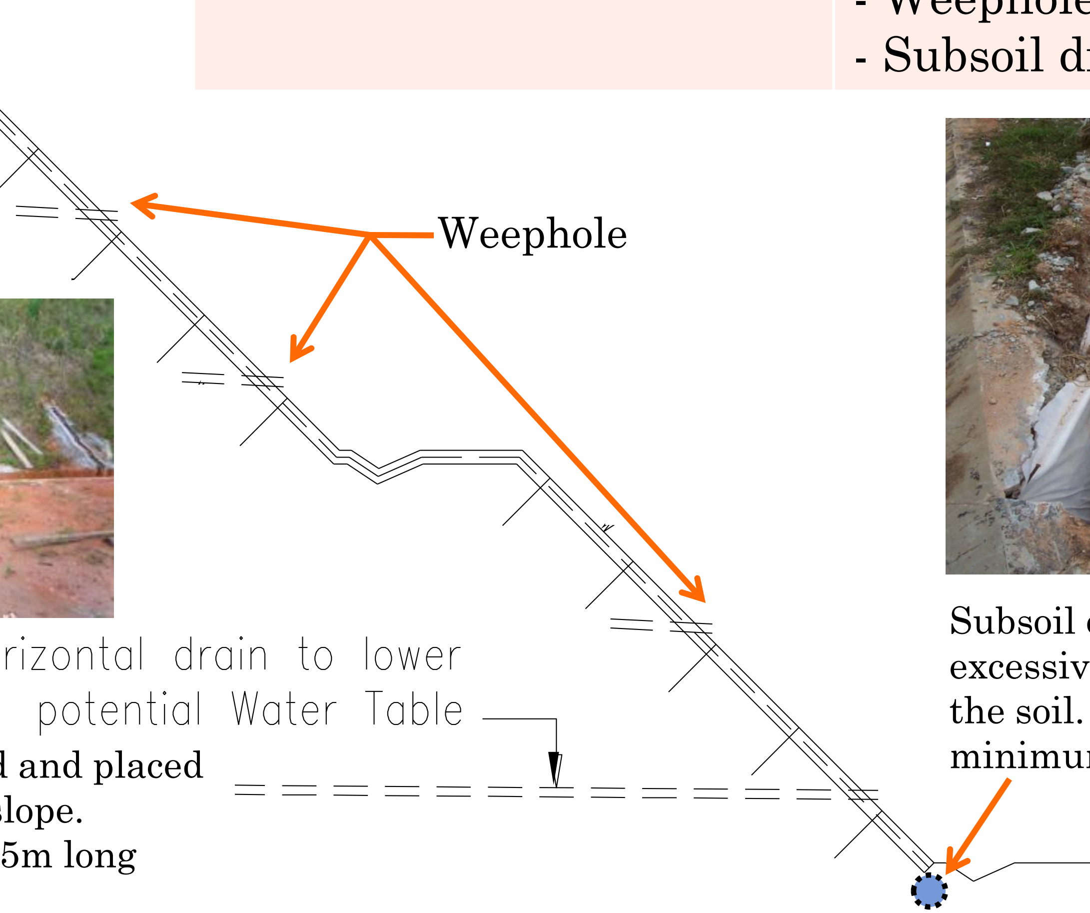




8.0 Basic of Drainage System for Unreinforced Slope

8.1 Basic Sub Surface Drainage System Required

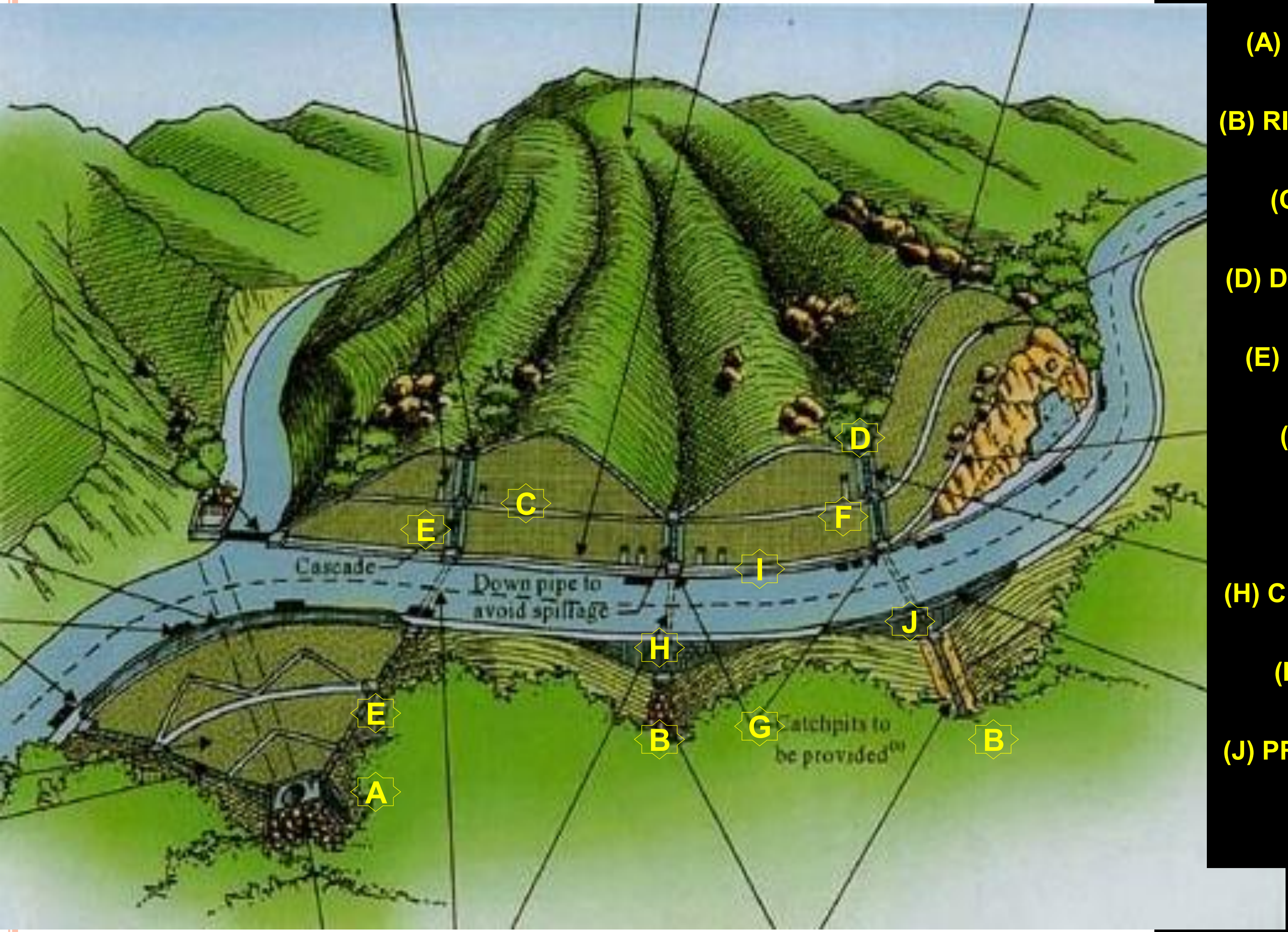
Sub-Surface Drainage	
Fill Slope & Embankment	Cut Slope
- Subsoil drain	- Horizontal drain - Weepholes - Subsoil drain



- Slope upward and placed low into the slope.
- Usually 6 – 25m long

Subsoil drain remove excessive water from the soil. Diameter minimum at 75mm.

8.2 Handling of Surface Water ?



(A) OUTFLOW APRON

(B) RIP-RAP (DISSIPATOR)

(C) BERM DRAINS

(D) DRAINAGE CHANNEL

(E) CASCADE DRAINS

(F) DOWNPIPES

(G) CATCHPITS

(H) CROSSROAD DRAINS

(I) TOE CHANNEL

(J) PREVENT OVERFLOW

ETC

8.3 Drainage System For Slope in General

9.0 Slope Surface Protection Type

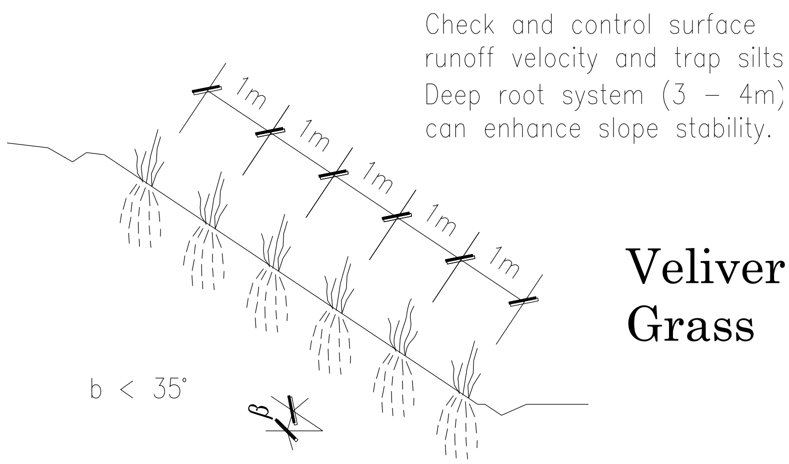
9.1 For Fill Slopes and Embankments

- Turfing
- GeoCell or MiraCell
- Rock Mattress and Gabion Mattress
- Surface Protection Mat

9.2 For Cut Slopes

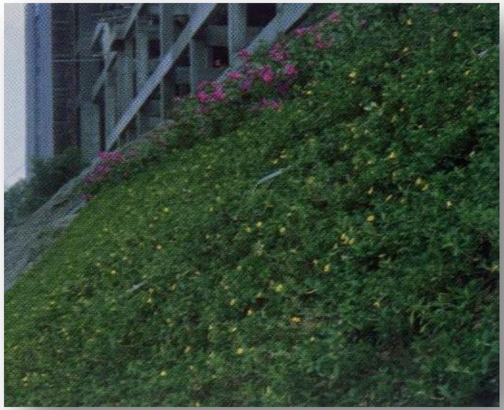
- Turfing
- GeoCell or MiraCell
- Rock Mattress and Gabion Mattress
- Surface Protection Mat
- Ruble Pitching and Stone Pitching
- Guniting and Shotcrete
- Rock Netting

Turfing



Veliver Grass

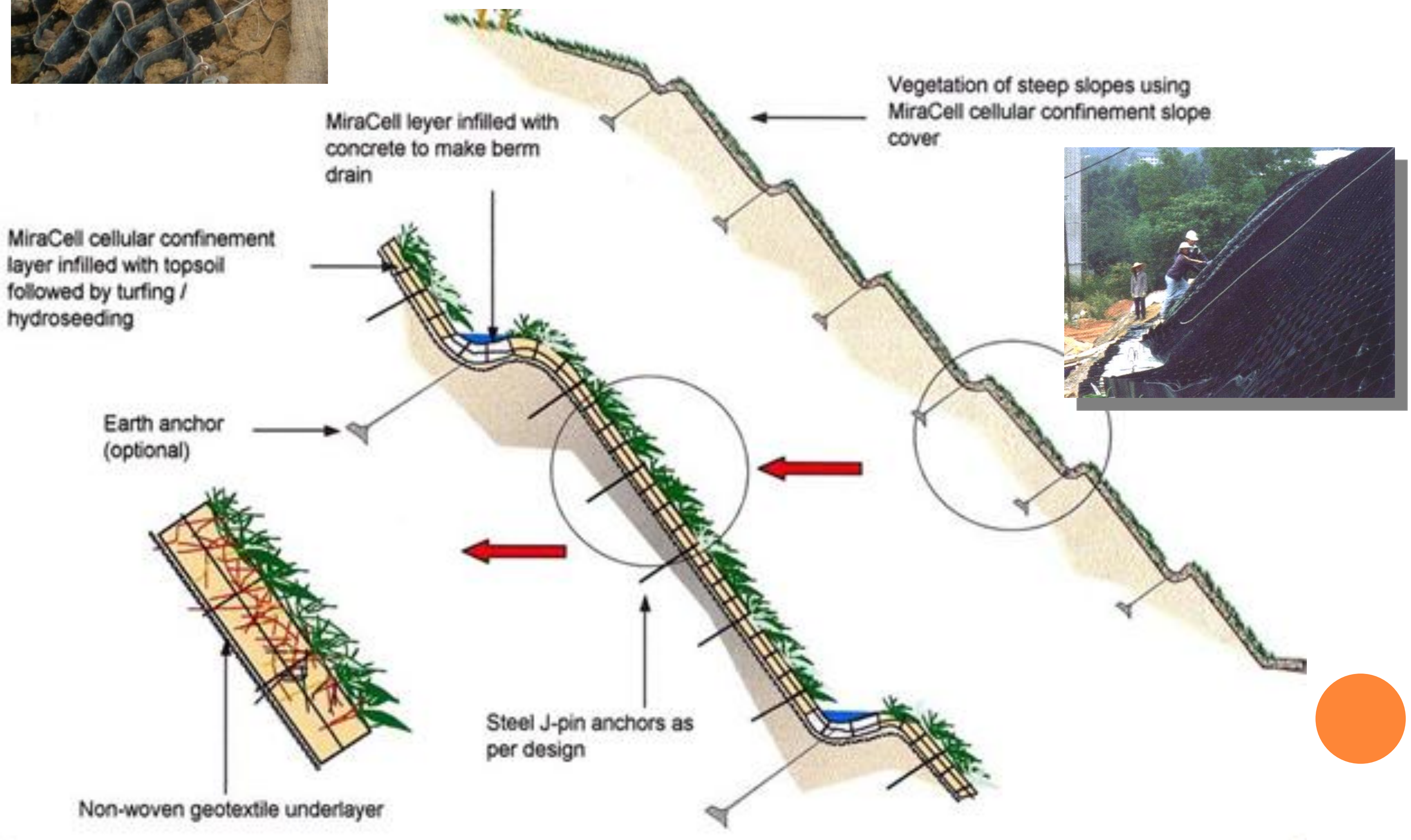
Hydroseeding



Close turfing

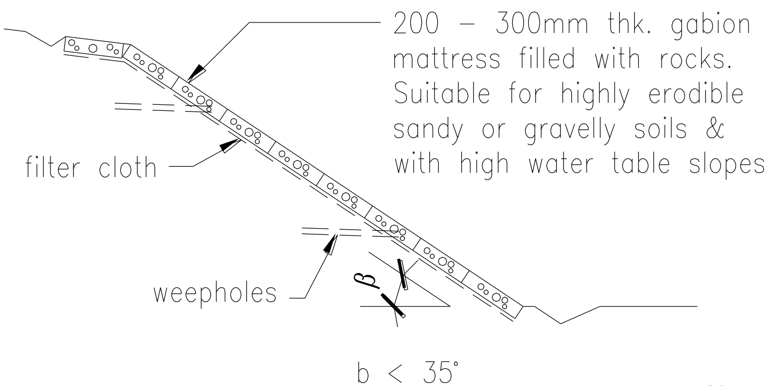
Note: Spot turfing is not aloud on any slope surface.

MiraCell / GeoCell



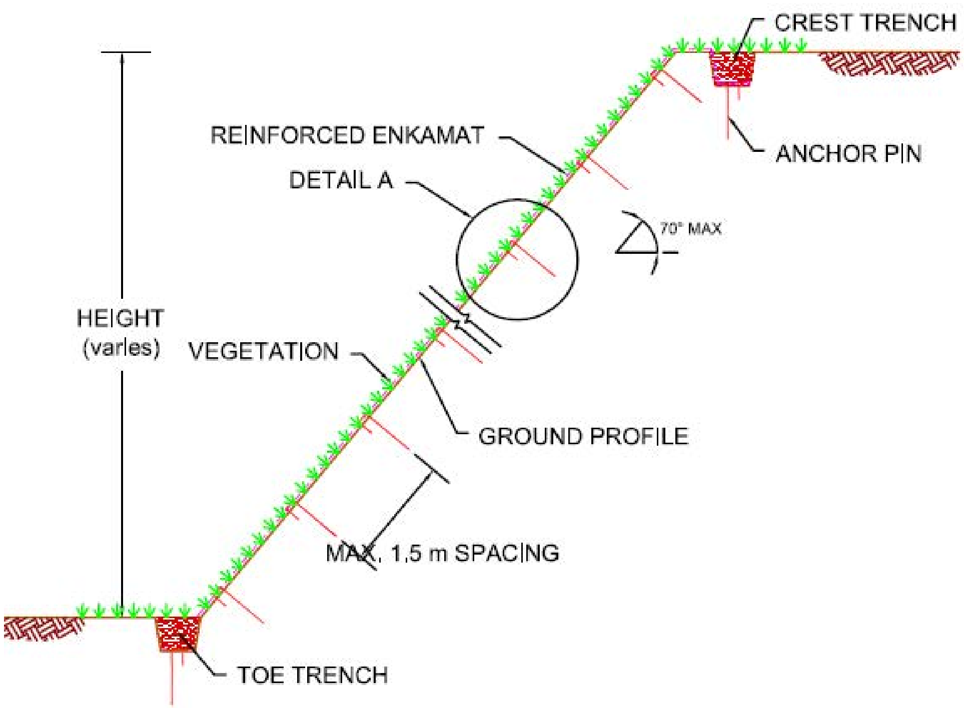
SURFACE PROTECTION MAT

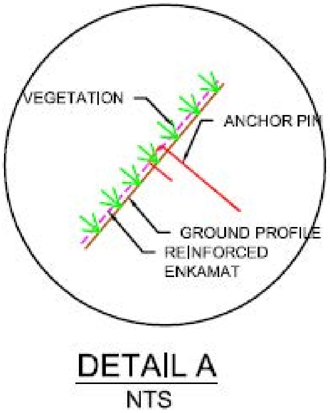
Fibromat



Gabion Mattress and Rock Mattress

Reinforced Enkamat





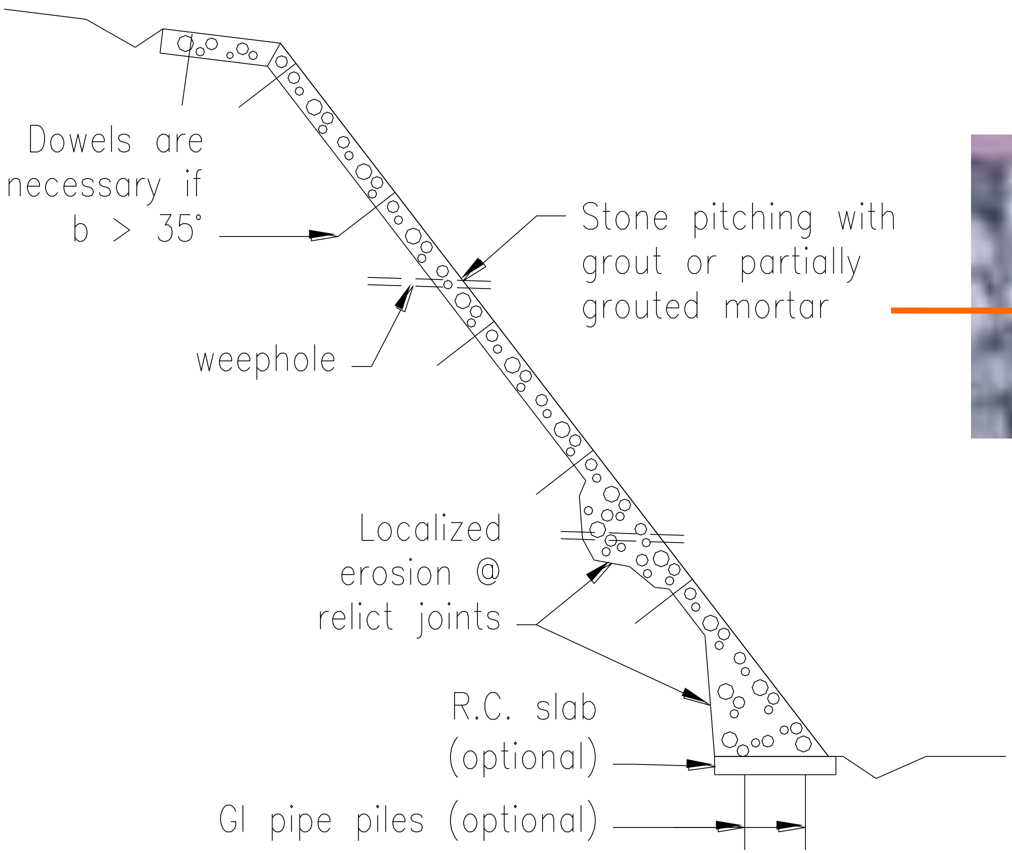
Guniting

- The process of spraying dry mix cement/sand mortar pneumatically at high velocity on soil or rock surface of slopes.
- Consists of dry cement (360-600kg/m3), sand (< 4mm size) and water;
- Comparatively smaller machines and compressor; applicable for thinner section and smaller output (0.5m3 – 2m2/hr);
- Dry mix (W/C = 0.45 – 0.50, to control shrinkage and crack problems).
- BRC A5 or A7; 75 – 100mm thick gunite.
- Enhance stability via reduction in infiltration and preservation of suction.

Shotcrete

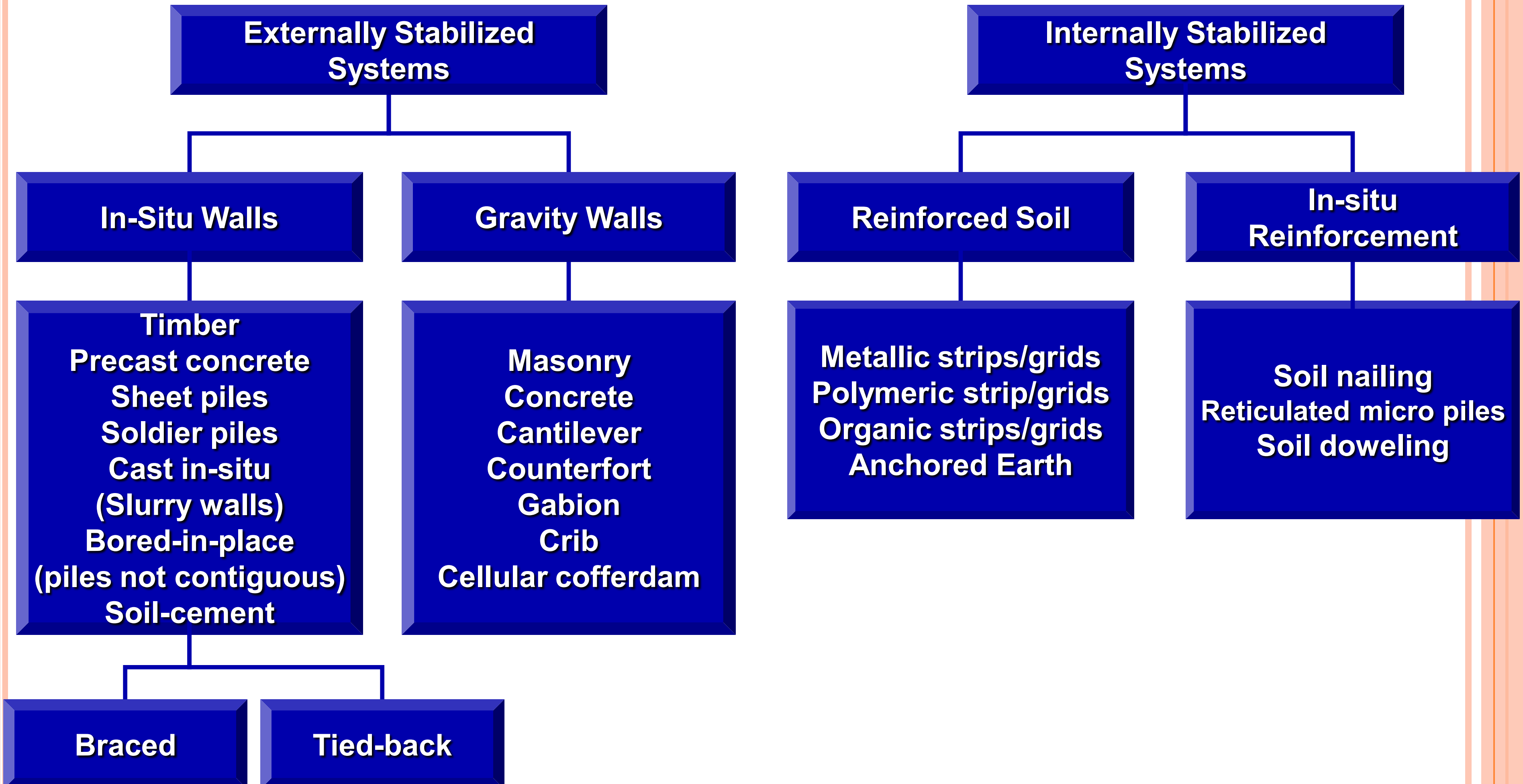
- Can be dry or wet mix, with aggregate size up to 15mm with more economic cement content (300-450 kg/m3)
- Requires very large machines but higher output (2-10m3/hr).
- More applicable for very thick section up to 400mm or more.

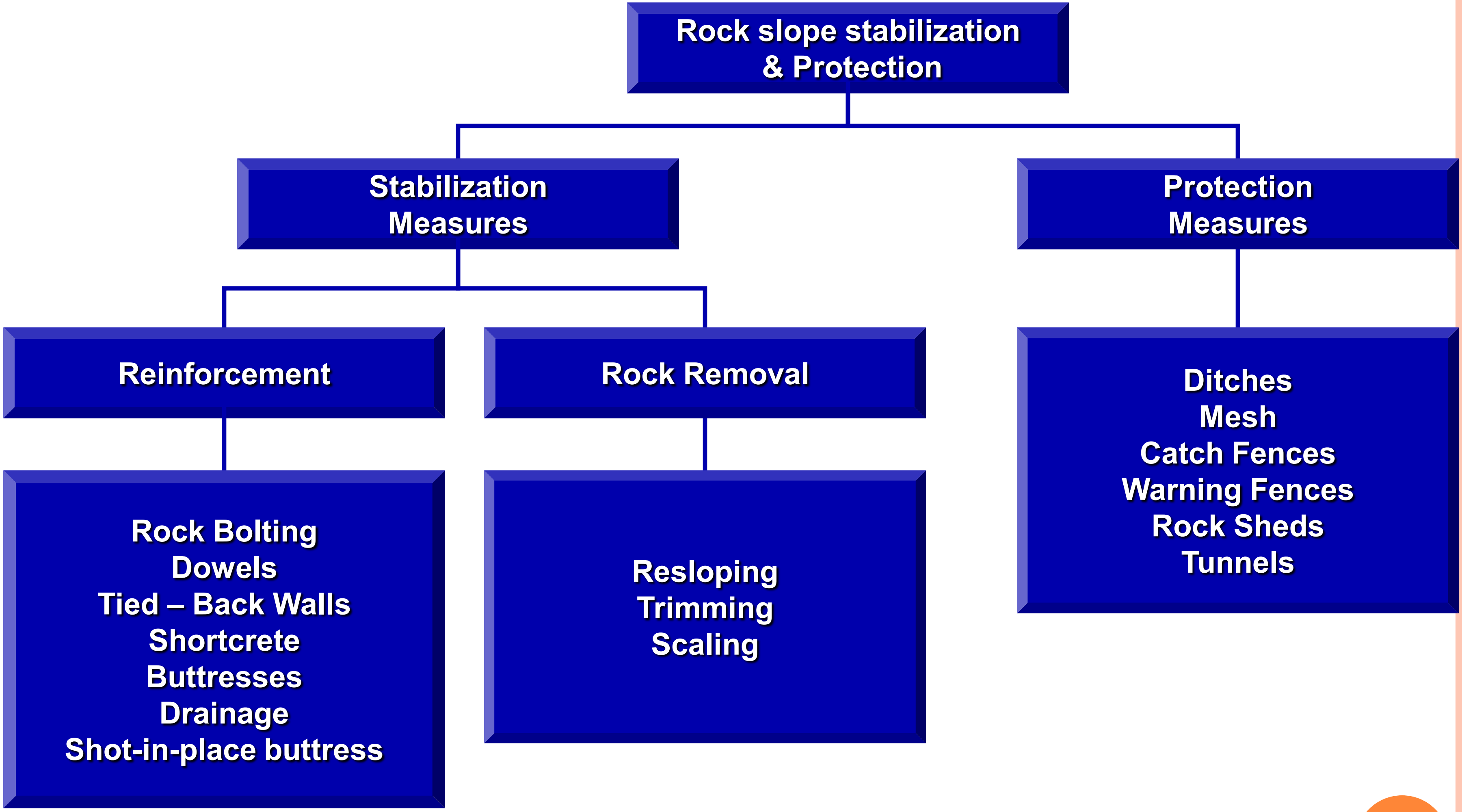
Stone Pitching



Rock Netting

- Rockfall protection netting is a hexagonal woven wire mesh, supplied in rolls 2m wide and 25m in length.
- Rock netting is draped down rock escarpments, secured at the top to guide falling rocks safely to the toe of the escarpment.
- Alternatively it can be pinned back to the rock face to retain loose spalling rocks in place.
- A woven mesh is preferable to a welded mesh as it can follow the contours of the rock face.


Externally Stabilized Systems
In-Situ Walls
Gravity Walls
Timber
Precast concrete
Sheet piles
Soldier piles
Cast in-situ
(Slurry walls)
Bored-in-place
(piles not contiguous)
Soil-cement
Masonry
Concrete
Cantilever
Counterfort
Gabion
Crib
Cellular cofferdam
Braced
Tied-back
Internally Stabilized Systems
Reinforced Soil
In-situ Reinforcement
Metallic strips/grids
Polymeric strip/grids
Organic strips/grids
Anchored Earth
Soil nailing
Reticulated micro piles
Soil doweling


Rock slope stabilization & Protection
Stabilization Measures
Protection Measures
Reinforcement
Rock Removal
Rock Bolting
Dowels
Tied – Back Walls
Shortcrete
Buttresses
Drainage
Shot-in-place buttress
Resloping
Trimming
Scaling
Ditches
Mesh
Catch Fences
Warning Fences
Rock Sheds
Tunnels

10.0 Example Construction Sequences

- Gravity Wall
- RC Cantilever Wall

10.1 Construction of Gabion Wall At Taman Hill View, Ampang

10.2 Construction of Rock Toe at KM 27.1 FT 068 Gombak-Bentong

10.3 Construction of RC Cantilever Wall

Inputs

Manpower
- Site Engineer
- Technical Officer
- Surveyor
- Operators
- Suppliers
- QSE officer
- Skilled labours

Machineries & Tools
- loaders
- dump trucks
- Shovels
- crow bars
- level instrument
- Concrete mixer
- Vibrator
- Safety equipments
- Traffic mandatory

Materials
- Cement
- Steel
- Fine Aggregate
- Coarse Aggregate
- Plywood sheets

Media
- Construction site
- Safe working environment

Methodology
- Schedule of the work programmed shall be included excavation work, formwork, reinforcement installation, concreting, backfilling, quality assurance, safety and environment control. It shall in line to the contract period.

i) Excavation
- Limits of the excavation to be identified from the drawing. Barricades with warning signs around the excavated area.
- Required levels and lines set out by the surveyor.
- Stock pile properly all suitable material
- unsuitable material would be disposed to a suitable disposal location.

ii) Formwork
- Wall section by 12mm thick plywood sheets. Firmly joint, edge to be supported by 2"x2" timbers.
- Outer surface to be supported by 2"x2" timbers at their centers to avoid undesirable movements.
- Form work sheets in wall section to be tight by tie rods.

iii) Reinforcement
- For bottom vertical portion of the foundation, arrangement in the active and passive side.
- Required lapping with previous bar arrangement at 1/3 of the wall height from bottom or top.
- Place PVC pipes inside in a spacing according to drawing for providing of weep holes. It encloses by geotextile and stone packing.

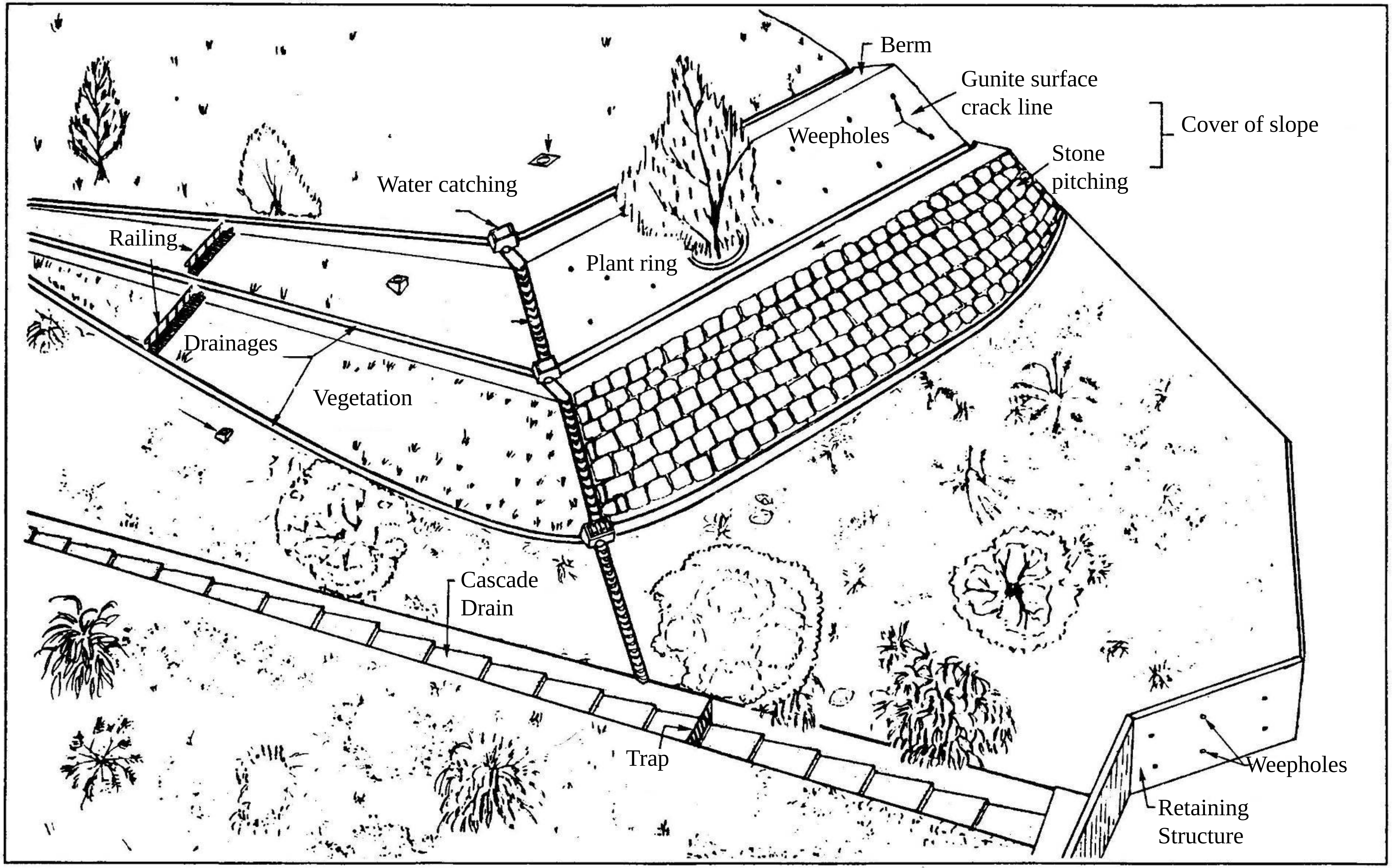
iii) Concreting
- Remove all the unsuitable matters.
- Test the slump mix.
- 1 set of cubes made per $10m^3$ concrete. At least 1 sample taken by engineer each day and test (7 & 28 days).
- Place concrete in successive layers (apply vibrator).
- Curing would be done for base concreting after 24 hrs of concreting.

iv) Backfilling
- Behind the structure
- Suitable filling materials
- Compaction in successive layers (apply vibrator)

v) QSE
- Ensure all activities being performed with the expected quality; an inspection check list to be filled by QSE officer.
- Environment: slope cutting, rules/ noise and pool area pollution prevention/ disposal.
- Safety: equipment/ first aid/ induction/ housekeeping.
- All traffic safety arrangements be implemented as specified.

11.0 Slope Maintenance

What Shall Maintain ?



Do & Don't

Do & Don't

Do & Don’t

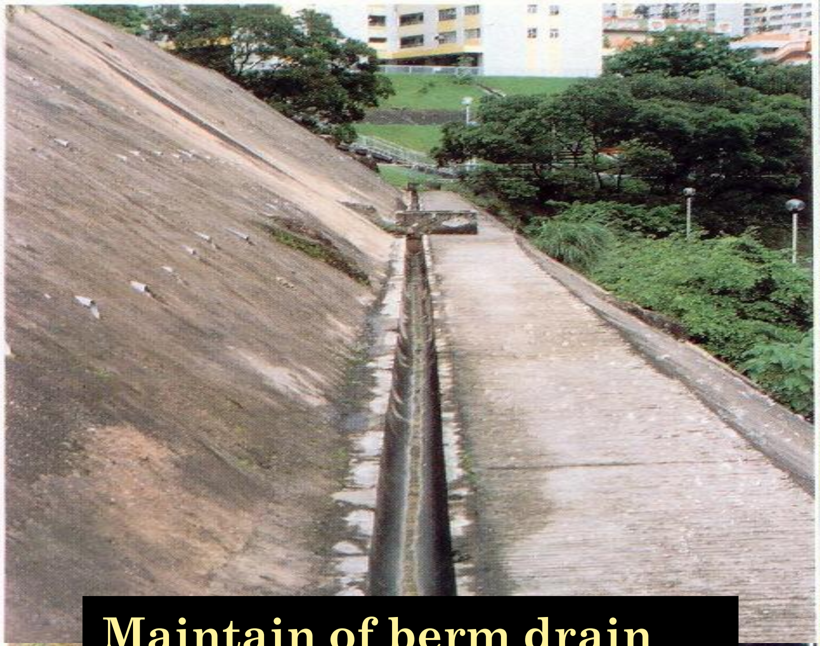
Change the temporary cover (plastic) immediately and repair the slope

Do & Don't

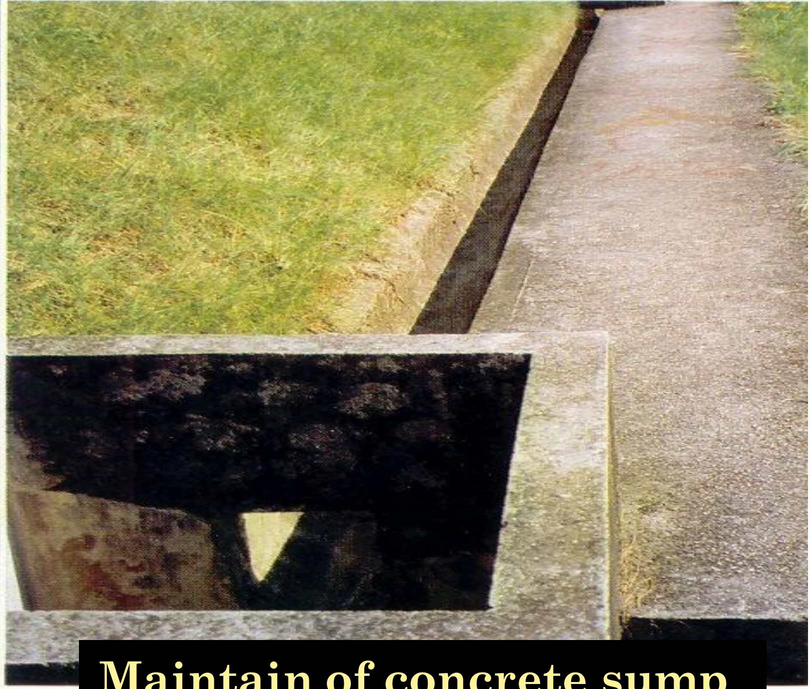
Do & Don't

Do & Don't

Do & Don't

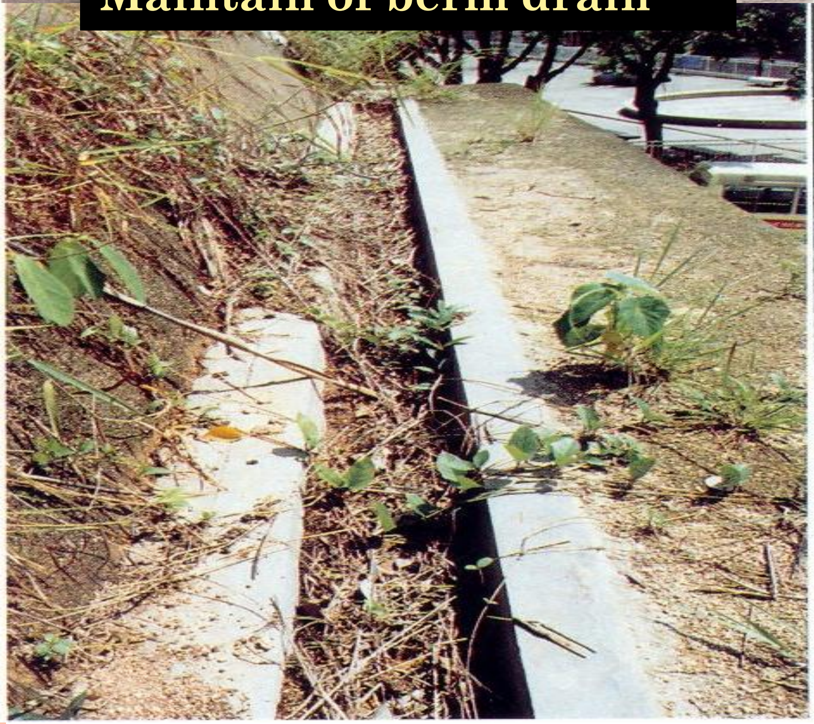


Maintain of berm drain



Maintain of concrete sump

✓



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Thank You

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Rock Slope Engineering (Duncan C Wyllie & Christopher W Mah)
Earth Pressure & Earth-Retaining Structures (CRI Clayton, J Milititsky, RI Woods)
Mekanik Tanah (RF Craig)
Fundamentals of Geotechnical Enginerings (Braja M Das)