Slope protections and improvements

Slope face protection methods, turfing and drainage system and the use of geotextiles.
THE PRINCIPAL TYPES OF WATER EROSION

- SHEET
- RILL
- GULLY
Sheet erosion

- impact of falling rain drops
- removed by surface runoff
- uniform removal of a thin layer
- occurs on smooth soil surface
- uniform slope
- only a few millimeters of soil are removed during each rainy season
- transformation of the soil from a dark to a lighter colour
Rill erosion

- Detachment and transportation of soil particles are greater than in the sheet erosion
- due to acceleration of the moving water
- amount of soil particles detached by moving water is proportional to the square of its velocity
- soils erode downwards and may extend into the subsoil
RILL EROSION
Gully erosion

- among the most spectacular and damaging form of erosion
- ugly scars on the landscape
- reduce the economic value of the land, damage installations and completely devastate the agricultural potential of the land
- gully development is closely related to the amount and velocity of runoff water

- The cross sections of gullies are either
  - V - the subsoil is resistant to rapid cutting because of fine soil texture or compactness
  - U - both the surface soil and the subsoil are easily eroded
Illustrated Erosion Types:

- Raindrop Erosion
- Sheet Erosion
- Rill Erosion
- Gully Erosion
- Channel Erosion
SOIL EROSION FEATURES

- **SHEET**: Washing of surface soil from lands
- **RILL**: Water concentrates into small channels in the expose areas
- **GULLY**: Eroded channels are larger
• Purpose of slope protection is to protect the slope against erosion by surface runoff, to reduce infiltration and also to enhance slope landscape with environmental friendly outlook.

• Slope protection is very crucial to enhance slope stability.
• Successful slope protection mainly depend on the appropriate selection of methods, proper specifications, proper construction and good maintenance.
“Soft” Landscape Treatment For Slope

- Planting of shrubs and herbaceous plants at the toe of the slope with creepers or climbers covering the slope face
- Mature trees close to slope should be well maintained and blended with ornamental shrubs on slope
- Climbers on the treated slope face and decorative trees and shrubs immediately in front
Decorative facing of retaining wall. Toe planter for trees and shrubs

Artificial rock and stone from Fero-cement. Can be used to decorate gunited wall or retaining wall

Artificial rock can be used to blend the surrounding natural landscape

“Hard” Landscape Treatment For Slope
MULTILAYER GEOWEB PROTECTION OF CUT SLOPE

VEGETATED GEOWEB SLOPE PROTECTION

EMBANKMENT FILL

SOIL NAIL REINFORCEMENT

NATIVE SOIL
- Geomembrane / Geotextile Underlayer
- Geoweb Slope and Crest Protection
- Geotextile Underlayer
- Vegetated Geoweb Infill
- Reinforced Earthfill Containment Dike
- Integral Polymer Tendon
- Contained Fluid
a. Turfing

Turfing with shrubs, trees and cow grass is very effective to provide immediate protection.

This method usually applied on the gentle slope (1V : 1½H) with grade 6 to 4 residual soils.
There are two types of turfing which is:

- **Spot Turfing**

  Revegetation technique where clumps of grass are planted in spots on a bare earth worked or slope area.

  Clumps of well grown grass, about 150mm diameter are placed about 100mm apart, compacted and left to grow with frequent watering.
• Close Turfing

Same as open turfing except that clumps or grass are placed near to each others in most instances, covering the entire exposed slope.

It is an effective method for surface soil erosion control where a rapid establishment of dense grass cover is required.
b. Mulching

Mulching is a method to use the plant residue, saw dust, straws or other suitable materials to cover the soil surface.

Provide a high degree of erosion control and improves moisture availability to establish plants.
The Application of Mulch on The Surface of The Slope
c. Hydroseeding

Hydroseeding without quality seedings and horizontal grooves on slope usually not successful.

Inclusion of biodegradable mat will protect the seedings and the roots of young grasses from being washed away by surface runoff or burnt by hot sun.
Typical GeoComposites – Turf Reinforced Matrix (TRM)
- The Application of TRM on the Surface of the Slope
The Application of Rolled Erosion Controls Blankets (RECB) on the Surface of The Slope
Coirlog Application for Slope Protection
Important Parameter for Hydroseeding:

- Quality controls on seedings
- Formulae application
- Spraying rate
- Slope surface preparation
Hydroseeding involves the mixing of a slurry of selected grass seed varieties, fertiliser, paper or wood pulp (cellulose fibre) and water in a large tank.
Terracing / Benching

Slope terracing/benching involves principally transforming the relative steep land (20-50%) slope into a series of level or nearly level strips, or steps, running across the slope.

Terraces reduce erosion losses by shortening slope length and by conducting water across the slope at non-erosive velocities to protect outlets.
Vertiver Grass

Vertiver grass is a coarse, tough bunch grass that grows up to 1m wide at its base. It can thrive on a range of soil. The roots hold firmly to soil particles and once established, it is very hard to uproot. This grass commonly use for slope protection.
Keystone Wall Slope
Crib Wall

Blocks of ready-made concrete structures are stacked in an interlocking manner for slope stabilization and protection. A reinforced concrete base is prepared prior to laying the blocks.

The interlocking pattern of the blocks provides ample opening between blocks to facilitate drainage of trap water behind the structure.
Reinforced Concrete Wall

A type of wall of medium strength, which is made of concrete and steel grating embedded into the concrete to give better strength.
Reinforced Earth Wall

Types of wall where soil is compacted between the two concrete wall. The concrete wall is made of interlocking concrete blocks of various shape and sizes. The reinforced earth wall is typically found in a highway construction and it used to stabilization of slopes.
REINFORCED EARTH WALL
Stone Laying Slope
Stone Pitching Slope
Reinforced Steel Anchor Wall

A structural wall where steel pins are anchored into steep slope followed by surfacing of the slope surface with concrete.
Rubber Wall

A medium strength structural wall of low slopes are made of rock cemented together in a neat orderly pattern and circular pipes are embedded at various point in the wall for release of trapped water behind the wall.
Plastic Sheet

A plastic sheet of durable strength and specified thickness is used to cover bare areas and it is limited to small area only for temporary surface protection.

For better protection, the plastic sheet should be embedded into the top part of the slope or topped with heavy rock to keep it in place.
Geotextile

Several types of geotextiles (geofabric or geocloth), netting woven from natural fibre such as jute or made from artificial fibre such as nylon, are now manufactured commercially for use in erosion control.

They are supplied in rolls, unrolled over hill slope from the top and anchored with large pins or stapled.

Geotextiles are designed to give temporary stability on roadsides and on steep slopes until such times as vegetation has a place to settle.
Geosynthetics Application in Landscape Treatment

Geotextiles
- Non-woven
- Woven
- Knitted

Geogrids

Geocomposites
- Geocell
- Geonet
- Turf Reinforced Mats
- Composite of geosynthetic material

“Geo-others”
- Threaded soil masses
- Polymeric anchors
- Encapsulated soil cells
Geotextiles Application on Slope Area
• Guniting

Guniting or shortcrete is expensive and is only adopted when turfing and hyroseeding cannot be effective and successful due to:

- Slope too steep (>45°) or high FOS (>1.2) is required
- Slope consists of very stiff or rocky soil (Grade 3/4/5 residual soils) or acidic soils
- Slope consists of very erodible and absorbent soil (sandy and silty soils or highly fractured weathered rocks)
- Slope consists of a lot of loose fractured rocks / boulders or relict joints

- Slope consists of permeable soil (colluvium) there is requirement to reduce infiltration and the stability cannot be improved by flattening the slope.
Adequate subsoil drainage should be provided (short horizontal drains 0.3m to 1m drains @ 1.5m spacing should be adequately provided, especially where water is observed seeping from the surface or where water seepage may be expected.
Typical gunite slope protection should consist of minimum 75mm to 100mm thick sprayed cement/sand mixture (1:3) with a layer of wire mesh (A4 or A6) to reduce shrinkage and thermal cracking.

Guniting if properly designed, constructed and maintained can preserve the soil suction which can be great contributor to slope stability.
Drainage System

• To control the flow of water by spreading and ponding

• By means of collect surface runoff from slope as much as possible and convey away from the slope as fast and as far as possible so as to reduce infiltration and erosion cause by rainfall
Slope with FOS<1.2 or slopes with a lot of localized slips should be treated before guniting. Typical thickness of shortcrete be 100-200mm.

Guniting should be applied immediately after cutting before exposure to rain. Slopes after subjected to rains should be covered by tarpaulin for a few days for drying up before guniting.
Concrete Mixer: TT

Compressor
Capacity:
370cfm 98psi Ht<50ft.
600cfm 98psi Ht>50ft.

Operating Pressure:
50 – 70psi

Guniting Machine
Capacity: 3m³/HR
Rotation: 9 – 11rpm.

Hose: 2” ID
Length: 50m at 50psi

Water Pump
Type: Piston
Operating Pressure:
5 – 10psi above nozzle pressure
Type of drain system:

- **Catch Drain**

  Serving as temporary and permanent stormwater drainage, are usually excavated with a grader blade with the depth and width depending on the condition of the side of the drain.
• Berm Drain

These are horizontal concrete catch drain laid on the berm/terraces of steep hill slopes along the road / highway to channel flow collected from the slope surfaces to cascading drains down the slope and subsequently to catch drains at the base.
• Cascading Drain

These are concrete stepped catch drain laid on the steep terraced slope to guide flow from the berm drains down to catch drain at the base. They are effective in channelling concentrated flow down slope and thereby contributing to slope stability.
• Table Drain

Formally designed permanent concrete catch drains at the base of the slope near road sides for channelling the storm runoff to sumps traps.
Check Dam (Loose-Rock Dam)

Check dams are small dams. Constructed from either semipervious or impervious materials including timber, rock, concrete, sheet piling and sandbags, are built across gullies to trap sediments. These dams would control minor gully erosion and serve as a simple silt trap.
6 in (152 mm) drop from sides in center
2-3 in (51-56 mm) diameter stone
The factor of safety depends on both the shear stress and the shear strength therefore …… Stabilization must decrease the stress and / or increase the strength.

1. UNLOADING

- Simplest way to decrease shear stresses in slope is to unload it.
- By reducing slope height or reduce the slope angle.
- Another method of unloading involves construction of lightweight fills.
2. BUTTRESSING

- Over-excavate the proposed cut slope, then bring it back to the design grades using high-quality fill (i.e. one with higher $c$ and $\phi$ values than the natural soil).
- The size of the buttress must be such that the potential failure surfaces that pass through the buttress gain enough additional strength to raise the FOS to an acceptable value.
- And the potential surface that pass below the buttress also have an acceptable FOS.
- To meet these objectives, buttress often must include downward extensions called shear keys.
- Buttress fill is usually made up of crushed gravel or other high-quality soils.
- Buttress can also be constructed without over-excavation where they become stabilization fills placed at the toe of the slope. This is applicable especially for unstable slopes that would not tolerate steep construction excavations.
3. RETAINING WALLS

• These are structural members that maintain adjacent ground surfaces at two different elevations.
• Retaining walls can be categorised as externally stabilized system and internally stabilized system.

Externally stabilized system

• Those that resist the applied earth loads by virtue of their weight and stiffness.
• This was the only type available before 1960.
• These structures can be sub-divided into gravity walls and in-situ walls.

  Massive gravity walls.
  Made up of mortared stones, masonry, unreinforced concrete. Resisted the lateral forces by virtue of their large mass.

  Cantilever gravity walls.
  Made of reinforced concrete and thus require less material.

  Crib walls.
  Another type of gravity retaining structure. Made up of precast concrete members linked together to form a crib.

  Sheet pile walls.
  Sheet pile is a thin wide pile driven into the ground using a pile hammer.

  Slurry walls.
  Cast-in-place concrete walls by digging a trench along the proposed wall alignment and keep it open using the slurry. Then the reinforcing steel is inserted and concrete is placed using tremie pipes or pumps.
Use of reinforced concrete retaining wall to stabilize slope

Use of tieback anchors to stabilize slope

Stabilize by increase in the effective stress and dowelling effect
Grouted drilled near-horizontal holes with steel tendons

Soil nail wall to stabilize slope
**Internally stabilized system**

- Internally stabilized systems reinforced the soil to provide necessary stability.
- Being developed since 1960.
- These structures can be sub-divided into reinforced soils and in-situ reinforcement.

*Reinforced earth system.*

Soil is strong in compression, but has virtually no tensile strength. Therefore the inclusion of tensile reinforcing members in a soil can significantly increase its strength.

*Soil nailing.*

Drilling near horizontal holes into the ground, inserting steel tendons and grouting. The wall face is covered with shotcrete. Very useful when space is limited since does not required construction excavation.

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**4. DRAINAGE**

- Water is the enemy in slope stability problem.
- Stabilization measures often involve draining water, both surface and subsurface.
- The objective is to prevent excessive water from percolating into the ground, and to remove water that already exist.
- Drainage improve stability by lowering GWT and in turn decrease pore water pressures and thereby increase the strength.
- Drainage also make the soil above ground water table unsaturated and thereby increase the strength.
Surface drainage

- A good surface drainage system captures surface water and carries it to a safe discharge point and not seeping downwards into the slope.
- Temporary remedial measures after a landslide include (1) uses of sandbags to divert water runoff away from the failure zone to ensure stability is not further worsened (2) Sealing cracks with surface coating such as shotcrete or bitumen to reduce water infiltration (3) Cover the slope with plastic sheets to reduce infiltration.

Subsurface drainage

- Objective is to remove water that infiltrate into the ground.
- Several methods include (1) Perforated pipe drains buried in the ground to collect water and remove it from the slope (2) Provide wells which are vertical holes drilled into the ground and equipped with pumps to lift the water out from the slope (3) Provide horizontal drains by drilling from the slope face that incline slightly upward to intercept groundwater and drain it by gravity.

5. VEGETATION

- Vegetation is an important part of most slope stabilization plans.
- It provides erosion protection.
- Draw and transpire water out of the ground.
- Provides some reinforcement of the soil.
- Important aesthetic value.
INSTRUMENTATION

• Geotechnical instrumentation is employed to determine the subsurface conditions and to monitor unstable slope.
• Instrumentation is often expensive to install and monitor but it can provide valuable information that may not be available otherwise.

Inclinometers
• Inclinometers is an instrument to monitor ground movement with respect to depth.
• In slope stability it can be used to locate shear surfaces and monitor the rate of shear displacement in slow-moving landslides.

Installation of inclinometers
1. Drill a vertical hole to a depth well below the potential zone of movement.
2. Insert a special plastic casing.
3. Backfilled the annular zone around the casing to hold it firmly in place.
4. If the ground moves horizontally the casing deform with it.
5. Lower down the inclinometer probe to obtain the initial set of readings.
6. Probe measures the inclination of the casing in two perpendicular direction.
7. Repeat the readout at some future date and compare the data to obtain the magnitude and direction of horizontal movement versus depth.
Conventional surveying

1. Slope movement can be monitored by installing survey stations at various locations on the ground surface.
2. Measure their positions using conventional surveying equipment.
3. This technique provides information on surface movement and does not provide information on the subsurface movement.
4. This method is becoming even more attractive with the availability of the global positioning system (GPS) receivers which make use of signals from satellites.

Groundwater monitoring

1. Groundwater has a significant impact on slope stability.
2. Geotechnical engineers monitored GWT through observation wells and piezometers.
3. This technique provides information on surface movement and does not provide information on the subsurface movement.
4. This method is becoming even more attractive with the availability of the global positioning system (GPS) receivers which make use of signals from satellites.
An open standpipe piezometer consists of a perforated pipe installed in a boring.

Electronic probe water level indicator

PIEZOMETER