Slope Protection
Classification of slope

Natural slope – in various conditions, including rock slope

Man-made slope - including cut-back slope or slope formed by filled material with adequate compaction, usually provided with surface and surface drainage

Man-made slope – formed mainly with the support by retaining structures
Components on a well-designed and maintained man-made slope

1. Surface protection such as vegetation (rigid cover (masonry, plaster or shotcrete))

2. Surface drainage (including surface channels, catch pits and sand traps)

3. Subsurface drainage (including weepholes and subsoil drain etc.)

4. Other protective provision such as prestressed ground anchors

Note – try to avoid the placing of water-carrying services onto a slope
How a slope fail?

The most common failures in slopes of Hong Kong are come from the relatively shallow top soil, which further worsened by the depth of weathering and infiltration during rainstorms situations.

Slope can collapse easily by shear if the soil is nearly saturated and high pore pressure can be built up rapidly. The falling debris carried by its potential and momentum can rush down the slope at very high speed and travel a long distance causing huge damages.

Besides, highly decomposed rock in a slope may behave very similar to soil.
Typical failure profile for slope
Factors affecting the stability of slope

1. Topography and its surrounding physical conditions. Detail analysis can be done by appropriate site investigation process.

2. Geological conditions such as the nature and depth of its subsoil, degree of decomposition, or location of fracture etc. This data can be obtained by soil investigation.

3. Shear strength of the slope-forming materials. Data can be obtained using appropriate laboratory tests.

4. Surface and ground water condition

5. External loading and surcharges, such as from traffic, nearby structures, possible vibration etc.
Physical environment and Typographical conditions of a very large site
(Tseung Kwan O site formation)
Another example of large scale slope work as part of the site formation for the Tsing Yi North Coastal Road
Stability of slope can be effectively improved by the provision of an appropriately design drainage system, this can be achieved by:

1. A surface drain system that is capable to discharge all the storm water within the rain water catchment area affecting the slope in a designated period of time (say, 200mm rainfall/hour).

A surface drain system usually consists of:
- surface channel
- stepped or trapezoidal channel
- catchpit or sand trap

2. A subsoil drain system that is laid below surface for the discharging of ground water and to maintain the water pressure be kept in a safe level
- filter layer behind the slope leading water to outlets
- weepholes
- subsoil drain pipe
- cut-off drain
Drainage detail for retaining walls
Forming surface drainage channel to slope
Protection and treatment to Rock Slope

Most rock slopes need some forms of treatment to ensure continued stability. Improvement methods include:

1. Scaling – loose blocks or boulders to be removed from exposed rock surfaces, this is usually done by manual method.

2. Construct buttress support – this is concrete or masonry gravity structure use to retain the unstable rock mass

3. Dentition – exposed soft material in a rock face be trimmed back. The resulting slot be filled with filter material and protected by masonry or concrete to prevent erosion.
Protection and treatment to Rock Slope (continue)

4. Sprayed concrete – apply concrete protection to zones of weak or highly fractured rock faces by spray-on method.

5. Dowel – a hole is drilled and provide untensioned steel bars, usually 25mm to 35mm dia. and 1m to 3m long, to stabilize a weak rock zone. The hole would be grouted afterward.

6. Rock bolt/nail – this is tensioned bar inserted into rock forming a short anchorage zone in rock so that an unstable slope area being reinforced by tension. Typical rock bolts are 25mm to 40mm in dia. 3m to 6m long, and have a tensile working load around 100kN.
Scaling a rock slope surface

Forming a steep slope in set-back benches and in phases starting from the top downward. Note that the upper benches are strengthened by soil nails.
Various methods to stabilize a rock slope
Improvement the slope profile by forming benches
Protecting a slope by the use of buttress wall
Forming soil nail and rock bolts
Protection and treatment to Earth-filled slope

Where a slope is to be stabilized to eliminate possible flow-slide, the surface layers should be stripped to a vertical depth not less than 3m and replaced it with dry and well compacted fill.

A drainage system is also required between old and re-compacted fill to prevent development of water pressure behind the filled zone.

If it is possible, try to reform the profile of the slope to a safe angle which is determined by mathematic analysis.
Protection to slope by rigid surface

Rigid surface protection on slopes are commonly used to reduce rainwater infiltration and to prevent erosion of the slope-forming materials. This can be done by:

Chunam plastering – this is an applied-on surface protection to slope using a clay and cement mixed plaster. Thickness of the plaster is around 40mm to 50mm for permanent works.

Sprayed concrete (shotcrete) – protection by applying a spraying mortar onto surface of slope.

Masonry or stone pitching – lay stone rubble or block (with filter layer underneath) onto surface to protect slope from weathering.

In general, rigid surface may create a very awkward appearance. Besides, the surface is highly impermeable thus weep holes are required for draining out of the ground water to avoid the development of high water pressure behind the slope.
Preparing the surface of slope during maintenance process
Forming a slope by scaling, cutting back into benches, and protect surface by rock nail and shotcrete
Improvement to slope by soft surface

After the preliminary protection treatment, slope can be further improved by some softer means, such as:

1. Hydroseeding – is the application of grass seed mixed with fertiliser and Nutriant in aqueous solution by spraying method. The grass seed will grow eventually and the root of the grass will act as an organic reinforcing fiber and hold the surface soil.

2. Turfing – Turfing is the direct application of grass with developed roots onto the slope surface. The relatively matured grass will grow easier and extend its root into the soil to strengthen the overall surface.

3. Planting of tree – usually done at the same time with the other method to provide better visual result and provide further strengthening effect to the slope by its deep root.
Various methods to treat a slope surface using vegetation.
Turfing a slope surface

Nylon mesh for sub-surface drainage and to reinforce the root of grass

Turfing a slope surface
Stage of greening a newly treated slope

1st month

2nd month
Stage of greening a newly treated slope

3rd month

4th month
Seeing the difference between a slope treated with and without landscaping provision
Protect a slope by the use of retaining wall

Retaining wall are structures usually provided at the toe of a slope to stabilize it from slide, overturn or collapse.

A slope will be relatively stable when its profile (section angle) is kept below its angle of repose.

Angle of repose is an angle that maintains naturally to a safe equilibrium by the composing material of a slope. This angle deviates from differing materials depending on their compaction, particle size and the nature of the material itself. (e.g. cohesiveness and shear strength)

Principle to retaining wall design can be of 2 main types
- cantilever type
- Gravity type
- Earth reinforced type
Various forms of RC cantilever type retaining wall structures.
Common failure modes of a retaining wall

(a) Loss of Overall Stability

(b) Sliding Failure

(c) Overturning Failure

(d) Bearing Capacity Failure
Construction of typical gravity type retaining wall and its drainage arrangement
Construction of typical cantilever type retaining wall and its drainage arrangement
Stone mass at the toe of a bench serves to provide a gravity hold for the retaining soil-filled slope.

Using stone pitching as a rigid slope surface.
Construction of RC cantilever/gravity mixed type retaining wall

Buttress of wall

Footing of wall
Construction of Earth-reinforced retaining wall
Construction of Earth-reinforced retaining wall, with a temporary sheet-pile wall as stage one set-back arrangement
Detail of the precast panel as surface panel of the retaining wall
Detail seeing the tie behind the panel of the earth reinforced wall
External view of some of the partially completed earth reinforced retaining wall
Other example of using earth reinforced wall to obtain extra space for a road widening project
Examples where large-scale slope works are required in construction

1. Building work – obtaining of land space for building development by land/site formation

2. Roadwork – road or highway project including new projects, extension, widening or improvement works

3. Emergency/Major repair of slope, e.g. after serious land slide
Example of slope works for
Building related project
Site formation to obtain a terraced land for the placing of a building - producing a retaining structure to support an adjacent structure
Sequence showing the forming of a multi-construction retaining wall using bore-pile and soldier-pile wall with in-situ concrete facing wall
Sequence showing the forming of a multi-construction retaining wall using bore-pile and soldier-pile wall with in-situ concrete facing wall.
Forming of a temporary vertical cut as part of the site formation work to acquire land for building construction project – Festival Walk

Diaphragm wall panel tie back using ground anchor
Site formation producing a temporary slope as part of a building construction component – CityU Academic Exchange Centre
Site formation producing a temporary slope as part of a building construction component – South China Sport Association Extension
Site formation producing a temporary slope as part of a building construction component – South China Sport Association Extension
Tree under preservation by encasing with a concrete trough and supported using horizontal steel pipes.

Other examples with tree to be preserved in a development – KCR East Tsim Sha Tsui Station.
View of the preserved tree and the re-touched landscape environment after the completion of the station complex.

The preserved tree grows in healthy condition along the re-aligned road side.
Setting-back and stabilizing of a natural slope using buttress wall for a residential development project in Repulse Bay, Hong Kong
Example of slope works for Civil Engineering related project
Slope stabilization to form a new coastal roadway near Cyberport
Slope setting back to give way for the passing of an elevated roadway for Route 8 near Butterfly Valley
Stabilization of a vertical face as strengthening provision for a new roadway
Forming a widened roadway along a strip of virgin land under Tai Po Road involving slope treatment/stabilization on both side of a valley
Cutting of large volume of slope to give way for the passing of a series of carriageway in Tai Wai, Shatin
Cutting into a surcharged slope to accommodate a series of column to support an elevated roadway (slope stabilized with sheet-pile wall tied back with anchor)
Drilling machine to form the bore-hole for the anchor tendon

Installing the soil anchor and tighten the skin wall with a row of waling beam
Cutting back of slope using bore-pile wall
Cutting back of slope using soldier pile wall
Cutting back of slope using in-situ RC retaining wall in plant-box design
Detail of the stepped planter-box type retaining wall

Precast units for retaining wall facing panel with a surface drain channel
Preliminary treated slope with geo-textile and surface greening
Widening of roadway by obtaining land cut to the edge of a building
Widening of roadway by obtaining land cut to the edge of a building
Stage 1 cutting back of slope stabilized by ground anchors.

Stage 2 permanent wall supported by using bored-piles.
Widening of existing roadway by cutting and afterward filling
Widening of existing roadway by cutting, temporary stabilizing and afterward filling
Widening of existing roadway by cutting, temporary stabilizing and afterward filling
Stabilizing large area of slope along a servicing roadway

Future alignment of a new trunk road (Route 8)
Other examples of slope treatment or stabilization of more complex in nature

Widening of Castle Peak Road near Sham Tseng
Other examples of slope treatment or stabilization of more complex in nature –problem and method to collect and discharge storm water due to very large catchment area.
Other examples of slope work or stabilization provision of more complex in nature – complicated topographic condition and work layout.
Maintenance of slope

Conditions of a slope can be easily deteriorated within a certain period of time thus continual observation and maintenance should be carried out from time to time.

In Hong Kong, the responsibility of slope maintenance are:

- For lands belong to the government – by the government, responsible/managed by the Civil Engineering Department.

- For private lands – owner of the land. Very often the exact responsibility for the maintenance of a slope is specified in some legal documents such as in the land lease. Detail information for the lease documents and records of the land owners can be obtained at the Government’s Land Registry.
Maintenance Inspection (including slope and retaining walls)

Inspection should be carried out regularly to determine the conditions of a slope. These inspections can be sub-divided into 3 levels/categories.

1. Routine inspection – by non-professional person bases on some general visual guideline.

2. Engineer inspection – by qualified geotechnical engineer according to some engineering indications and standards.

3. Regular monitoring process – by a quality engineering firm with special expertise and may involve the use of some monitoring devices or analysis.
Routine Maintenance Inspection

As a preliminary inspection to ensure the basic stability of a slope, routine inspection is recommended to carry out on a regular basis. The following elements should be observed during the inspection:

1. Ensure the slope surface and its drainage channels are free from debris.

2. Damaged or cracked protective surfaces and drainage system should be repaired and keep in good condition.

3. Unblock the weep holes and drains from time to time.

4. Remove over-grown vegetation that may crack the surface.

5. Observe any damage appears on the slope or other retaining structures.

6. Observe any irregularity appears on or nearby the slope.
Common condition of a slope
Typical man-made items on slope and retaining wall that require maintenance
Typical preventive maintenance works for soil slope
Typical preventive maintenance works for rock slope
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<th>Item</th>
<th>Typical Maintenance Works Required</th>
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| Surface Drainage Systems (e.g. drainage channels and catchpits) | (a) Clear debris, undesirable vegetation and other obstructions.  
(b) Repair minor cracks with cement mortar or flexible sealing compound.  
(c) Rebuild severely cracked channels. |
| Weepholes and Surface Drainage Pipes      | (a) Clear obstructions (e.g. weeds and debris) in weepholes and pipe ends.  
(b) Probe with rods for deeper obstructions. |
| Rigid Surface Cover (e.g. chunam and shotcrete) | (a) Remove undesirable vegetation growth.  
(b) Repair cracks or spalling.  
(c) Regrade and repair eroded areas.  
(d) Replace surface cover which has separated from underlying soil. |
| Vegetation Surface Cover                  | (a) Regrade eroded areas with compacted soil followed by replanting.  
(b) Replant vegetation in areas where the vegetated surfacing has died. |
| Rock Slopes and Boulders                  | (a) Remove undesirable vegetation growth.  
(b) Seal up open joints or provide local surfacing to prevent ingress of water.  
(c) Remove loose rock debris. |
| Structural Facings                        | (a) Re-point deteriorated mortar joints on masonry face.  
(b) Repair cracking or spalling of concrete surface and replace missing or deteriorated joint fillers and sealants. |