

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-design 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

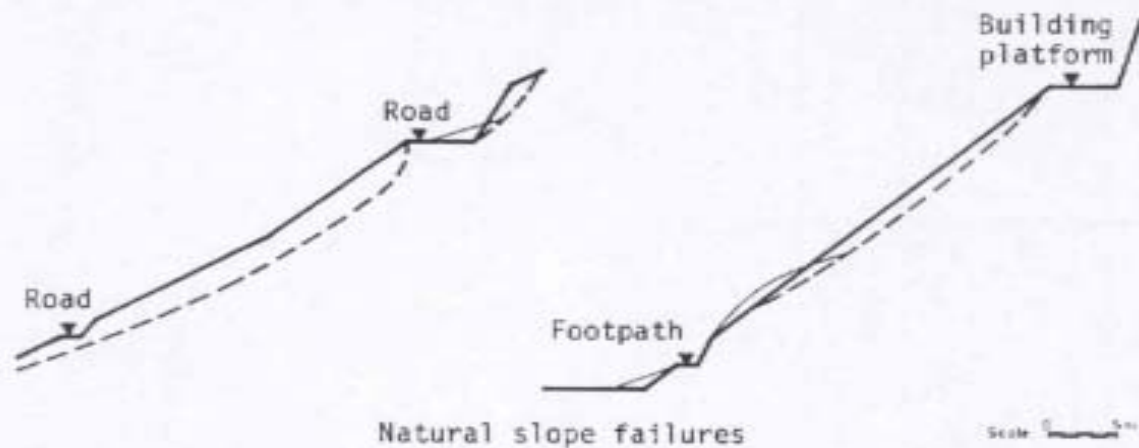
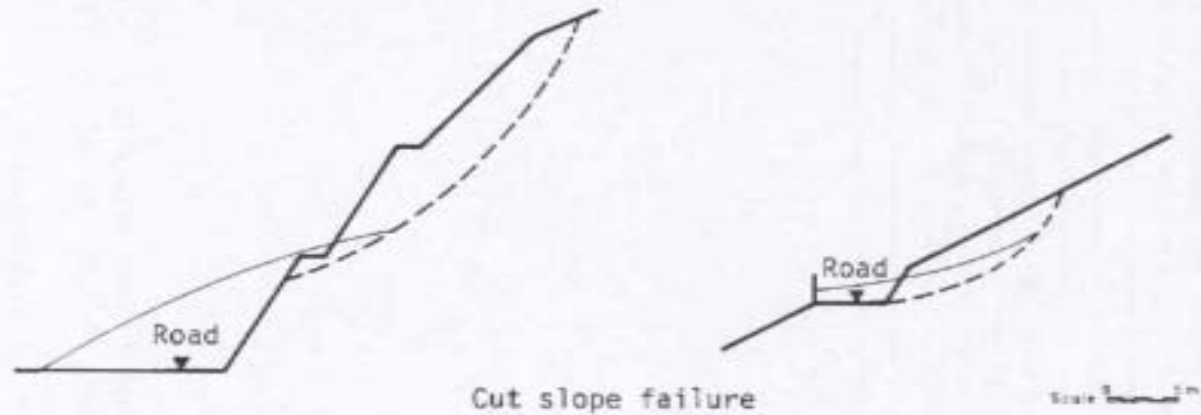
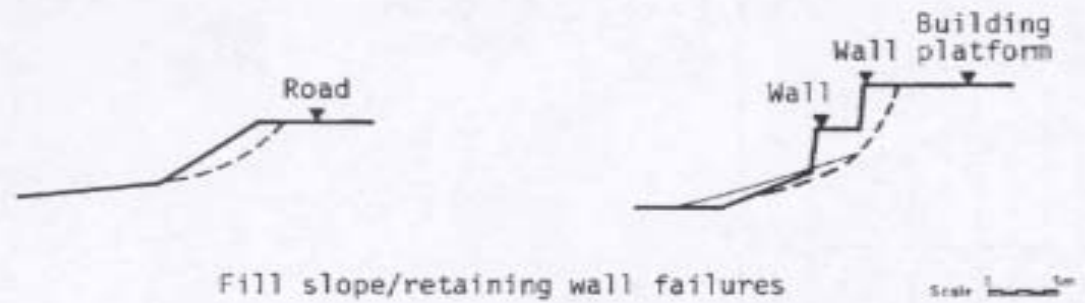
How a slope fail?

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



Legend :

- Pre failure geometry
- - - Post failure geometry
- Extent of debris

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 cab 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).

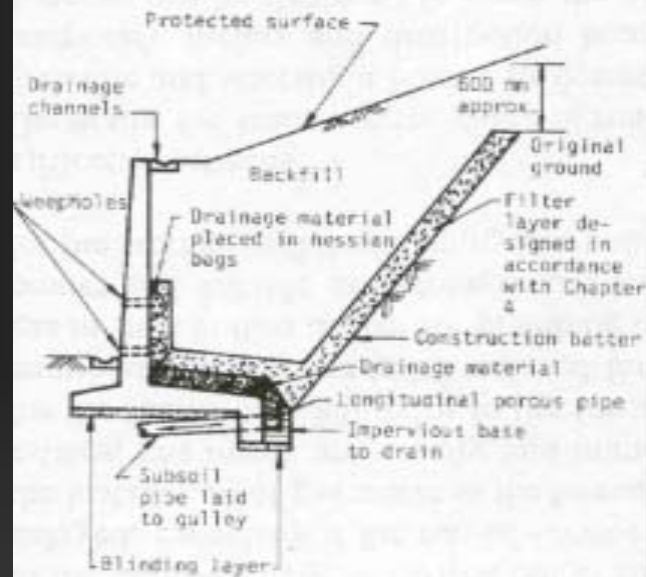
A surface drain system usually consists of:

- surface channel
- stepped or trapezoidal channel
- catchpit or sand trap

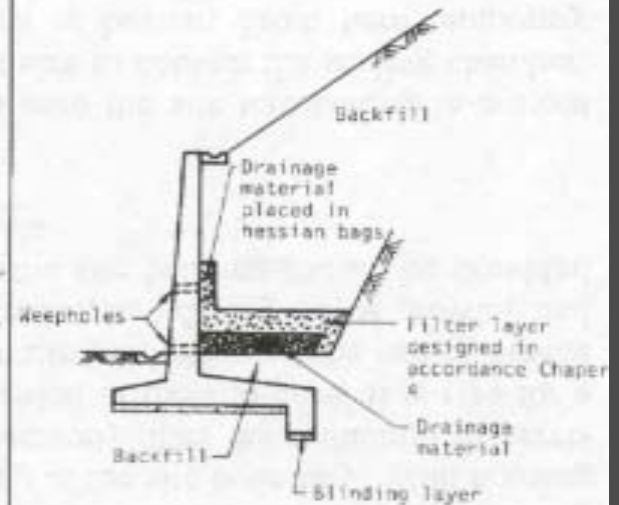
2. A subsoil drain system that is laid below surface for the discharging of ground water and to maintain the water pressure be kept in a safe level

- filter layer behind the slope leading water to outlets
- weepholes
- cut-off drain
- subsoil drain pipe

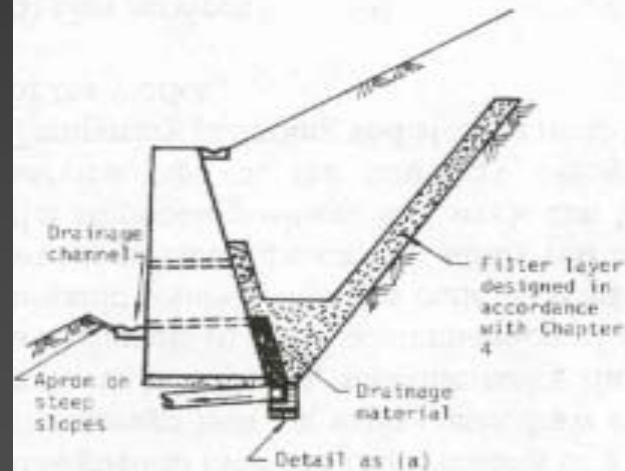
Drainage detail for retaining walls



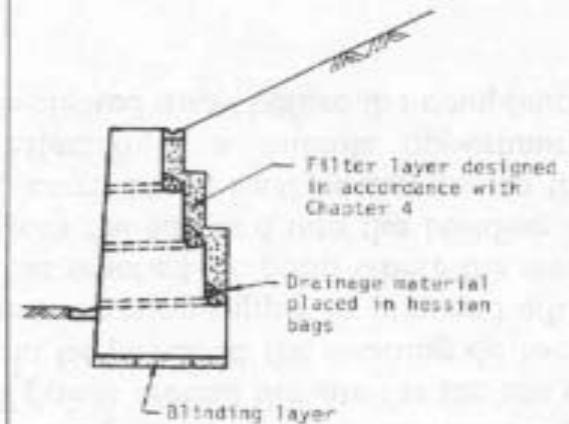
(a) CANTILEVER/COUNTERFORT



(b) CANTILEVER/COUNTERFORT
used when (a) is not possible



(c) GRAVITY TYPE



(d) GRAVITY TYPE
used when (c) is not possible



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)

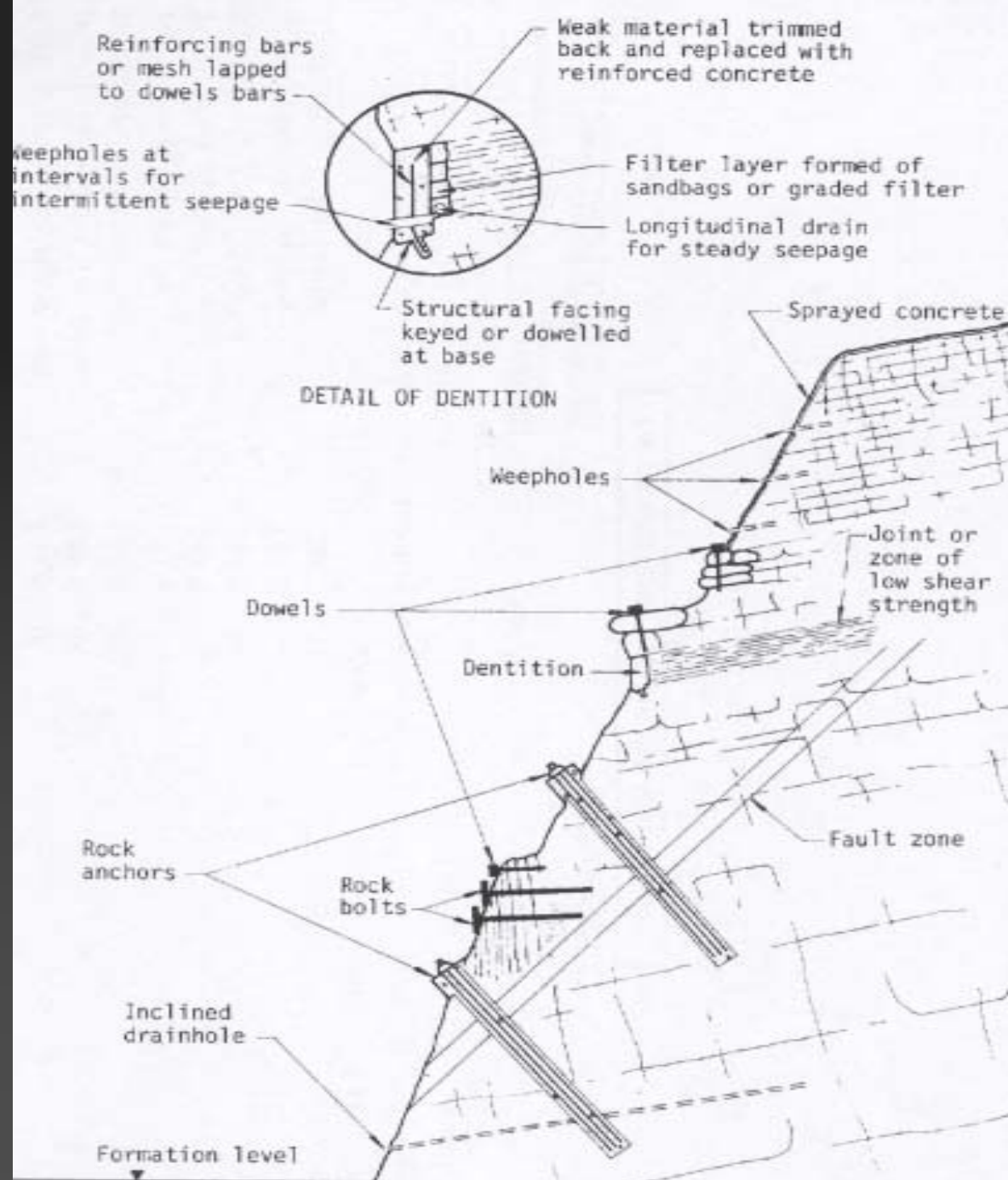
4. Sprayed concrete – apply concrete protection to zones of weak or highly fractured rock faces by spray-on method.
5. Dowel – a hole is drilled and provide untensioned steel bars, usually 25mm to 35mm dia. and 1m to 3m long, to stabilize a weak rock zone. The hole would be grouted afterward.
6. Rock 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 workign load around 100kN.



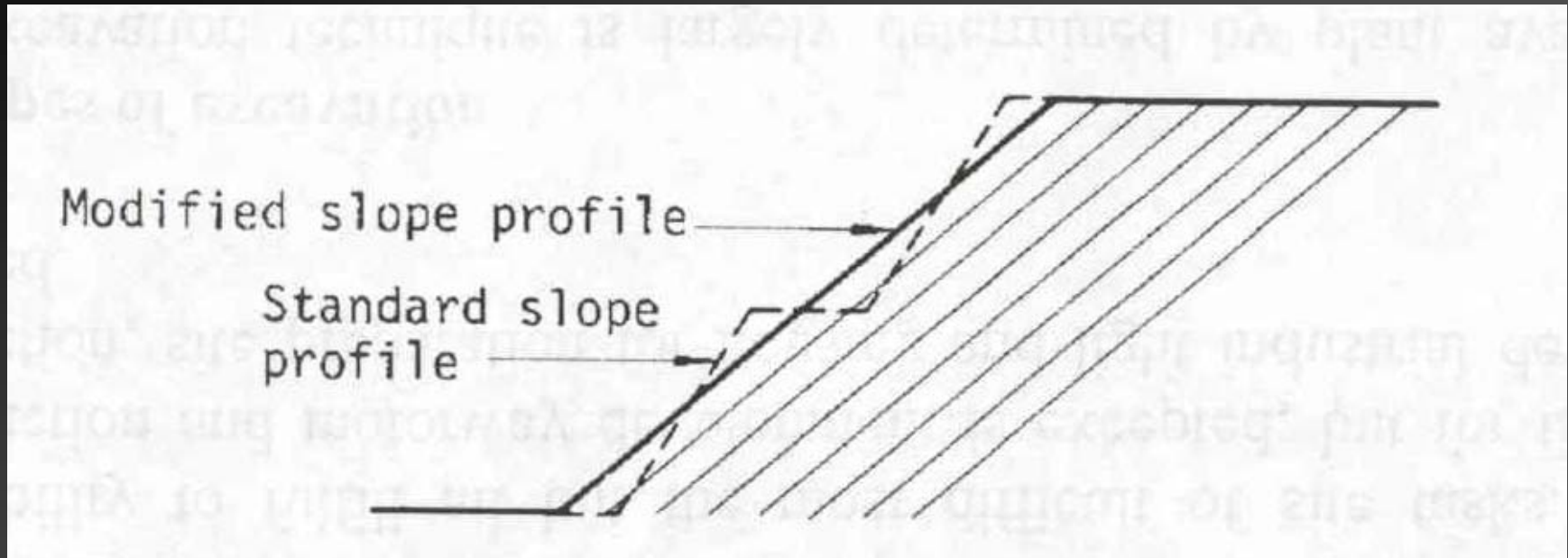
Scaling a rock
slope surface



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

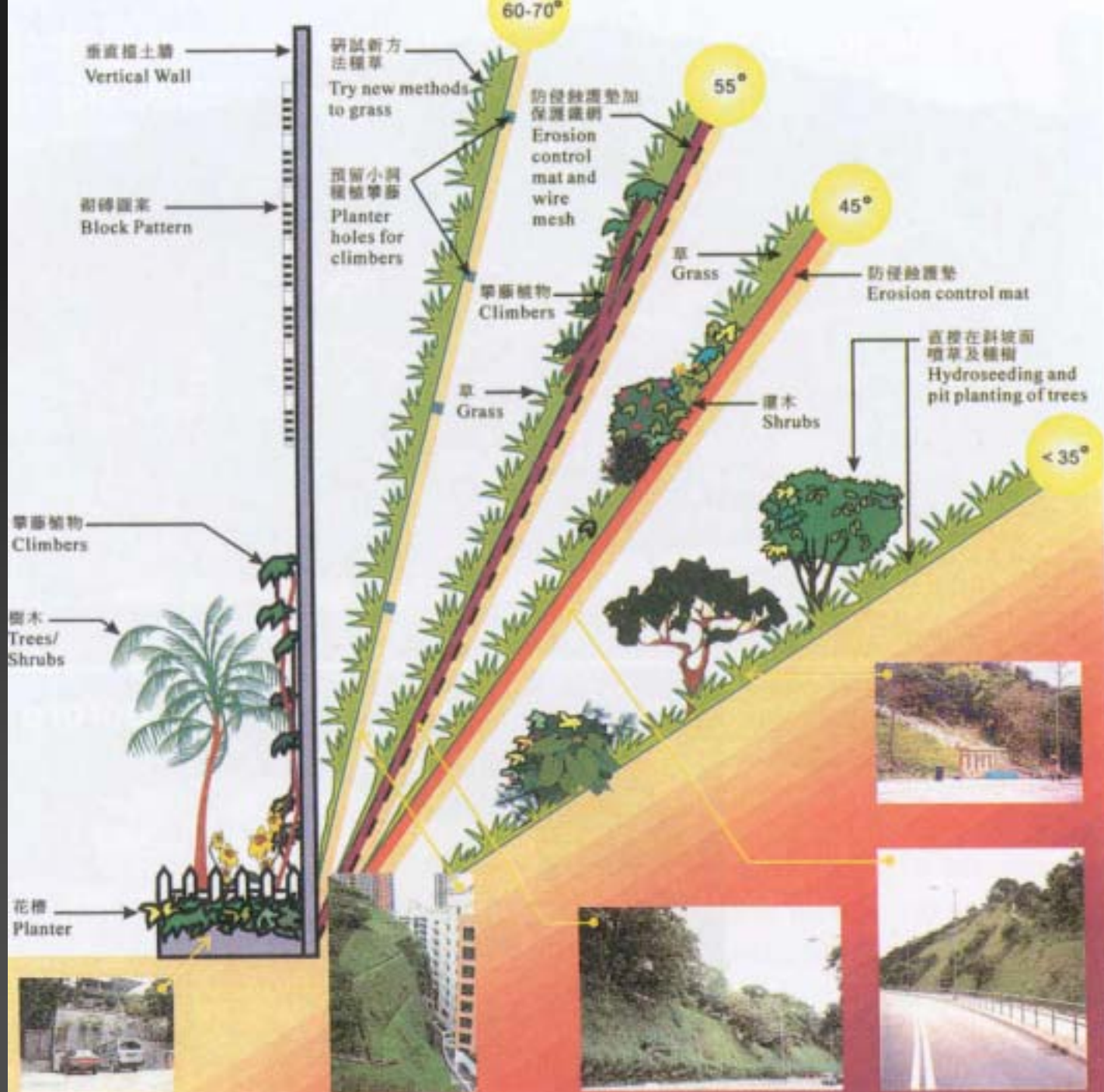


Improvement to slope by soft surface

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 method to treat a slope surface using vegetation





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.

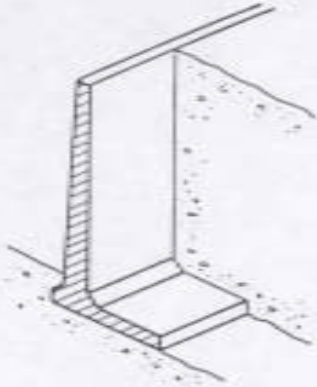
A slope will be relatively stable when its profile (section angle) is kept below its angle of repose.

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)

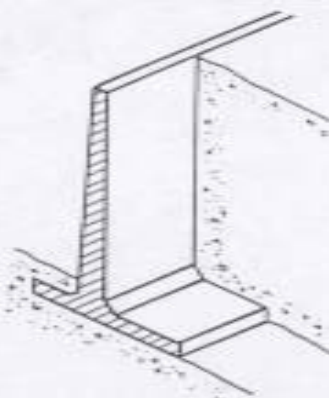
Principle to retaining wall design can be of 2 main types

- cantilever type
- Gravity type
- Earth reinforced type

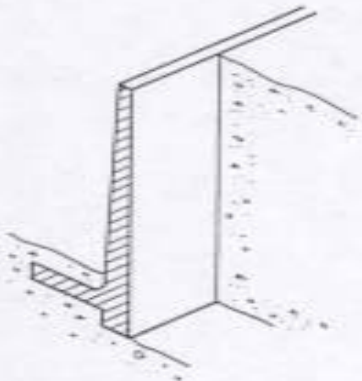
Various forms
RC cantilever
type retaining
wall structures



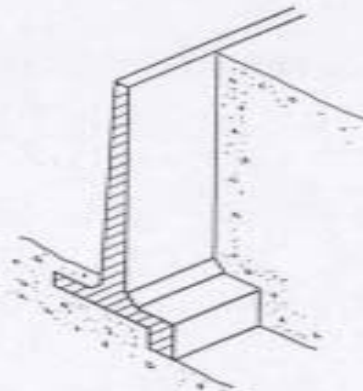
(a) L-shaped Cantilever Retaining Wall



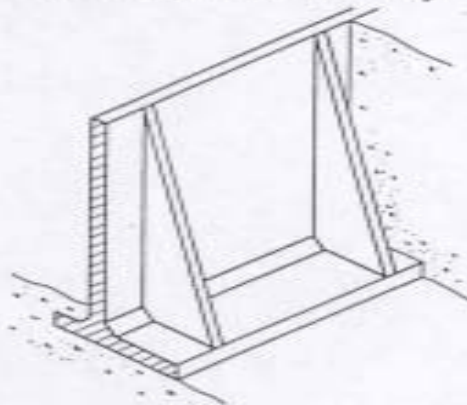
(b) Inverted T-shaped Cantilever Retaining Wall



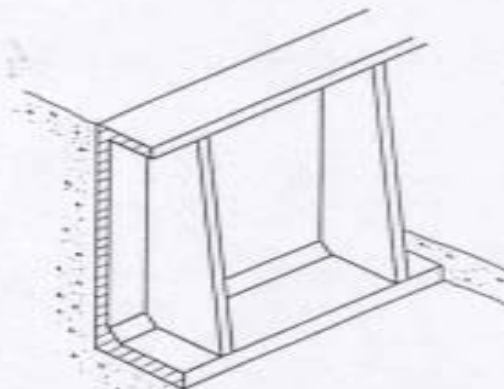
(c) Reversed L-shaped Cantilever Retaining Wall with Key



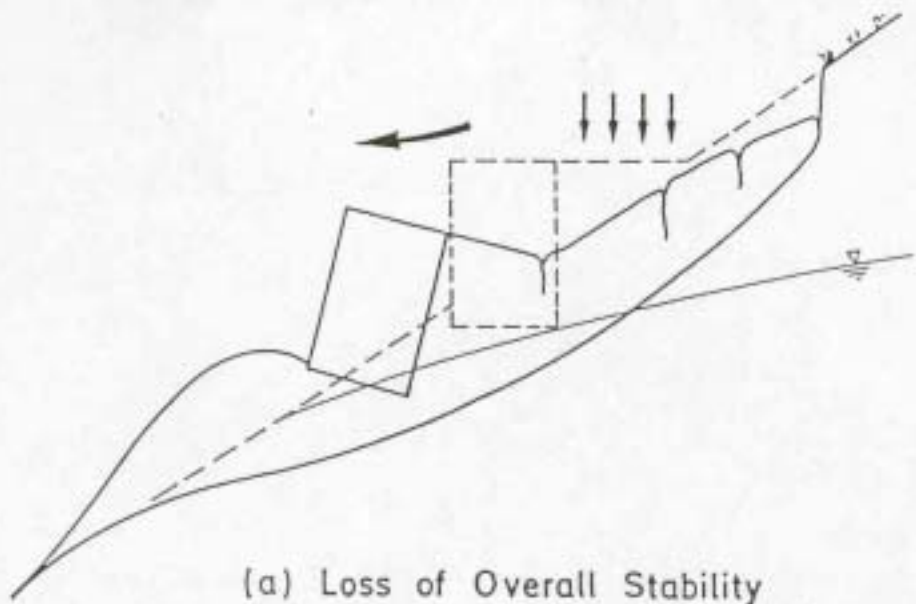
(d) Inverted T-shaped Cantilever Retaining Wall with Key



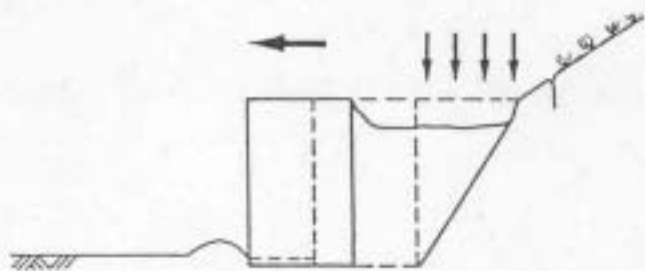
(e) Retaining Wall with Counterforts



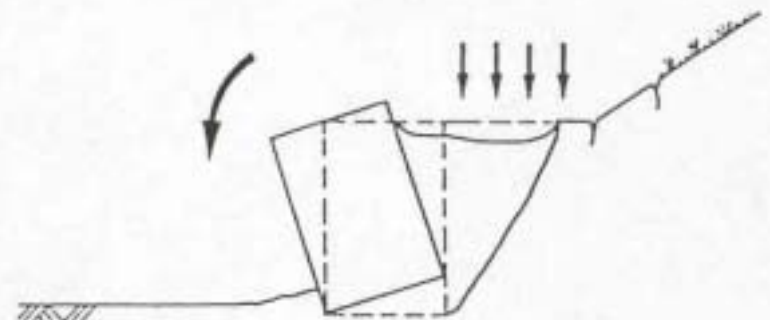
(f) Retaining Wall with Buttresses



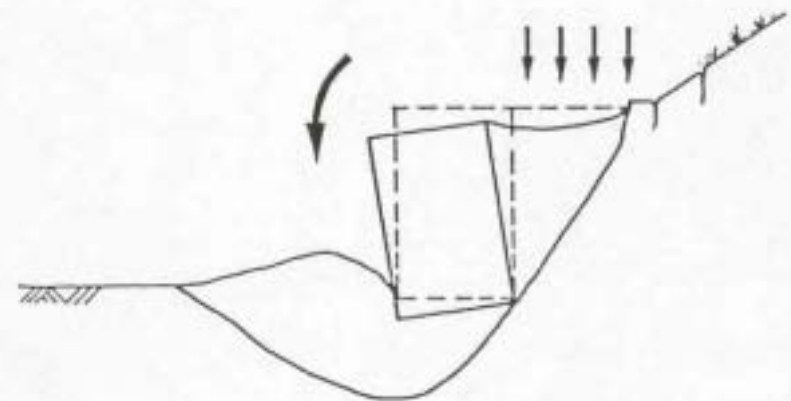
(a) Loss of Overall Stability



(b) Sliding Failure



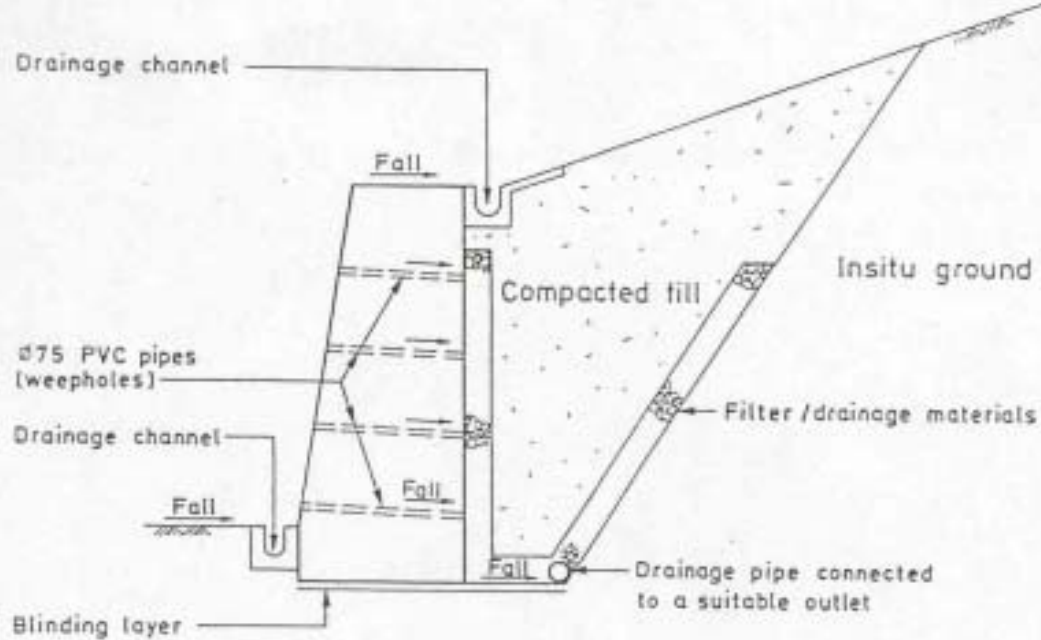
(c) Overturning Failure



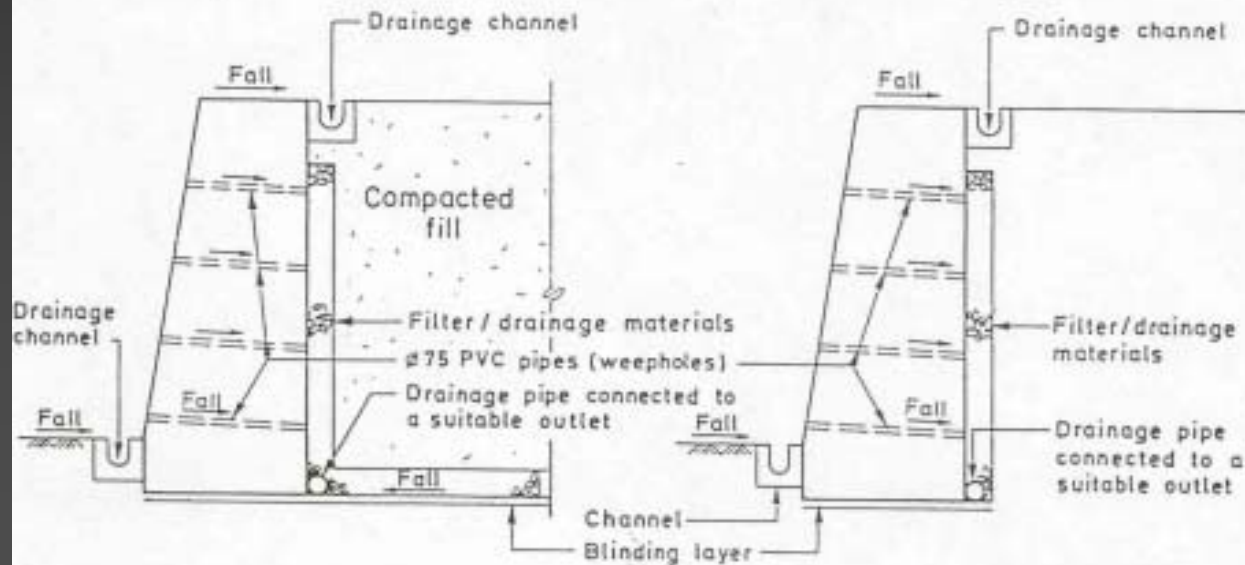
(d) Bearing Capacity Failure

Common failure modes of
a retaining wall

Construction of typical gravity type retaining wall and its drainage arrangement

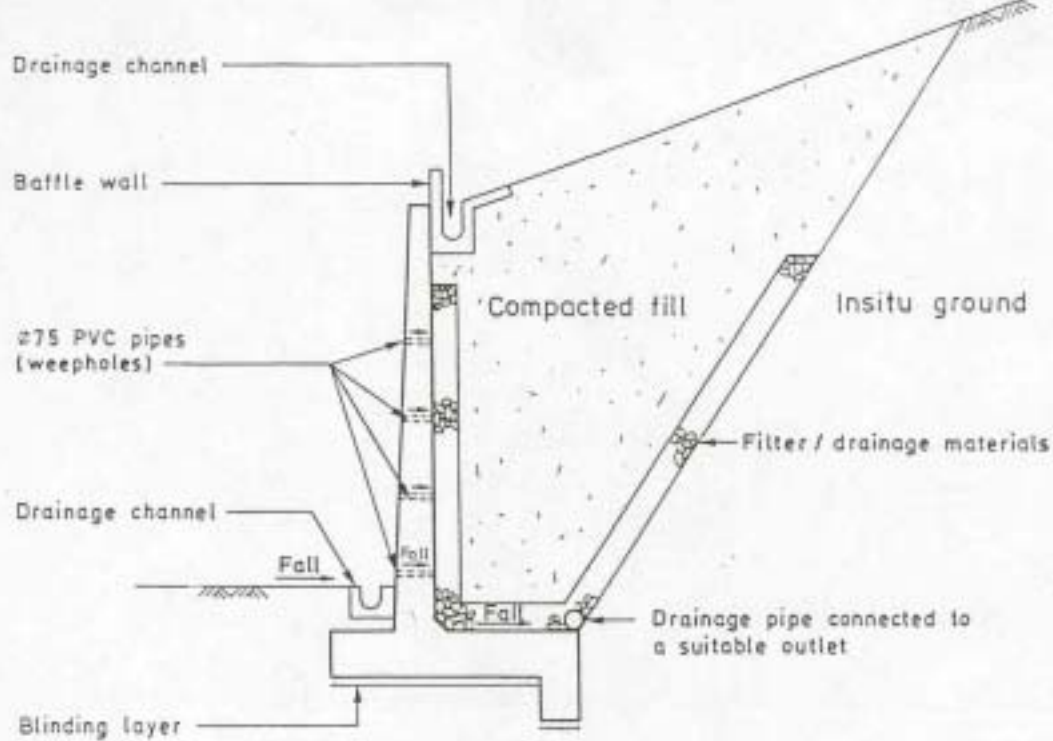


(a) Preferred Drainage Scheme A

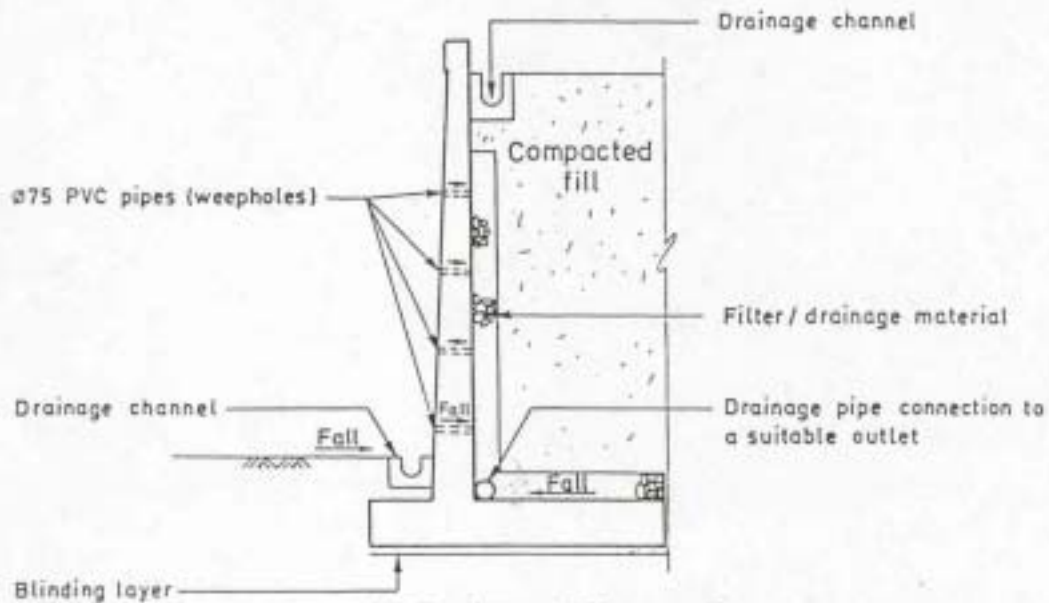


(b) Preferred Drainage Scheme B

(c) Drainage Scheme C



(a) Preferred Drainage Scheme A



(b) Drainage Scheme B

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



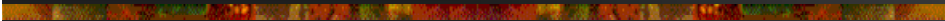


Other example of using earth reinforced wall to obtain extra space for a road widening project




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



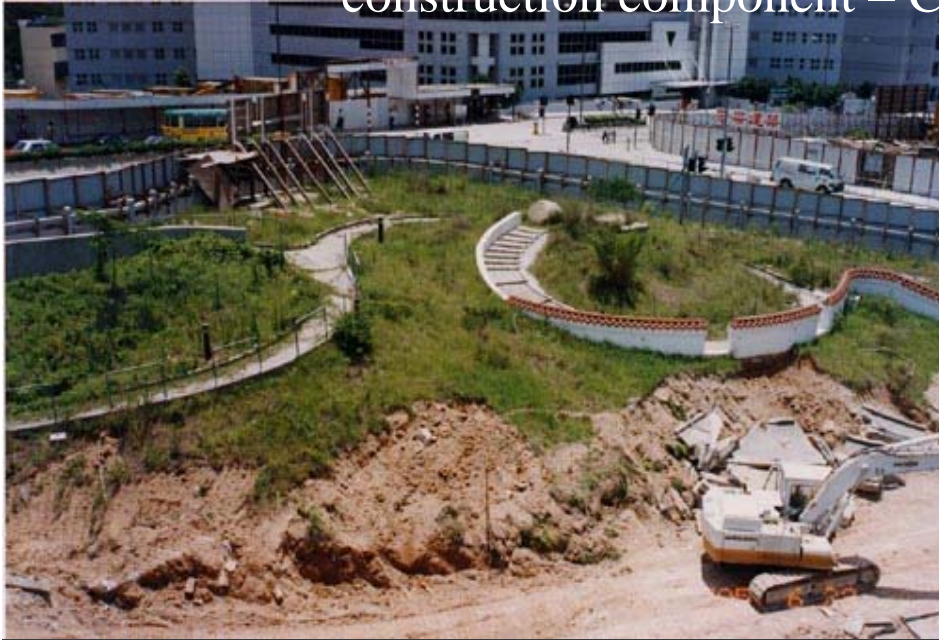
Forming of a temporary vertical cut as part of the site formation work to acquire land for building construction project – Festival Walk



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

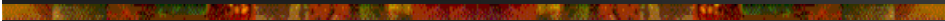


The preserved tree grow in healthy condition along the re-aligned road side




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)





Installing the soil anchor and tighten the skin wall with a row of waling beam



Drilling machine to form the bore-hole for the anchor tendon

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





Main Carriageway

Reinforced fill embankment

Natural terrain

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





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)

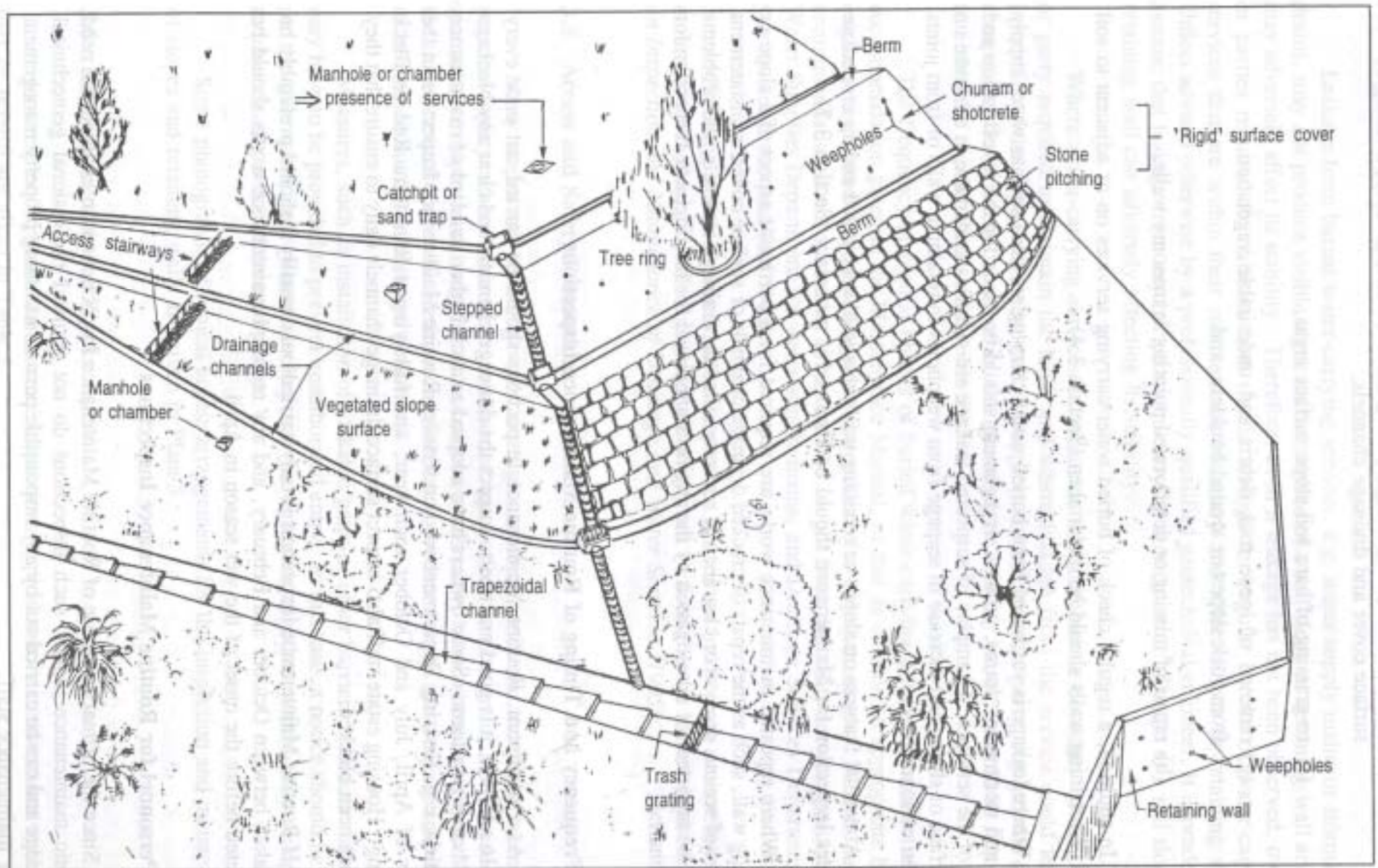
Inspection should be carried out regularly to determine the conditions of a slope. These inspections can be sub-divided into 3 levels/categories.

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

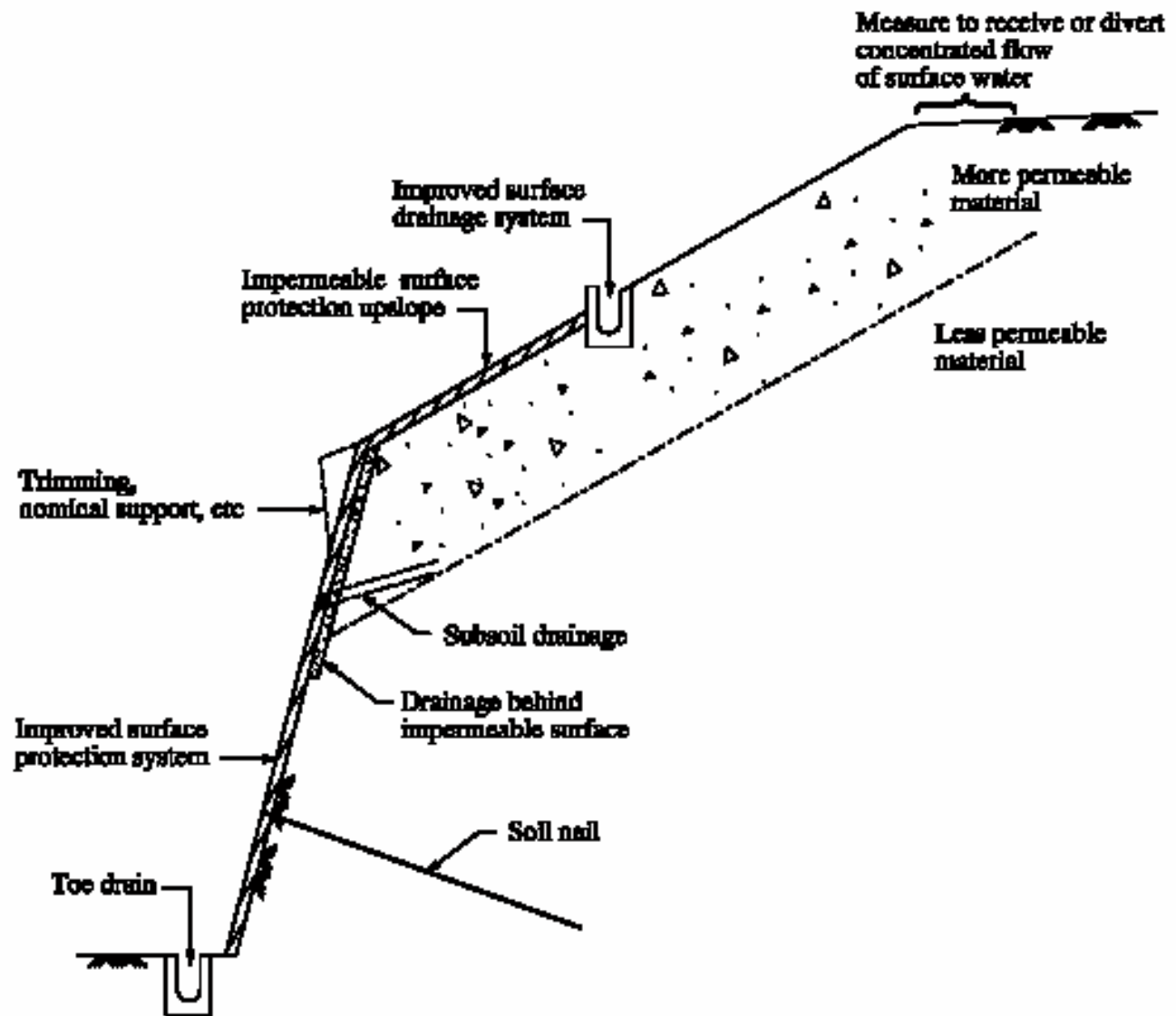
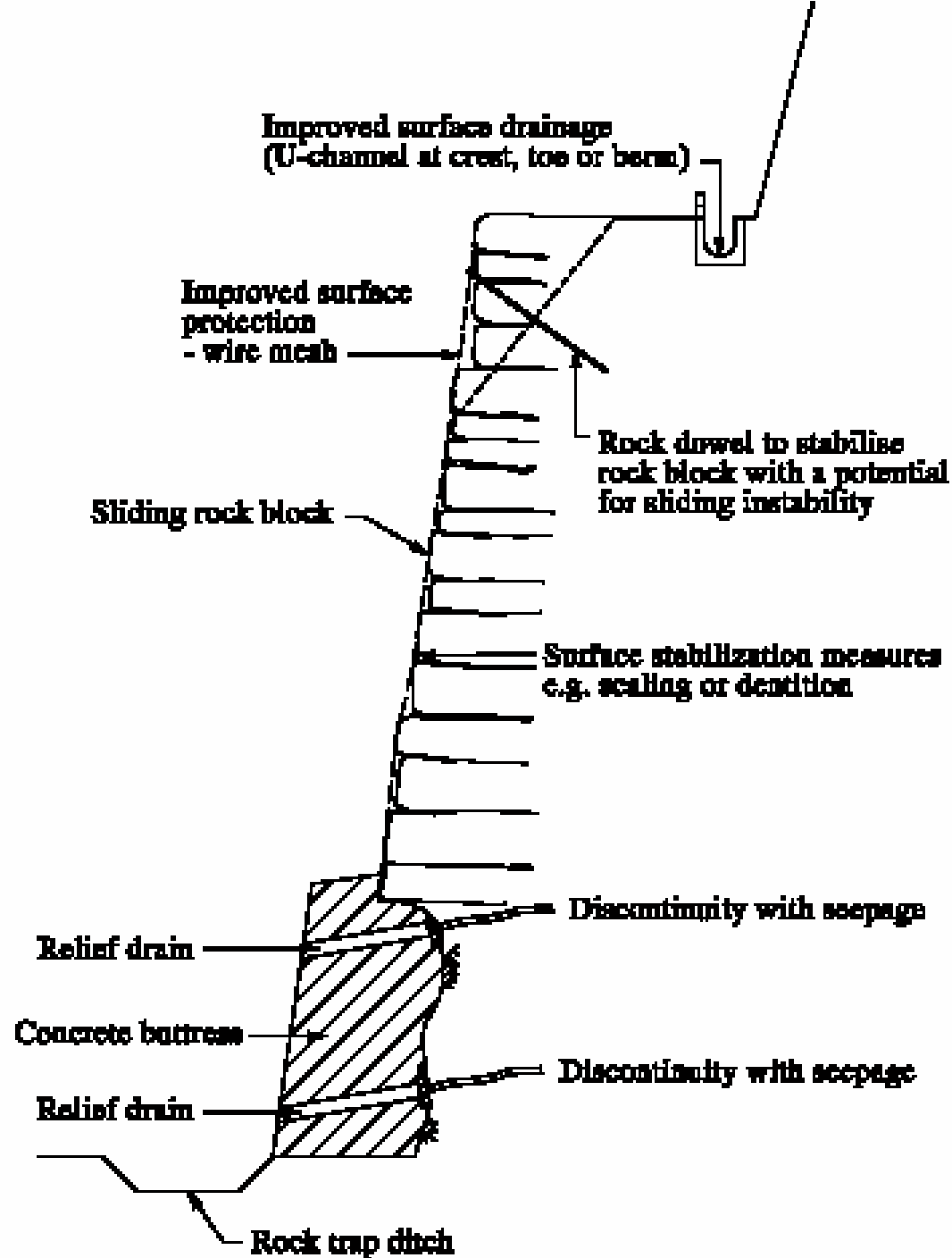


Figure 5.1 Typical Preventive Maintenance Works for Soil Slopes

Typical preventive maintenance works for soil slope



Typical preventive
maintenance works
for rock slope

| Item | Typical Maintenance Works Required |
|---|--|
| Surface Drainage Systems (e.g. drainage channels and catchpits) | <ul style="list-style-type: none"> (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 | <ul style="list-style-type: none"> (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) | <ul style="list-style-type: none"> (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 | <ul style="list-style-type: none"> (a) Regrade eroded areas with compacted soil followed by re-planting. (b) Replant vegetation in areas where the vegetated surfacing has died. |
| Rock Slopes and Boulders | <ul style="list-style-type: none"> (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 | <ul style="list-style-type: none"> (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. |

Typical Routine Maintenance Works for slopes and retaining walls