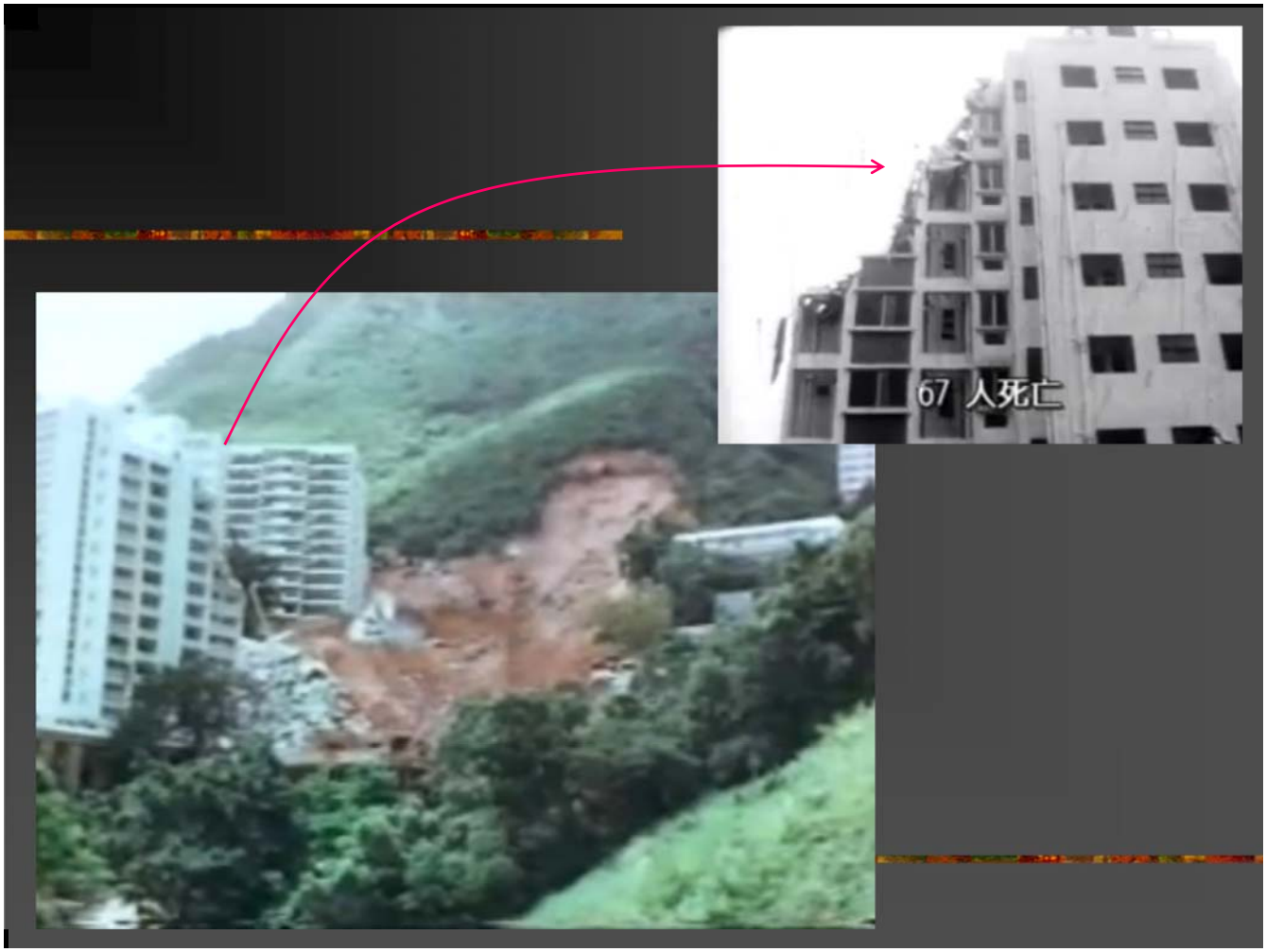
Slope Protection,

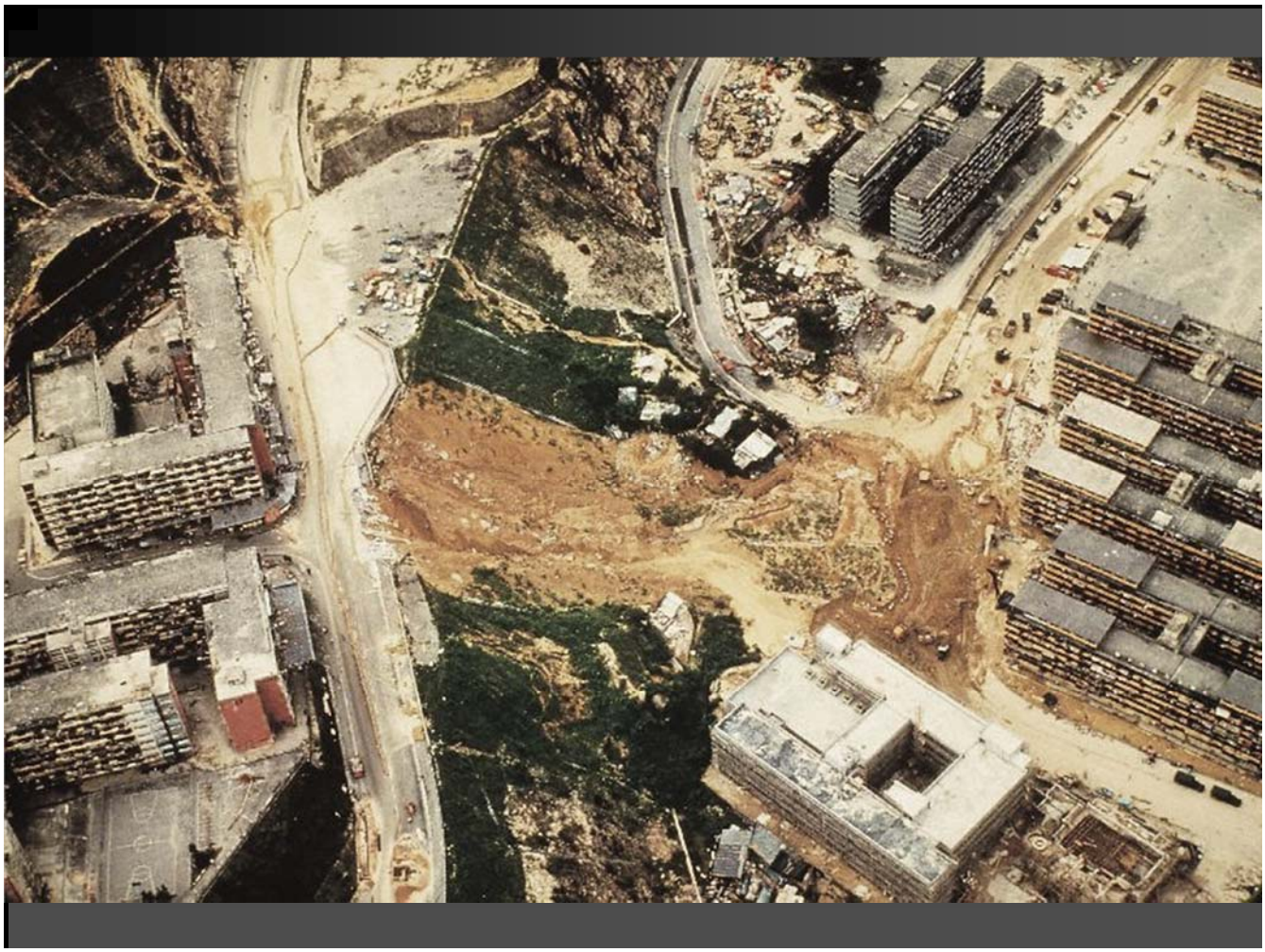
landscaping and greening

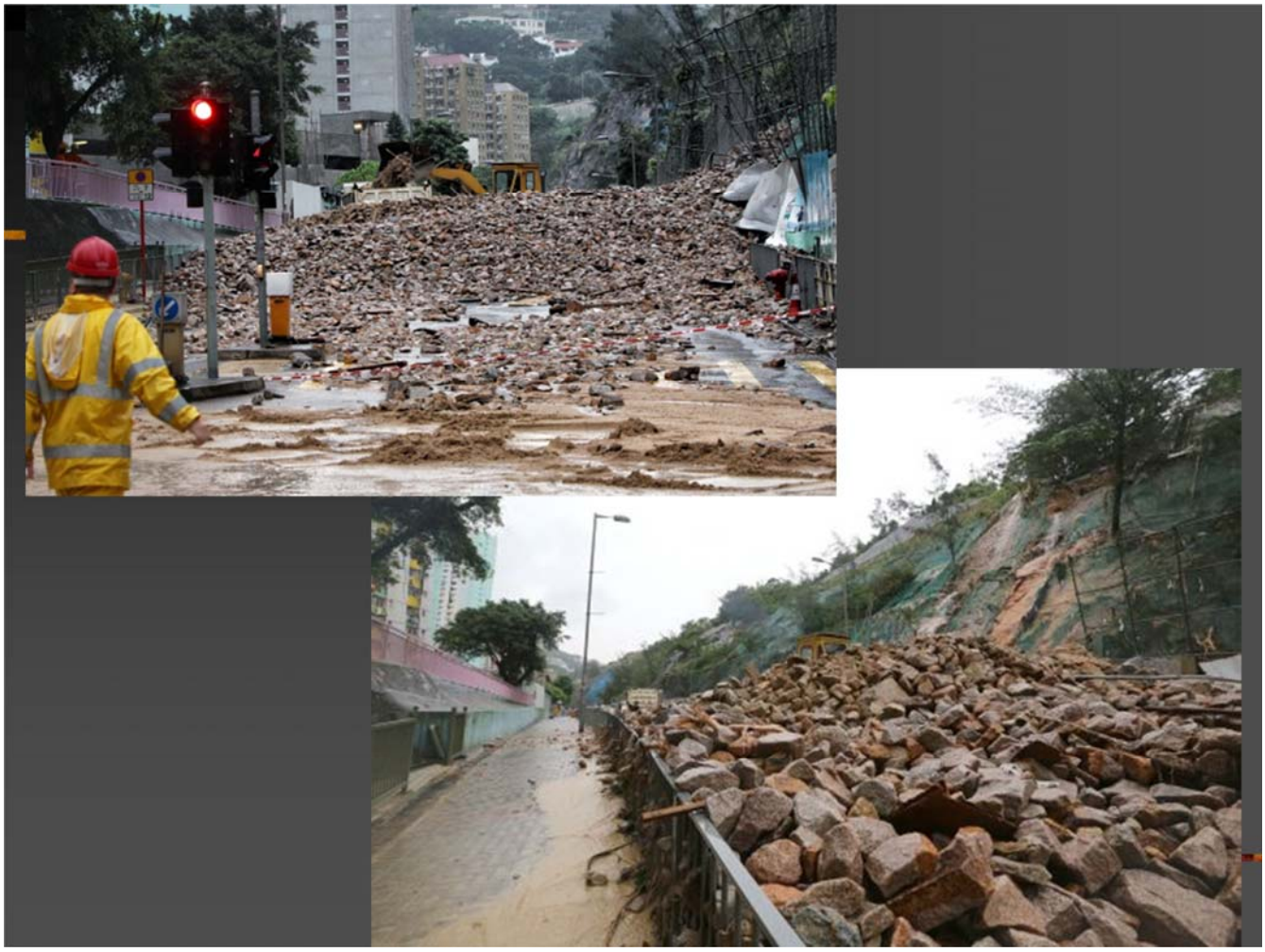
https://www.youtube.com/watch?v=Y5R-bkUX2_Q

Slope is very dangerous to hilly environment like Hong Kong – landslide in Po Shan Road/Kotewall Road, Mid Level, Hong Kong (18 June 1972)


67 人死亡

https://www.youtube.com/watch?v=7rlscQ9LN8M





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

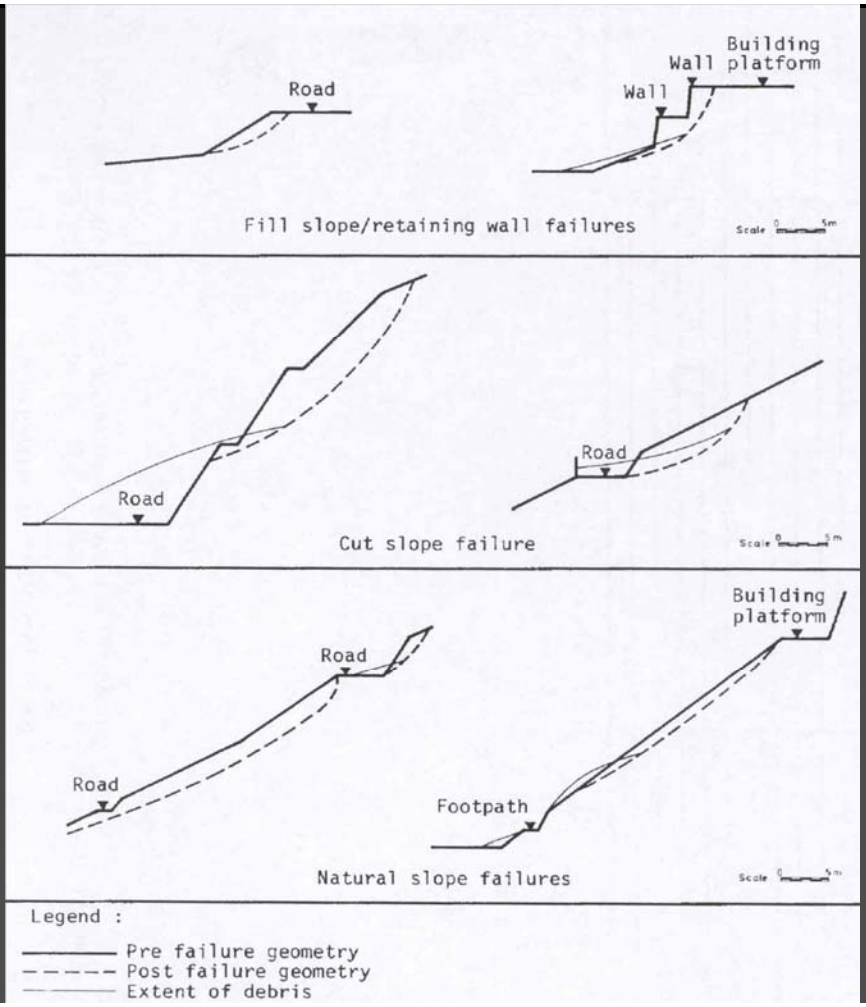
How a slope fail?

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

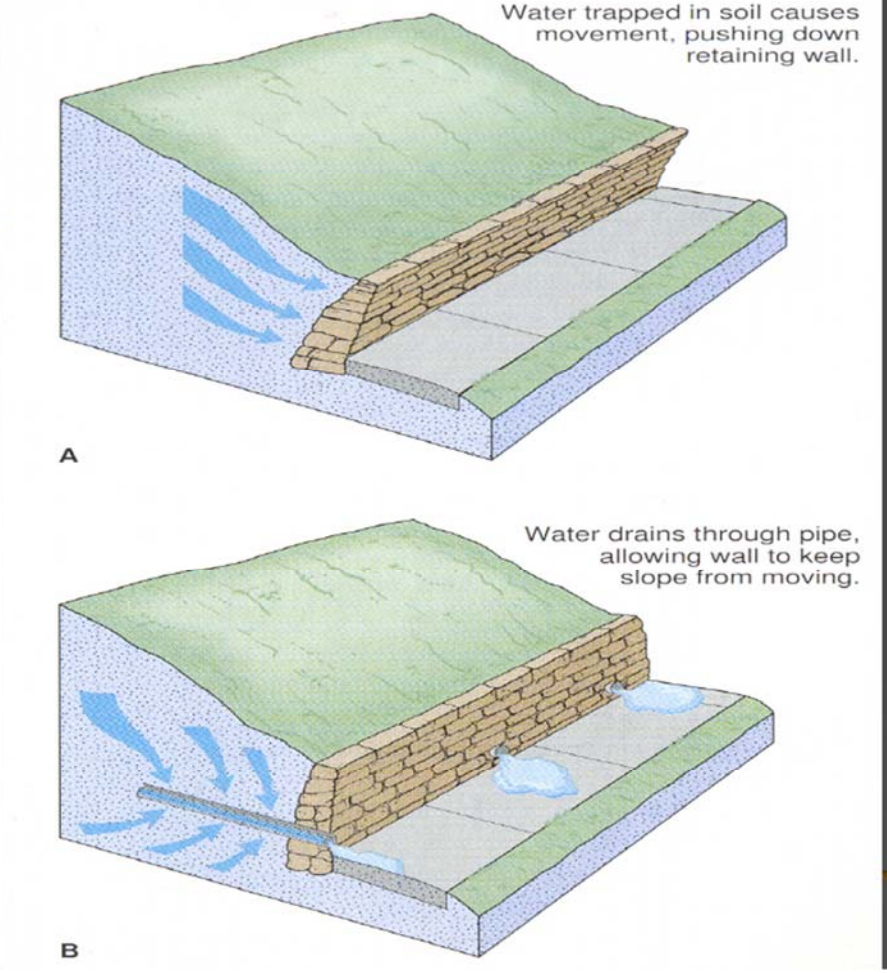


Factors affecting the stability of slope

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



Effect of ground water affects the stability of slope

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).

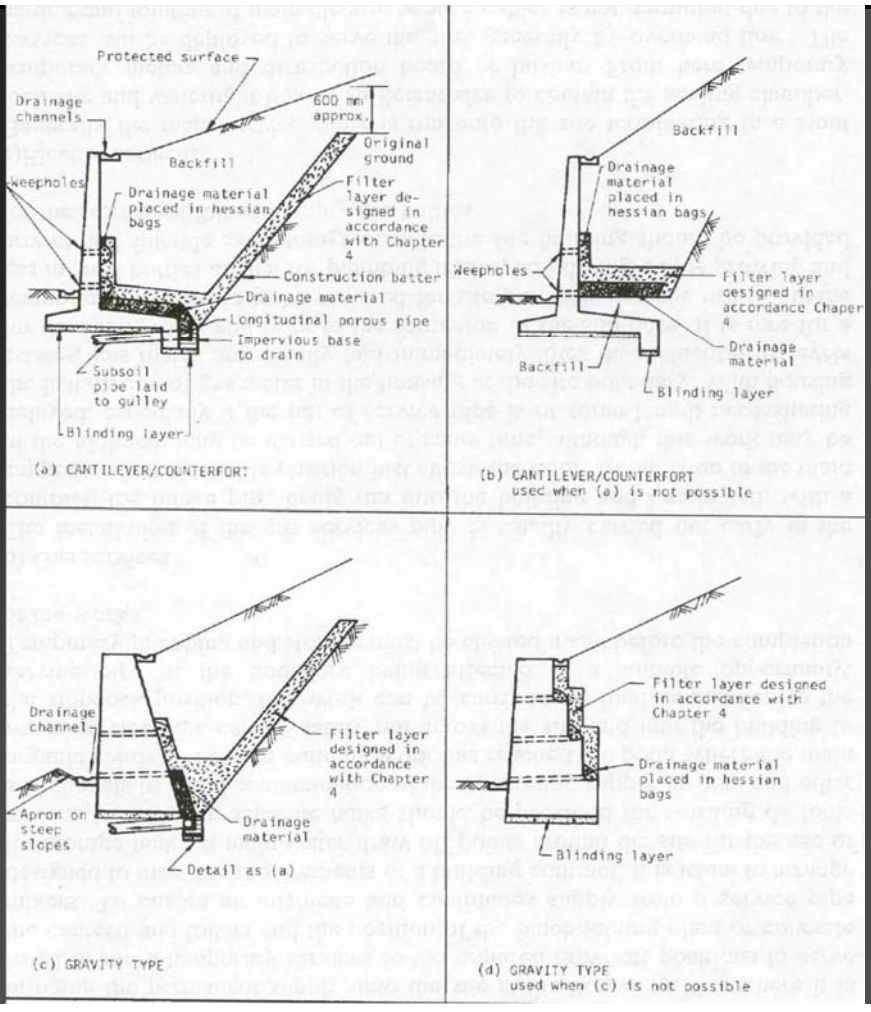
   A surface drain system usually consists of:

   - 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

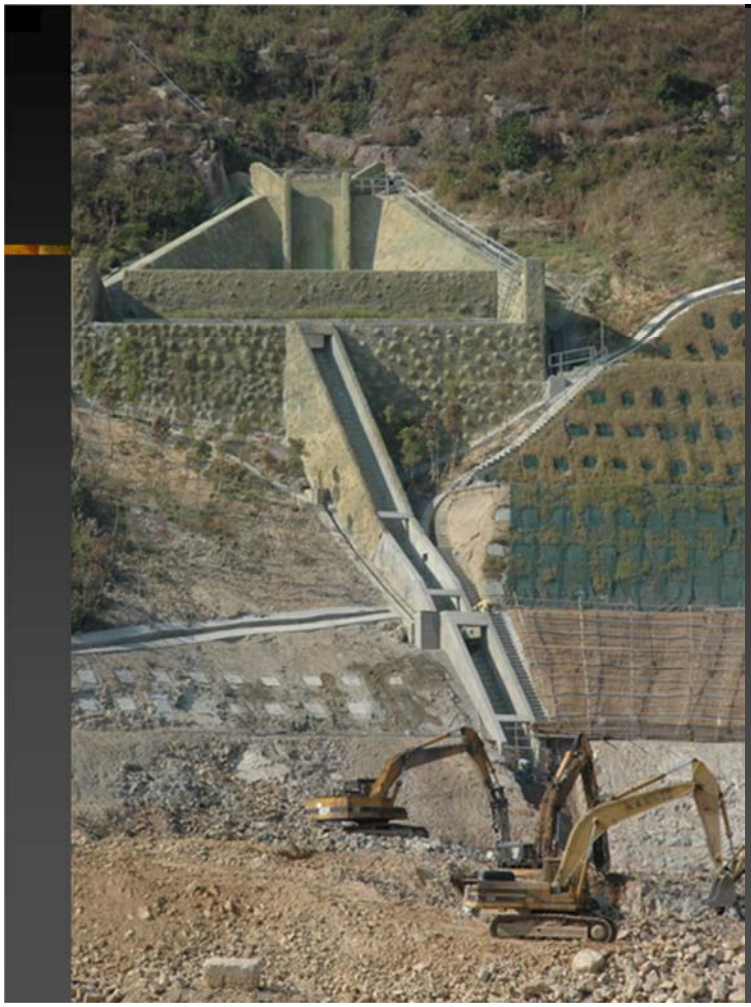
   - filter layer behind the slope leading water to outlets
   - weepholes
   - cut-off drain
   - subsoil drain pipe

Drainage detail for retaining walls



Forming surface drainage channel to slope

Surface drain before and after the formation



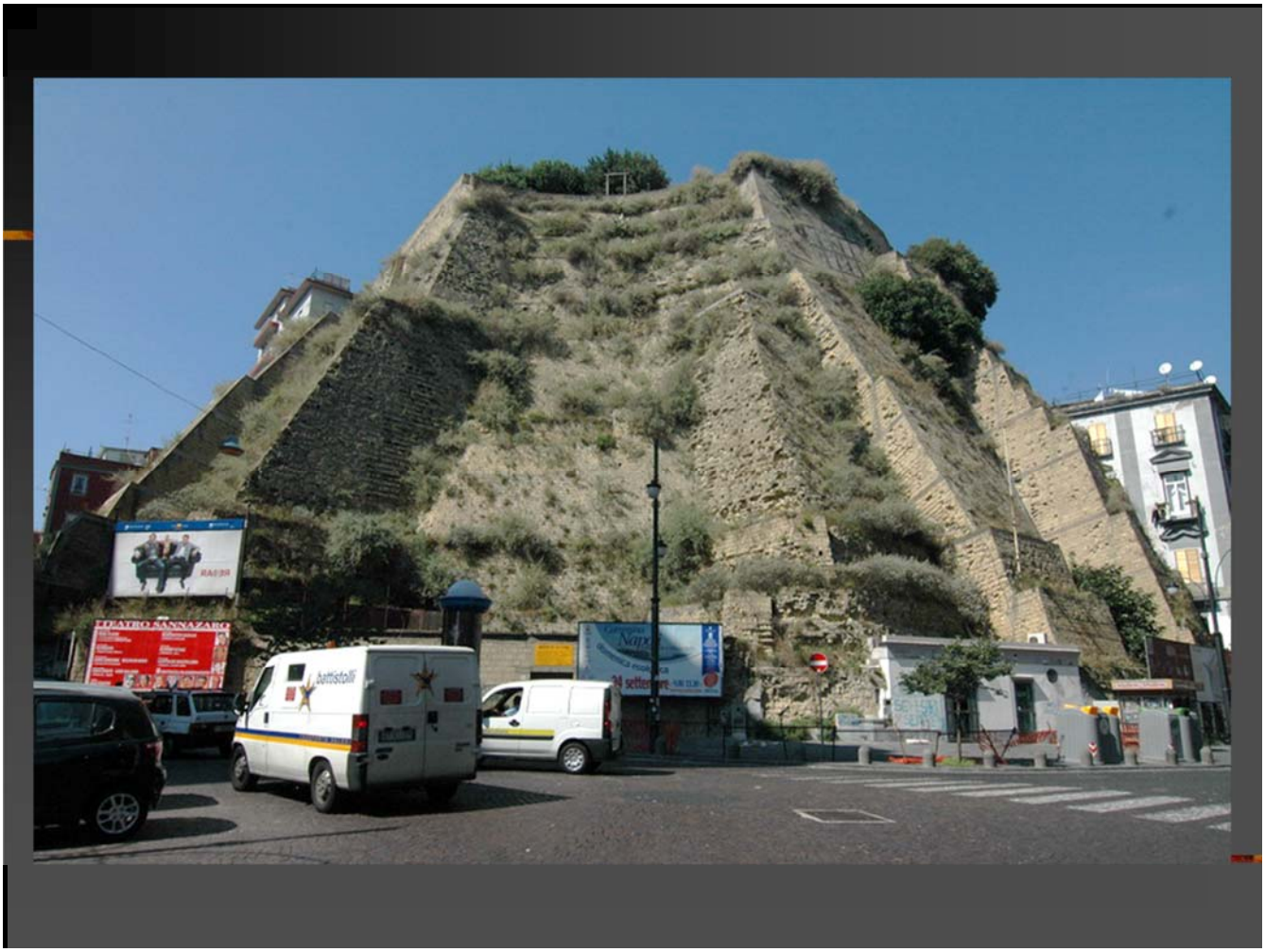
Drainage system for large area of slope

Sub-drain for filled slope

Protection and treatment to Rock Slope

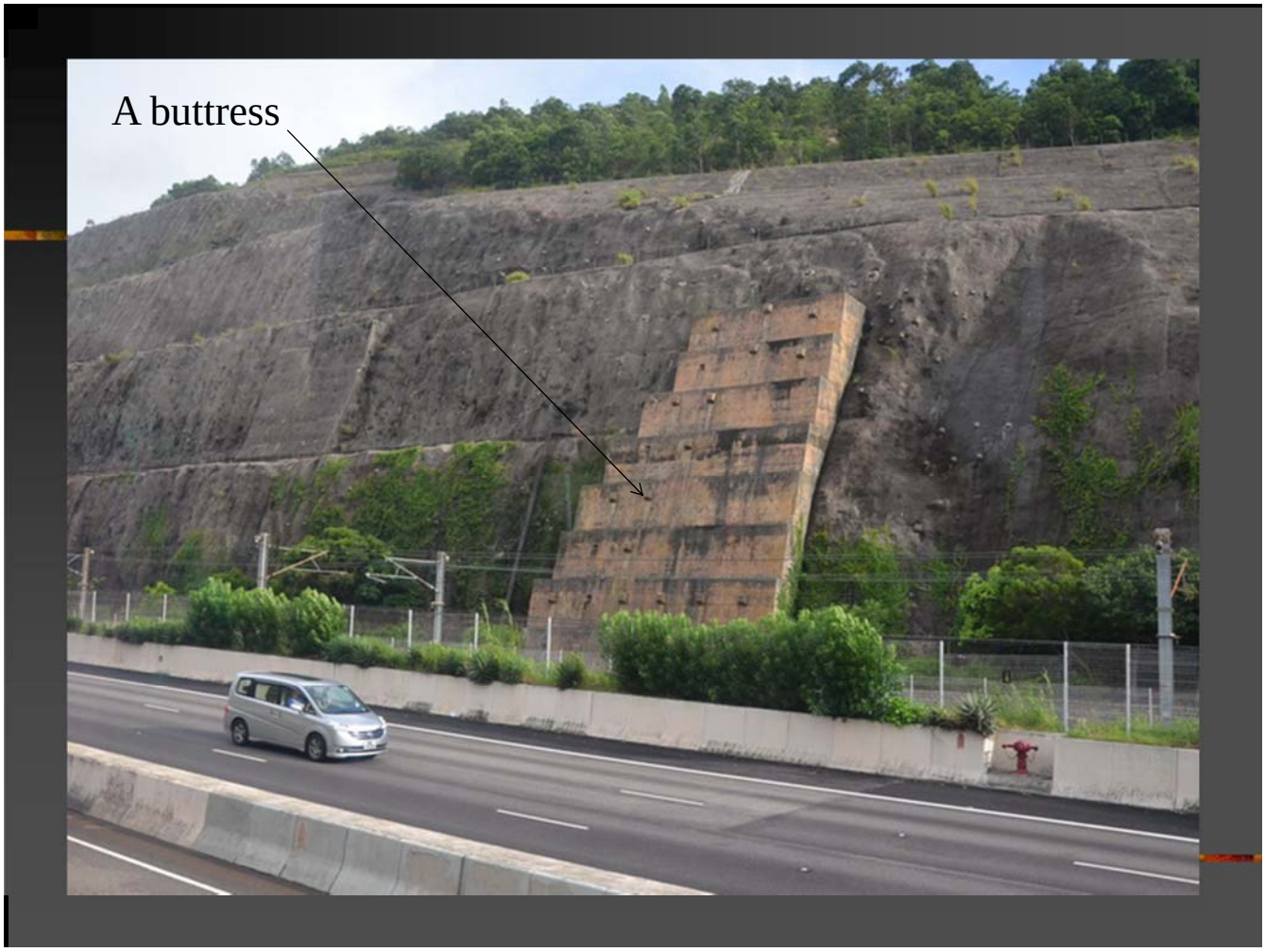
Most rock slopes need some forms of treatment to ensure continued stability. Improvement methods include:

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.



Protecting a slope by
the use of buttress wall

Protecting a slope by
the use of buttress wall



Toe of slope strengthened by buttress wall

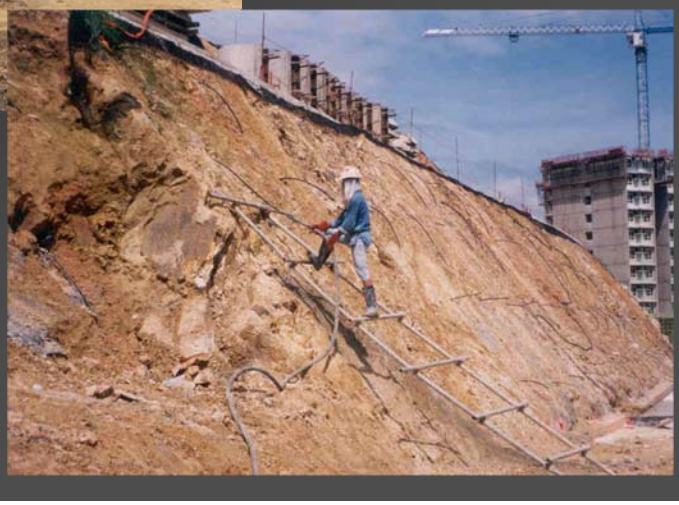
Protection and treatment to Rock Slope (continue)

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.

Provide a buttress to support an unstable rock

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

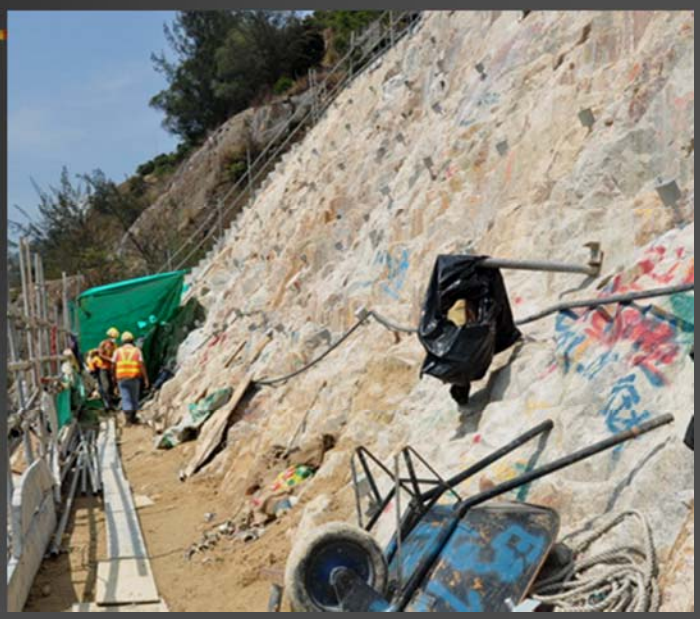
Scaling a rock slope surface



Scaffold set-up prepare for the carrying of scaling a rock slope surface

Loosened rock needed to be scaled

Loosened rock stabilized using closely placed dowel



Dowel heads

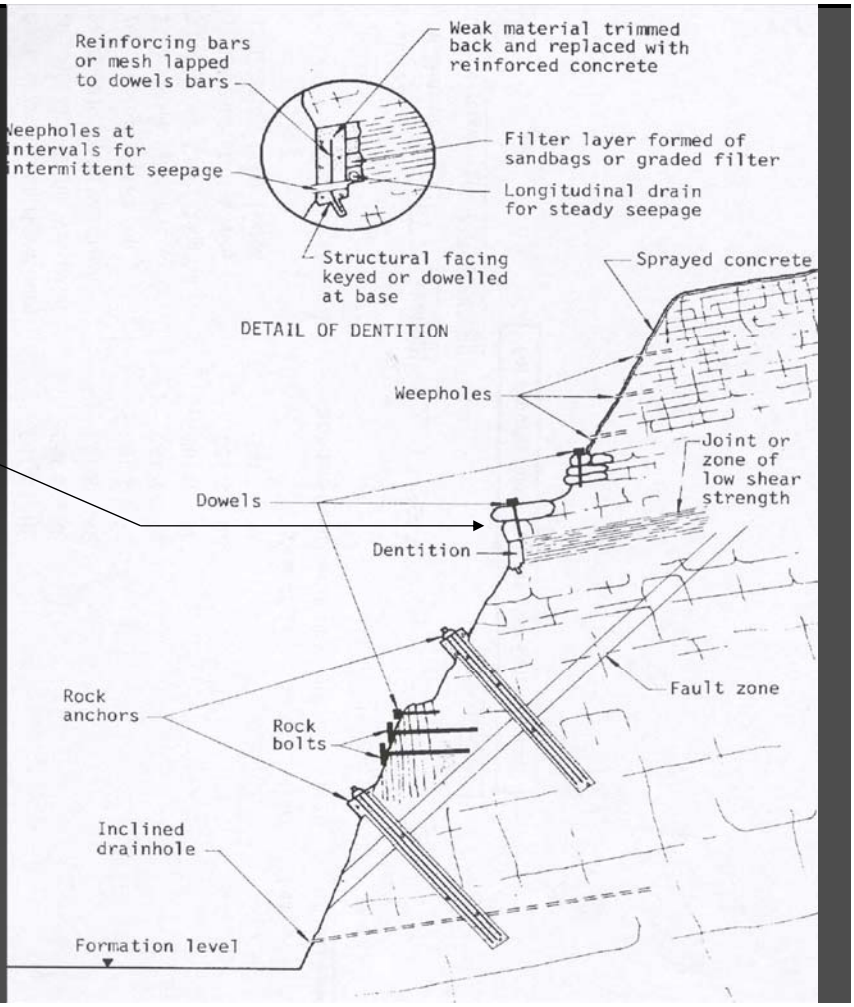
Cutting of rock using pneumatic (compress-air driven) breaking machine

Cutting of rock using manual breaking method (by drilling row of holes and forced cracking usinf lever action)

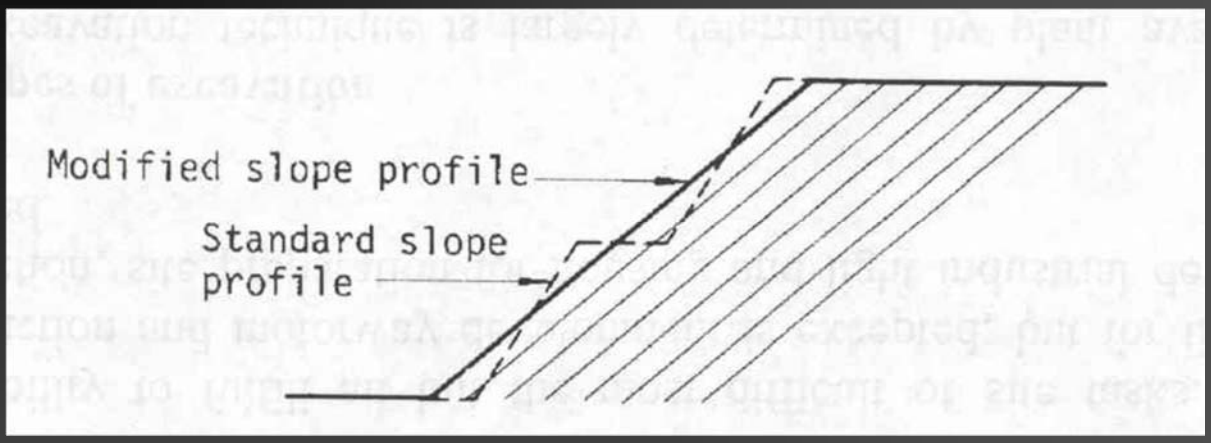
pneumatic breaker

Row of holes to form a crack

Rock cracked and split



Various methods to stabilize a rock slope



Improvement the slope profile by forming benches

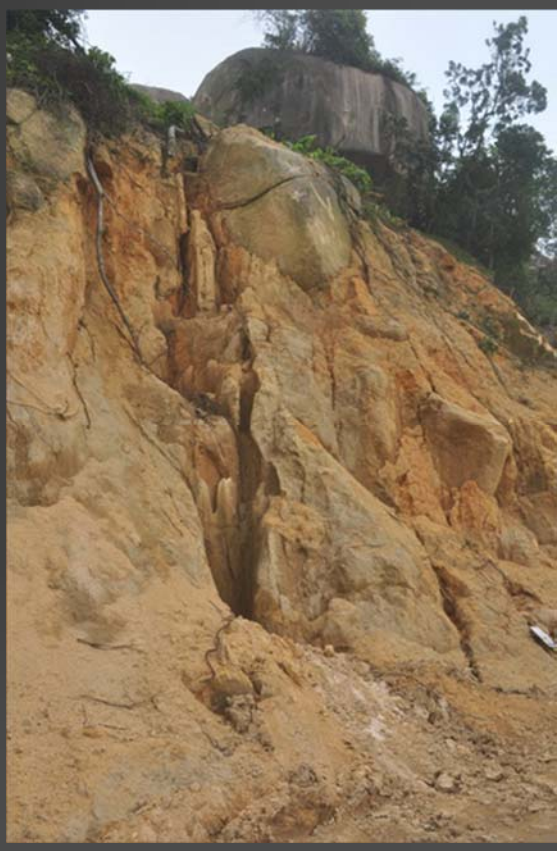
Forming soil nail and rock bolts

Rock anchor tying the exposed surface of slope with anchor head being covered for protection and future maintenance

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.

Slope without surface protection having the problem of erosion with the surface soil wash-away by rain



Signs of slope instability
or heavy surface erosion

Protection to slope by rigid surface

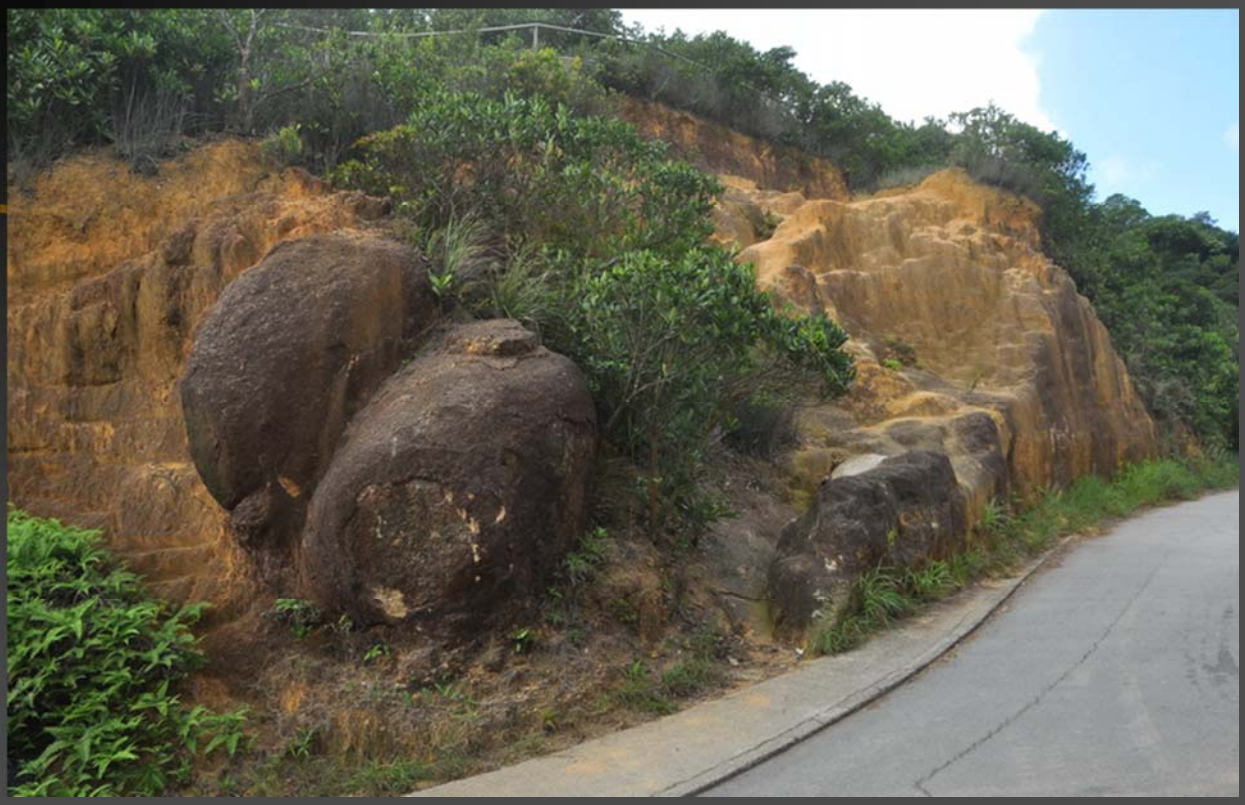
Rigid surface protection on slopes are commonly used to reduce rainwater infiltration and to prevent erosion of the slope-forming materials. This can be done by:

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.

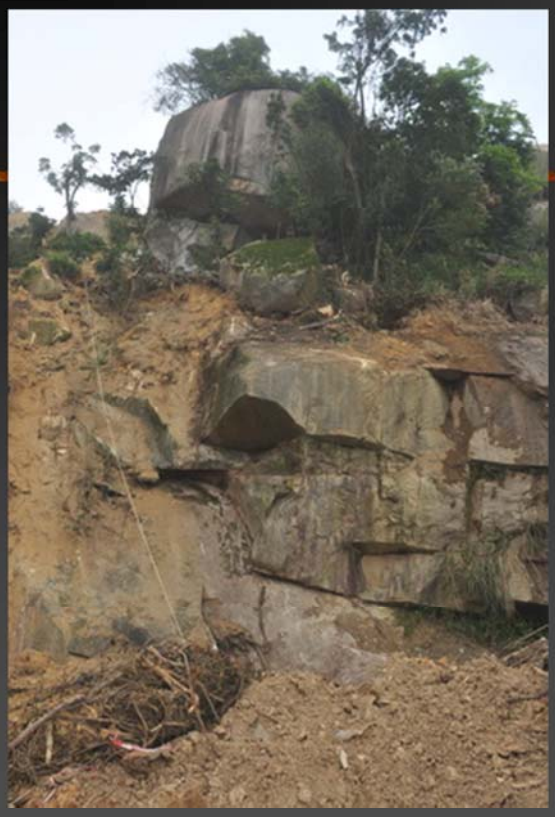
Sprayed concrete (shotcrete) – protection by applying a spraying mortar onto surface of slope.

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

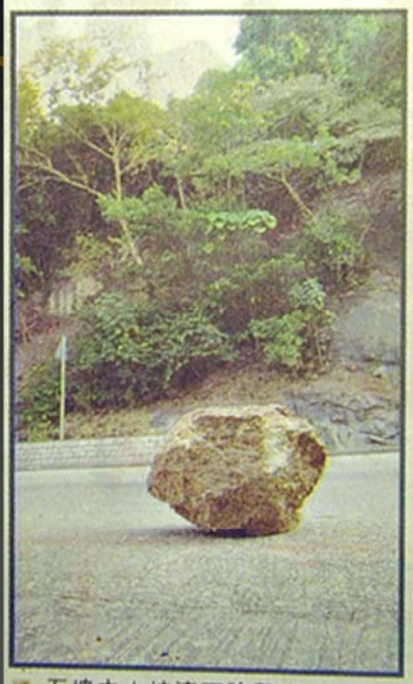


Top soil of slope surface without protection will easily be washed away.



Exposed rocks during slope cutting become unstable that require temporary or permanent protection

巨石滾落山險擊中巴士



石塊由山坡滾下險擊中途經巴士。 （梁卓明攝）

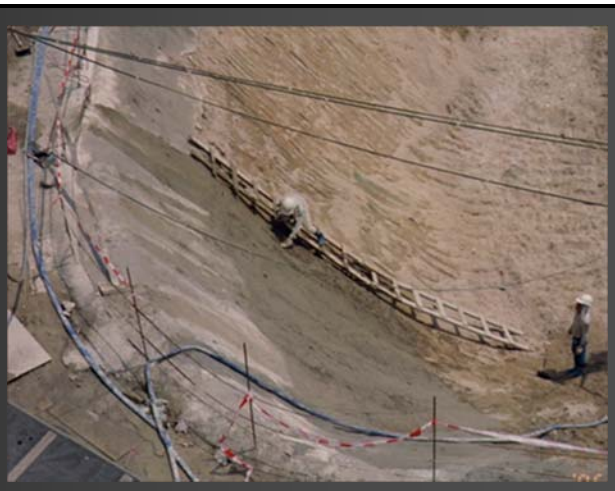
【本報訊】跑馬地發生巴士險被大石擊中意外。一塊有如籃球大的石塊，昨晨在山坡突滾下馬路，一輛巴士剛途經，幸司機及時煞車，避過被大石撞中巴士釀意外，警員到場將石塊移到路旁，待有關部門處理。

車長急煞避一劫

昨晨八時許，一輛雙層巴士沿大坑道落斜擬往北角碼頭，途至一一三號對開時，路旁山坡上一塊直徑逾一呎石塊突然鬆脫，從五米高山坡跌下，並滾出馬路，巴士車長驚見大石滾出，急忙煞車，大石在巴士車頭滾過，車長擔心再有石塊滾下，隨時擊中路過車輛及路旁巴士站候車乘客，立即報警求助。

警員接報到場，將石塊搬到行人路上，交通亦恢復正常。警方相信因泥土鬆脫，令石塊滾下，稍後將聯絡相關部門進行檢查。

News from Oriental Daily, 27 January 2012



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

Spraying concrete by compress air and nozzle

Spray concrete sometimes used as temporary protection for cutting slope

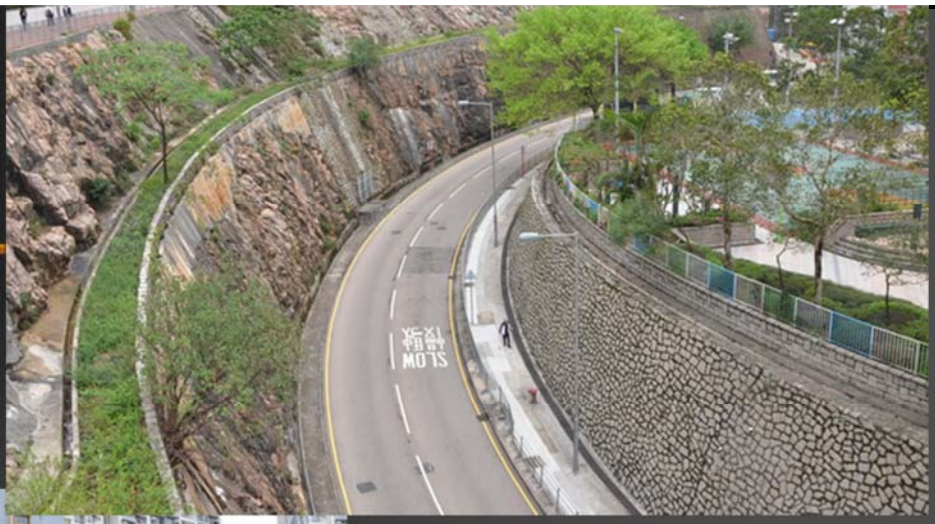
Spraying concrete by
compress air and nozzle

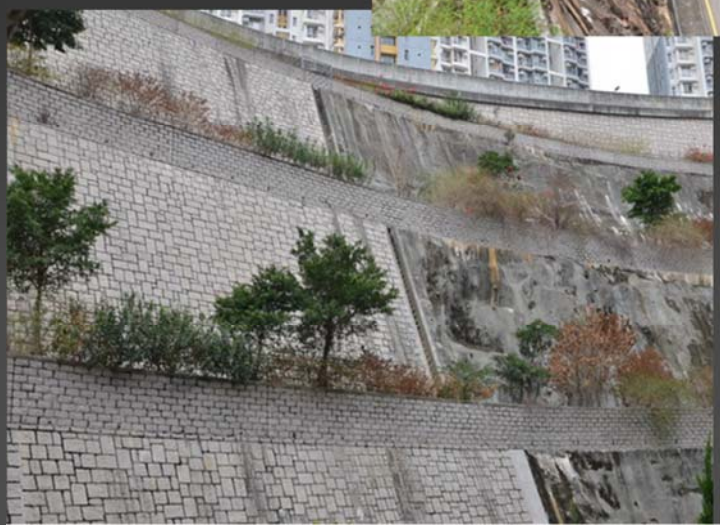
Slope rock will be scaled off, covered with wire mesh and spray on with shotcrete as final protection. Sub-soil drain (weep hole) to be provided where necessary

Protection to slope by rigid surface (continue)

- 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 permeable thus weep holes are required for draining out of the ground water to avoid the development of high water pressure behind the slope

Using stone pitching as a rigid slope surface





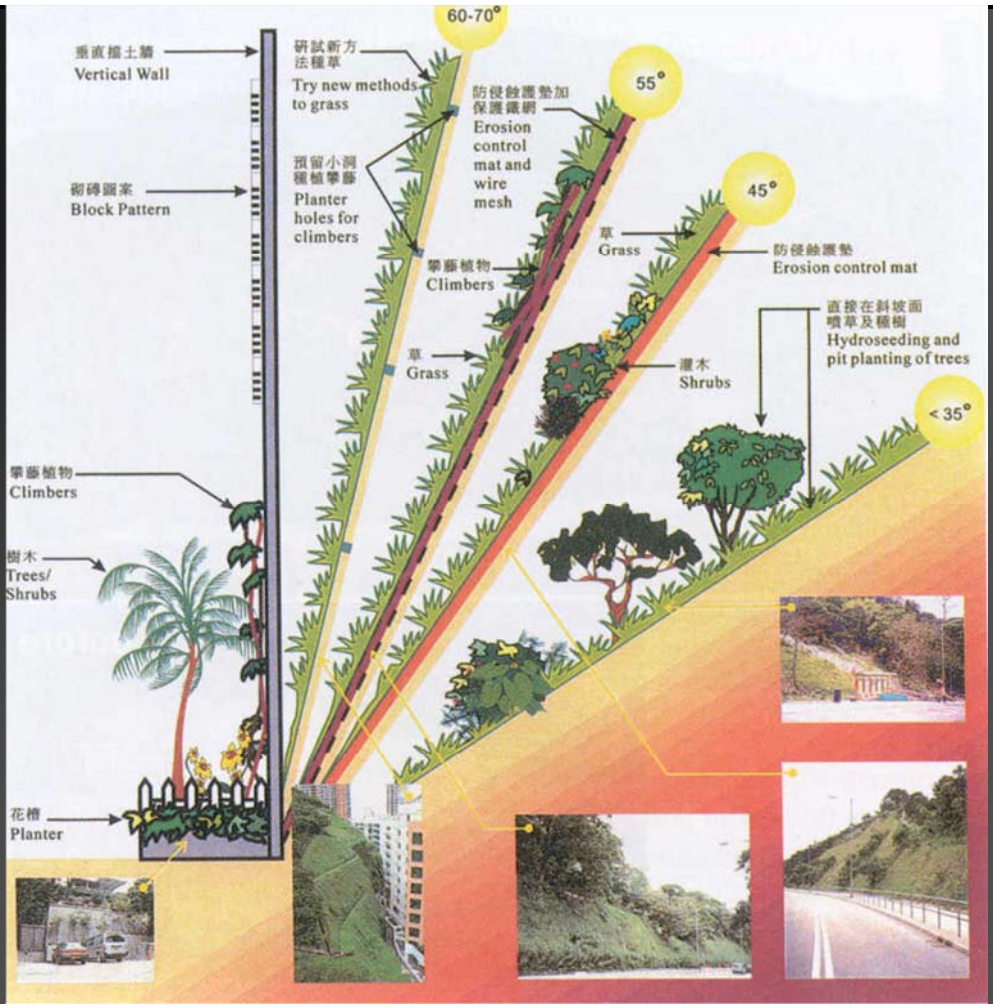
Using stone pitching as a rigid slope surface

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.

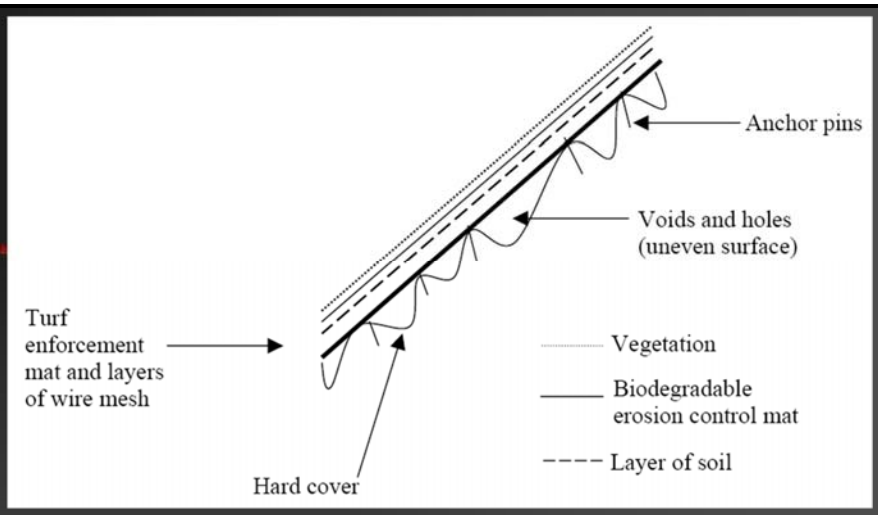
Various method to treat a slope surface using vegetation

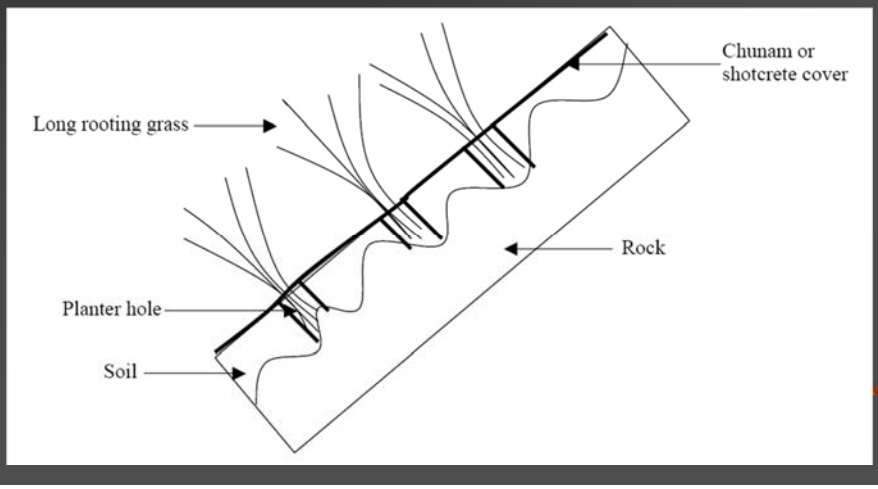


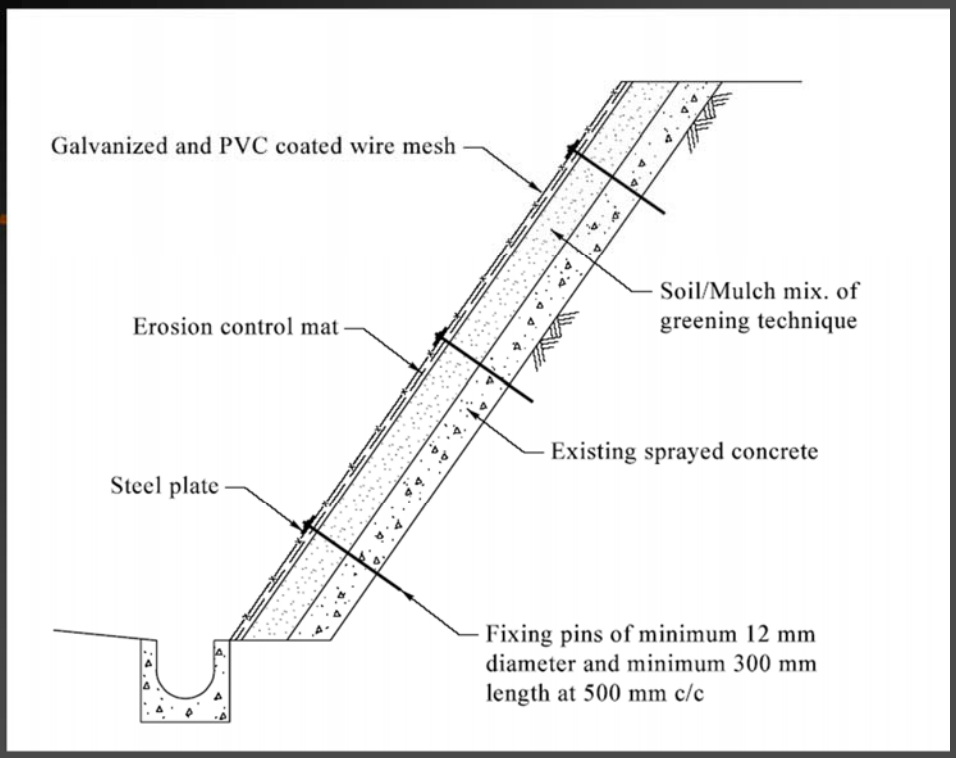
Turfing by the laying of glass carpet

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

Turfing a slope surface







Detail using addition erosion control mat and wire mesh to improve hard-spray 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

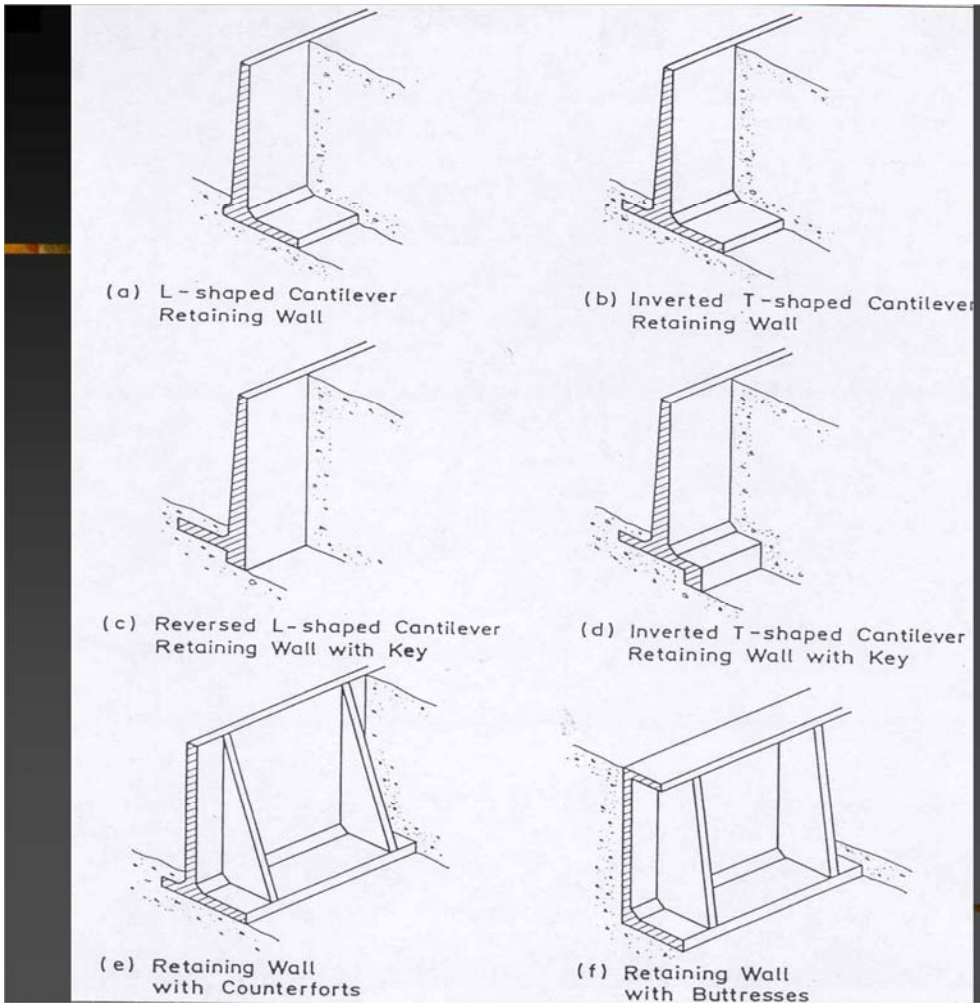
Retaining wall are structures usually provided at the toe of a slope to stabilize it from slide, overturn or collapse.

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)

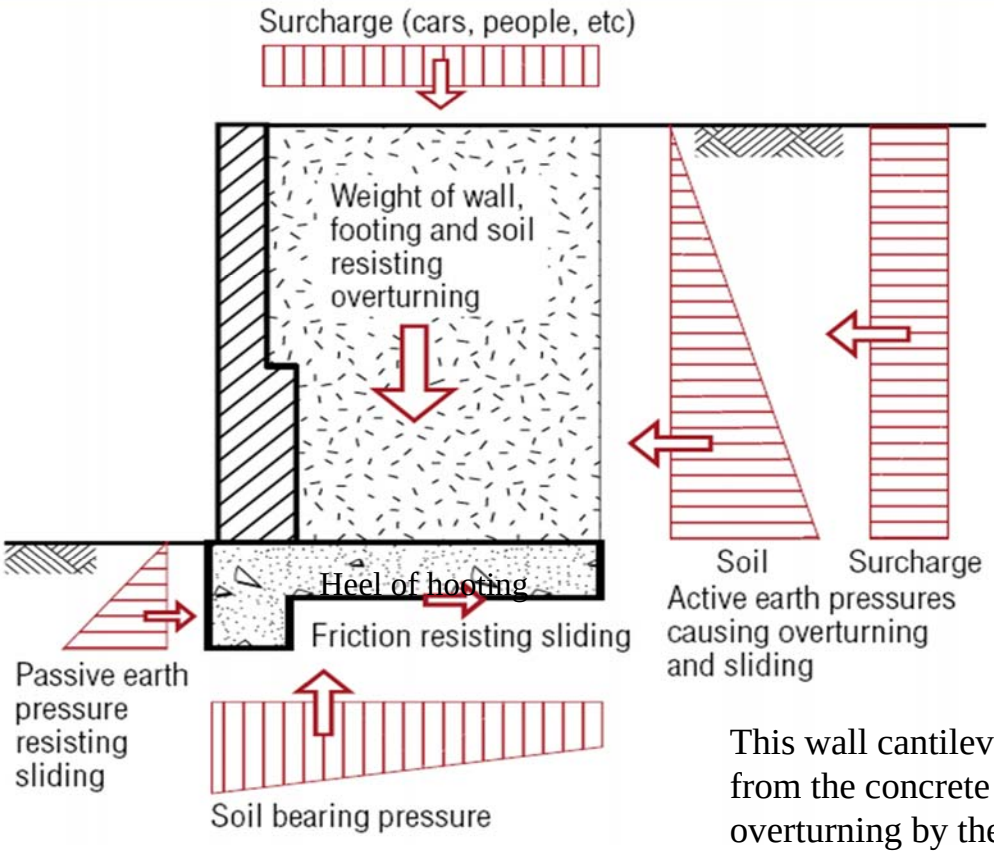
Principle to retaining wall design can be of 2 main types

- cantilever type
- Gravity type
- Earth reinforced type

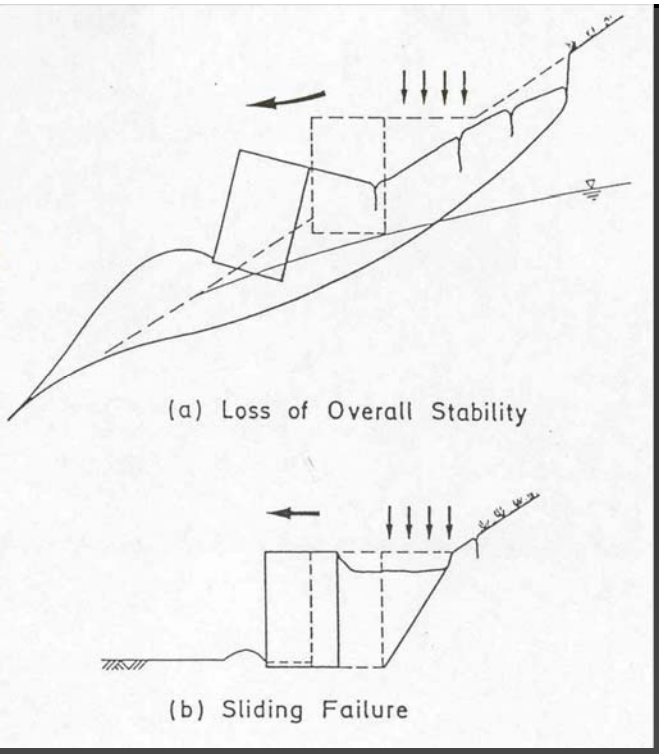


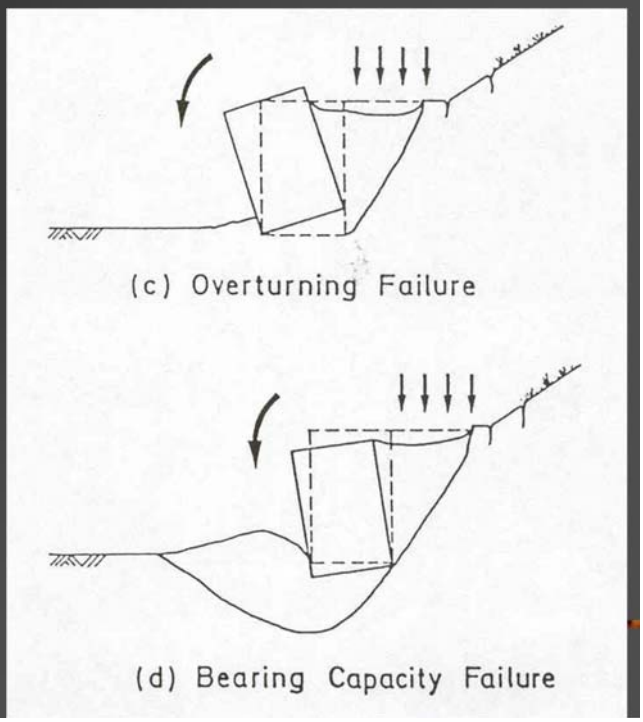
Various forms RC cantilever type retaining wall structures

This wall cantilever vertically from the concrete footing and resist overturning by the mass of the soil material on the heel of the footing

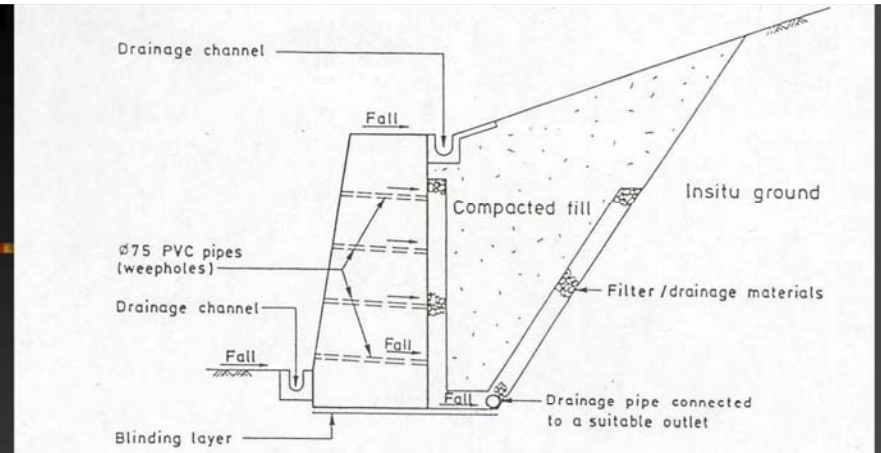


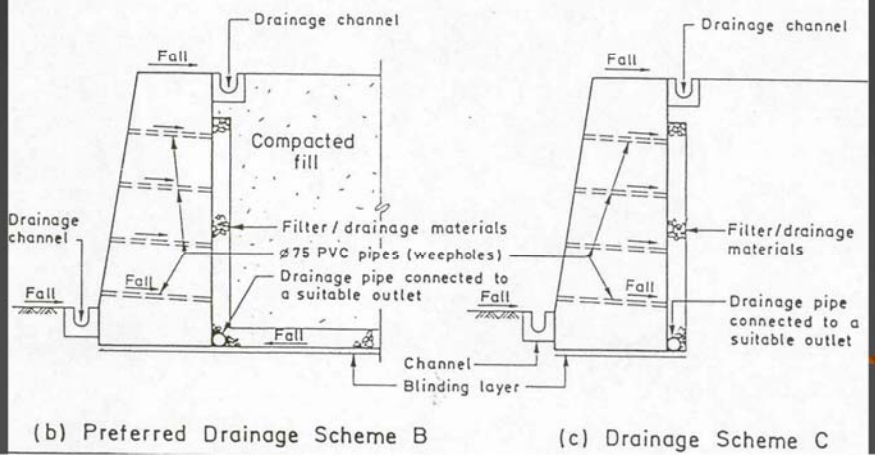
This wall cantilevers vertically from the concrete footing and resist overturning by the mass of the soil material on the heel of the footing



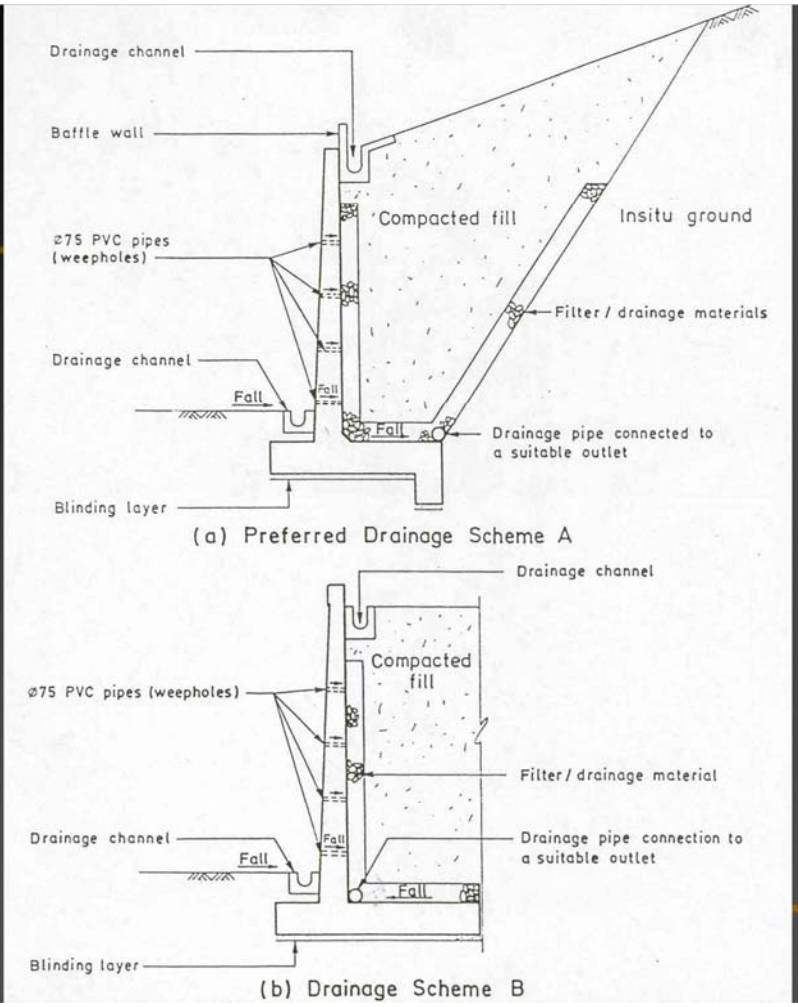


Common failure modes of a retaining wall

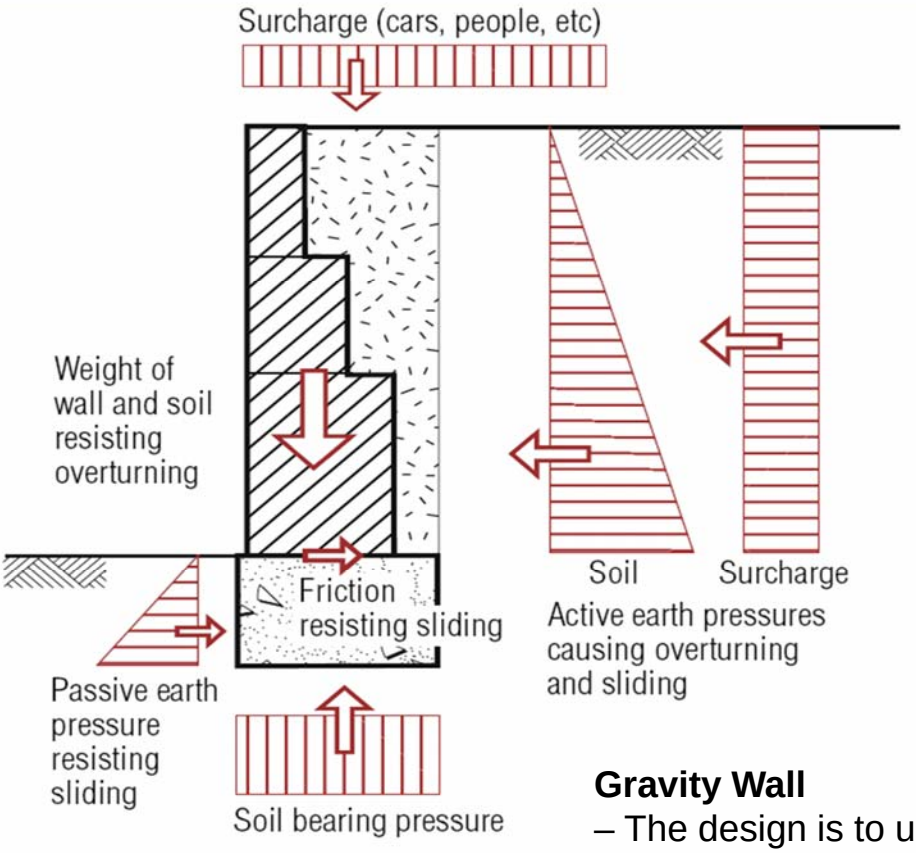




Construction of typical gravity type retaining wall and its drainage arrangement



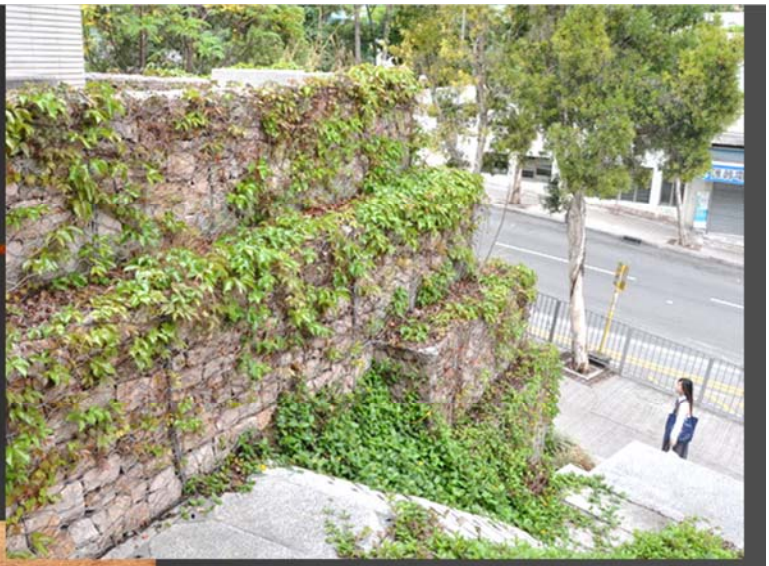
Construction of typical cantilever type retaining wall and its drainage arrangement



Gravity Wall

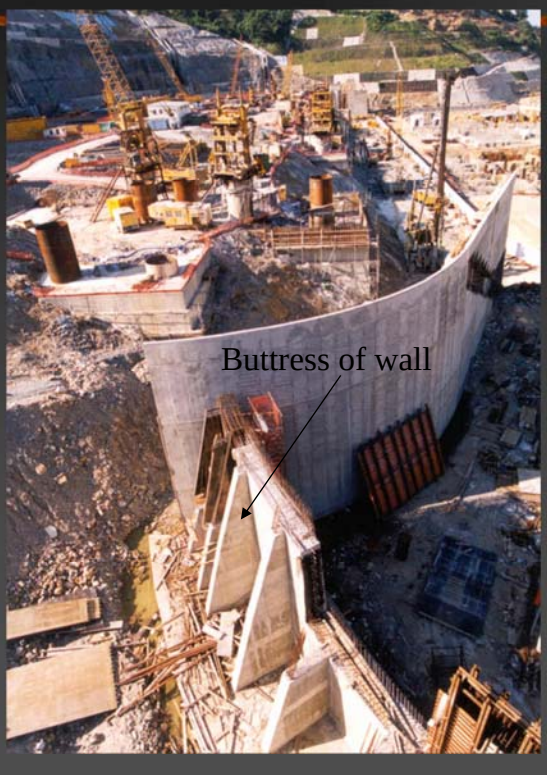
– The design is to use the own weight of wall and the weight of any captured soil/fill to resist the lateral soil pressure

Example of gravity wall using solid stone block



Stone mass at the toe of a bench serves to provide a gravity hold for the retaining soil-filled slope

Construction of RC cantilever/gravity mixed type retaining wall and finally formed a terrace to construct buildings

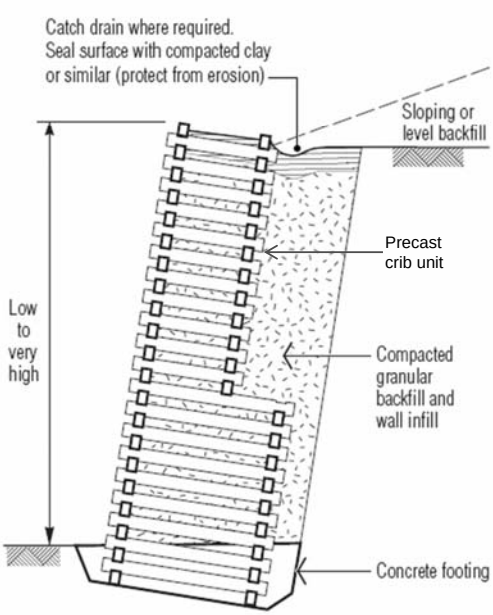


Precast crib units

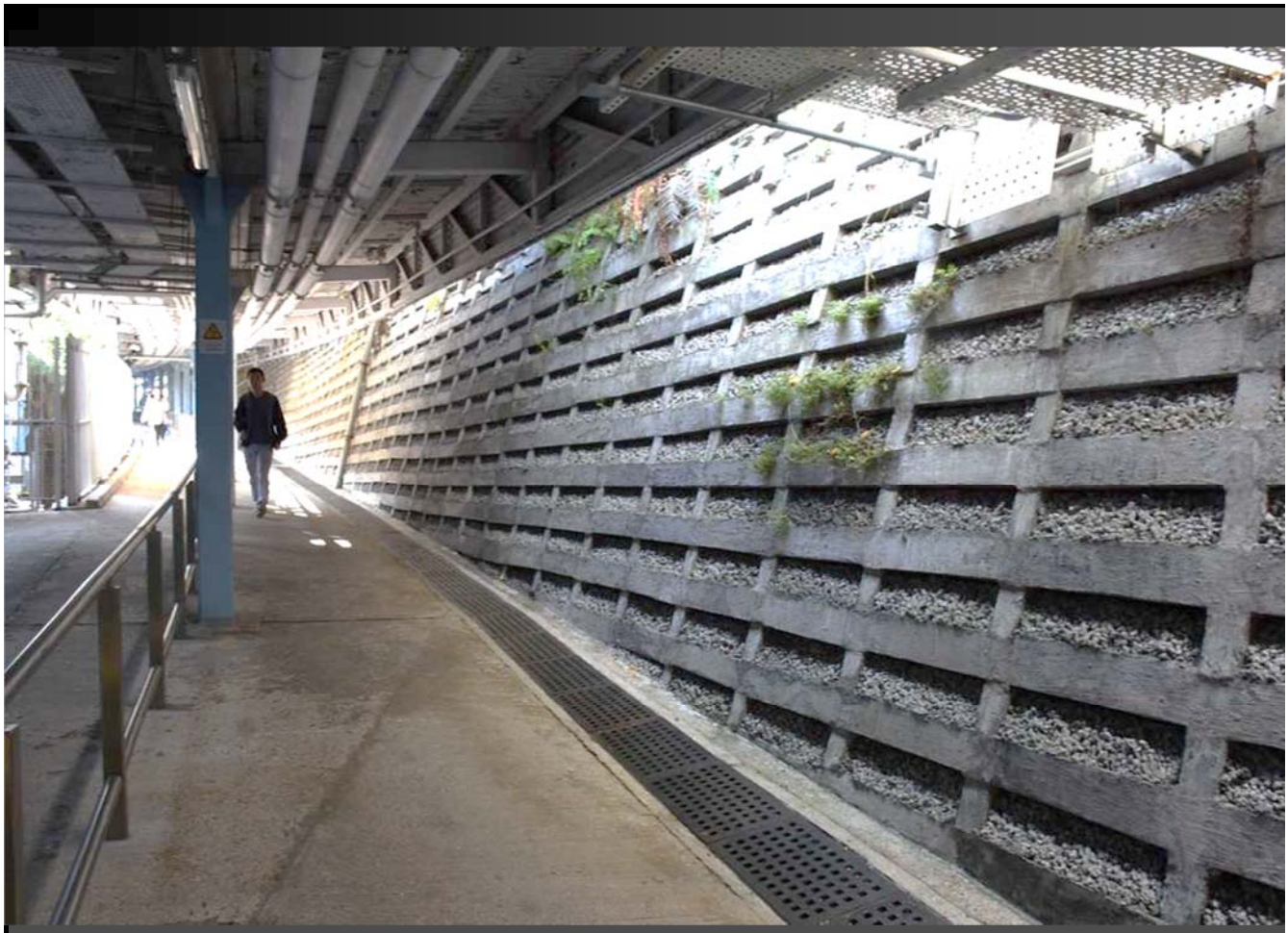
Crib wall

– constructed from precast concrete components that interlock to form an open grid.

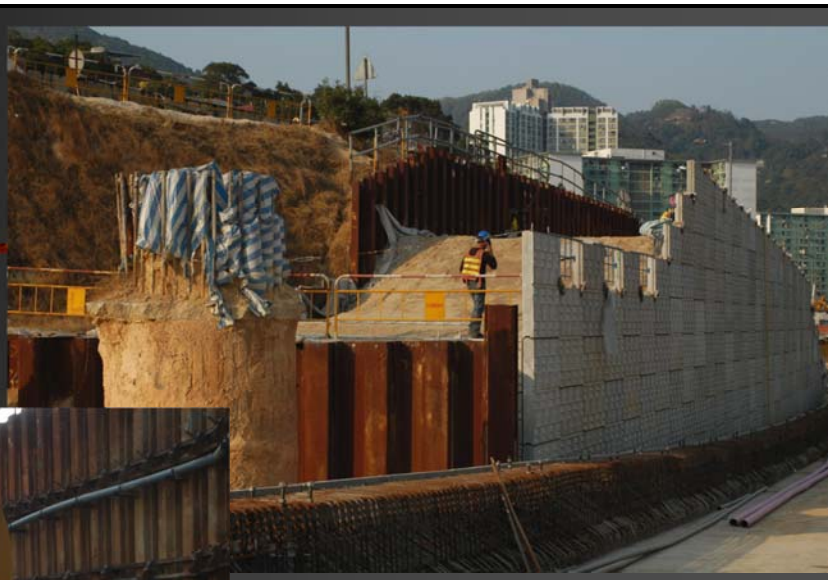
The spaces between the units are filled with gravel making the system free draining. Crib walls can be economically designed and built for a wide range of wall height ranging from 2m to more than 10m. Wall can also be enhanced aesthetically by landscaping and planting vines on the top of wall or in the spaces above the cribs.



Crib wall with vegetation as part of the greening treatment



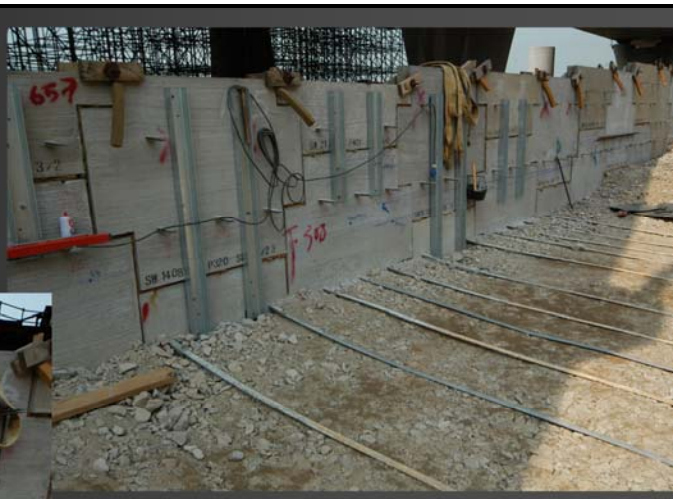
Construction of Earth-reinforced retaining wall

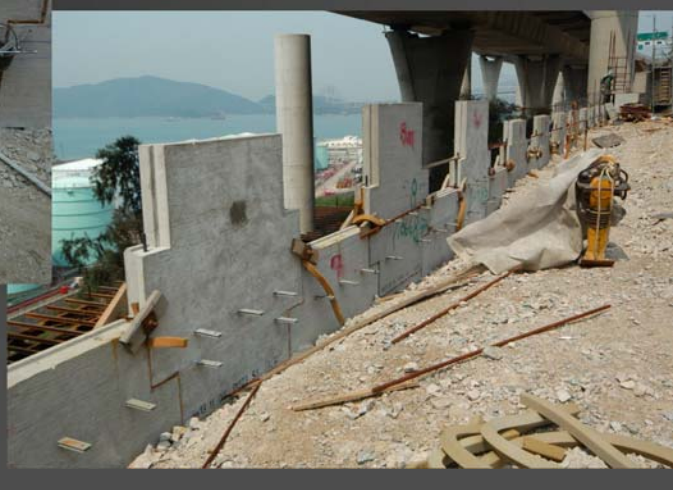


Construction of Earth-reinforced retaining wall, with a temporary sheet-pile wall as stage one set-back arrangement

Detail of the precast panel as surface panel of the retaining wall

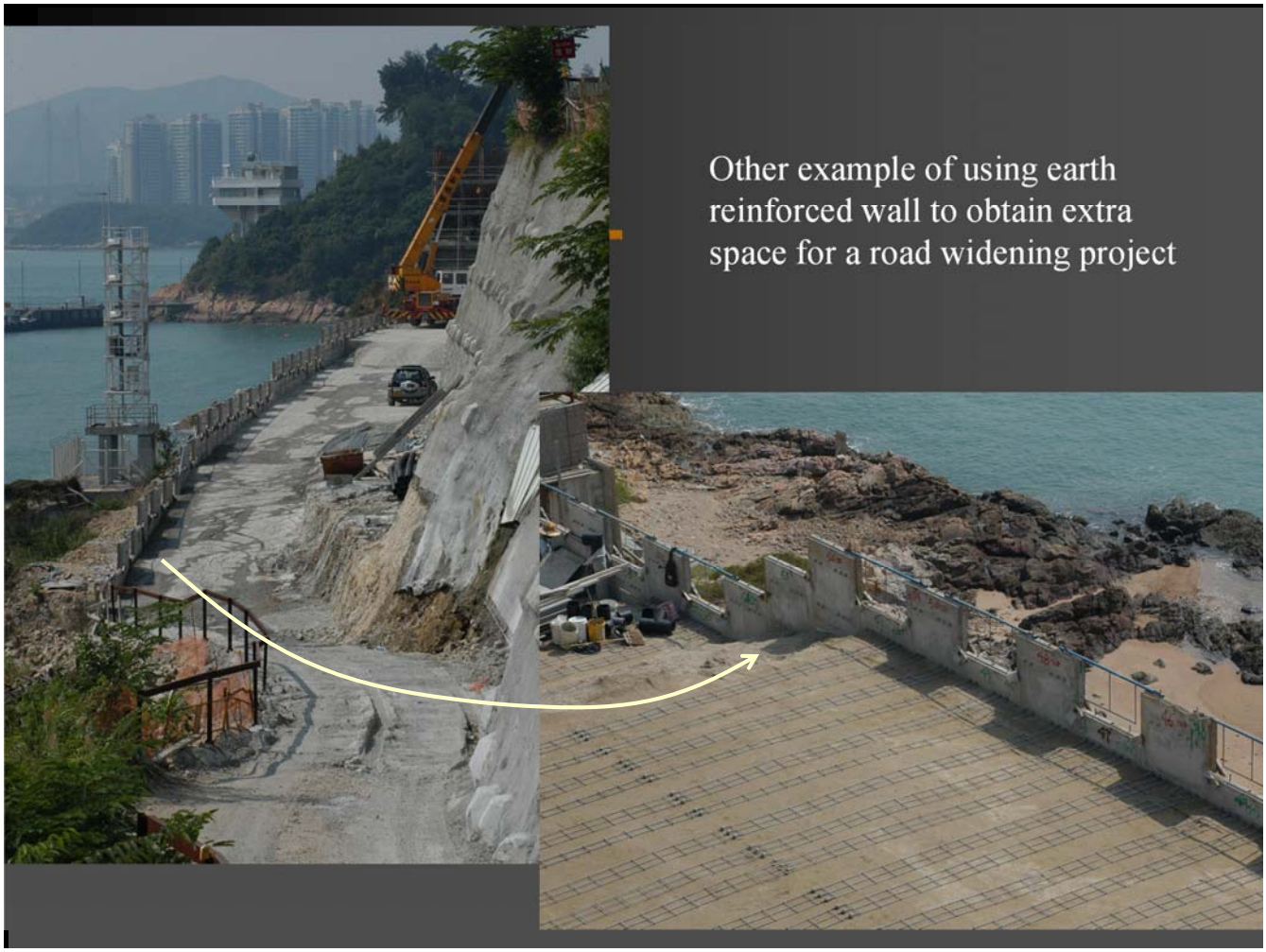
Detail seeing the tie behind the panel of the earth reinforced wall





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



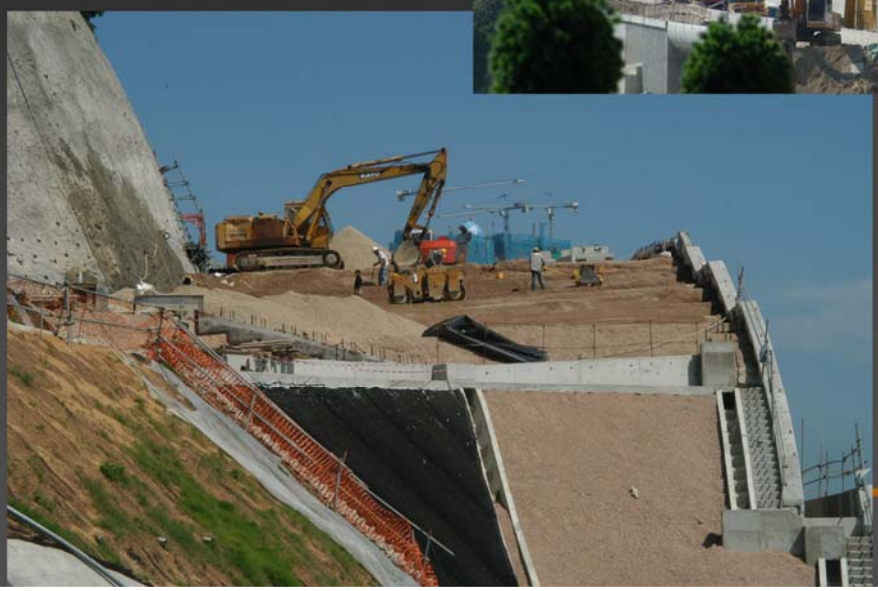
External view of some of the partially completed earth reinforced retaining wall

Examples where large-scale slope works are required in construction

1. Building work – obtaining of land space for building developemnt 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 large-scale site formation or other Civil Engineering related projects

Slope stabilization to form a new coastal roadway near Cyberport

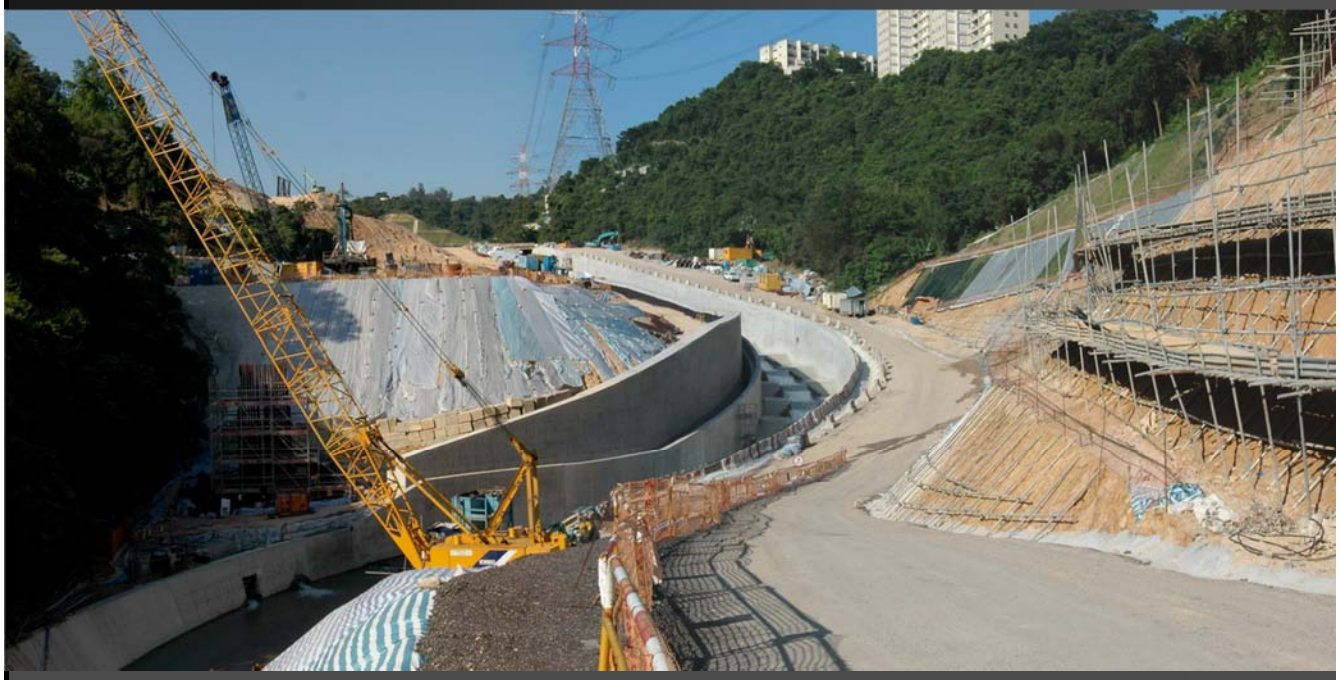


Completion of the new roadway with the treated slope on the side heading toward Cyberport

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)

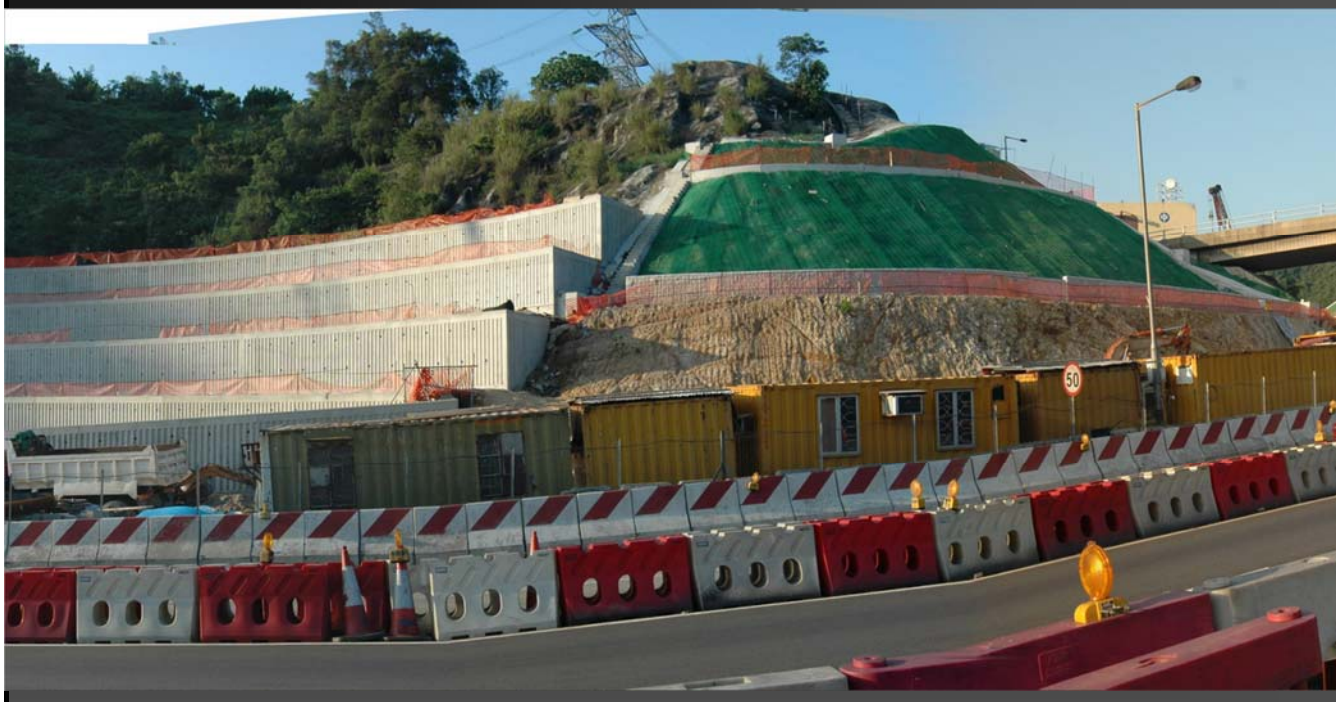
Installing the soil anchor and tighten the skin wall with a row of waling beam

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

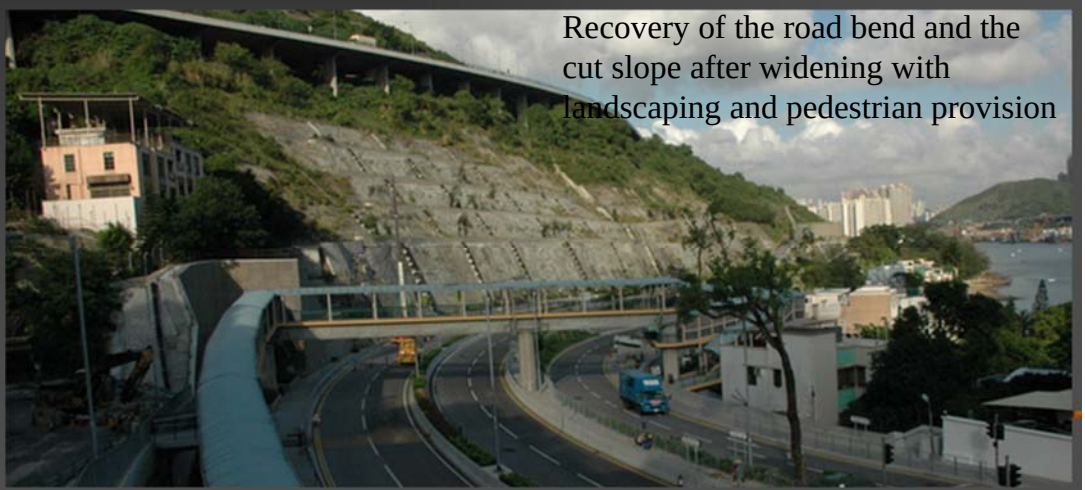
Precast units for retaining wall facing panel with a surface drain channel

Preliminary treated slope with geo-textile underlay as support for growing plant or grasses

Preliminary treated slope with geo-textile and the growing of new grass afterward

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



Recovery of the road bend and the cut slope after widening with landscaping and pedestrian provision

Stage 1 cutting back of slope stabilized by ground anchors.

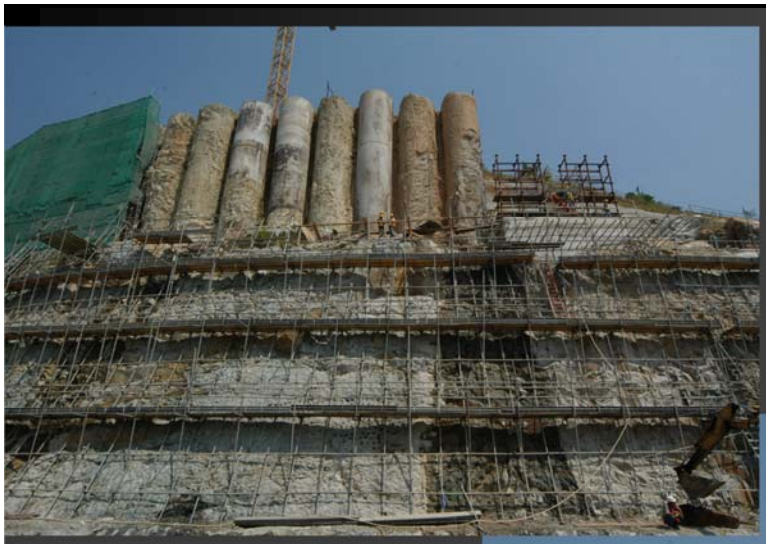
Stage 2 permanent wall supported by using bored-piles.

Widening of existing roadway by cutting and afterward filling

Widening of existing roadway by cutting, temporary stabilizing, forming of retaining structure and afterward filling

Widening of existing roadway by cutting, temporary stabilizing and afterward filling

Stabilizing large area of slope along a servicing roadway



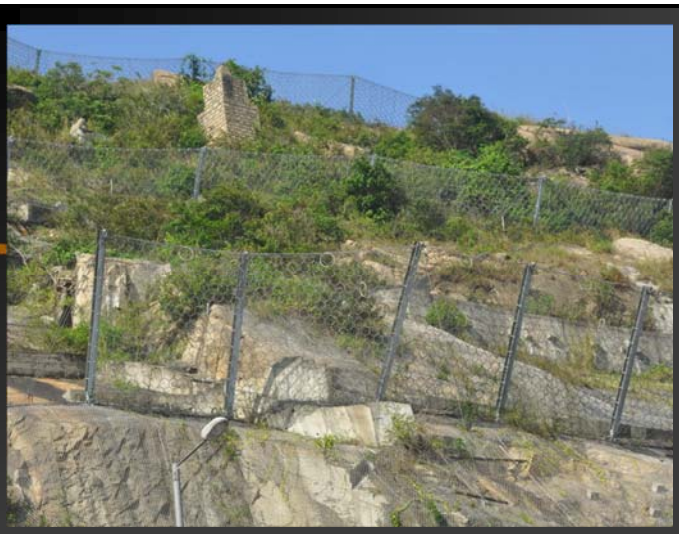
Other examples of slope treatment or stabilization of more complex in nature

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

Final finished slope with drainage, retaining wall structure, surfacing treatment and other maintenance access path in place

Other examples of slope work or stabilization provision of more complex in nature – complicated topographic condition and work layout



Examples of some provisions to keep a slope safe from possible falling of loose materials by the use of catch-fence

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)

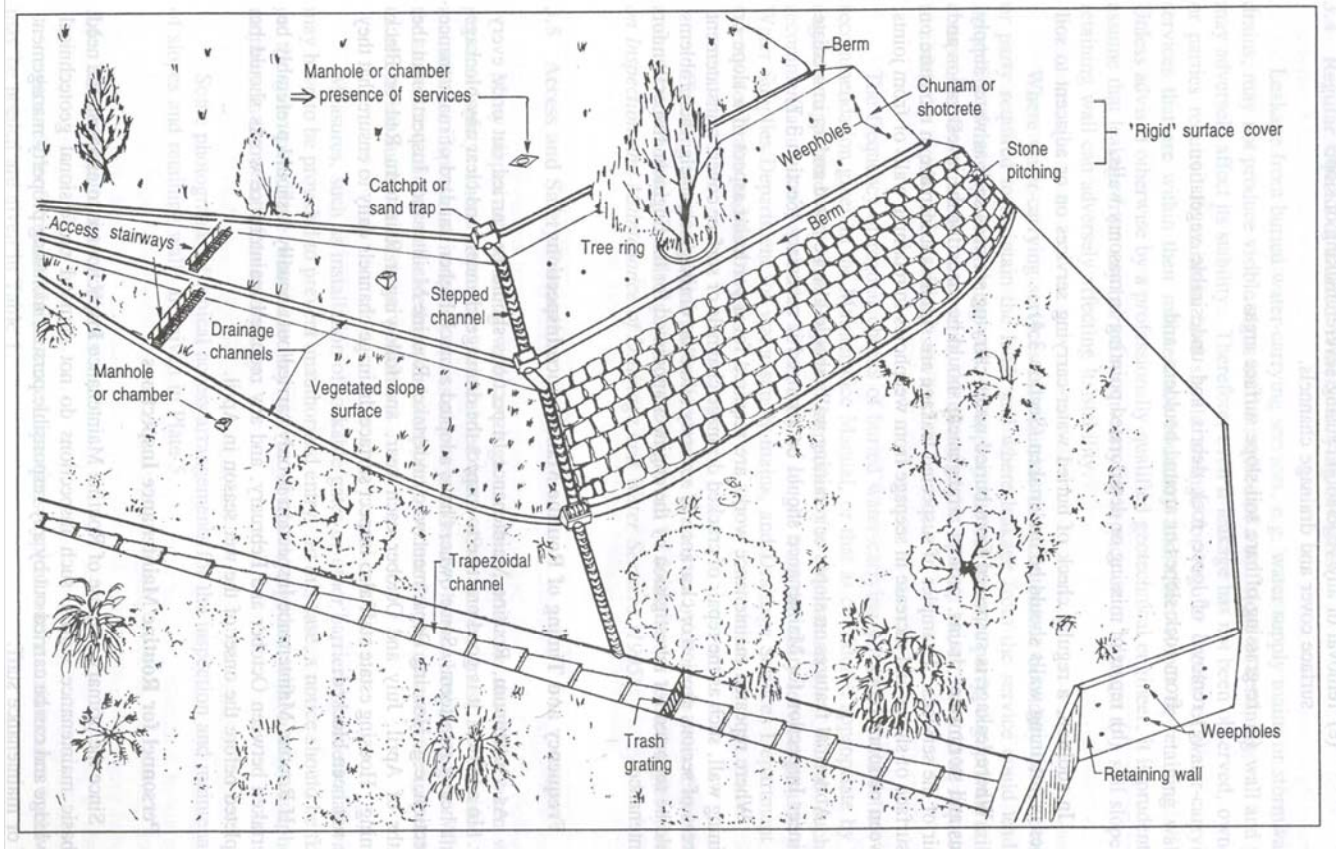
Inspection should be carried out regularly to determine the conditions of a slope. These inspections can be sub-divided into 3 levels/categories.

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

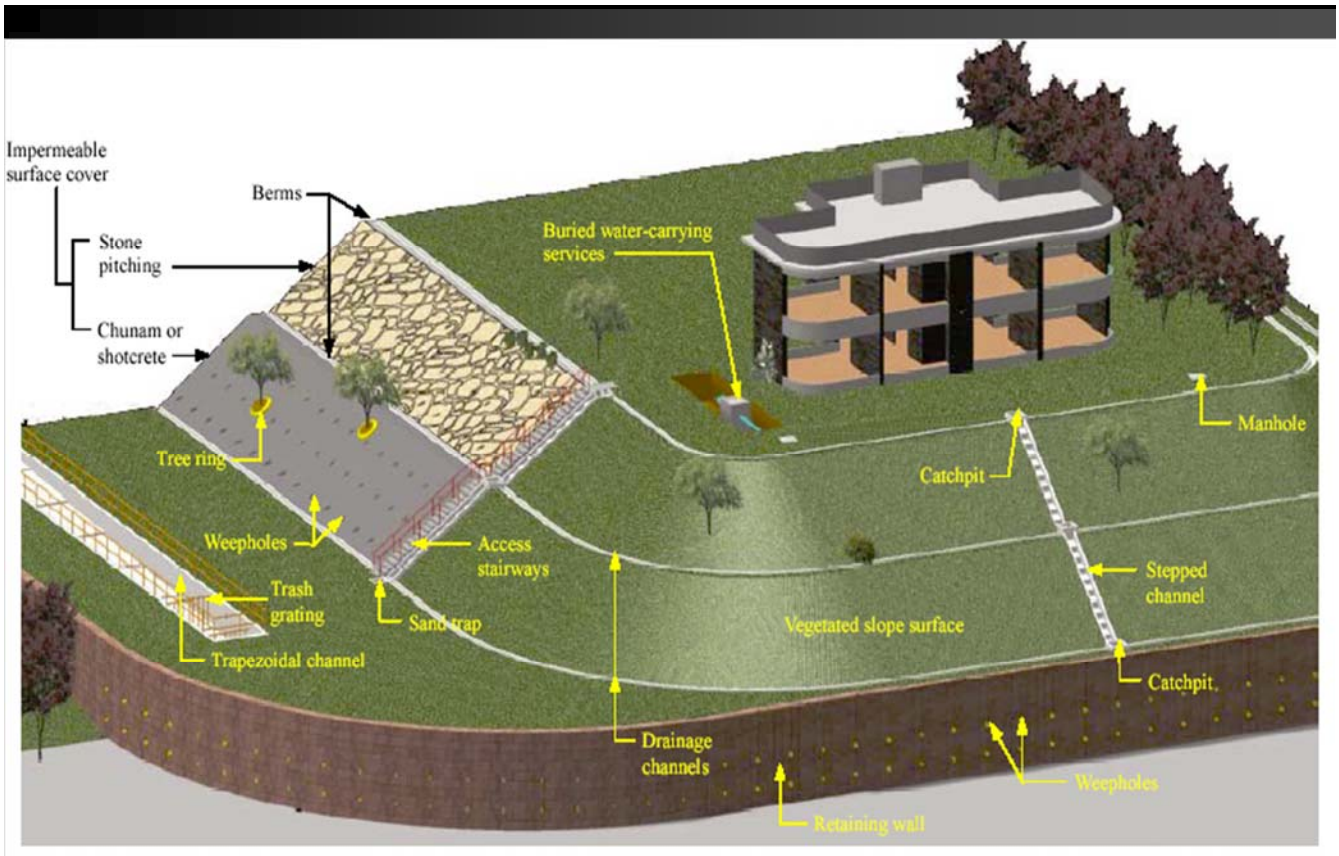
Routine Maintenance Inspection

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

(1) Vegetated Surface

(2) Shotcreted Surface

Examples of poorly maintained slope

(3) Chunam Surface

(4) Masonry Facing

Examples of poorly maintained slope

(1) U-channel along Crest of Slope

(2) U-channel along Berm of Slope

Examples of poorly maintained surface drainage

(3) Catchpit at Toe of Slope

(4) Catchpit at Crest of Slope

Examples of poorly maintained surface drainage

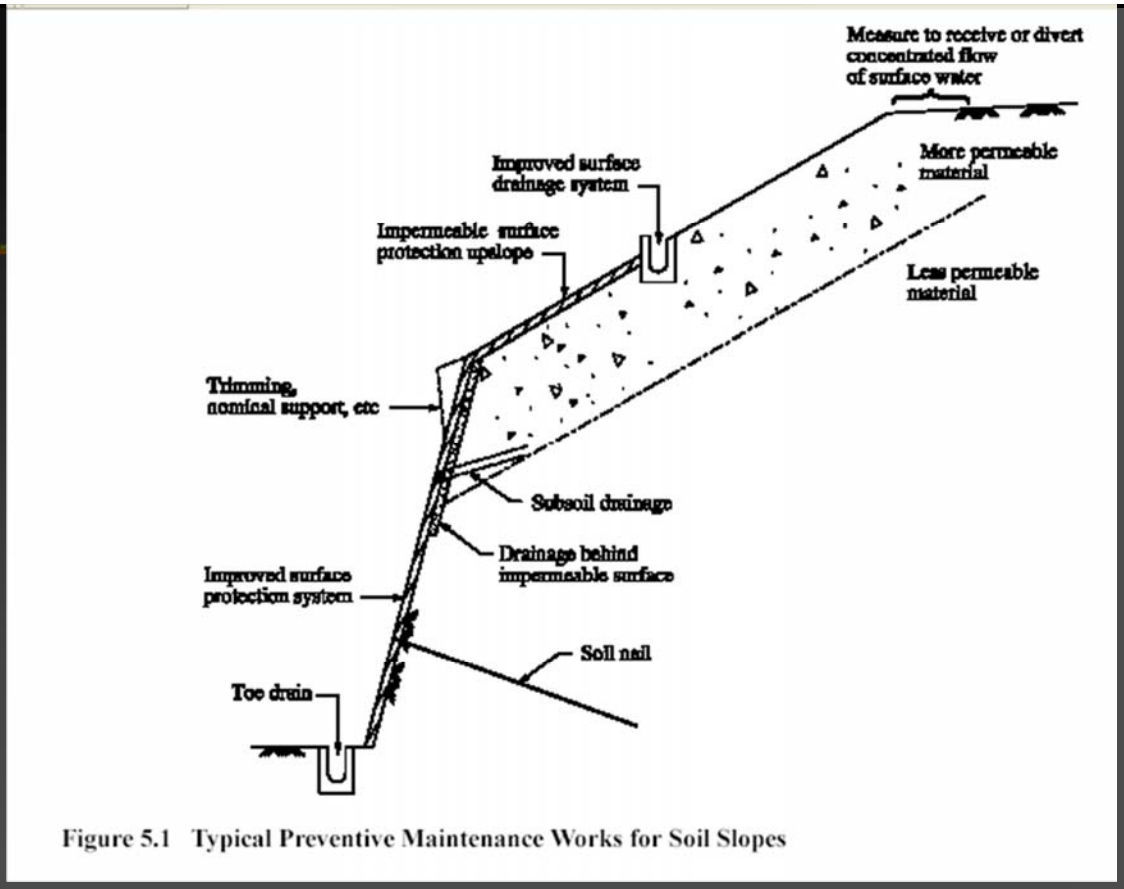
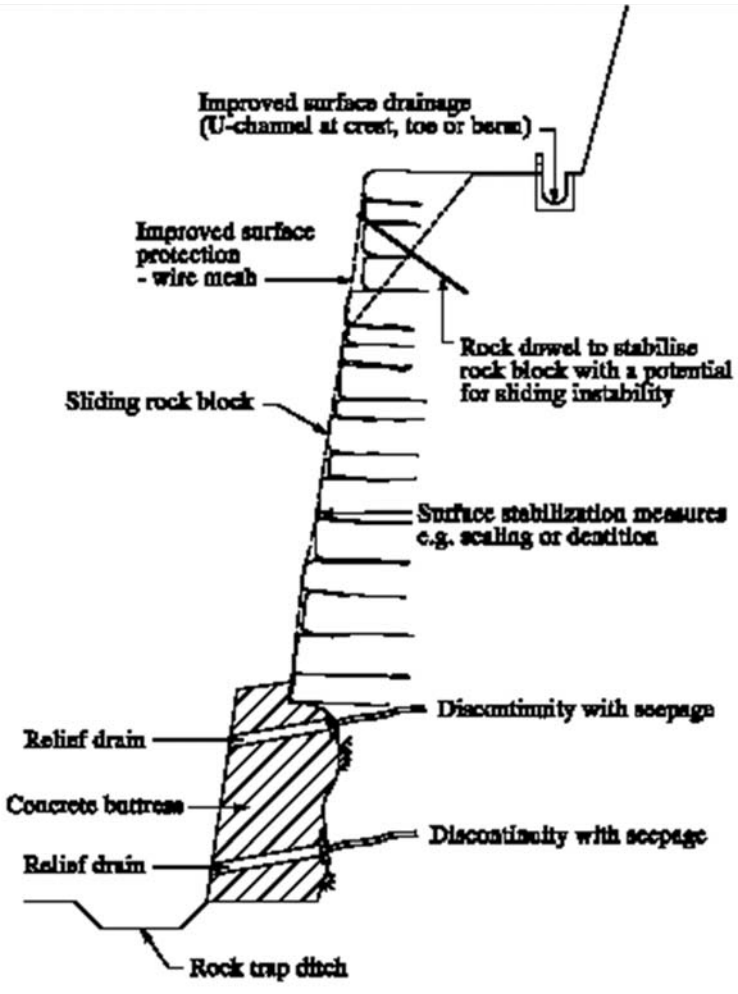


Figure 5.1 Typical Preventive Maintenance Works for Soil Slopes

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)	(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 re-planting. (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.

Typical Routine Maintenance Works for slopes and retaining walls

The site check list below may be used as a guide for landslide inspections during emergency, but it is by no means exhaustive. It includes the possible sources of danger and causes of failure which should be noted by the engineer in the course of his inspection.

(a) As water is normally the key element in triggering landslides, consider and look for the sources of water that are likely to adversely affect the situation and obtain the related information:

- (i) rainfall and the time of failure (for correlation with development of rainfall at the nearest raingauge),
- (ii) flooding and its timing,
- (iii) concentrated surface water flow, channelised flow or areas of water ponding above the slope or along the road,
- (iv) sewers and stormwater channels and drains, gullies, catchpits, cross road drains, etc., and their conditions,
- (v) buried or exposed fresh or salt water pipes along the road and their conditions,
- (vi) prominent water courses such as nullahs, natural drainage lines, etc., and their conditions, and
- (vii) diversion of flow due to blockage of natural drainage lines and seepages from slopes.

(b) Look for indications of ground movement such as displacement and/or cracking of:

- (i) paved ground, road kerbs and drainage channels,
- (ii) slope drainage channels, catchpits, and
- (iii) trees or other normally vertical features.

(c) Look at surface features for signs of distress:

- (i) tension cracks on the ground surface or road pavement,
- (ii) bulging of slopes or heave of ground or road,
- (iii) local depression of paved ground or road,

Check List for Slope/Landslide Inspections

(iv) subsidence of ground or road,

(v) excessive water seepage (indicative of high groundwater level or distressed services),

(vi) landslide debris, and

(vii) scouring or undercutting of the slope face, ground or road features by surface water.

(d) Check retaining walls including masonry type walls:

(i) tilt and horizontal misalignment,

(ii) settlement and undermining of foundations,

(iii) cracking (including broken tell-tales),

(iv) bulging,

(v) fallen debris or dislodgement of masonry blocks, and

(vi) excessive seepage and/or weephole flows.

(e) Look for other adverse features in the area where further deterioration may cause collapse:

(i) boulders/corestones (inadequate embedment),

(ii) open-jointed soil/rock faces,

(iii) leaning trees,

(iv) blocked slope or road drains,

(v) damaged slope surface protection,

(vi) pre-existing tension cracks,

(vii) old drainage lines,

(viii) recent changes to upslope or downslope environment (e.g. any resurfacing, demolition, site formation, utility installation, etc.) which could adversely affect the drainage characteristics of the area around the slope and road, and

(ix) material that has moved or been disturbed during the present landslide but has not yet detached from the slope.

Check List for Slope/Landslide Inspections

End of presentation for Slope Wors