The Stability of Slopes

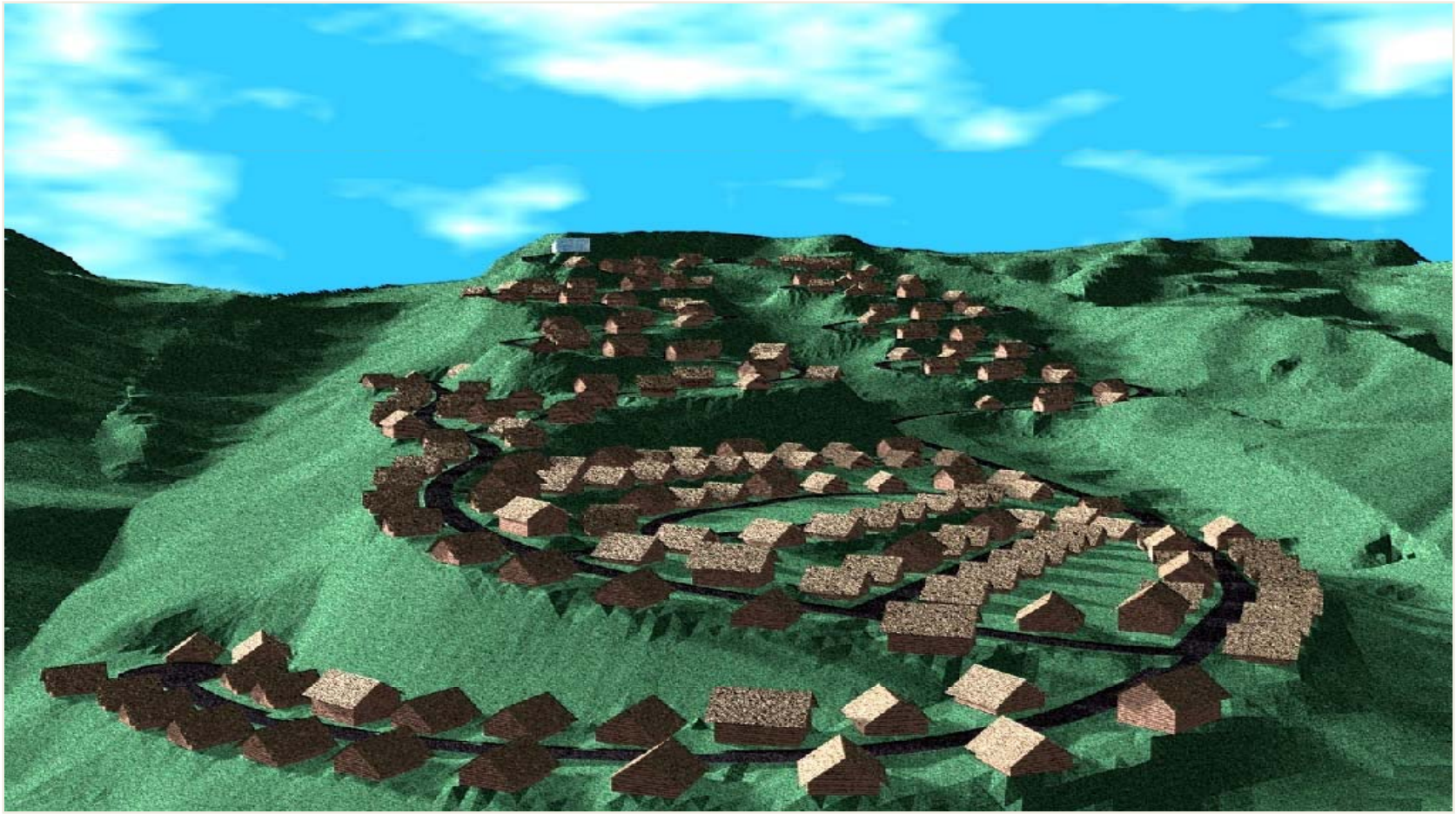
Emil M. Morales MSCE

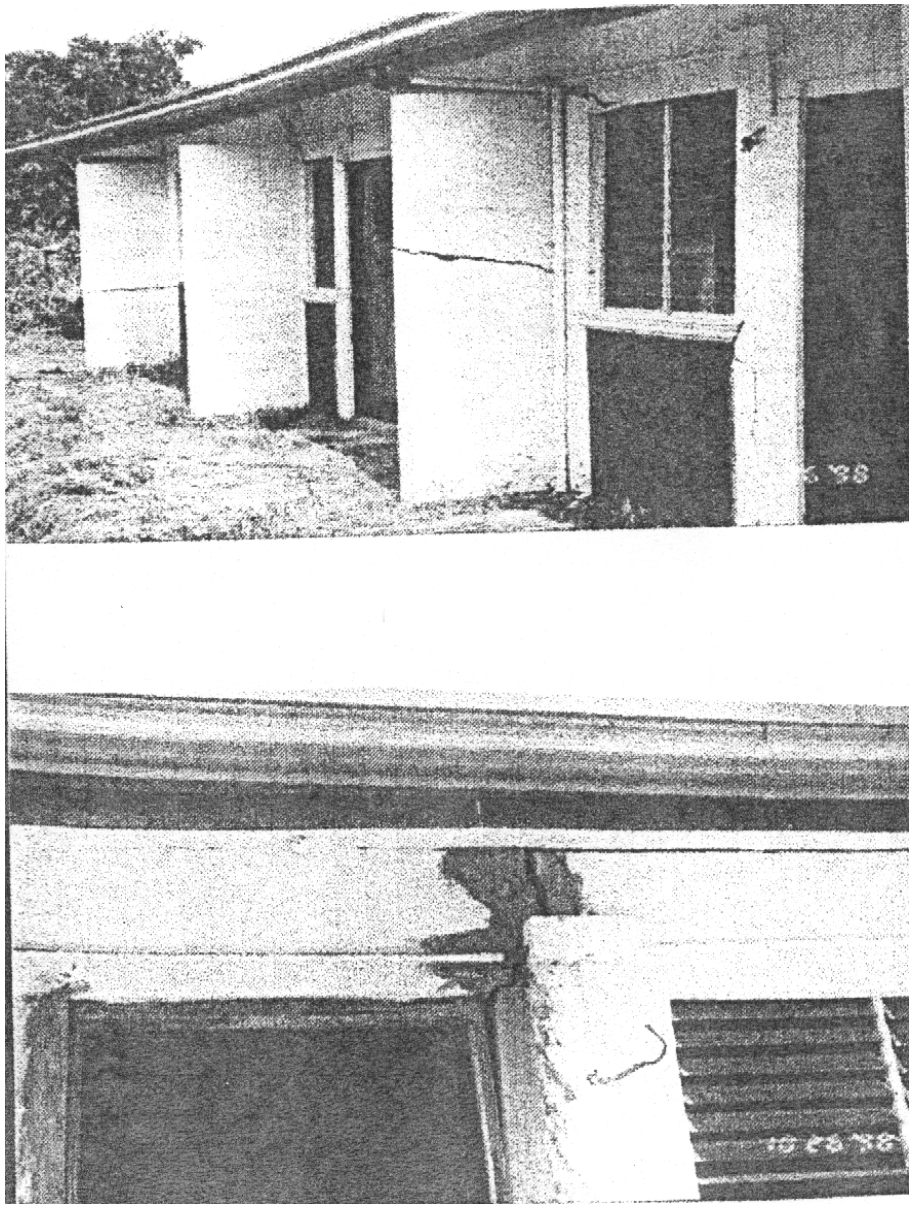
Ground Instability: Nature vs Man

- We have always read about natural landslides, topples and debris falls.
- However, in most cases the word "*natural* " is misleading because man is always behind such destabilization effects.
- Nature may try to alter and reshape the earth such as through faulting or erosion or glacial movements, but more and more man is the *causative agent* in most landslide disasters as man encroaches on the natural environment and disrupts it as the demand for even marginal land grows due to population growth.
- Man alters the Natural landscape much faster than nature and in the case of nature, most of the processes are "*realignments* " that heal themselves.

However, efficient Land development even in marginal lands can be achieved with proper application of Soil mechanics and with minimal harsh engineered structures through use of

Biotechnical protection.



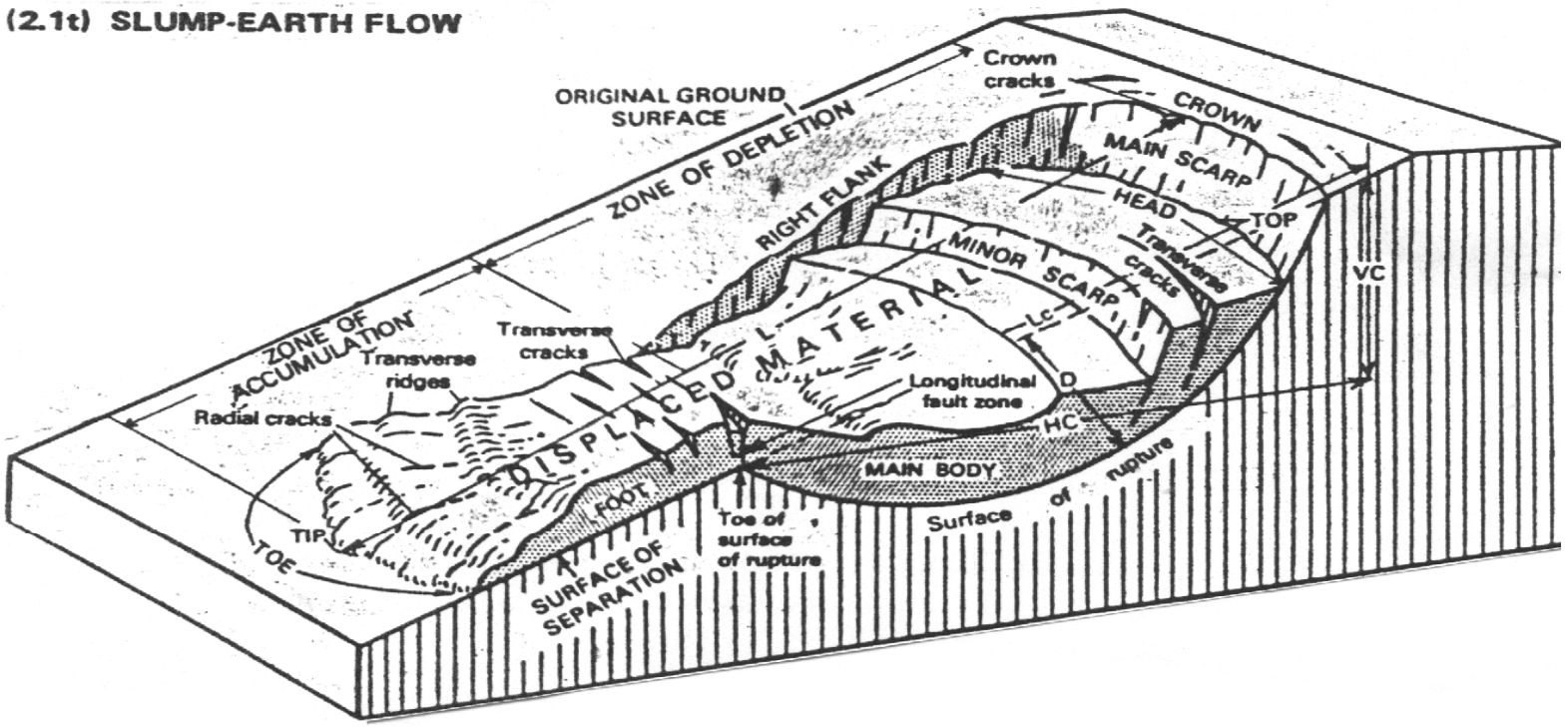


- Fast tracked development of low cost housing on slopes sometimes lead to oversights that are costly to repair.
- In this case, the contractor neglected quality control in Fill compaction along the slopes leading to Gross settlements and subsequent distress in numerous housing units.

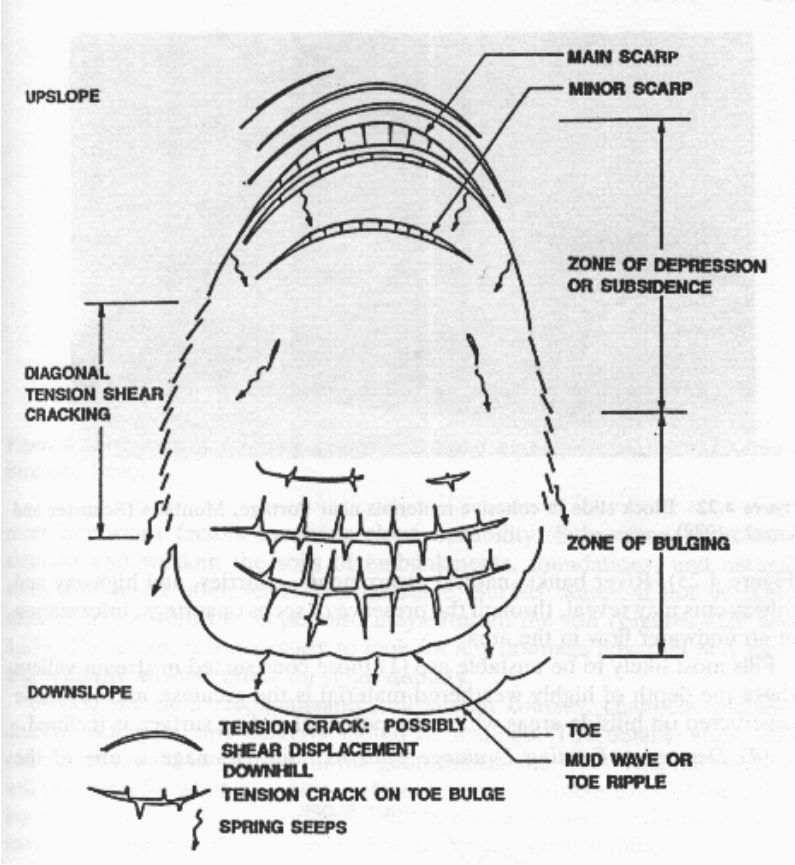
We shall now try to understand the basic Principles and causes of landslides and how we can best detect or predict, avoid or mitigate the Damage that is annually sustained by the Philippines and other Nations.

Slide Nomenclature

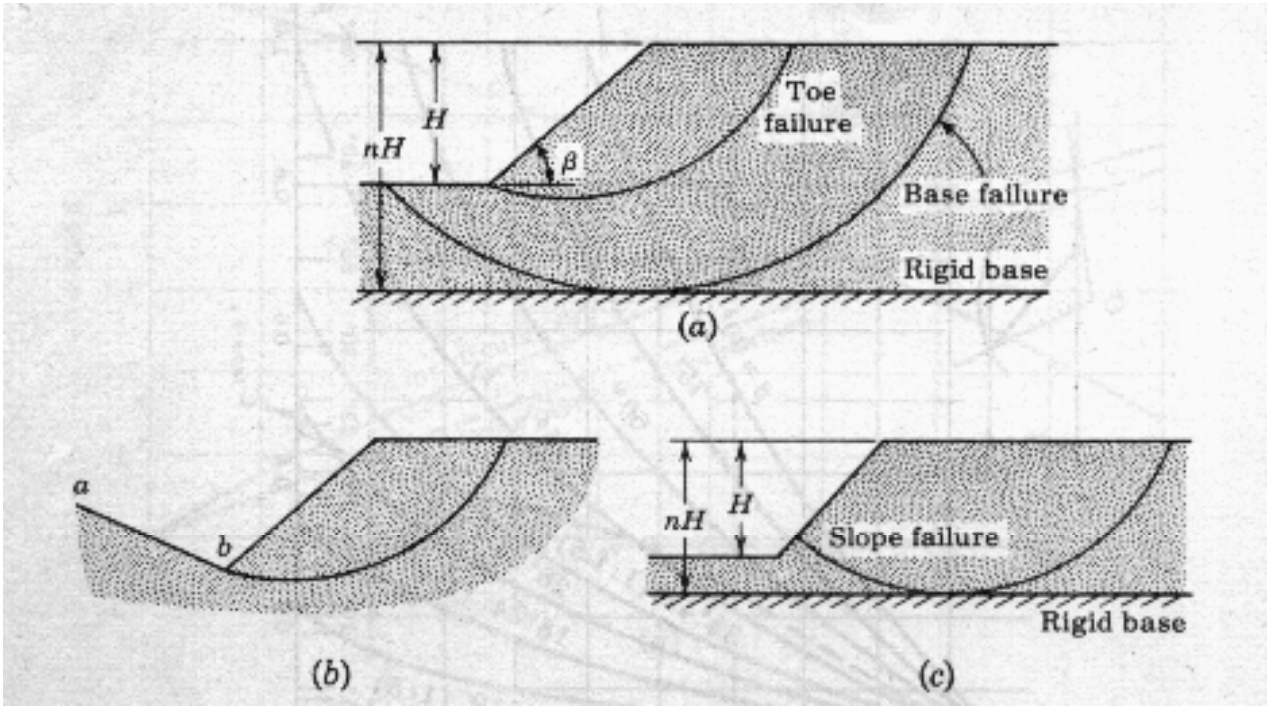
Slide Nomenclature



Typical Plan of a Slide Zone.



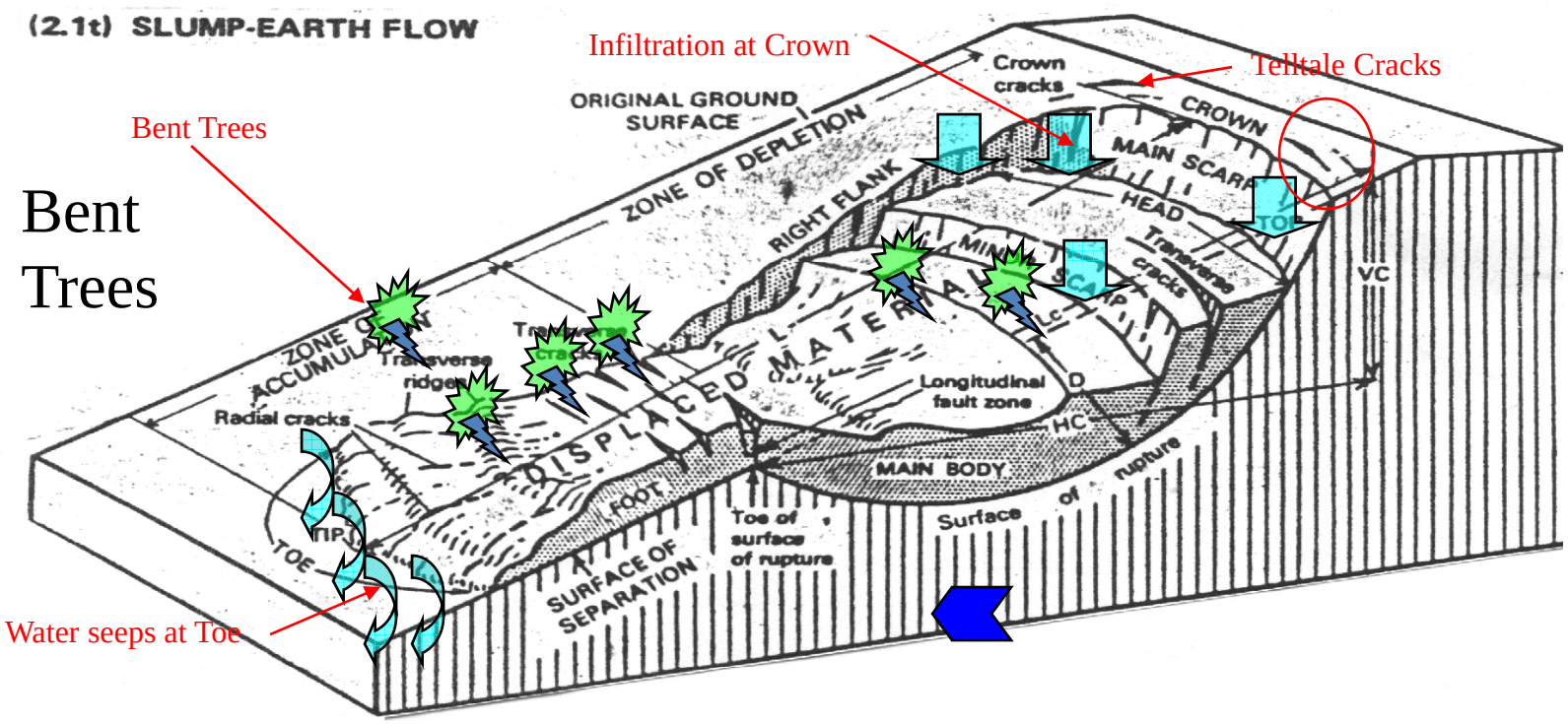
Failure Modes of Slopes



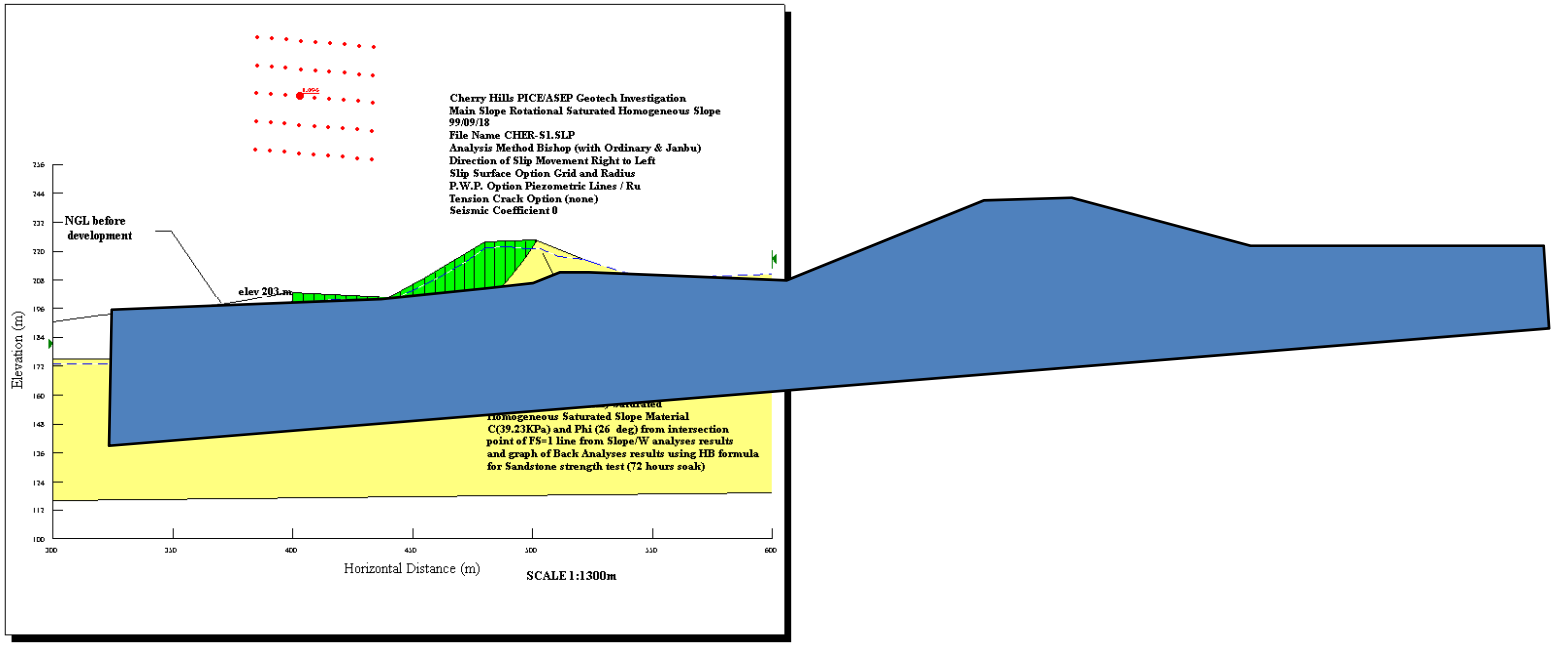
Telltale Indications of an Impending Slide

- Cracks on the ground
- Bent trees and leaning Foliage
- Daylighting of streams along the toe of Slopes.
- Interruption of Natural Drainage
- Rock falls and increased soil erosion

Slide Manifestations



- The Cherry Hills landslide was a Rotational type of Failure Triggered by instability due to lack of lateral support and build up of Pore pressure due to Impoundment at the Back of the slope.



- The mechanics of Soil erosion needs to be properly understood to avoid costly and extensive repair
- Of all the known agents affecting soil behavior, none is more important than water.
- Hydraulics and seepage through porous media needs to be well understood.
- Man is one of the best agents for destabilization of Natural slopes

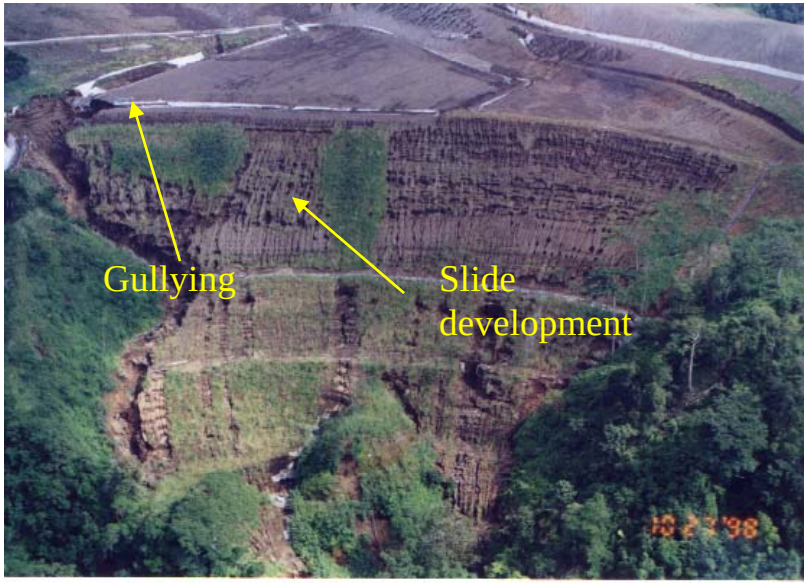
Well planned developments which take into consideration The care and protection of slopes at the outset helps to keep costs down by eliminating costly reworks and remediation measures

Let’s look at how a landslide could propagate in a typical land development project……..

Concentrated discharge of Runoff combined with damage to the vegetative cover leads to bigger problems. Rilling leads to gullying which destabilizes slopes and leads to massive landslides.

Destruction of the Natural Vegetative cover by end dumping and pushed over materials help to accelerate erosion and the Propagation of Landslides

The result is massive erosion and slide initiation.



Rilling

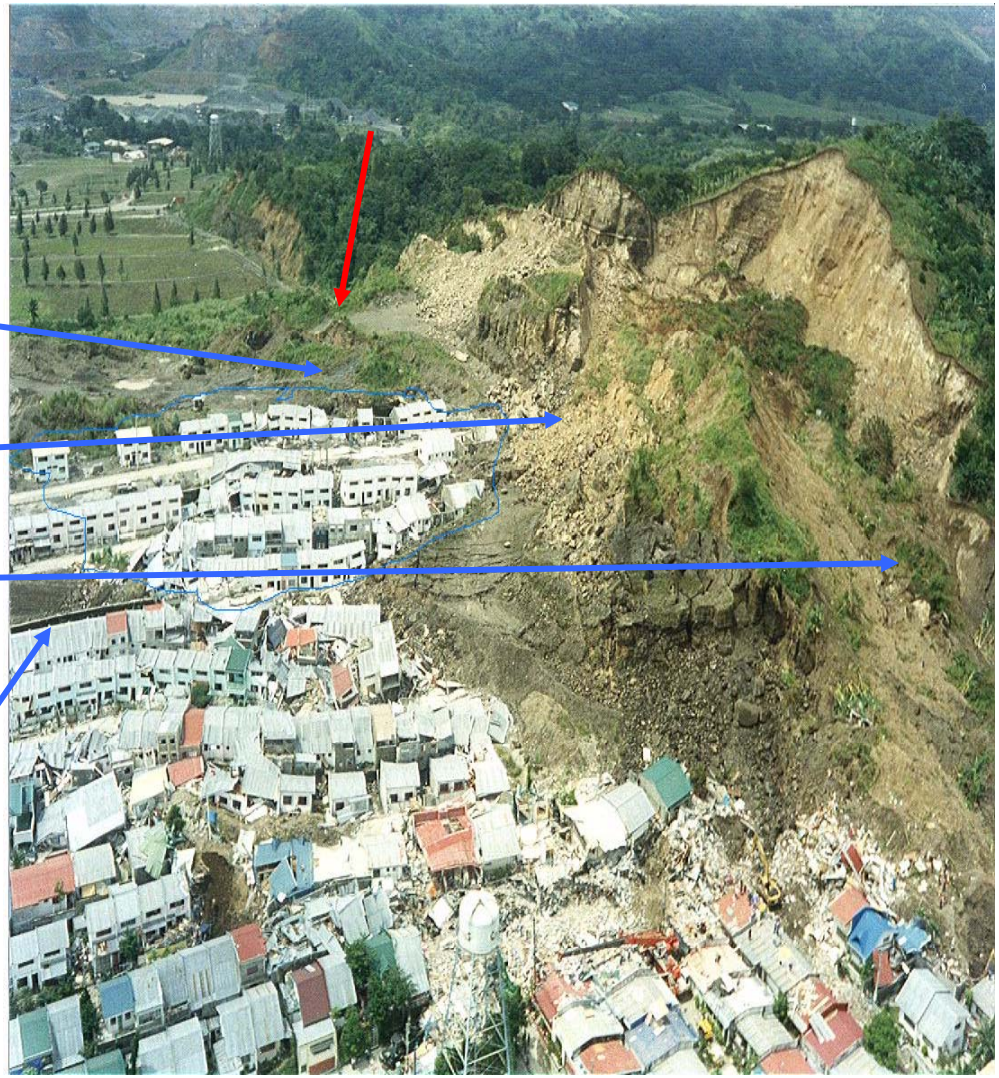
The Cherry Hills Slide

PHOTOGRAPH COURTESY OF MINES & GEOSCIENCES BUREAU / PHIVOLCS

Summary of Findings in the Cherry Hills Landslide.

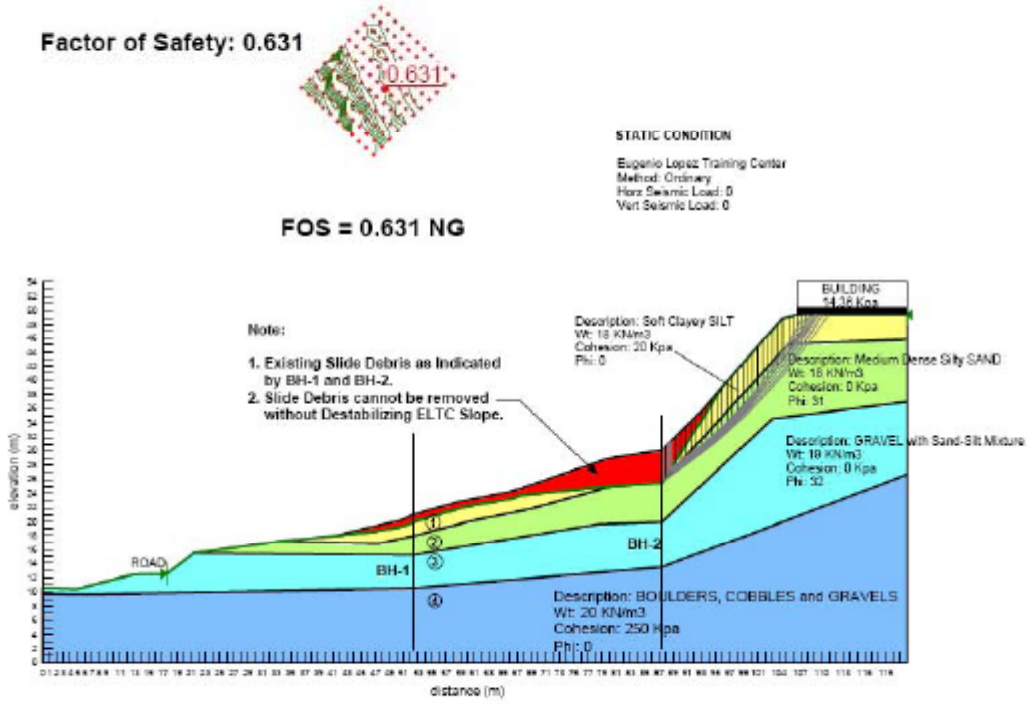
The Findings of the Committee are as Follows:

1) The Slide that occurred at Cherry Hills on the night of 3 August 1999 was a compound slide made up of a slump and a Rotational component.
2) The Lateral deformation of several roadways was caused by a separate although associated mass slumping to the North.
3) The Rotational Component towards the E to W direction was the main slide mechanism. Corollary slides (Debris and Mudflow) occurred in the North and South Directions, with the latter being more massive in terms of volume of earth and Debris that were displaced.
4) Creep and subsequent Folding of a Thin layer of Highly Fractured rock caused the accordion like folding of a large area within the Subdivision but beyond the toe of the slide.
5) Water Saturation of the Slope triggered the Main Slide although Creep was occurring well before this slide event.



ANTIPOLO LANDSLIDE

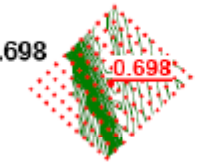
Sumulong Highway was Blocked for over a Week



1 / G 2 **SLOPE FACE ACTUAL CONDITION OF SLIDE DEBRIS REMOVED BASED ON ACTUAL SOIL PARAMETERS**

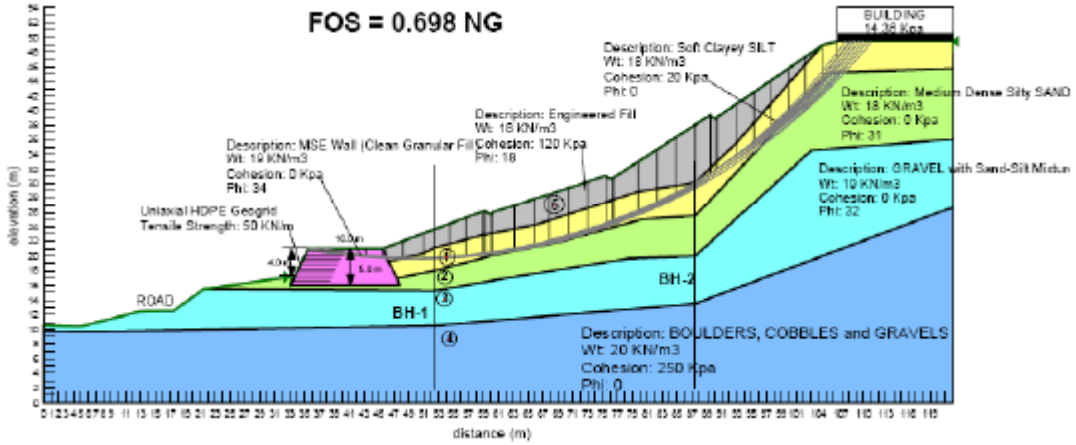
SCALE NTS

Factor of Safety: 0.698



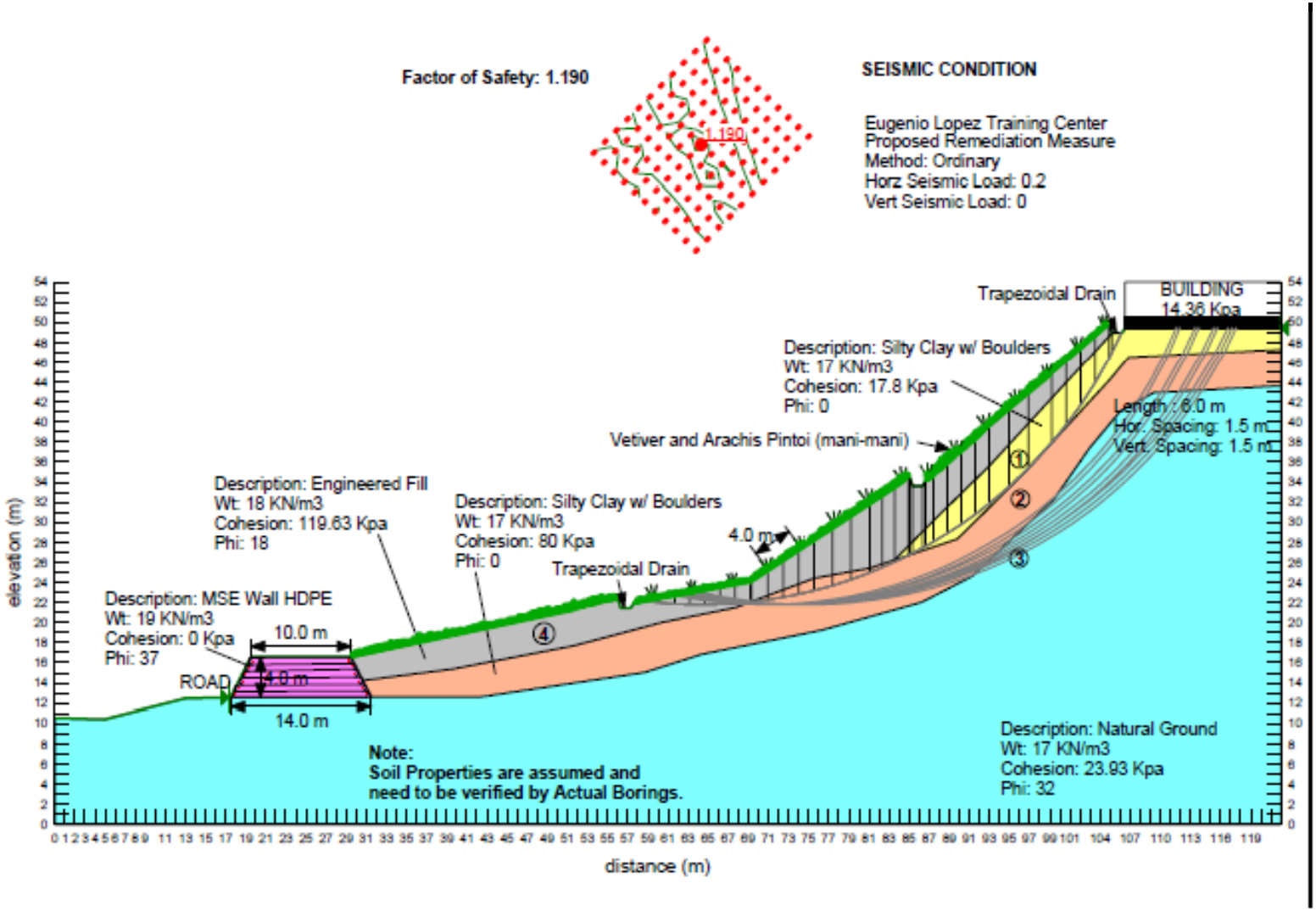
STATIC CONDITION

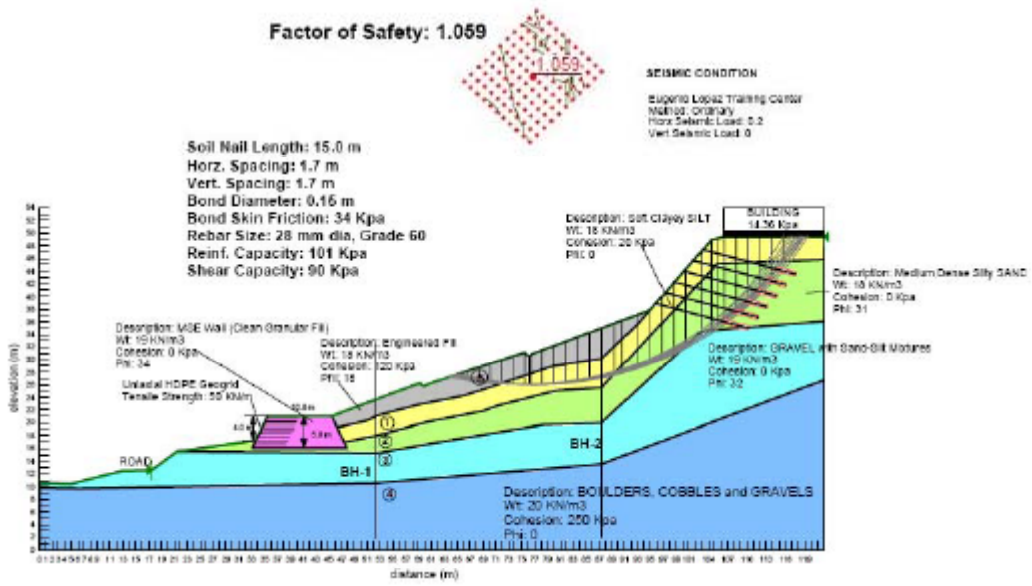
Eugenio Lopez Training Center
Method: Ordinary
Horz Seismic Load: 0
Vert Seismic Load: 0



1 / G 3 **ORIGINAL SLOPE GEOMETRY USING ACTUAL SOIL PARAMETERS**

SCALE NTS

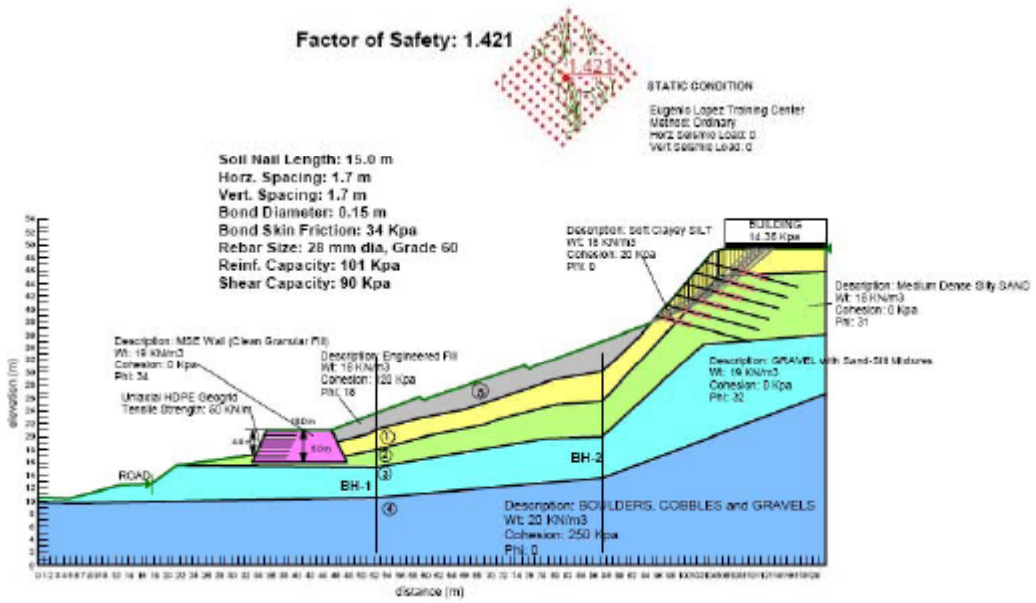

Factor of Safety: 1.190
1.190
SEISMIC CONDITION
Eugenio Lopez Training Center
Proposed Remediation Measure
Method: Ordinary
Horz Seismic Load: 0.2
Vert Seismic Load: 0
Trapezoidal Drain
BUILDING
14.36 Kpa
Description: Silty Clay w/ Boulders
Wt: 17 KN/m3
Cohesion: 17.8 Kpa
Phi: 0
Length : 6.0 m
Hor. Spacing: 1.5 m
Vert. Spacing: 1.5 m
Vetiver and Arachis Pintoi (mani-mani)
Description: Engineered Fill
Wt: 18 KN/m3
Cohesion: 119.63 Kpa
Phi: 18
Description: Silty Clay w/ Boulders
Wt: 17 KN/m3
Cohesion: 80 Kpa
Phi: 0
4.0 m
Trapezoidal Drain
Description: MSE Wall HDPE
Wt: 19 KN/m3
Cohesion: 0 Kpa
Phi: 37
10.0 m
ROAD
14.0 m
14.0 m
Note:
Soil Properties are assumed and
need to be verified by Actual Borings.
Description: Natural Ground
Wt: 17 KN/m3
Cohesion: 23.93 Kpa
Phi: 32
elevation (m)
distance (m)



4 / G 3 SCALE

FINAL REMEDIATION CONFIGURATION WITH SOIL NAIL BASED ON ACTUAL SOIL PARAMETERS

NTS



3 G 3 SCALE

FINAL REMEDIATION CONFIGURATION WITH SOIL NAIL BASED ON ACTUAL SOIL PARAMETERS

NTS


NO TRESPASSING
BAWAL PUMASOK

SLOPE DESTABILIZATION

An innocent pipe discharging down slope……..

Slope erosion and ……

Producing a dangerous condition.

Care of water, proper compaction of Fill areas, care of water and protection of slopes are keys to cost effective land development.

Sheetwash and Rilling could lead to Gully formation. All this needs is to reverse the slope at the crest to prevent costly collapses. These slopes would need benching or Gravity Walls augmented by Biotechnical Slope Protection.

The care and protection of slopes during the construction stage can prevent accidents and reduce costly reworks.

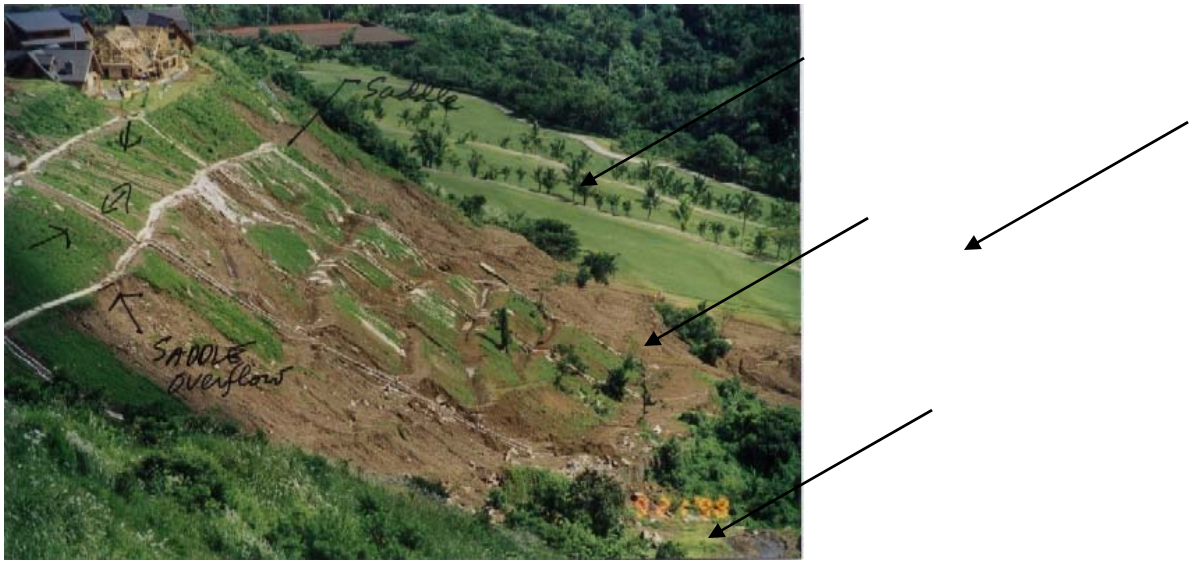
This is a classic case where engineering plans were not followed and uncompacted pushed over materials were deposited along the slopes..

The Remediation

- Extensive Remediation using Biotechnical Measures and Chevron Drains needed to be deployed

1-Chevron drains discharges into ski Jump and overflows
2- Spillage outside of ski Jump causes undermining of Structure leading to collapse.
3- Spillage spreads wider causing more progressive damage.

Extensive drainage and Biotechnical protection measures needed to be introduced to save the slopes. Even with this intervention, mistakes in construction of the remedial measures led to costly reworks. Chevron drains were not properly laid out and overflows were not prevented causing sheetwash erosion and reconstruction of the slope drains.



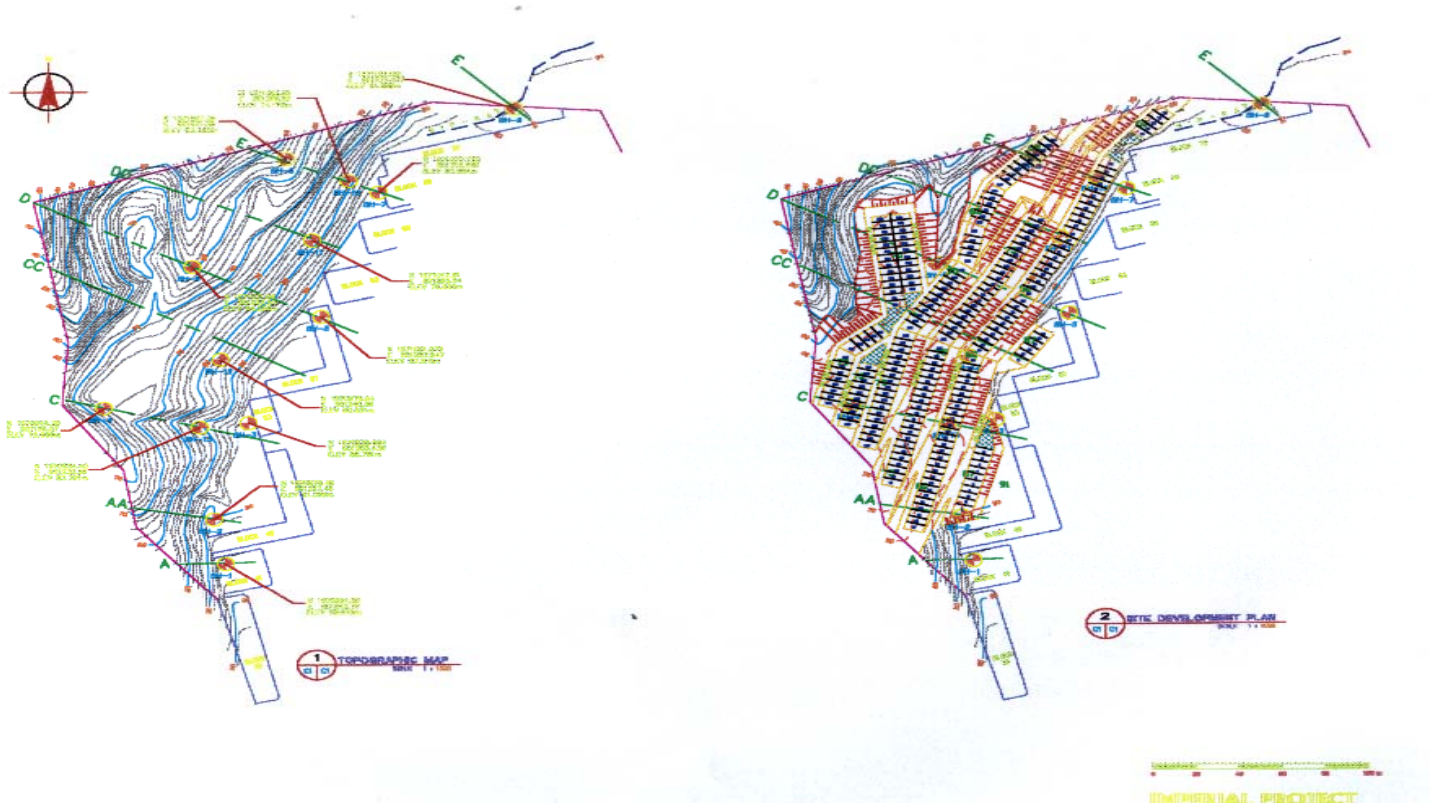
Finally, successful stabilization of slopes without the use of “hard” Structures through Biotechnical means and use of adequate drainage.

Harsh Engineered Slope protection can be made environmentally friendly with use of Plantings

Highly weathered soils sandwiched by otherwise competent bedrock can cause problems when eroded, leading to rockfalls and topples.

Control of Groundwater

- This land development filled up a gully without providing relief for water springs and conveyance of surface runoff.
- Heavy rainfall mobilized the uncompacted fill causing abandonment of several housing blocks.



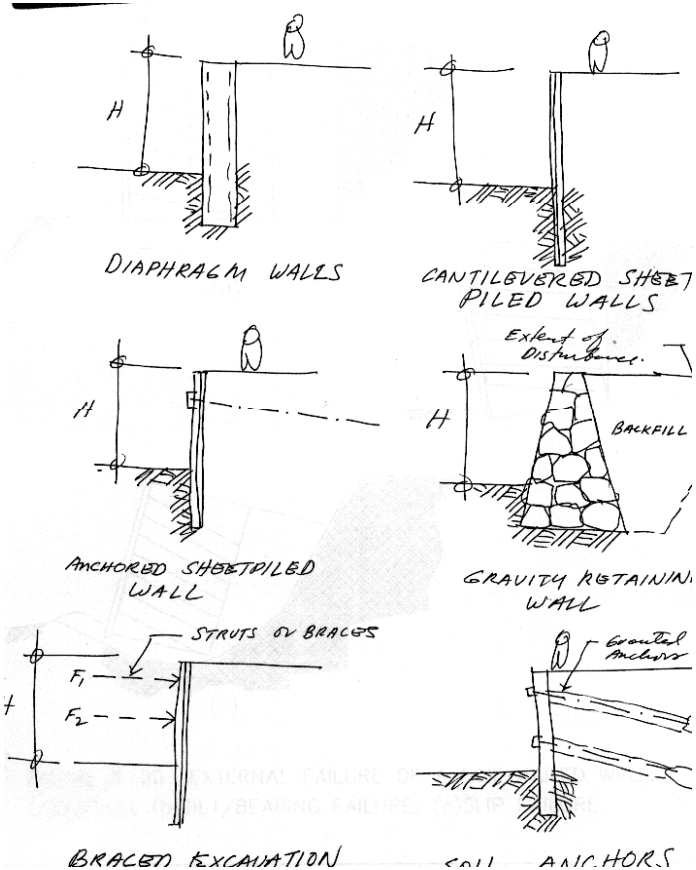
This specific project proved to be very costly to the developer because slope failures and careless and uncontrolled dumping of spoils resulted in demolition of about 20 low cost housing units. We had to come in to study remediation to avoid further damage and also reclaim the failed slopes.

Slope Protection Measures

Care and Preservation of the Natural Vegetative Cover is Paramount

If the Natural Vegetative cover is Disrupted or Damaged, then EXTENSIVE and sometimes VISULLY HARSH ENGINEERED SOLUTIONS are NECESSARY

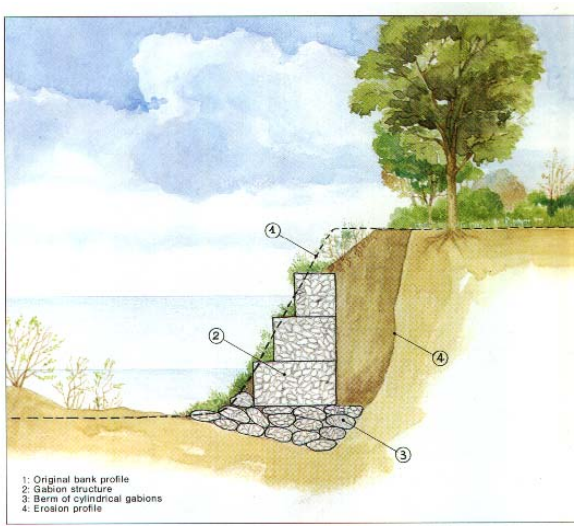
Slope Retention Structures



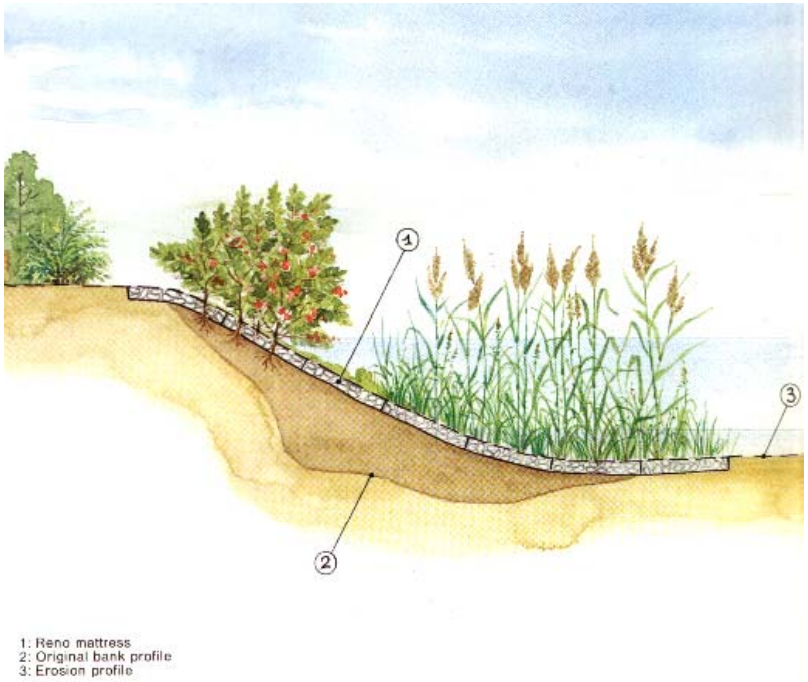
- Various Kinds of Slope retention structures are available and adoption depends on the actual conditions Present at the site.

Use of Gabions for Slope protection

The characteristics of box gabions and Reno mattresses and the protection which they provide also allow selection of the optimum system. It is possible to select the best structure for any particular bank protection, using either mass structures in box gabions or thin linings in Reno mattress units.
Box gabion structures are useful for the highest eroded banks, where any trees on the banks can be protected. On the other hand thinner revetments of Reno mattresses are especially suitable for protecting less steep and lower banks, where the typical vegetation consists of reeds and various types of water-side plants.

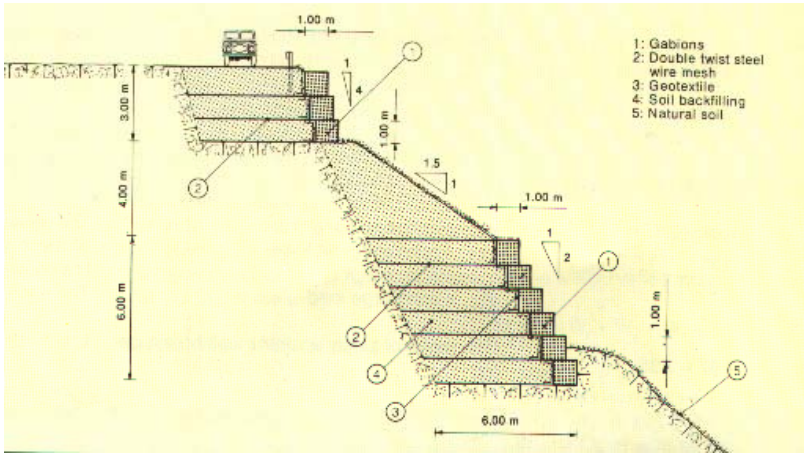


Slope Protection against wave wash or Bank erosion

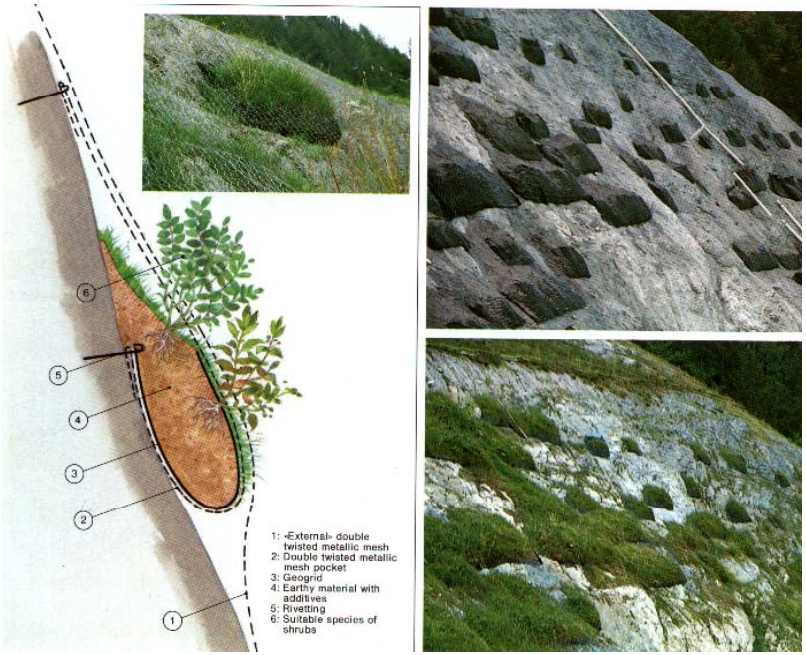


1: Reno mattress
2: Original bank profile
3: Erosion profile

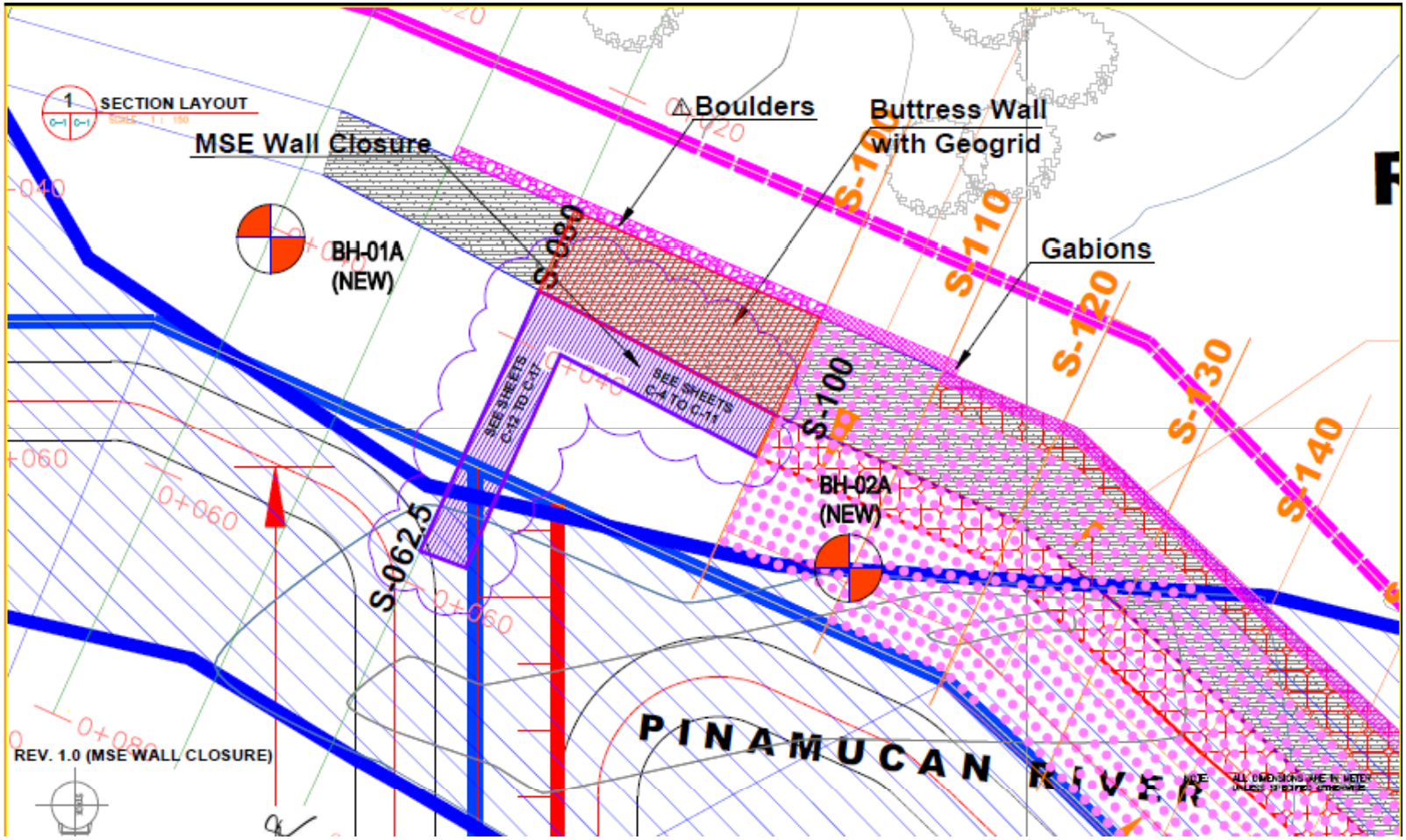
The TERRAMESH™ System for Slope Protection



Protection of Slopes on Fractured Rock faces in combination with Plantings



Layout for River Reclamation and Slope Protection



River Training and a 17 meter high Fill Embankment needed to be Reinforced with Geogrids and Gabion Toe Protection.

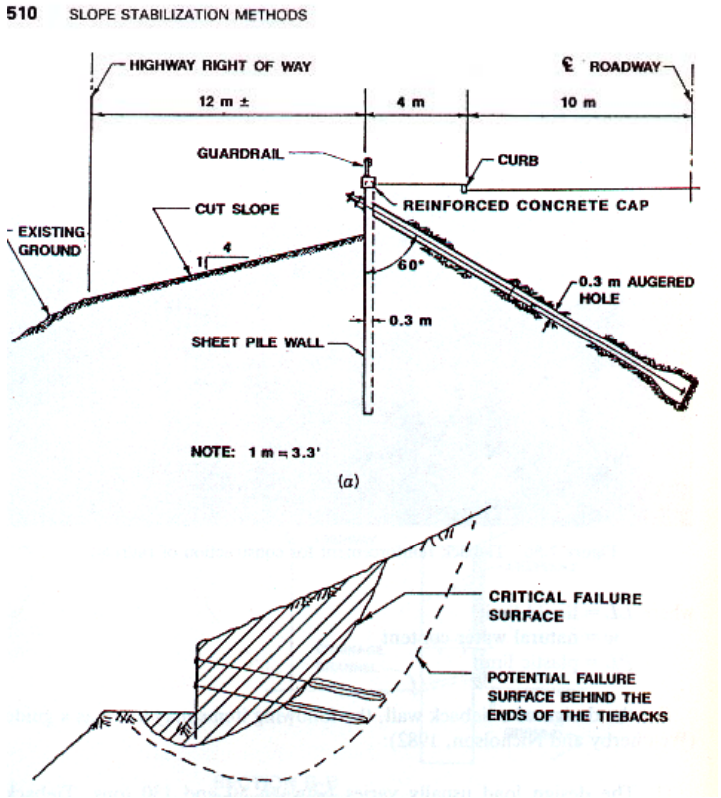
THE FINISHED PRODUCT WAS NOT ONLY COST EFFECTIVE BUT IT WAS ALSO AESTHETICALLY PLEASING PARTICULARLY WHEN THE PLANTINGS OVERRUN THE SLOPE FACES

View of 16 Meter high MSE wall and River Toe Protection

Erodible Material Undermines Competent Material

Mountain Cut Exposes Erodible Layers

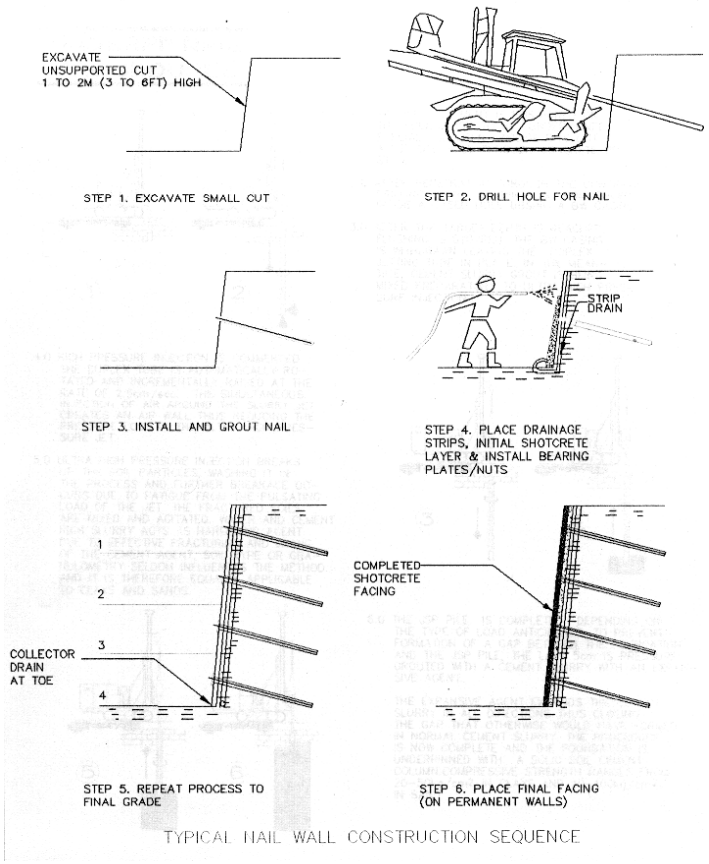
Uncontrolled Water Flow can Cause Slides and Rock Falls



- Instabilities induced by earth cuts can be anticipated and provided for using various procedures such as Earth Anchors.

New VETIVER Plantings

Soil Nailing



- Soil Nailing is best put to advantage in soft or loose soils if installation can be synchronized with the excavation procedure.
- The technology consists of introducing Grouted or ungrouted steel rebars or inclusions into the soil by Driving or drilling holes normally inclined at about 15 degrees from the Horizontal.
- This results in a stable mass of soil much like a gravity wall where the reinforced mass behaves as a single gravity block.
- Stress transfer is quite complex but already fully understood and is best solved by computerized analytical methods as the process is highly iterative.

The End

Part 1