Prevention is Better than Cure: Bioengineering Applications for Climate Resilient Slope Stabilization of Transport Infrastructure Assets

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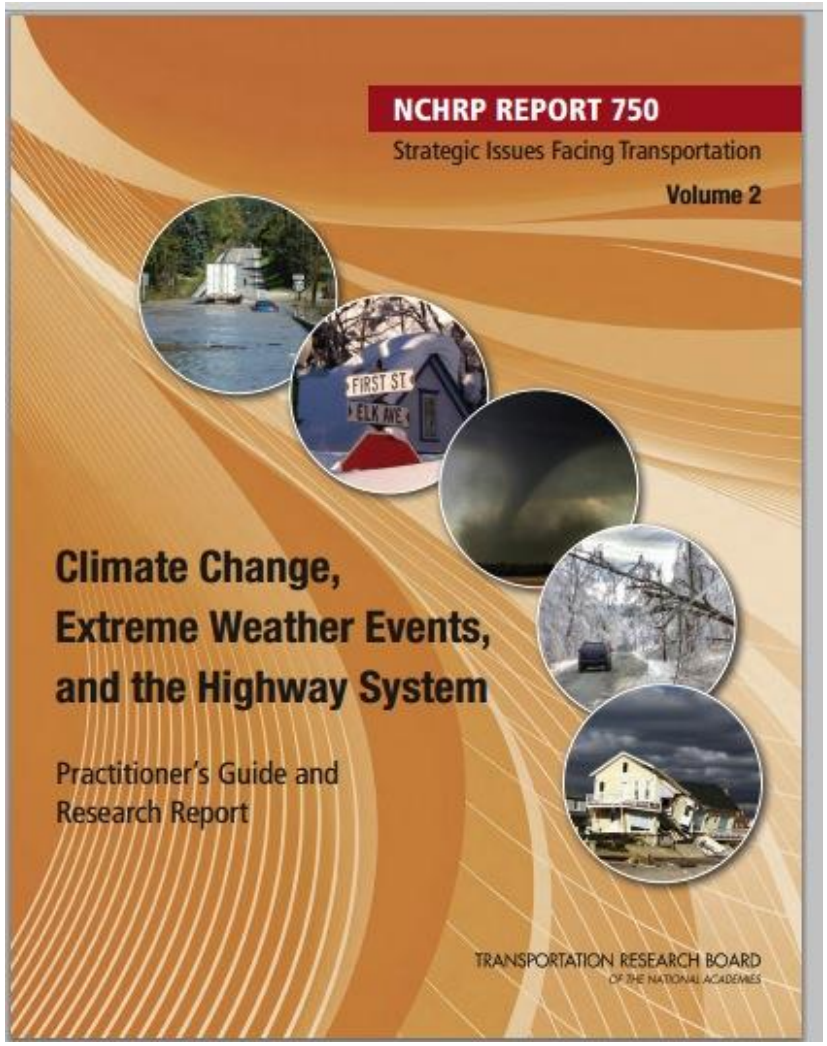


Impact of Climate Change and Extreme Weather Events

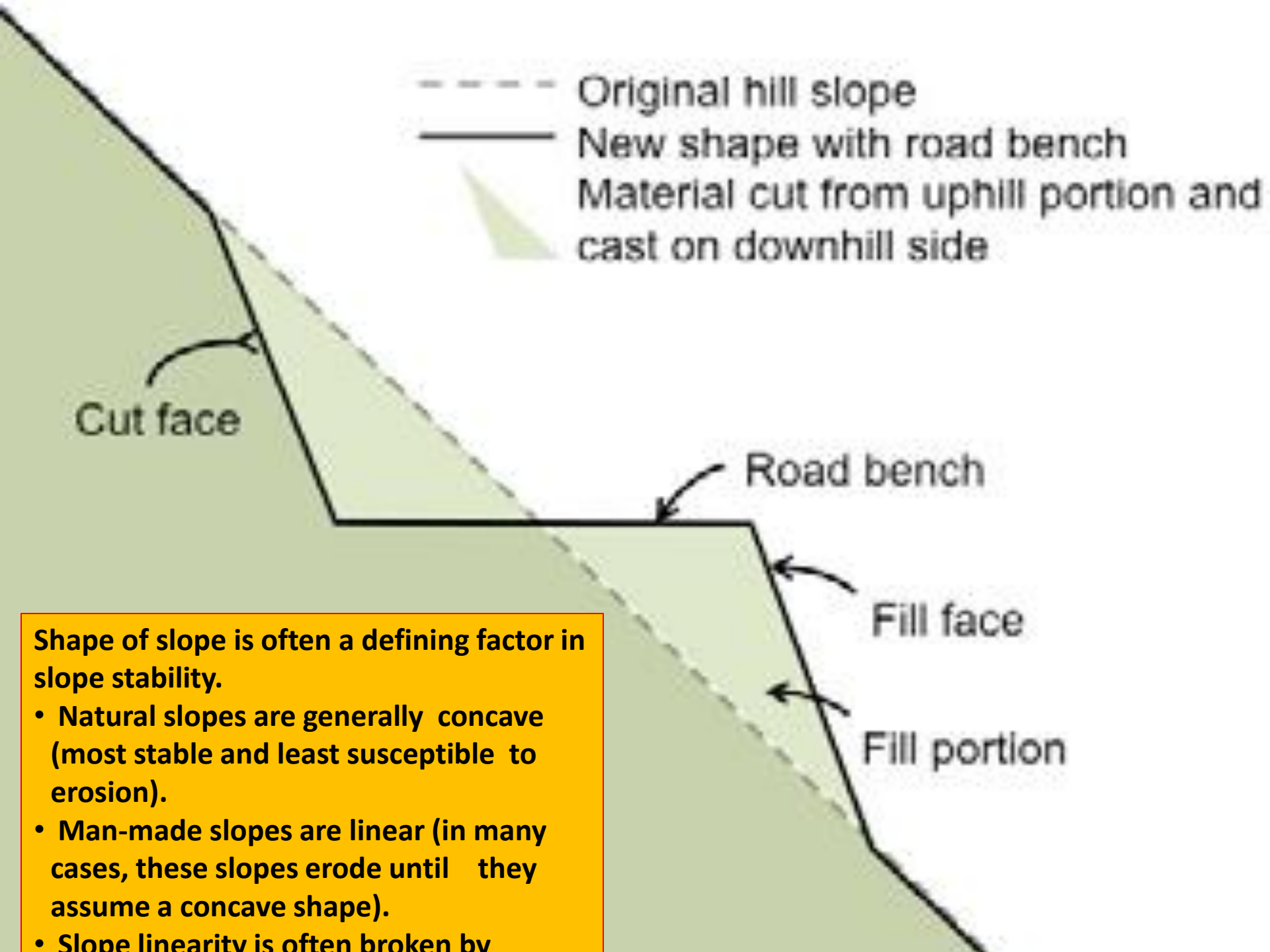
Increased Precipitation and More Intense and Frequent Storms

Increased Risk of Unstable Slopes and Landslides

What causes slope instability ?

- Most landslides and slope stability problems involve water-related factors– intense rainfall (cloudbursts), rapid snowmelt, floods, rapid changes in water table and soil pore pressures, stream erosion.

- Other isolated causes include earthquakes, Other isolated causes include earthquakes, volcanic eruptions, but above all human activity, including improper road construction techniques– e.g. uncontrolled clearing and grubbing, blockage of natural drainage paths, side-cast construction, poor placement of fill material, uncontrolled blasting, vibrations from passing vehicles.



Shape of slope is often a defining factor in slope stability.

- **Natural slopes are generally concave (most stable and least susceptible to erosion).**
- **Man-made slopes are linear (in many cases, these slopes erode until they assume a concave shape).**
- **Slope linearity is often broken by**


KOMATSU


Side –casting of excavated material

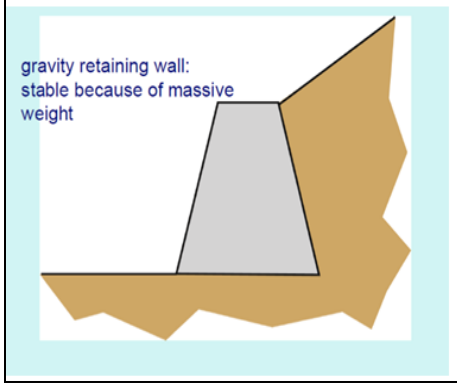

Rill formation

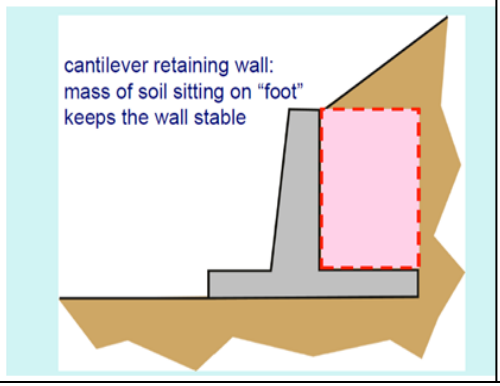

Rills increase in size and become gullies

How to ensure climate-resilient slopes in transport infrastructure?

- Basic Principle: *Address slope protection and surface runoff and groundwater issues during road location, design and construction– not as an after thought*.
- Key Elements: Use a combination of drainage, slope protection and stabilization measures, including both inert (engineered) and vegetative components.
- Techniques: Retaining structures and earthworks; Mechanical stabilization; Erosion control; Soil bioengineering; Biotechnical stabilization.

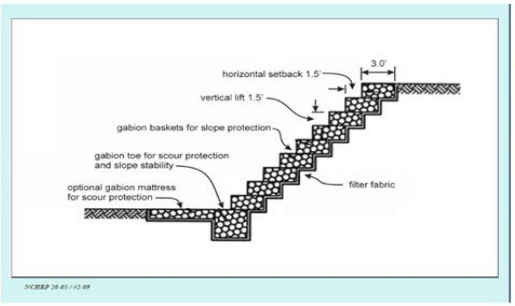
Retaining Walls



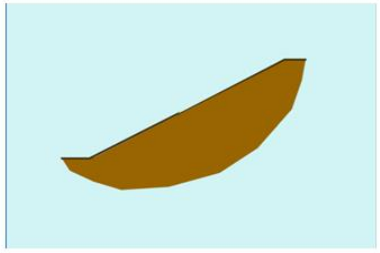


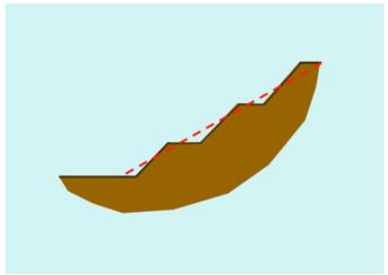
Gabion Walls

Gabion baskets can be used for the retaining element-- galvanized steel wire baskets, hand-filled with cobbles or large rocks



Benched Slopes





Source: Rob Douglas and Gordon Keller

Slope Protection with Shotcrete

Sources: Robert Douglas, Gordon Keller , Bashir H. Shah

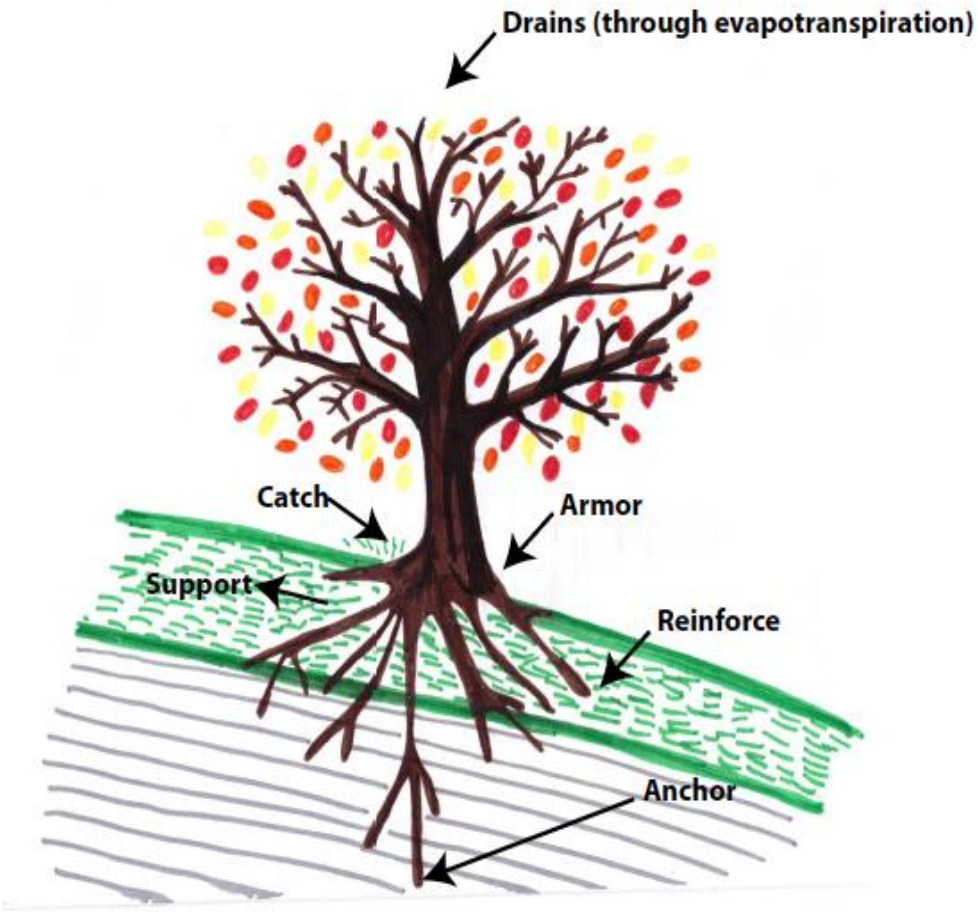
Soil Bioengineering and Biotechnical Slope Stabilization

- Soil bioengineering uses locally available plants and plant material and a minimum of equipment to inhibit slope failure and treat unstable critical slopes. It attempts to mimic nature.

- Biotechnical stabilization uses plants in conjunction with more traditional engineering measures and structures to control landslides and eroding stream banks.

These preventive measures can help to avoid costly post-failure slope remediation measures employing traditional structural/geotechnical solutions.

Vegetative Stabilization Mechanisms



1. To *catch* eroded materials with physical barriers (e.g. vegetated walls, plants, trees);
2. To *armor* the slope from erosion caused by runoff or rain splash using vegetative cover, partial armoring using lines of vegetation;
3. To *reinforce* soil physically with plant roots;
4. To *anchor* surface material to deeper layers using large vegetation with deep roots;
5. To *support* soil by buttressing with vegetated walls or large vegetation; and
6. To *drain* excess water from the slope through evapotranspiration and the use of drains.

Planting trees and vegetative growth alone can play an important role in stabilizing slopes by intercepting and absorbing water, retaining soil below ground with roots and above ground with stems, controlling runoff by providing a break in the path of the water and increasing surface roughness, and improving water infiltration rates, soil porosity, and permeability

Comparison of Geotechnical Engineering and Soil Bioengineering Systems by Function

Function	Geotechnical Engineering System	Soil Bio-Engineering System
Catch	Gabion wire bolster Check dams Catch walls	Contour lines (grass lines; brush layers) Live check dam Shrubs and bamboo (many stems)
Armor	Revetment walls Stone pitching	Mixed plant stories, giving complete cover Grass carpet (dense, fibrous roots)
Reinforce	Reinforced earth Soil nailing	Densely-rooting grasses, shrubs, and trees Most vegetation structures
Anchor	Rock anchors by bolting	Deeply-rooting trees and shrubs (long string roots)
Support	Retaining walls , Breast walls, Prop walls	Large trees and bamboo (deep and dense root system)
Drain	Surface drains French drains	Down slope and diagonal vegetation lines Angle fascines, pole drain

Source: Shankar Rai, 2012; Bashir H.Shah, 2008

Soil Bioengineering Components and Related Engineered Structures and Devices

Grass Planting Systems

- Planted grass lines
- Grass seeding (hand, hydro)
- Turfing, Sodding

Woody Planting Systems

- Shrub and tree planting
- Shrub and tree seeding
- Large bamboo planting
- Mulching

Vegetative Structures

- Brush and hedge layering
- Fascines (brush wattles), hedges
- Palisades
- Branch packing
- Live stakes, fences, poles
- Live check dams, live sills
- Rock joint planting
- Vegetated gabions and walls
- Vegetated soft gabion & live brush wood walls

Related Engineered Structures and Devices

- Wire bolsters(gabions)
- Geotextiles , mats ,blankets (jute/coir)
- Dry masonry, stone pitching
- MSE, Soil Nails, Micro-piles, Plate piles
- Surface drains, soil subdrains
- Slope benching and terracing.
- Timber/masonry crib walls, used tire walls.
- Gravity retaining walls (concrete, rock, masonry)

Soil Bioengineering Applications For Slope Stabilization

Structure	Components
Retaining walls	Vegetated soft gabions, timber crib walls and used tire walls; Live brushwood
Diversion channels	Sodding treatment and stone pitching
Surface drains	Sodding treatment and stone pitching with live sills
Check dams	Vegetated poles, live brush wood, palisades, vegetated brush wood
Barriers for fixing loose debris	Brush wattles, brush layering, brush fences, semi-dead fences with live hedges, seeding and turfing

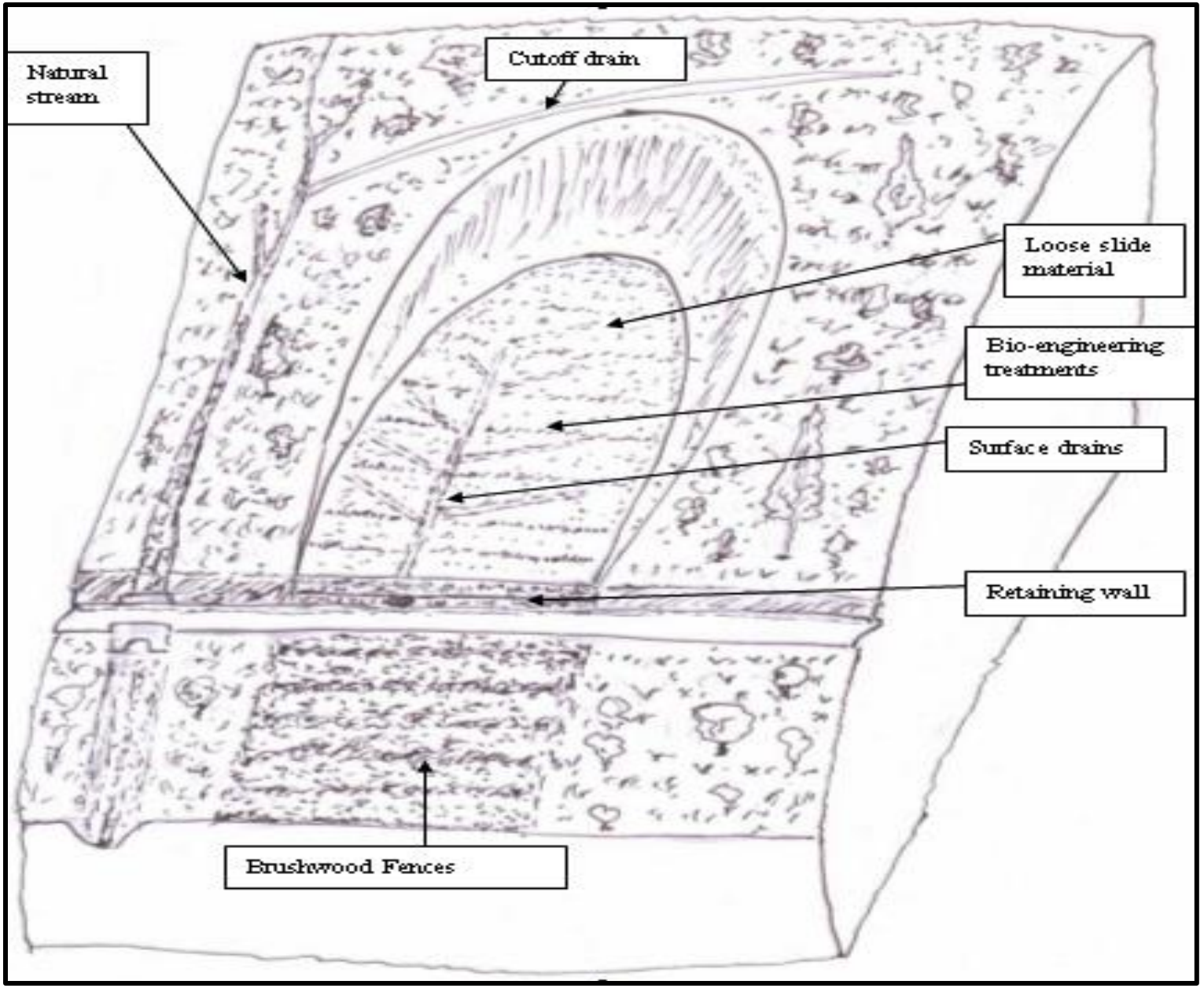
Merits of Soil Bioengineering

- Soil bioengineering is low cost and sustainable.
- It is labor intensive and a source of job creation-- an advantage in labor abundant economies.
- Only local (native) plant material is needed for establishment.
- Simple; does not require sophisticated engineering designs.
- Long lasting; gets stronger with passage of time.
- Creates a productive asset by providing timber, fuelwood and fodder.
- Environment friendly; helps in reducing GHG emissions (could be used in developing countries to attract climate finance under various REDD mechanisms).
- Enhances aesthetic value.

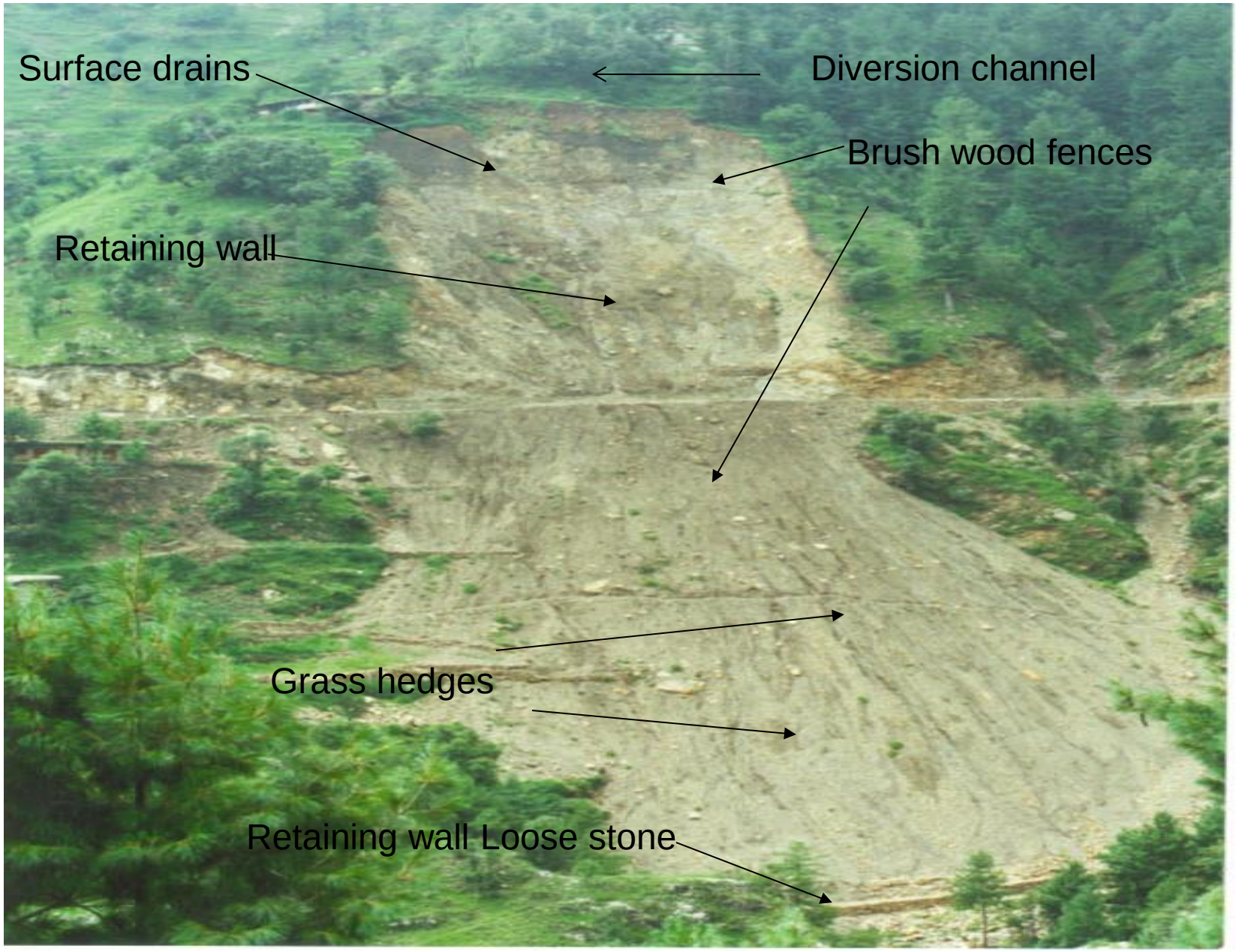
Demerits of Soil Bioengineering

- It is a season bound activity and cannot be carried year round; affected by both high and low temperatures.
- Requires on-the-job training and skilled oversight; and support and vigilance of local communities to protect newly established vegetation and structures.
- Requires an interdisciplinary approach and interagency coordination (e.g. between forestry and roads departments).
- Plants need protective fencing from foraging/grazing animals for 4-5 years, and from humans seeking fodder, firewood, and forage.
- The bioengineered structures can be adversely affected by droughts and intense storms (damage from wind, rain, hail and snow) especially during the first 2-3 years.

Schematic Presentation of Landslide Stabilization



Proposed Landslide Stabilization Treatment Plan



Application of Bioengineering Treatments

Bio-Stabilized Landslide Treatment and Results

Before

After

Vegetated Soft Gabion Wall (One Seasonal Cycle)

A –Newly Constructed; Winter

B – Sprouted Vegetation; Spring

C - Fully Vegetated ; Late Summer

Vegetated Crib Wall

A – Concrete crib wall with soft gabions and vegetated check dams.

B – Sprouted vegetation and some debris flow.

C - Slope fully vegetated and stabilized.

Vegetated Used Tire Wall, Islamabad-Murree Expressway, 2015

Combination of Concrete, Vegetated Soft Gabion and Live Brushwood Retaining Wall

Vegetated Check Dams
(Pole and Soft Gabion Construction)

Vegetated Gabion Check Dams
Islamabad-Murree Expressway , 2015

Jhelum Valley Road (Pakistan) - Landslide Treated with Brush Layering , Surface Drains and Check Dams - Before Monsoon

Jhelum Valley Road (Pakistan)– Landslide Stabilized (6 months later)- After Monsoon

Terraces to Control Erosion; Asmara-Assab Road, Eritrea

Towards More Sustainable and Cost-effective Slope Stabilization Options

How?

- **By integrating soil bioengineering and biotechnical stabilization with conventional slope stabilization technology.**

- **In general, combined slope protection systems have proven to be more cost effective than the use of vegetative treatments or structural solutions alone.**

- **Where technically feasible, soil bioengineering alternatives can be adopted to produce equal or better economic and environmental results than the sole application of conventional geotechnical solutions.**

Acknowledgement

This presentation draws generously from the information and materials given in Field Manual on Slope Stabilization (Bashir H. Shah, ERRA/UNDP, 2008) and NCHRP Synthesis 430, Cost Effective and Sustainable Road Slope Stabilization and Erosion Control (Fay, Akin and She, TRB, 2012). In addition, the information and illustrations provided by Rob Douglas, Gordon Keller and Shankar Rai are gratefully acknowledged.

The contents of this presentation do not reflect the operational policies and procedures of either the World Bank or the National Highway Authority (Pakistan). The presenters are affiliated with these organizations as independent consultants.


Thank You

Notes and Explanations

What are different types of mass wasting and erosion?

- Rock falls
- Rock Topples
- Rock slides
- Debris slides
- Debris avalanches/debris flow
- Earth slumps
- Earth Flow
- Earth Creep
- Landslips
- Rotational / Transitional Landslides

What are typical features of unstable slopes?

- Shape of slope is often a defining factor in slope stability.
  - Natural slopes are generally concave (most stable and least susceptible to erosion) .
  - Man-made slopes are linear (in many cases, these slopes erode until they assume a concave shape).
  - Slope linearity is often broken by benching and terracing , but poorly designed benches can cause severe gullying at water outfall.
- Excessive slope angle or height; increased slope loading (often due to slope toe cutting by streams and rivers and accumulated material/ man-made loadings at crest).
- Unstable geological strata and presence of joints, faults, disconformities, creep); weak foundation.
- Poor drainage; seepage, springs and high soil moisture; sewerage/irrigation outfalls and discharges; soil liquefaction.
- Eroded stony surfaces , stripped of vegetation and trees – resulting from uncontrolled logging, wildfires, animal grazing , foraging for fuelwood, construction and other solid waste disposal.

What is slope stabilization?

- Slope stabilization is the science and art of managing slopes (both natural and manmade) that pose a hazard to the built environment including roads, railways and other physical infrastructure.
- Slope Instability is generally a mass-wasting process while erosion is typically a surficial process. Stabilization solutions address both processes
- Slope stabilization can range from allowing grass to reestablish on a disturbed slope to building an engineered retaining structure.
- The treatment measure depends on the affected area, technical feasibility , and cost.
- “One-size-fits-all” approach does not work as site conditions and constraints vary greatly.

How is a slope stabilization treatment determined to be sustainable and cost-effective?

- Utilizes a multidisciplinary approach that draws on multiple fields of study- including civil engineering, geology, hydrology, forestry and landscape architecture- and combines treatment measures to obtain a composite, site-specific solution.
- Considers both short- and long-term (lifecycle) costs.
- Incorporates a detailed water management and drainage plan.
- Uses local or on-site materials –soil, rock, tree stumps, live vegetation, native seed stock.
- Ensures balanced distribution of cut and fill materials, avoids deep and steep cuts into slopes, and maintains the natural landscape.
- Disturbs the least amount of soil and rock, keeps topsoil on site, reuses on-site vegetation to strengthen the slope, and incorporates native plants with minimal disturbance to local ecosystems.
- Ensures that slope stabilization structures blend into the natural landscape and the site is restored as close to its previous condition as possible.

“We’re not friends of creation. Sometimes we treat it like our worst enemy. Think of deforestation, misuse of water, methods of extracting minerals with elements like arsenic and cyanide that end up making people sick.”

-- Pope Francis

Sept 2015