Bio-engineering for Landslide Control in Upland Watersheds

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What is a landslide?

A landslide is generally defined as the failure of a slope mainly under the action of its own weight in which the displacement has both vertical and horizontal components of considerable magnitude. A landslide consists of downward and outward movements of slope-forming materials composed of natural rock, soil, artificial fill or a combination of these materials. The moving mass follows any one of three principal types of movement: falling, sliding, flowing or their combinations. The rate of movement may vary from slow to rapid.

Bio-engineering is a specialised branch of engineering in which living plants and plant parts are used as building materials for erosion control and landslide stabilisation. Bio-engineering methods are the most important stabilisation techniques for watershed management in the upland where the use of other stabilisation techniques is neither economically justified nor technically possible. It makes bio-engineering the most appropriate alternative for upland watershed management in developing countries.

The process of movement downslope of soil particles, stones, rocks and soil masses is called erosion and landslide. Erosion and landslides are natural phenomena but can be accelerated by human activities such as road construction and environmentally destructive land use. In recent years, the risks have become greater due to upstream erosion and downstream sedimentation as human populations increase.

How many types of landslide are there?

Types of landslide

Landslides vary in both occurrence and characteristics, ranging from small slumps to enormous masses involving huge volumes of earth materials. They range in displacement from vertical to nearly horizontal, in shape from sheets and slabs to blocks, wedges and tongues, in duration of activity from a few seconds to years. The velocity of landslide movement may range from a few millimetres per year for creep movement to several dozens of metres per second for falls and avalanches.

Different criteria are used for classifying the types of landslide, such as form of sliding surface, types of materials involved, rate of movements, type of movement, age and state of activity. However, the classification proposed by Varnes (1978) is the most commonly used around the world (Table 1).

Table 1: Varnes (1978) Classifications System

Type of movement			Type of material		
			Engineering soils		Bedrock
			Predominantly line	Predominantly coarse	
Falls			Earth fall	Debris fall	Rock fall
Topples			Earth topple	Debris topple	Rock topple
			Earth slump	Debris slump	Rock slump
Slides	Rotational	Few units	Earth block slide	Debris block slide	Rock block slide
	Translational	Many units	Earth slide	Debris slide	Rock slide
Lateral spreads			Earth spread	Debris spread	Rock spread
Flows			Earth flow	Debris flow	Rock flow
			(Soil creep)		(Deep creep)
Complex			Combination of two or more principal types of movement		

Components of a landslide

Generally a landslide has distinct parts. Recognising and assessing these individually helps to understand the characteristics of the landslide, in particular, its severity.

A landslide occurring on a steep slope generally has four zones.

- Cracking zone: above the crown of the landslide and sometimes around its sides.
- Failure zone: the head scar (crown) and failure surface which may occupy only a relatively small area at the top of the slide.
- Transport zone: a damaged slope, scarred by the passage of debris on its way down the slope, this part of the slope may be stable and may recover on its own.
- Deposition zone: failed material deposit area (the moved, detached material).

If the landslide occurs at the foot of a slope, it usually does not have transport zone; the failure zone and deposition zones are joined together.

Depth of landslide

The depth of a landslide varies from dozens of centimetres to some dozens of metres and it is controlled by topography, geology and its structure. In bio-engineering, it is considered that shallow landslides below 0.5 m deep can be treated. This is the depth to which vegetation can be used for stabilisation because 60 per cent of a tree's roots are found in the top 0.5 m of the soil. For planning and designing of bio-engineering, landslides can be classified into five types by depth: (1) very shallow slope surface failure up to 25 mm; (2) shallow slope surface failure, 25 to 250 mm; (3) deeper slope surface failure, 250 to 500 mm; (4) deep slope mass failure, 500 to 1,000mm; (5) very deep slope mass failure, more than 1,000mm.

What are the interactions between vegetation and civil engineering structures?

Measures for landslide stabilisation

In the past 40 years, many methods have been developed to stabilise landslides. These measures can generally be divided into the following three categories: heavy hard structures, light soft structures and 'living' structures.

Heavy hard structures are mostly large civil engineering and geo-technical methods such as reinforced concrete walls, anchored retaining walls, dilled horizontal underground drains, etc. They need sophisticated calculation and design and skilled workers for implementation. They are used to stabilise large and complex, deep landslides.

Light soft structures are mostly small-scale civil engineering works such as gabion surface and sub-surface drains, small walls, stone arches, anchored wire netting, etc. They do not need sophisticated calculation for construction. These methods are suitable for stabilising failures of steep slopes with shallow topsoil layers where bio-technical stabilisation alone is not successful for which initial support is needed.

'Living' structures are called bio-engineering or biotechnical slope stabilisation structures or vegetation structures.

Functions of vegetation in slope stabilisation

The manual written by Howell et al. (1991) identifies seven functions that vegetation fulfills in the context of bio-engineering. These are summarised below.

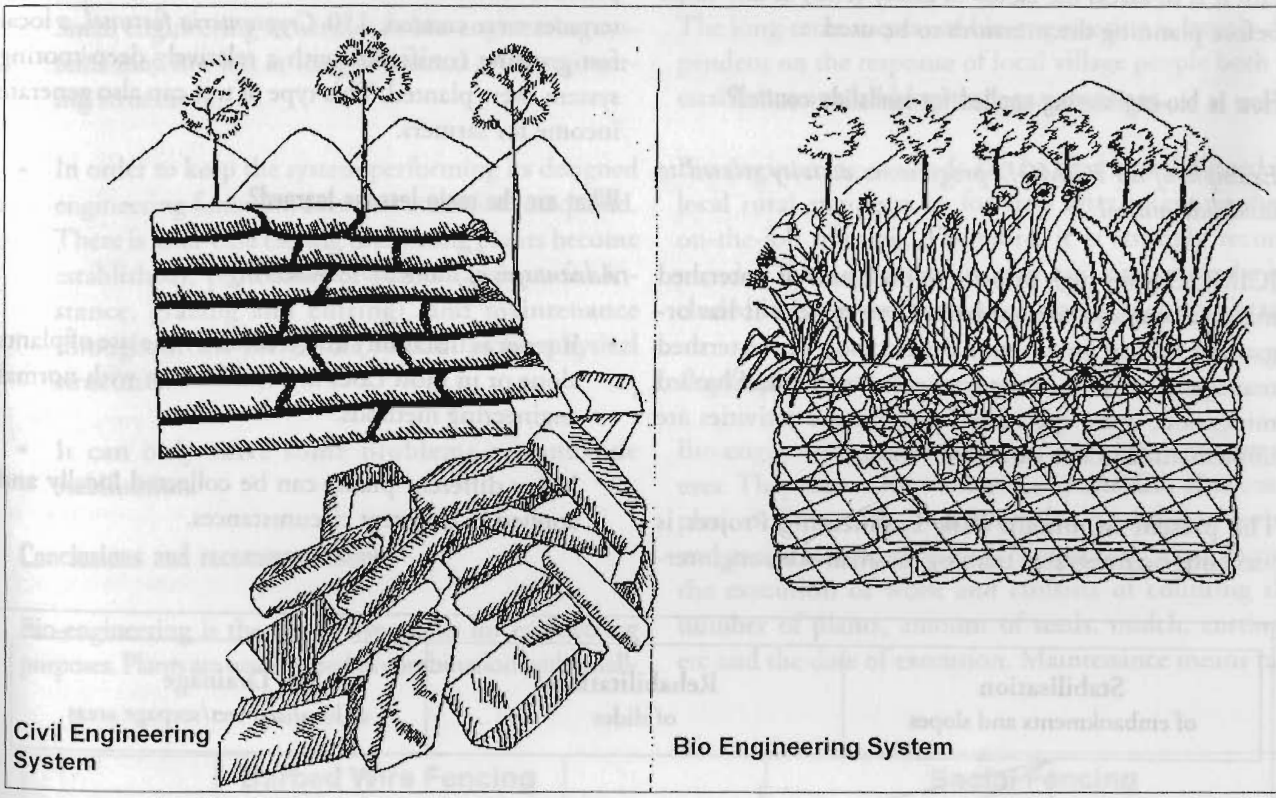
- Catching material that is moving down the slope in the process of erosion. This is done by the stems of the vegetation.
- Armouring the slope against surface erosion from runoff and rain splash.
- Supporting the slope by preparing from the base. This requires large, mature plants such as fully grown bamboo clumps or trees.
- Reinforcing the soil by increasing the shear strength of the soil. This depends on the strength of plant roots.
- Drainage of the soil profile to avoid slumping of saturated surface material.
- Limiting the extent of slope failure by binding soil.
- Improving the soil and micro-climate and so encouraging regeneration.

Functions of vegetation compared to civil engineering structures

Civil engineering structures have six main functions. Bio-engineering systems work in the same way as civil engineering systems (Table 2).

Table 2: Main engineering functions of vegetation compared to civil structures (after Geo-environment Unit, Department of Roads, Nepal, 1997)

Function	Civil engineering system	Bio-engineering system
Catch	Gabion wire bolsters Catch walls, catch fences	Contour lines (grass lines, brush layers) Shrubs and bamboo (many stems)
Armour	Revetments Surface rendering	Mixed plant storeys 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, soil anchors	Deeply-rooting trees (long, strong roots)
Support	Retaining walls Prop walls	Large trees and large bamboo (deep, dense root systems)
Drain	Masonry surface drains Gabion and French drains	Downslope and diagonal vegetation lines Angled fanciness



Apart from the six main functions, there are three more benefits of vegetation.

- Environmental improvement: a cover of vegetation encourages other plants and animals to live on the slope.
- Limiting the lateral extent of instability: the rooting system of trees can interrupt the shear plane and stop it spreading further in the current phase of active instability.
- Plants provide useful products such as thatch, fruit, and fuelwood.

Interaction between vegetative and civil engineering structures

The strength of a civil engineering structure varies at different stages of its life. It has its maximum strength as soon as it has been completed. The strength of vegetative structures will build up rapidly from no strength during the first year and will reach full strength in about four years for shrubs and in about six years for trees. There is a great risk for all vegetative structures in the first few years of planting. A combination of both accounts for the decreasing strength of the civil engineering structure and the increasing strength of the plants: by properly selecting the functions of the two structures, the function of the engineering structure will be handed over to the plants. This hand-over of function from an engineering system to a vegetative system is important in the design of bio-engineering works. This application, starting with small-scale engineering structures and adding bio-engineering structures, has proven to be suitable for landslide stabilisation. Therefore, bio-engineering is most commonly used in combination with civil structures. It does not replace any form of civil engineering. The art of using vegetation in engineering is to combine it carefully with civil works to give the best results in terms of cost and effect. Figure 1 shows certain aspects of slope stability as they relate to the use of bio-engineering in combination with other engineering measures. This demonstrates how important it is to assess the factor of safety (FoS) of any slope before planning the measures to be used.

How is bio-engineering applied for landslide control?

Example of an ICIMOD programme activity related to landslide control

ICIMOD gives high priority to problems of watershed management and natural hazard mitigation. It has organized its first international workshop on watershed management. Within the framework of natural hazard mitigation, more specialised programme activities are implemented under various divisions.

The present Mountain Risk Engineering Project is focussing on integrated training on small-scale engineering and bio-engineering practices for junior technicians, farmers ,and community leaders.

Yujiago bareland rehabilitation

The purpose of the work implemented at this location was to reclaim the disposal talus of an old quarrying site situated at the side of a still exploited quarry and to create a sustainable example of land reclaim for this area. The disposal material was too coarse (though bearing some topsoil) to reclaim as farmland and the only possibility was to afforest the area. The measures consisted of terracing the talus and planting pioneer trees. Terracing was completed using cordon construction since this method fits well with the irregular terrain and is appropriate for soil and water conservation. Twelve 2-m wide terraces were created. 150 *Cryptomeria fortunel,* a local fast-growing coniferous with a relatively deep-rooting system, were planted. This type of tree can also generate income for farmers.

What are the main lessons learned?

Advantages of using bio-engineering

- It reduces instability and erosion by the use of plants alone or in most cases in combination with normal engineering methods.
- Many different plants can be collected locally and applied in different circumstances.

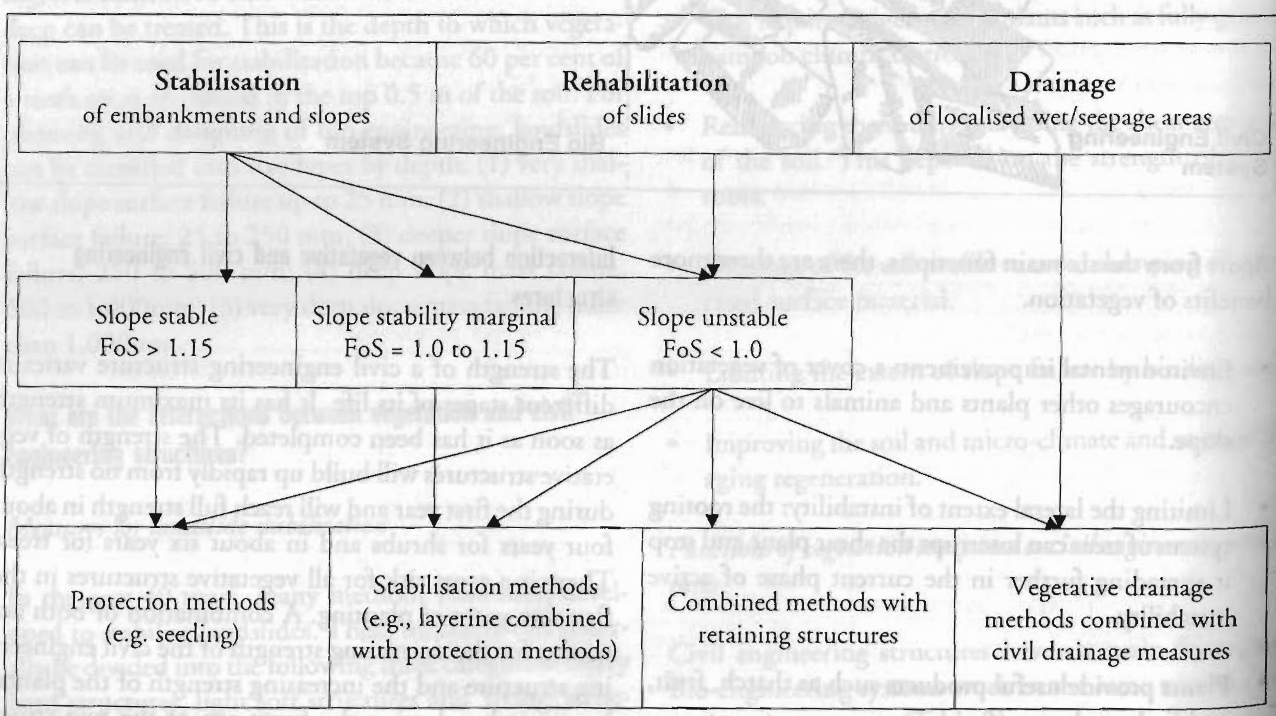


Figure 1: *Slope Stability and Bio-engineering Techniques (Kuonen 1983)*

- Bio-engineering is cost effective and can be applied without a high degree of technical knowledge.

- Bio-engineering improves habitats for greater biodiversity and reduces siltation of streams.

- Implementation of bio-engineering uses local labour and the production of by-products is of benefit to the local community.

Disadvantages of using bio-engineering

- It takes time for the plants to reach maturity: in the meantime they make no contribution to slope stability and only strengthen year by year.

- Small engineering structures in bio-engineering systems may not last as long as normal civil engineering structures.

- In order to keep the system performing its designed engineering function, constant attention is required. There is after-care (seeing that young plants become established), protection of plants (against, for instance, grazing and cutting), and maintenance throughout the life of the system, as for physical structures.

- It can only solve some problems of landslide stabilisation.

Conclusions and recommendations

Bio-engineering is the use of live plants for engineering purposes. Plants are usually used in combination with small-scale engineering structures. Bio-engineering represents an additional set of tools for the engineer, but does not normally replace the use of civil engineering structures.

Bio-technical slope stabilisation methods are cost effective and can be applied without a high degree of technical knowledge. They use mostly local materials, such as plants, plant material, and rocks, that can be collected at the site itself.

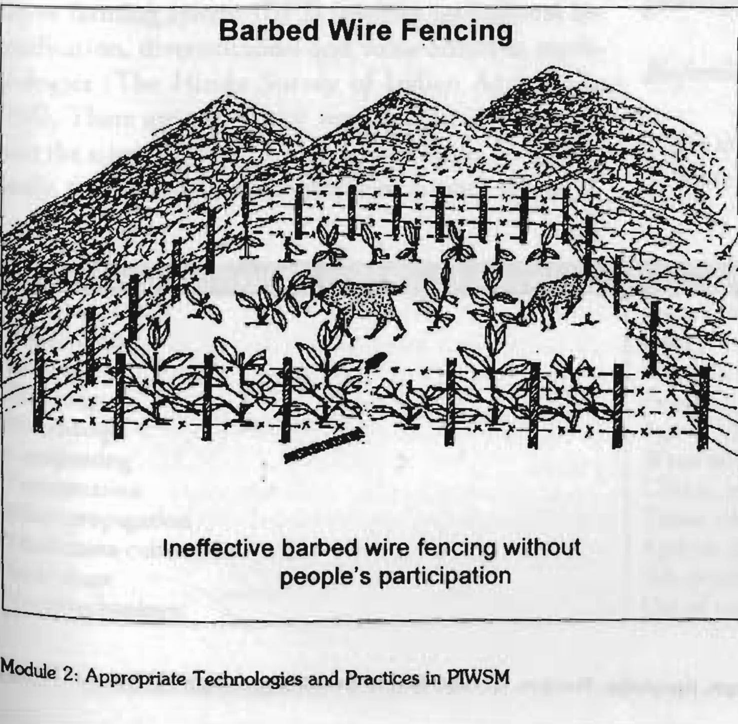
Bio-engineering methods are typically long-term measures. They need careful maintenance of all structures for 3-5 years after execution of the work. Maintenance consists of replacement work, repair, cutting back of trees, etc.

The long-term success of bio-engineering is largely dependent on the response of local village people both in establishment and long-term maintenance.

Bio-engineering methods can be used and designed by local rural engineers or foresters after receiving short on-the-job training. Therefore, it is strongly recommended that an on-the-job training component be included in integrated watershed management projects.

People's participation

Bio-engineering methods are normally long-term measures. They take at least two years to establish after completion of the work. This fact makes careful monitoring and maintenance necessary. Monitoring starts during the execution of work and consists of counting the number of plants, amount of seeds, mulch, cuttings, etc and the date of execution. Maintenance means tak-



Ineffective barbed wire fencing without people's participation

Effective social fencing-stall feeding with people's participation ing care of all structures and plants for at least five years after execution of the work. Maintenance consists of replacement work, repair, cutting back of trees, cutting of shrubs and grasses, watering, fencing, and running the nursery.

Monitoring and maintenance should be part of every bio-engineering project. They can be done by skilled project labour and local people with a supervisor or the bio-engineer in charge. The involvement of local people is important in order to build up their expertise/experience, since these people will have to continue maintenance for several years after execution of the work. For the active participation of local people in maintenance, the following approaches may be used.

- Raise awareness among the local community concerning the problem associated with monitoring and maintenance of bio-engineering.

- Some kind of management committee or group may be formed. These are normally associated with local forest management and are invested with special powers by the local forest or soil conservation department together with the project.

- Private planting (management) is the most direct and, perhaps, the easiest way to maintain the bio-engineering structures. The site is often close to farmers' houses which is convenient for both the farmer and he project.

- An arrangement can be made with local people to monitor and maintain bio-engineering sites. This is often the most long-lasting situation, but it is also the hardest to achieve.

References and further reading

DOR, 1997. *Use of Bio-engineering*. Kathmandu: Geo-environmental Unit, Department of Roads.

Howell J. H.; Clark J. E.; Lawrence C. J. and Sunwar I., 1991. *Vegetation Structures for Stabilising Highway Slopes*. Kathmandu: Department of Roads.

ICIMOD, 1997. *Integrated Training on Mountain Risk Engineering in the Himalayas*. Kathmandu: ICIMOD.

Kuonen, V. 1983. *World and Genterstrassen* (Industrial/agricultural goods and forest way construction). CH-Pfafhausen: Eigenverlag.

Varnes, D. J., 1978. *Slope Movement, Types and Processes in Landslides: Analysis and Control Transportation Research Board*. National Research Council Special Report. USA: National Academy of Sciences.