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Bioengineering Techniques for Roadside Slope Stabilization in Nepal

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Abstract:*In order to prevent shallow-seated instability and erosion on slopes, bio-engineering techniques are used, either alone or in combination with non-living plant materials and civil engineering structures. Plants have long been used to defend against soil erosion and stabilize slopes. It is the application of biological, mechanical, and ecological principles to stabilize slopes, protect soil, and minimize or control erosion using plants or a combination of vegetation and building materials. For landslide mitigation, bioengineering methods are frequently combined with civil and social engineering. Bioengineering is a technique of choice to control soil erosion, slope failure, landslides, and debris flows, and thereby to help minimize the occurrence of floods and flash floods. It offers an environmentally friendly and highly cost- and time-effective solution for slope instability problems in mountainous and hilly areas. Construction methods used in civil engineering and bioengineering differ significantly in that physical structures offer protection right away while vegetation takes time to develop to its full potential. Thus, the use of both physical and vegetative measures provides both short- and long-term protection, as well as the reduction of some physical projects' adverse ecological effects.*

Keywords:*bio-engineering, slope failure, soil erosion, vegetation, slope stabilization*

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I. INTRODUCTION

About 77% of Nepal's land area is made up of hills and mountains, making it mostly a mountainous nation. The country has a 147,181 square kilometer territory and is roughly rectangular in shape. The east-west length can reach up to 800 km, while the north-south length can reach up to 200 km. Its altitude spans from 60 meters to 8848 meters, which is the widest on the planet. The Himalaya, located in the north, is covered in snow and ice. The Terai, or southern plain, is about 30 km broad, with an altitude range of 75 to 280 m, and fertile low ground (also swampy). The climate, vegetation, culture, and religion of the nation are incredibly diverse.

1. BASICS OF BIOENGINEERING

Building geotechnical and hydraulic structures as well as stabilizing unstable slopes and banks need the use of bioengineering techniques, which rely on biological understanding. In conjunction with other (dead) construction materials, whole plants or their pieces are utilized as building materials to stabilize unstable areas. Therefore, bioengineering complements and improves other technical engineering procedures rather than replacing conventional small-scale civil engineering structures.

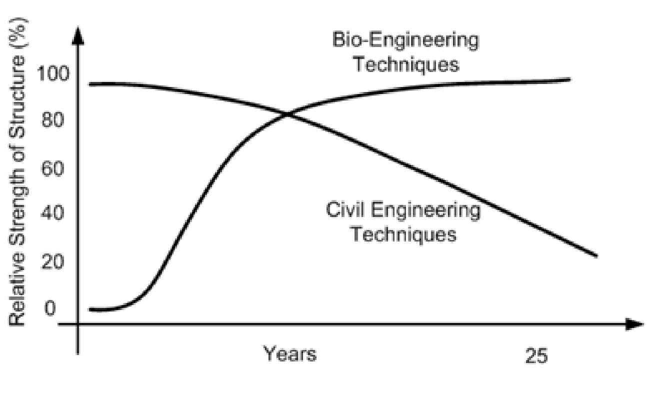

Figure1: Relative Strength of Bio-Engineering Civil Engineering Techniques (Source: Road side Bio-engineering Reference Book, John Howel)

2. FUNCTIONS OF VEGETATION IN BIOENGINEERING

Basically, bioengineering functions in following ways.

I. Hydrological Function

a. Interception: The amount of rainfall intercepted (IC), assuming that rain falls vertically, can be determined from the straightforward connection.IC = Rain * % Canopy Cover

A portion of the rain that was diverted is retained on the leaves and stems and eventually evaporated back into the atmosphere. In the form of stem flow or leaf drainage, some rainfall that was intercepted makes it to the ground.

b. Evapo-transpiration: Evaporation is the process through which water can leave the soil surface and leaf surfaces. Through their roots and leaves, plants absorb water and emit it. It's known as transpiration. Evaporation and transpiration from the vegetation cover work together to remove moisture from the earth's surface.

c. Infiltration: Through an increase in the infiltration rate, there will be decrease in the quantity of runoff generated during a storm, and also increases the time taken for runoff to occur.

d. Surface Crusting:On Silty soils, the finer particles detached by raindrop impact block up the pores and cracks and reduce the infiltration rate. A 50% reduction in infiltration can occur in one storm. The infiltration capacity of sandy soils in Mali ranges from 100 to 200 mm/h but, when a crust has developed, it is reduced to 10 mm/h.

e. Stem flow: A portion of rainwater is intercepted by trees and bushes and flows along the branches and stems to the ground at low velocity. Some rainwater is stored in the canopy and stems.

II. Engineering Function

a. Reinforce: The shear strength of the soil can be increased by planting vegetation. The roots bind the grains of soil. The level of reinforcement depends on the nature of the roots.

b. Armour: Some slopes are very water sensitive. They start moving and/or are easily liquefied when water falls on them. Vegetation can protect the surface from water infiltration and erosion by rain splash.

c. Anchor: Layers with a tendency to slip over each other can be pinned to each other and the stable underlying layer by penetration of woody taproots from vegetation which functions as anchors.

d. Catch: Loose materials have a tendency to roll down a slope because of gravity and erosion, and this can be controlled by planting vegetation. The stems and roots can catch and hold loose material.

e. Support: Lateral earth pressure causes a lateral and outward movement of slope materials. Large and mature plants can provide support and prevent movement.

f. Drain: Water is the most common triggering factor for slope instability. Surface water drains away more easily in areas with dense rooted vegetation. Thus draining can be managed by planting small and dense rooted vegetation such as durva grass.

3. MAJOR TECHNIQUES IN BIOENGINEERING

In general, it is preferable to use native plant species when bioengineering because they have already been acclimated to their environment, are more likely to be disease-resistant, are more easily available, and are probably a less expensive option. Choosing species that can serve several functions as they develop, such as producing fruit or having branches and leaves that may be used for fire wood, fodder, or other household uses, can also be helpful. The locals will gain more from the measures and will accept them more readily as a result. The following are the main criteria to take into account while choosing species for bioengineering.

a. Method of propagation
b. Biological and social considerations
c. Establishment, vigor and persistence
d. Site suitability
e. Potential value to local farmers
f. Availability

4.1 BIOENGINEERING TECHNIQUES TO CONTROL SLOPE FAILURE

Bioengineering can be used to increase slope stability in a variety of ways (Li and Clarke 2007; Lammeranner et al. 2005), in particular:

a. Mechanical reinforcement: The dense network of coarse and fine roots from vegetation can work as a reinforcement mechanism on the slope by binding and stabilizing loose materials. The stabilizing effect of roots is even greater when roots are able to connect top soil with underlying bedrock, with the root tensile strength acting as an anchor. Small dense roots also contribute to the shear strength of a slope and thus reduce the risk of landslides and debris flows. Trees and bamboos can stabilize the whole soil layer in slope terrain, whereas bush and shrub roots mainly protect soil up to 1 m deep, and grasses can conserve top soil to a depth of around 25 cm (Jha et al. 2000).

b. Controlling erosion: Bare soil-covered slopes are easily affected by the splash effect of intense rain leading to heavy erosion. The surface runoff rate is also very high, and the flowing water can carry the soil particles away and trigger a debris flow. A dense cover of vegetation protects the soil from splash effects and reduces runoff velocity, while the roots bind the soil particles, thus hindering surface erosion.

c. Increasing the infiltration ratio: As decayed roots shrink, they leave a gap which provides a passage for water seepage, which leads water away from the surface and reduces the likelihood of surface soil saturation. This reduces slope instability and hinders the development of debris flows.

d. Reducing runoff: Vegetation can be used to reduce runoff in a number of ways including trapping of moisture in leaves and branches, slowing the flow of water across the rough surface, increasing infiltration, and through structures designed to deflect flow away from the top of a slope and channel it along a desired pathway down the slope.

e. Soil moisture adjustment: Soil moisture is a key factor in slope stability. Vegetation can directly influence soil moisture through interception and evapo-transpiration. In interception, precipitation is captured by the vegetation canopy and returned directly to the atmosphere through evaporation. The rate of interception varies according to various factors including leaf type and size, canopy density, temperature, and humidity. In evapo-transpiration, the plants channel moisture from the soil to the leaves and stems, from where it returns to the air via evaporation. These two processes combine to reduce the overall soil moisture content.

4.2 BIOENGINEERING TECHNIQUES FOR THE ROAD SIDE SLOPE PROTECTION

The selection of the appropriate bioengineering treatment for a particular area depends on the site conditions, and requirements. Resource availability is a crucial factor. The following sections describe some of the techniques that can be used to control soil erosion, debris flows, landslides, and floods and flash floods in the road side.

4.2.1 Grass Planting

Provide a surface cover, reduce the speed of runoff and catch debris, thereby armoring any slope less than 65°. Grass planting may be following types: Horizontal/Contour grass planting, Down slope/Vertical grass planting, Diagonal grass planting and Random grass planting. The construction steps of grass planting are as follows.

a. Preparing the site well in advance of planting
b. Starting grass planting at the top of the slope and work downwards.
c. Marking out the lines with string, using a tape measure
d. Splitting the grass plants out to give the maximum planting material.
e. With a planting bar, making a hole just big enough for the roots. Place the grass into the hole
f. Cateing a few handfuls manure around the grasses consider watering the plants by hand if no rainfall

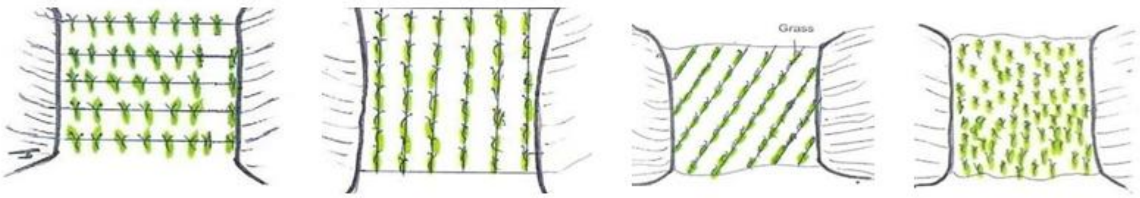

Figure 2: Grass Planting Types (Source: Road side Bio-engineering , Site Hand Book, John Howel)

4.2.2 Grass Seeding

Grass is sown directly on to the site, often used in conjunction with mulching and jute netting to aid establishment. The main functions are armor and later to reinforce. It is suitable for almost any bare site with slopes up to 45°. The construction steps of grass seeding are as follows.

a. Preparing the site well in advance
b. Immediately before sowing, scarifying the surface of the slope
c. Sowing from the top of the slope and work downwards. (@ 25 gm/m^2)
d. Covering the seeds completely with a layer of mulch Wide mesh jute netting (150 mm × 500 mm mesh size) should be used to hold mulch on to the surface if the slope is greater than 30°.

Figure 3: Grass Seeding (Source: Road side Bio-engineering, Site Hand Book, John Howel)

4.2.3 Shrub and Tree Planting

Shrubs and trees are planting directly on to the site. The main functions are reinforced and later to anchor, slope support in long term. It is suitable for almost any slope up to 30°, upto 45° with care. The construction steps for shrub and tree planting are as follows.

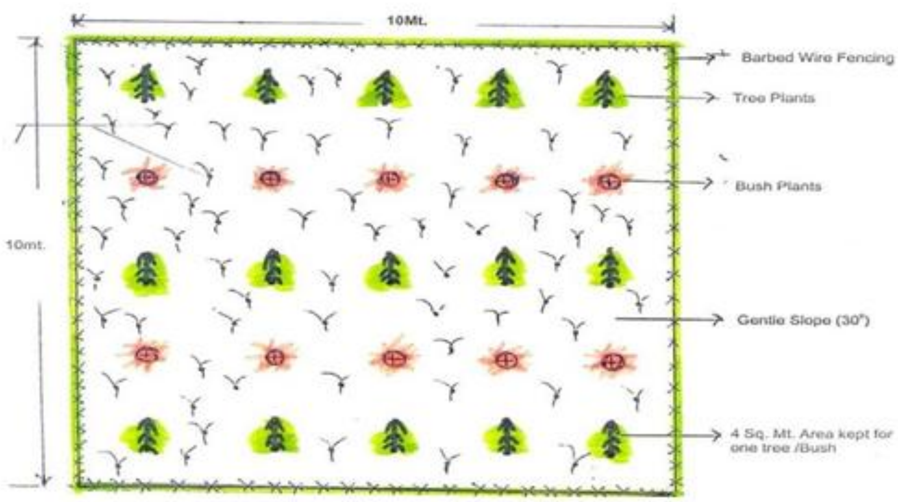

Figure 4: Shrub and Tree Planting (Source: Road side Bio-engineering , Site Hand Book, John Howel)

a. Preparing the site well in advance of planting
b. Digging pits of size 300 mm deep and 300 mm in diameter
c. Carefully removing the polypot by slicing it down the side with a razor blade
d. Planting the seedling in the pit, filling the soil carefully around
e. If available, mixing a few handfuls compost and water
f. Removing any weeds around the plant

4.2.4 Brush Layering

Cuttings of wood, also known as hardwood cuttings, are spread over the slope in straight rows, usually following the contour. It creates a solid barrier that hinders the growth of rills and the movement of trap material down the hill. A little patio will eventually grow. The primary purposes are to catch debris and to fortify and armour the slope. It aids in draining the slope if it is inclined. Brush layers offer a very durable and affordable barrier. It works best on debris sites and is acceptable for practically all temperatures up to roughly 45°. Avoid using it on poorly drained soil. The following are the construction steps for brush layering.
a. Marking the lines to be planted and form a small terrace (min. width 50cm)
b. Laying the first layer of cuttings along the terrace, with a 50 mm interval between the cuttings
c. Laying a 20 mm-thick layer of soil in between the cuttings to provide a loose cushion.
d. Laying a second layer of cuttings on top of this, staggered with the first layer.
e. Partly backfilling the terrace with the excavated materials. This should not be more than 50 mm thick.

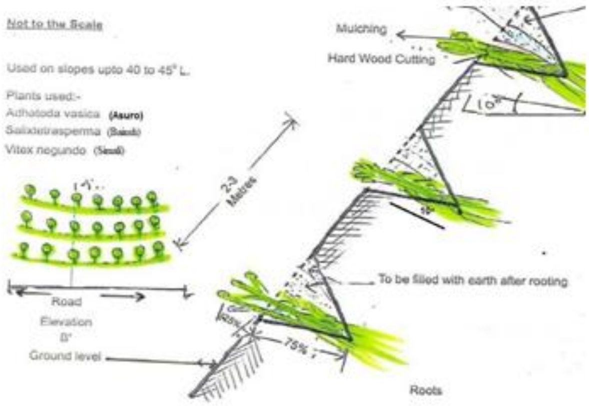

Figure 5: Brush Layering (Source: Road side Bio-engineering , Site Hand Book, John Howel)

3.2.5 Palisades

Cuttings of woody (or hardwood) are planted over the slope in straight rows, usually following the contour. These provide a solid barrier that stops the material from sliding down the slope. A little patio will eventually grow. The slope's reinforcement and trash collection are its primary purposes. Palisades can be angled in some places to serve as a drainage system. It works best on steep landslide debris slopes and can be introduced to locations up to roughly 60°. The following are the palisade building steps.

Figure 6: Palisades (Source: Road side Bio-engineering, Site Hand Book, John Howel)

a. Trimming and clean the site well
b. With string, marking out the lines to be planted
c. Always starting at the top of the slope and work downward.
d. Using a pointed bar, making a hole in the slope that is bigger than the cutting and deep enough to take at least two-thirds of its length
e. Carefully placing the cutting in the hole, so that at least two-thirds is buried. Firm the soil around it.

4.2.6 Live Check Dam

Large woody (or hardwood) cuttings are typically planted along a gully's contour. These create a solid barrier that traps stuff that is falling. Longer future, the gully's floor will change into a little step. The major purposes are to protect and fortify the gully floor as well as to catch debris. This method can be applied to a variety of gully sites with slopes up to 45 degrees. However, it is best to stay away from materials with high rates of small-scale slumping. The following are the steps in the construction of a live check dam.

a. Making a hole deep and big enough to insert vertical hardwood cuttings
b. Inserting the vertical cuttings by carefully pushing them into the hole and firming the soil around them.
c. Placing long hardwood cuttings on the uphill side of the vertical stakes.
d. Making key in these horizontal members into the wall of the gully.
e. Backfilling around the check dam and compact the soil with foot pressure.

Figure 7: Live Check Dam (Source: Road side Bio-engineering, Site Hand Book, John Howel)

4.2.7 Fascines

The definition of "fascine" is a collection of sticks (John Howel). Live branch bundles are placed in small ditches. They sprouted roots and shoots after being buried in the trenches, creating a sturdy line of vegetation. The slope's reinforcement and trash collection are its primary purposes. Fascinates may be angled to provide drainage in some places. On consolidated debris or gently cut slopes, fascines work well. A 45° slope is the highest. The steps for building a fascine are as follows.

a. Preparing the site well in advance of planting
b. Marking on the slope and start work from the bottom of the slope, and work upwards.
c. Digging about five meters of trench at a time
d. Laying the cuttings together, filling the trench and with their ends overlapping
e. Backfilling the trench as soon as possible.
f. If the slope angle is more than 25°, pegging the fascine.

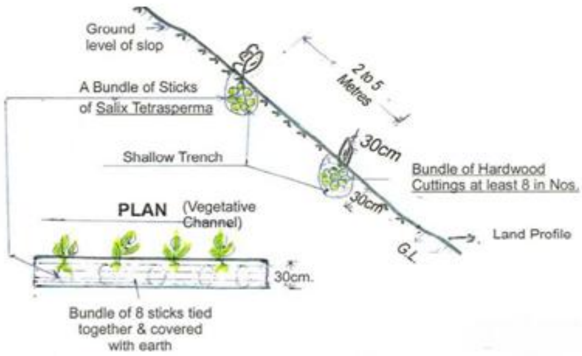

Figure 8: Fascines (Road side Bio-engineering , Site Hand Book, John Howel)

4. CHOICE OF BIOENGINEERING TECHNIQUES

In various places of the world, erosion and slope failure are controlled using various bioengineering methods. Depending on the resources available, the site's state, and the desired function, the approaches best suited for a certain region should be chosen. The suitable bioengineering methods for reducing various landslide and debris flow dangers are shown in the following table.

Table 1: Basic Techniques for Bioengineering

Phenomenon	Erosion problem and condition	Suitable bioengineering techniques
Landslide	Deep-rooted landslide (>3 m depth)	Smoothing to a suitable slope gradient Diversion canals, channel lining, catch drains, waterways
	Slumping	Stone pitching and planting of trees, shrubs, and grass slip
		Bamboo fencing with live poles, planting and seeding grass

	Planar sliding	Terracing and planting with bamboo, trees, shrubs, grass
	Shear failure	Live peg fence, wild shrubs, live check dams
	Cut and fill area at deep and shallow-rooted landslide (<3 m depth)	Contour strips planted with grass, shrubs, and pegs Fascines, brush layering, and palisades Planting bamboo with or without a structure Check dams planted with deep-rooted species (e.g., bamboo, trees)
	Bare and steep slope or newly exposed surface	
	Cracking zone	Bamboo fencing above zone; zone covered with polythene sheet Catch drain with vegetation Fascines, brush layering, and palisades
	Head scarp of landslide or slope failure	Slope excavated to an appropriate gradient and rounded (when high and steep) and planted with deep-rooted plants (e.g., bamboo, trees) Bamboo fencing, planting grass, seeding, and mulching Fascines, brush layering, and palisades Jute netting or straw mat covering soil, seeds, and compost mixture; turfing Stone pitching; planting of trees, shrubs, and grass slip Planting grass slip and seeding gras
Debris flow	Sediment production zone	As for landslides
	Sediment transportation zone	Series of gabion check dams, retaining wall, and side wall planted with deep-rooted species (e.g., bamboo, trees) Bamboo fencing; grass planting, seeding, and mulching
	Sediment deposition zone	Diversion canal, channel lining, retaining wall, and side wall planted with trees, shrubs, and grasses Plantation of deep-rooted species (e.g., bamboo, trees)
Soil Erosion	Sheet and rill erosion	Planting of bamboo, trees, shrubs, and grass with or without terracing Live peg fence, wild shrubs, and live check dams Contour strips planted with grass, shrubs, trees, and pegs Fascines, brush layering, and palisades with wild and thorny shrub species.
	Gully erosion	Diversion canals, channel lining, catch drains, waterways, cascade retaining wall, and side wall, planted with trees, shrubs, and grasses Bamboo fencing with live pegs Planting of bamboo, trees, with or without check dams Series of retaining walls and plantation Vegetated stone pitching in small gullies and rill beds
	Erosion on bare land, degraded steep sloped land, dry and burnt area	Planting of deep-rooted species (e.g., bamboo, trees) Bamboo and live peg fencing and live check dams Vegetated stone pitching in small sheets and rill beds Stone pitching and planting of trees, shrubs, and grass slip
	Degraded shifting cultivation areas, newly excavated or exposed areas on terrace bund, degraded forest, and grazing land	Bamboo fencing with live poles, planting and seeding grass Planting of bamboo, trees, shrubs, and grass with or without terracing and structure Live peg fencing and live check dams Vegetated stone pitching in small gullies and rill beds Contour strips planted with grass, shrubs, trees, and pegs Planting fascines, brush layering, and palisades
	Water induced degraded land (spring, water source damaged area, canal command area)	Planting of bamboo, trees, shrubs, and grass with or without terracing and structure Stone pitching and planting of trees, shrubs, and grass slip Planting of deep-rooted species (e.g., bamboo, trees) Live peg fences and live check dams Vegetated stone pitching and loose stone masonry walls or check dams

	Cut and filled area or newly exposed area on slope*	Jute netting and straw mats covering soil, seeds, and compost Live peg fences and stone masonry walls Plantation, seeding, and planting grass Live wattling with terracing and seeding

Source: DWIDP/JICA 2004a
*Exposed slope surfaces must be carefully maintained. A cut and newly exposed slope surface should usually be covered, depending on the type of soil material and other factors.

6. CONCLUSION

The technical benefits of bioengineering include protection against rock fall, protection against surface erosion, and increased slope stability due to root strengthening and soil drainage. Everything should be done with sustainability in mind. The bio engineering method is an environmentally friendly strategy to manage the side slope of a road. The bioengineering method primarily takes into account national economic, social, and environmental challenges. In addition to using diverse soil bioengineering techniques to assure slope stability and erosion management, bioengineering techniques incorporate soil conservation as an environmentally beneficial strategy. It encourages the best possible use of locally produced building supplies, machinery, and laborers at every level of the project. It motivates the locals to assume responsibility of the location for the long-term upkeep of the bioengineering method. The bioengineering method is the most environmentally friendly method of protecting roadside slopes in this situation.

REFERENCES

[1]. ADB. (2006). ADB Completion Report, Rural Infrastructure Development Project, Manila, 2006.

[2]. Anselm, H. 1976. Analyse der Ausbauverfahren, Schäden und Unterhaltungskosten von Gewässern. Mitteilungen des Instituts für Wasserwirtschaft, Hydrologie und Landwirtschaftlichen Wasserbau, TU Hannover, Report 36:11-191.

[3]. District Roads Support Programme. (DRSP, 2006). 2002-2006 Phase II Report, Program Support Unit, SDC, Kathmandu.

[4]. Klatzel Frances. (2000). Green Roads: Building environmentally friendly, low maintenance rural roads through local participation, Best Practice report, spring, GTZ, Kathmandu.

[5]. Road side Bio-engineering – Reference book and Site Hand Book, John HowelSlope Stabilization and Erosion Control – A bioengineering Approach, R.P.C. Morgan and R.J. Rickson

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