10 Application of Bio-Engineering in Slope Stabilisation: Experience From Nepal

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This paper gives an introduction to the use of bio-engineering for slope stabilisation and erosion control in Nepal. It describes the scope of the subject, including both the basic principles and practice. These are applied specifically to the prevailing conditions in Nepal. It is based on the author's experience of the development of bio-engineering in the Nepal road building programme over about twelve years.

Introduction

Bio-engineering is the use of live plants or plant parts to control soil erosion and the mass movement of land, in order to fulfil engineering functions. Other terms that have been used to describe this process include: vegetation structures, bio-technical engineering, vegetative soil conservation, and engineering biology. Bio-engineering does not replace standard civil engineering procedures, nor does it offer magic solutions. It does, however, increase the number of available ways to address roadside slope stability problems.

Bio-engineering is especially useful in developing countries such as Nepal where it is relatively cheap to apply. The materials are locally available and cost little and the main input is labour - a low cost resource in Nepal.

Bio-engineering is not a new subject with the first recorded use in the Fifth Century AD in ancient China. There is evidence of it being used in Europe during the Dark Ages and Medieval times (between about 500 and 1500 AD). It has also been practised widely in other parts of the world for many years. It may have been used in Nepal in the past but what we know of as bio-engineering today has been brought into Nepal and adapted for local conditions only over the last 25 years. Shrestha (1991) and Clark (1992) give more details of the development of bio-engineering in Nepal.

The Himalayas present major environmental difficulties for the development of infrastructure. The most notable are:

- young and active geology, giving weak materials and steep slopes (Plate 10.1);
- a harsh climate, giving long periods of drought and intense rainstorms.

These combine to give unstable mountains and extremely high rates of erosion. Even in plain areas the harsh climate can create extreme conditions on steep embankment slopes. On the micro scale, there is little difference between the hills and the Terai.

There are many publications that deal with the evolving geology and geomorphology of the Nepal Himalaya. Most are academic publications and are of little direct practical help in bio-engineering practice. They do however give a good introduction to the subject and include: Brunsden et al

Plate 10.1: **The Trisuli-Somdang road above Syabrubesi (central Nepal)**

(1981), Carson (1985), Fookes et al (1985), Deoja et al (1991), and Transport Research Laboratory (1997).

In the mountains of Nepal there is a large variety of forms of erosion and instability (Table 10.1). Resolving slope problems depends on a clear understanding of exactly what is happening on the site. This does not just mean the major landslide or gully features, but also the micro-sites in every part of the main site. Careful site assessment is the key to the successful resolution of any instability. The engineer's design must be based on the results of this site survey. Kappeler (1984), Schaffner (1987) and Deoja (1994) give descriptions of construction methods specifically adapted for these environmental conditions.

Basic Principles and Techniques of Bio-Engineering

There are different methods of using vegetation to protect and stabilise slopes. The main categories are:

- simple planting (e.g. grass seeding; planting trees, shrubs and bamboos);
- structures using vegetation (e.g. lines of grasses or of shrub cuttings, in the form of brush layering); and
- composite systems (e.g. planted jute netting or vegetated stone pitching).

The author's long experience suggests that bio-engineering should always be used as part of an overall design when resolving any particular slope problem. It must always be integrated in such a way that it complements and enhances any other measures. In this way, bio-engineering is often used as part of a broad design, in conjunction with a number of standard civil engineering measures such as check dams, prop walls, toe walls, wire bolsters, and jute netting.

Table 10.1: **The most common forms of erosion and slope instability**

Mechanism	Description
Erosion on the surface	Rills and gullies form in weak, unprotected surfaces. Erosion should also be expected on bare or freshly prepared slopes.
Planar sliding (translational landslide or debris slide)	Mass slope failure on a shallow slip plane parallel to the surface. This is the most common type of landslide, slip or debris fall. The plane of failure is usually visible but, depending on site conditions, may not be straight. It may occur on any scale.
Shear failure (rotational landslide)	Mass slope failure on a deep, curved slip plane. Many small, deep landslides are the result of this process. Large areas of subsidence may also be due to these.
Slumping or flow of material when very wet	Slumping or flow of material that is poorly drained or has low cohesion between particles. Often occurs where liquefaction is reached. These sometimes appear afterwards like planar slides, but are due to flow rather than sliding. The resulting debris normally has a rounded profile.
Debris fall or collapse	Collapse due to failure of the supporting material. This normally takes the form of a rock fall where a weaker band of material has eroded to undermine a harder band above. These are very common in mixed Churia strata.

Information on commonly used bio-engineering techniques may be found in Schiechtl, 1980; Gray and Lieser, 1982; Coppin and Richards, 1990; Morgan and Rickson, 1995; and Schiechtl and Stern, 1996). Methods specifically relevant to Nepal are described in manuals by Meyer (1987), ITECO (1990 and 1991), Howell et al (1991), Nepal SPWP (1992), Eastern Region Road Maintenance Project (1993), and Geo-Environmental Unit (DOR) publications (1997a and 1997c).

Bio-engineering measures can contribute by achieving the following.

- Preventing scour erosion: by strengthening the surface so that gullies cannot be formed. Also, roots will strengthen the surface layers of soil.
- Reducing the incidence of shallow planar landsliding: as the roots add strength to the surface soil layers and increase the shear strength. Vegetation also reduces the extent of shallow failures by binding the surface together laterally.
- Channelling runoff to alter slope hydrology: Lines of grass or cuttings can channel water into gullies or down the slope, so that infiltration is reduced. At the same time, the plants strengthen the surface and prevent erosion from starting.
- Providing support to the base of the slope and trapping material moving downwards: Vegetation can be used in this way to form a kind of flexible, growing retaining structure.
- The provision of social, economic and environmental benefits.

Table 10.2 gives more detail on the physical and hydrological effects of vegetation on slopes. Not all vegetation effects are good for engineering purposes. The thesis by Clark (1992) and the manual by Clark and Hellin (1996) cover this topic well.

In Nepal most erosion and slope failures take place towards the end of extreme rainfall events. These usually occur during the monsoon season when the soil is already near saturation. With more intense rainfall slopes becomes super-saturated. Slopes are most likely to fail at this point, when the material is at its lowest level of cohesion and has maximum weight. Under these conditions, the interception of rain by vegetation and the contribution to moisture reduction by plant transpiration is negligible making this type of bio-engineering benefit inapplicable in Nepal during the monsoon.

Table 10.2: The main effects of vegetation on slope stability

Hydrological mechanisms		Mechanical mechanisms	
1. Foliage intercepts rainfall causing absorptive and evaporative losses that reduce rainfall available for infiltration.	NA	1. Roots reinforce the soil and increase soil shear strength.	B
2. Roots and stems increase roughness of the ground surface and the permeability of the soil, leading to an increased infiltration capacity.	A/B	2. Tree roots may anchor into firm strata providing support to the upslope soil mantle through buttressing and arching.	B
3. Roots extract moisture from the soil, which is lost to the atmosphere via transpiration, leading to lower water pressures.	NA	3. Weight of trees surcharges the slope, increasing normal and downhill force components.	A/B
4. Depletion of soil moisture may accentuate desiccation cracking in the soil, resulting in higher infiltration capacity.	A	4. Vegetation exposed to wind transmits dynamic forces into the slope.	A
5. Lines of vegetation affect runoff and infiltration, depending on the surface micro-topography.	A/B	5. Roots bind soil particles to the ground surface and reduce their susceptibility to erosion.	B

A = adverse effect B = beneficial effect NA = not applicable in Nepal

A single plant gives a point of strength on a slope. The depth of its effectiveness depends on the size of the plant. A structure gives a line or area of strength, rather than just a point. For different purposes, it is necessary to use different levels and sizes of vegetation to cover the same area (Table 10.3).

While the properties of single plants can be valuable to stabilise certain areas of slopes, often more can be achieved by using plants as part of a structure. This may take the form of a simple line of planted grass, or may be more intricate, such as a fascine (a bundle of live cuttings buried in a trench) or a live check dam (an inter-woven construction of cuttings from different types of plant). Table 10.4 lists the main bio-engineering options available in Nepal, and what they contribute to strengthening slopes. Of all of these, the planting of grass lines is by far the most cost-effective and robust method of protecting slopes, and is recommended in the majority of situations.

Table 10.3: The effective rooting depths of different plant types

Plant type	Examples	Effective rooting depth (m)
Small grasses	Dubo (*Cynodon dactylon*) Kikiyu (*Pennisetum clandestinum*)	0.1
Large grasses	Kans (*Saccharum spontaneum*) Amliso (*Thysanolaena maxima*) Khar (*Cymbopogon microtheca*)	1
Large bamboo	Choya bans (*Dendrocalamus hamiltonii*) Mal bans (*Bambusa nutans*)	1.5
Shrubs	Bhujetro (*Butea minor*) Dhanyero (*Woodfordia fruticosa*)	1.5
Trees	Bakaino (*Melia azedarach*) Khayer (*Acacia catechu*) Utis (*Alnus nepalensis*)	2

Table 10.4: Common bio-engineering techniques appropriate to Nepal and their contribution

Class	Technique	Contribution to the slope
Simple planting	Grass seeding	Surface protection against erosion
	Tree and shrub seeding	Anchoring of the surface layers; reinforcement
	Grass planting	Surface protection against erosion
	Tree and shrub planting	Anchoring of the surface layers
	Big bamboo planting	Support to the slope; trapping of debris
	Turfing with grass	Surface protection against erosion
Structures using vegetation	Lines of grasses	Protection against erosion; trapping of debris; channelling of runoff
	Lines of shrub cuttings (brush layering and palisades)	Protection against erosion; trapping of debris
	Bundles of cuttings (fascines)	Protection against erosion; trapping of debris; channelling of runoff; drainage
Composite	Planted jute netting	Protection against erosion on very steep slopes
	Vegetated rip-rap	Protection against erosion in areas where there is a lot of running water
	Other inert structures with vegetation added	Numerous: these often need to be designed specifically for individual sites.

Practical Application of Bio-Engineering

Detailed appraisal of bio-engineering methods

The range of bio-engineering techniques adopted for use on the steep slopes in Nepal's road programme are versatile and robust, and can be recommended for use throughout the country. These are described in Howell et al (1991), Geo-Environmental Unit (1997a and 1997c) and Shrestha et al (1998). Table 10.5 gives details of the various methods in some detail. Some of these techniques are illustrated in Plates 10.2, 10.3 and 10.4.

In most situations it is best to use a combination of techniques (Plate 10.3). This can be done in two ways.

- Where a site needs several different techniques used in the same place to give the optimum effect. Examples might be:
  - wire bolster cylinders and grass slip planting;
  - grass seeding, mulching and wide mesh jute netting; and
  - standard mesh jute netting and grass slip planting.
- Where a site consists of a number of different components such as different slope segments, each of which require different techniques to be applied. Examples might be:
  - a steep head slope requiring standard mesh jute netting and grass slip planting;
  - a moderate, middle slope portion requiring contour grass lines; and
  - a gentle slope toe requiring bamboo planting.

The basic rules of bio-engineering design are:

- make a thorough site investigation;
- always consider each site independently;
- break the site down into manageable sections; and
- use any combinations of techniques, depending on what is appropriate.

As with any civil engineering work the use of bio-engineering techniques must be based on sound site investigation. Designs should be site-specific rather than "typical", and must be carefully created to resolve the specific problems on each site.

Selection of the Right Technique

To select the right technique for stabilising a slope first it is necessary to look at a site and its surroundings and make a number of investigations.

Plate 10.2: **A steep cut slope in a weak sand deposit on the Naubise-Mugling road (central Nepal), stabilised with jute netting and grass planting**

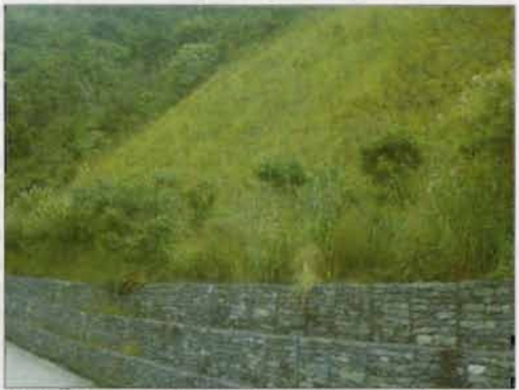

Plate 10.3: **A typical cut slope in deep colluvium on the Dharan-Dhankuta road (eastern Nepal), stabilised using a combination of a gabion toe wall and bio-engineering**

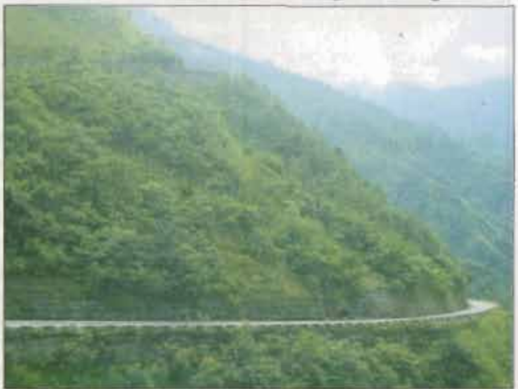

Plate 10.4: **Large scale civil and bio-engineering works on the Dharan-Dhankuta road (eastern Nepal)**

Table 10.5: **Bio-engineering techniques appropriate to Nepal and their structural contribution (adapted from Shrestha et al, 1998)**

System	Design and function
Planted grass lines: contour (horizontal)	Grass slips (rooted cuttings), rooted stem cuttings or clumps grown from seed are planted in lines across the slope. They protect the slope with their roots and, by providing a surface cover, reduce the speed of runoff and catch debris, and 'armour' the slope.
Planted grass lines: downslope (vertical)	Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running down the slope. They protect the slope with their roots, provide a surface cover and help to drain surface water. They do not catch debris. Using this technique, a slope is allowed to develop a semi-natural drainage system, with gullying happening in a controlled way.
Planted grass lines: diagonal	Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted in lines running diagonally across the slope. They armour the slope with their roots and by providing a surface cover. They have limited functions of catching debris and draining surface water. This technique offers the best compromise of the grass line planting systems in many situations.
Planted grasses: random planting	Grass slips (rooted cuttings), rooted stem cuttings or seedlings are planted at random on a slope, to an approximate specified density. They armour and reinforce the slope with their roots and by providing a surface cover. They also have a limited function of catching debris. This technique is most commonly used in conjunction with standard mesh jute netting, where complete surface protection is needed on very steep, harsh slopes. In most other cases, however, the advantages of one of the grass line planting systems (contour, downslope or diagonal) offer better protection to the slope.
Grass seeding	Grass is sown direct on to the site. It allows easy vegetation coverage of large areas. This technique is often used in conjunction with mulching and jute netting to aid establishment.
Turfing	Turf, consisting of a shallow rooting grass and the soil it is growing in, is placed on the slope. This technique is commonly used on gentle embankment slopes. Its only function is armouring.
Shrub and tree planting	Shrubs or trees are planted at regular intervals on the slope. As they grow, they create a dense network of roots in the soil. The main engineering functions are to reinforce and, later, to anchor the slope. In the long term, large trees can also be used for slope support.
Shrub and tree seeding	Shrub (or tree) seeds are applied directly to the site. This technique allows very steep, rocky and unstable slopes to be revegetated where cuttings and seedlings cannot be planted. There are two methods: (1) direct sowing and (2) broadcasting. In the first method, seeds are placed individually, whereas the second involves scattering the seed all over the site. The main engineering functions are to reinforce and, later, to anchor the slope.
Large bamboo planting	Large bamboos can reduce the movement of material and stabilise slopes. Large bamboos are usually planted by one of two methods: (1) the traditional planting method or (2) planting rooted culm cuttings from a nursery. Large clumps of the larger stature bamboos are one of the most substantial vegetation structures available to reinforce and support slopes. However, they do not have deeply penetrating roots and so do not have an anchoring function; also, they can add weight (surcharge) high up on the slope.
Brush layering	Woody (or hardwood) cuttings are laid in lines across the slope, usually following the contour. These form a strong barrier, preventing the development of rills, and trap material moving down the slope. In the long term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, brush layers can be angled to provide a drainage function.
Palisades	Woody (or hardwood) cuttings are planted in lines across the slope, usually following the contour. These form a strong barrier and trap material moving down the slope. In the long term, a small terrace will develop. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, palisades can be angled to give a drainage function.

Table 10.5: Bio-engineering techniques appropriate to Nepal and their structural contribution (adapted from Shrestha et al, 1998)	
System	Design and function
Live check dams	Large woody (or hardwood) cuttings are planted across a gully, usually following the contour. These form a strong barrier and trap material moving downwards. In the longer term, a small step will develop in the floor of the gully. The main engineering functions are to catch debris, and to armour and reinforce the gully floor.
Fascines	The word "fascine" means a bundle of sticks. In this technique, bundles of live branches are laid in shallow trenches. After burial in the trenches, they put out roots and shoots, forming a strong line of vegetation. This technique is sometimes called live contour wattling. The main engineering functions are to catch debris, and to armour and reinforce the slope. In certain locations, fascines can be angled to provide drainage. Where time is at a premium, brush layers may be more appropriate as these are quicker to establish than fascines.
Vegetated stone pitching	Slopes are strengthened by a combination of dry stone walling or cobbling, and vegetation planted in the gaps between the stones. There are two distinct uses: (1) reinforced toe walls; and (2) protected gully beds. This technique provides a very strong form of armouring. Because it specifically uses vegetation to strengthen a simple civil engineering technique, it represents a stronger form of normal stone pitching.
Jute netting* (standard mesh)	A locally made geotextile of woven jute netting is placed on the slope. The four main functions of standard mesh jute netting (mesh size about 40 × 40 mm) are to: protect the surface by armouring it against erosion and by catching small debris; enable seeds to hold and germinate; improve the microclimate on the slope surface by holding moisture and increasing infiltration; and as it decays to act as a mulch once the vegetation is established.
Jute netting* (wide mesh)	A locally made geotextile of woven jute netting (mesh size about 150 × 450 mm) is placed on the slope. It is used to hold mulch on slopes that have been seeded.
*Any use of jute netting is a temporary measure designed to enhance vegetation establishment. It does not protect a surface in itself for more than one or two seasons of monsoon rains.	

There is no such thing as a simple 'text book' landslide. They all have a variety of processes at work and it is essential to identify them before remedial work is started.

What erosion processes are active on the site?

A site may contain one or more types of erosion. Examples of the processes of erosion which may be found are as given in Table 10.1.

- *surface erosion*, such as rilling and gullying;
- *planar sliding*, on a shallow slip plane parallel to the surface;
- *rotational sliding*, on a deep, curved slip plane;
- *slumping* of material when very wet, through low particle cohesion; and
- *debris falling* due to failure of the supporting material.

Secondly, there will be both "internal" and "external" factors affecting the site. Internal factors will include:

- small fault lines causing differential erosion in parts of the site;
- seasonal springs within the site; and
- small slip planes additional to the main failure mechanism.

External factors will include:

- gullies which may discharge on to the site;
- landslides which may supply debris on to the site; and
- rivers that may undercut the toe.

Initial assessment of treatment needs

A further series of questions helps to delineate the problems.

- *Is the site very long, steep and in danger of a massive failing below the surface?*
  If the answer is "yes", retaining walls should be used to break the slope into smaller, more stable lengths.
- *Is the foot of the slope undermined, threatening the whole slope above?*
  If the answer is "yes", toe walls should be considered.
- *Is there a distinct overhang or are there large boulders supported by a soft, eroding band?*
  If the answer is "yes", prop walls should be considered.
- *Is the slope made up mostly of hard rock, so that the planting of nursery stock would be impossible?*
  If the answer is "yes", direct seeding may be an option.
- *Is the slope rough, covered in loose debris or does it have any locally very steep or overhanging sections, however small?*
  If the answer is "yes", then it must be trimmed.

Once these questions have been answered, it is possible to move on to a more detailed examination of the slope segments.

Slope segments

A slope segment can be defined as a length of slope with a uniform angle and homogeneous material that is likely to erode in a uniform manner. The most straightforward way to approach the choice of stabilisation technique is by splitting sites into segments of slopes. The assumption is that each segment can be treated using the same technique or combination of techniques. But first, there are two important considerations which must be addressed:

- Is the slope segment longer than 15 metres?
  If it is, there may be a danger of surface scour. Therefore some kind of physical scour check should be used, such as wire bolsters.
- Is the slope made up of poorly drained material, with a relatively high clay content?
  If it is, there is a danger of shallow slumping. Techniques used on this sort of material must be designed to drain rather than accumulate moisture.

Drainage is the most critical consideration in many locations. This is shown by experience throughout Nepal, and is particularly highlighted by Kappeler (1984) and Schaffner (1987).

Guidelines for applying bio-engineering techniques for slopes

In Table 10.6, I have attempted to define which bio-engineering technique is most suitable for each of a range of site conditions. There are many different factors which determine the optimum technique or combination of techniques, but only the most important ones have been included here for the sake of simplicity. The following text examines the five columns of Table 10.6 one by one.

Slope angle: This is the primary distinction. Slopes of less than 30° usually need only mild soil conservation treatment whereas those with a slope steeper than 45° usually demand more attention as they will have greater erosion problems.

Table 10.6: **Choice of bio-engineering technique (adapted from Howell *et al*, 1991 and Howell, 1999)**

Slope angle	Slope length	Material drainage	Site moisture	Technique(s)
> 45º	> 15 Metres	Good	Damp	**Diagonal grass lines**
			Dry	**Contour grass lines**
		Poor	Damp	1 **Downslope grass lines and vegetated stone pitched rills**, or 2 Chevron grass lines and vegetated stone pitched rills
			Dry	**Diagonal grass lines**
	< 15 metres	Good	Any	1 **Diagonal grass lines**, or 2 Jute netting and randomly planted grass
			Damp	1 **Downslope grass lines**, or 2 Diagonal grass lines
		Poor	Dry	1 **Jute netting and randomly planted grass**, or 2 Contour grass lines, or 3 Diagonal grass lines
30º - 45º	> 15 metres	Good	Any	1 **Horizontal bolster cylinders and shrub/tree planting**, or 2 Downslope grass lines and vegetated stone pitched rills, or 3 Site grass seeding, mulch and wide mesh jute netting
		Poor	Any	1 **Herringbone bolster cylinders & shrub/tree planting**, or 2 Another drainage system and shrub/tree planting
	< 15 Metres	Good	Any	1 **Brush layers of woody cuttings** or 2 Contour grass lines, or 3 Contour fascines, or 4 Palisades of woody cuttings, or 5 Site grass seeding, mulch and wide mesh jute netting
		Poor	Any	1 **Diagonal grass lines**, or 2 Diagonal brush layers, or 3 Herringbone fascines and shrub/tree planting, or 4 Herringbone bolster cylinders & shrub/tree planting, or 5 Another drainage system and shrub/tree planting
< 30º	Any	Good	Any	1 Site seeding of grass and shrub/tree planting, or 2 Shrub/tree planting
		Poor	Any	1 **Diagonal lines of grass and shrubs/trees or** 2 Shrub/tree planting
	< 15 metres	Any	Any	**Turfing and shrub/tree planting**
	Base of any slope			1 **Large bamboo planting**, or 2 Large tree planting
Special conditions				
Any *	Any *	Any *	Any *	**Site seeding of shrubs/small trees †**
> 30º	Any	**Any rocky material**		**Site seeding of shrubs/small trees**
Any loose sand		Good	Any	**Jute netting and randomly planted grass**
Any rato mato (red clay)		Poor	Any	**Diagonal lines of grass and shrubs/trees**
Gullies ≤ 45º	**Any gully**			1 **Large bamboo planting**, or 2 Live check dams, or 3 Vegetated stone pitching

Notes for Table 10.6:

* Possible overlap with parameters described in the rows above.

† May be required in combination with other techniques listed on the rows above.

Any rocky material is defined as material into which rooted plants cannot be planted, but seeds can be inserted in holes made with a steel bar.

Any loose sand is defined as any slope in a weak, unconsolidated sandy material. Such materials are normally river deposits of recent geological origin.

Any rato mato (Nepali for red soil) is defined as a red soil with a high clay content. It is normally of clay loam texture, and formed from prolonged weathering. It can be considered semi-lateritic.

Techniques in **bold type** are preferred.

Chevron pattern: **<<<<<** (like a sergeant's stripes).

Herringbone pattern: ←←←←← (like the bones of a fish).

Slope length: The partly arbitrary length of 15 metres is usually taken as representing a good dividing figure between 'big' and 'small' sites. Slope segments longer than 15 metres are usually open to greater risks in terms of both gullying and deep-seated failures.

Material drainage: This is related to the internal porosity of soils and the likelihood of their reaching saturation and losing cohesion, thereby starting to flow. Those materials which have a high content of clay relative to sand and silt in the fine fraction tend to have poor internal drainage. They tend to be prone to shallow slumping if too much moisture accumulates. In this case stabilisation will require some kind of drainage in addition to protection.

Site moisture: The level of moisture across the entire site must be considered. Although aspect is usually the dominant factor in determining the moisture levels at a site the environmental dryness of each site also needs to be assessed. These include:

- altitude; topographical location; rain shadow effect; and
- stoniness; soil moisture holding capacity; winds and ex-monsoon rains.

To distinguish between one and the other of these factors usually involves a subjective judgement which a bio-engineer will develop as they become more experienced.

Technique(s): Table 10.6 recommends one or more technique for each of the given site types which are known to have been successful on similar sites in the field. Due to the large variation in site conditions the recommendations should only be viewed as general guidelines and are by no means comprehensive. Variations from these general given prescriptions will often be needed, and this is for the engineer to determine on site.

Table 10.6 gives guidelines for choosing bio-engineering techniques in Nepal. An example of a site on which these guidelines were successfully was at the Manohari River in central Nepal (Plates 10.5 and 10.6.

Selection of Plant Species: Principles and Practice

Physical features are usually the factors which dominate the selection of species for bio-engineering. It is necessary to choose plants which can grow in the prevailing conditions which often

Plate 10.5: **The Manohari River (central Nepal) embankment in May 1994, during construction**

Plate 10.6: **The Manohari River (central Nepal) embankment in Sept. 1995, two growing seasons after being planted with kans (*Saccharum spontaneum*)**

involve dryness, stoniness and extremes of temperature. Soil fertility is not usually a problem if local plants are used, as they will be naturally adapted to poor soils. Most forest soils in Nepal are infertile due to the young, unstable terrain and the weathering and leaching properties of the monsoon. As a result, it is hardly ever necessary to add topsoil to slope surfaces.

Principles of species selection

The main principles of selecting plants for inclusion in a bio-engineering programme are that they must be:

- known to grow well on similar sites;
- locally available in plentiful supply; and
- serve the right purpose technically and in socio-economics terms.

In general, species introduced from outside Nepal (exotics) should be avoided because they may become weeds, as happened with the highly invasive ban mara, or they may be prone to insect attack, as with ipil ipil.

Species need to be found which:

- have a good root system;
- show an ability to grow well on harsh, stony sites;
- are common in the locality; and
- can be easily propagated.

A number of species have been identified which have been successfully established on bio-engineering programmes in Nepal (Table 10.7). However, the identification of suitable species is not complete and many local species have still to be tried out.

In some areas there is a risk of damage to plantings from domestic animals. If this can be controlled, multipurpose plant species may be planted which not aid slope stabilisation but also yield useful products as well as. The best way to control damage from domestic animals is to get the people themselves to manage the plants. If it is not possible to manage the plants carefully, then it is usually best to select plants with few or no economic uses such as kans grass and bhujetro.

Preferred species for bio-engineering

Table 10.7 gives a list of the preferred species for bio-engineering in the road sector. The Geo-Environmental Unit publication (1997c) gives comprehensive lists of species, running to hundreds of potential bio-engineering plants. Table 10.7 gives only the plants found to be the best for use in bio-engineering on difficult sites throughout Nepal.

The species to avoid in bio-engineering include those that:

- are annual, not perennial (*e.g.* maize);
- have a poor, weak root system (*e.g.* ban mara, tite pate); and
- have a shallow root system (*e.g.* dubo grass).

Bio-Engineering Maintenance

Even though bio-engineered slopes get stronger over time they still need regular maintenance (Geo-Environmental Unit 1997b). Maintenance interventions of vegetation on slopes are either:

- routine, which means that action must be taken continuously or on a frequent or seasonal basis; or

Table 10.7: **Preferred species for bio-engineering (adapted from Geo-Environmental Unit, 1997c)**

Local name	Botanical name	Altitude	Sites	Best propagation
Grasses				
Amliso	*Thysanolaena maxima*	Terai-2000m	Varied	Slip cuttings
Babiyo	*Eulaliopsis binata*	Terai-1500m	Hot and dry	Slip cuttings/seeds
Dhonde	*Neyraudia reynaudiana*	Terai-1500m	Hot and dry	Stem/slip cuttings/seeds
Kans	*Saccharum spontaneum*	Terai-2000m	Hot and dry to moist	Slip cuttings
Katara khar	*Themeda* species	Terai-2000m	Varied	Slip cuttings/seeds
Khar	*Cymbopogon microtheca*	500-2000m	Hot and dry; varied	Slip cuttings/seeds
Khus	*Vetiver zizanioides*	Terai-1500m	Varied	Slip cuttings
Narkat	*Arundo clonax*	Terai-1500m	Hot and dry; varied	Stem/slip cuttings
Padang bans	*Himalayacalamus hookerianus*	1500-2500 m	Moist	Large slip cuttings
Phurke	*Arunduella nepalensis*	700-2000 m	Varied; stony	Slip cuttings/seeds
Sito	*Neyraudia arundinacea*	Terai-1500m	Varied	Slip cuttings/seeds
Tite nigalo bans	*Drepanostachyum intermedium*	1000-2500 m	Varied	Large slip cuttings
Shrubs and small trees				
Areri	*Acacia pennata*	500-1500 m	Hot and dry; harsh	Seeds/polypots
Assuro	*Adhatoda vasica*	Terai-1000m	Varied	Hardwood cuttings
Bainsh	*Salix tetrasperma*	Terai-2700m	Moist	Hardwood cuttings
Bhujetro	*Butea minor*	500-1500 m	Hot and dry; harsh	Direct seeding
Dhanyero	*Woodfordia fruticosa*	Terai-1500m	Hot and dry; harsh	Seeds/polypots
Dhusun	*Colebrookea oppositifolia*	Terai-1000m	Hot and dry; harsh	Seeds/polypots
Kanda phul	*Lantana camara*	Terai-1750m	Hot and dry	Hardwood cuttings
Kettuke	*Agave americana*	Terai-2400m	Hot and dry	Root suckers
Keraukose	*Indigofera atrotpurpurea*	Terai-2000m	Hot and dry; harsh	Seeds/polypots
Namdi phul	*Colquhounia coccinea*	1000-2000 m	Varied	Hardwood cuttings
Saruwa/ bihaya	*Ipomoea fistulosa*	Terai-1500m	Varied; sunny sites; stands waterlogging	Hardwood cuttings
Simali	*Vitex negundo*	Terai-1750m	Hot and dry; varied	Hardwood cuttings
Tilka	*Wendlandia puberula*	Terai-1500m	Hot and dry; harsh	Seeds/polypots
Large clumping bamboos				
Choya/tama bans	*Dendrocalamus hamiltonii*	300-2000 m	Moist	Culm cuttings
Dhanu bans	*Bambusa balcooa*	Terai-1600 m	Varied	Culm cuttings
Kalo bans	*Dendrocalamus hookeri*	1200-2500 m	Varied	Culm cuttings
Mal bans	*Bambusa nutans*	Terai-1500 m	Dry/varied	Traditional method
Nibha/ghopi/ lyas bans	*Ampelocalamus patellaris*	1200-2000 m	Varied	Traditional method
Tharu bans	*Bambusa nutans*	Terai-1500 m	Varied	Traditional method
Large trees				
Bakaino	*Melia azedarach*	Terai-1800m	Hot and dry; harsh	Seeds/ polypots
Chilaune	*Schima wallichii*	900-2000 m	Varied; dry to moist	Seeds/ polypots
Dabdabe	*Garuga pinnata*	Terai-1300m	Varied and dry	Seed/ hardwood cuttings up to 2m
Gobre salla	*Pinus wallichiana*	1800-3000 m	Dry; varied	Seeds/ polypots
Kalo siris	*Albizia lebbeck*	Terai-1200m	Hot and dry; harsh	Seeds/ polypots
Khanyu (khosro)	*Ficus semicordata*	Terai-2000m	Hot and dry; varied	Seeds/ polypots
Khayer	*Acacia catechu*	Terai-1000m	Hot and dry; harsh	Seeds/ polypots
Lankuri	*Fraxinus floribunda*	1200-2700 m	Varied; best in moist sites	Seeds/ polypots
Painyu	*Prunus cerasoides*	500-2400 m	Varied and dry; stony	Seeds/ polypots
Phaledo	*Erythrina* species	900-3000 m	Varied	Seeds/ hardwood cuttings up to 2m
Rani (khote) salla	*Pinus roxburghii*	500-1950 m	Hot and dry; varied	Seeds/ polypots
Rato siris	*Albizia julibrissin*	800-3000 m	Varied and moist	Seeds/ polypots
Seto siris	*Albizia procera*	Terai-1350m	Moist	Seeds/ polypots
Sisau	*Dalbergia sissoo*	Terai-1400m	Varied	Seeds/ polypots / stump cuttings
Utis	*Alnus nepalensis*	900-2700 m	Varied and moist	Seeds/ polypots

- recurrent, where action is required at regular, but less frequent, intervals, such as once per year.

Table 10.8 lists the main bio-engineering maintenance activities. Plate 10.7 shows an example of a maintained mature bio-engineering site.

Table 10.8: Bio-engineering maintenance activities

Category	Task description
Routine (continuous, seasonal or regular – such as once per month)	
Protection of sites	Control of access to sites by people and animals to avoid unacceptable damage to the vegetation.
Weeding	Remove unwanted vegetation which is competing with the growth of the desired plants.
Mulching	Place mulch around seedlings to keep the soil cool and moist, thereby enhancing growth. Mulch is made by cutting the stems and leaves of unwanted plants.
Grass cutting	Cut grasses once a year to encourage vigorous growth and the development of new shoots.
Watering (exceptional activity)	Spray water around plants at dry times of the year to improve the growth on harsh, newly planted sites.
Recurrent (such as once per year)	
Thinning of shrubs and trees	Thinning means removing selected shrubs or trees to decrease the density of the plants. Pruning is the removal of lower branches. Both open out the canopy and allow ground cover plants to grow better.
Repair of vegetation structures	The repair of any form of bio-engineering treatment: mainly palisades, fascines and brush layering, and re-turfing.
Vegetation enrichment	Planting more grasses, shrubs or trees within a site area or in gaps within the existing vegetation
Removal of shrubs and trees	The removal of any unwanted large shrub or tree from a site.

Conclusion

Bio-engineering continues to be developed in many parts of the Hindu Kush-Himalayan region. It needs to be adapted to the local conditions and the specific environment of each landslide. Knowledge can be applied from different areas, but must be done so with caution. Local resources and local skills form the basis of the successful use of bio-engineering techniques.

A considerable amount of extended knowledge is required. More needs to be known about the best species for bio-engineering in every ecological zone (of which there are many in these mountains). But perhaps the biggest change that is required is in attitude. In poor rural areas, it is necessary for engineers and others to improve their understanding of the function of vegetation in engineering, so that they can rely on it more. Only then can they avoid using expensive civil engineering structures in inappropriate locations, and begin to use a truly sustainable technology more wisely.

Plate 10.7: **A mature bio-engineering site: utis (*Alnus nepalensis*) forest on the Lamosangu-Jiri road (central Nepal)**

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