Chapter 4: Bioengineering Measures

Bioengineering is the application of engineering design and technology to living systems. In terms of flash flood mitigation, it refers to the combination of biological, mechanical, and ecological concepts to reduce or control erosion, protect soil, and stabilize slopes using vegetation or a combination of vegetation and construction materials (Allen and Leech 1997; Bentrup and Hoag 1998) (Figure 6).

Figure 6: Bioengineering for soil conservation

Source: DWIDP

Bioengineering techniques used in combination with civil and social engineering measures can reduce the overall cost of landslide mitigation considerably (Singh 2010). Bioengineering offers an environmentally friendly and highly cost and time effective solution to slope instability problems in mountainous and hilly areas and is a technique of choice to control soil erosion, slope failure, landslides, and debris flows, and thus ultimately to help minimize the occurrence of floods and flash floods.

One of the major differences between physical construction techniques and bioengineering is that physical structures provide immediate protection, whereas vegetation needs time to reach maximum strength. Thus the combination of physical and vegetative measures offers a combination of immediate and long-term protection, as well as mitigation of the ecologically damaging effects of some physical constructions.

Functions of Vegetation

Hydrological functions

Plants play a significant role in the hydrological cycle. Particularly riparian vegetation influences hydrological processes through effects on runoff; control of uptake, storage, and return of water to the atmosphere; and water quality (Tabacchi et al. 2000). The hydrological functions of vegetation can be summarized as follows:

- **Interception:** The vegetation canopy intercepts raindrops and reduces their size and mechanical strength, thus protecting the soil from erosion caused by rain splash.
- **Restraint:** The dense network of coarse and fine roots physically binds and restrains soil particles in the ground, while the above ground portions filter sediment out of runoff.
- **Absorption:** Roots absorb surface water and underground water thus reducing the saturation level of soil and the concomitant risk of slope failure.
- **Infiltration:** Plants and their residues help to maintain soil porosity and permeability, thereby increasing retention and delaying the onset of runoff.
- **Evapotranspiration:** Vegetation transpires water absorbed through the roots and allows it to evaporate into the air at the plant surface.
- **Surface runoff reduction:** Stems and roots can reduce the velocity of surface runoff by increasing surface roughness.

- **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.

Engineering functions

- **Catching:** 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.
- **Armouring:** 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.
- **Reinforcing:** 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.
- **Supporting:** Lateral earth pressure causes a lateral and outward movement of slope materials. Large and mature plants can provide support and prevent movement.
- **Anchoring:** 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 function as anchors.
- **Draining:** 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.

Choice of appropriate species

In general, it is best to use local species of vegetation in bioengineering as they are already adapted to the growing conditions, are more likely to be resistant to local diseases, are more readily available, and are likely to be a lower cost option.

It can also be useful to choose species that can be used for other purposes as they mature, for example, providing fruit or with branches and leaves that can be used for fuelwood, fodder, or other domestic purposes. This increases the benefit to local people and their acceptance of the measures.

Major species that can be used for bioengineering purposes in the Hindu Kush Himalayan region include broom grass (*Thysanolaena maxima*), Napier grass (*Pennisetum purpureum*), vetiver grass (*Vetiver zinzaniodes*), durva grass (*Cynodon dactylon*), turf grass (e.g., *Festuca arundinacea*, *Poa pratensis*), kans grass (*Saccharum spontaneum*), different types of bamboo, giant cane (*Arundo donax*), Malabar nut (*Adhatoda vasica*), male fern (*Dryopteris filix-mas*), artemesia (*Artemisia* spp.), weeping willow (*Salix babylonica*), mulberry (*Morus alba*), five-leaved chaste tree (*Vitex negundo*), ghogar tree (*Garuga pinnata*), coral tree (*Erythrina variegata*), tiger's milk spruce (*Sapium insigne*), and eastern cottonwood (*Populus deltoides*). Further suitable grass, shrub, tree, and bamboo species can be found in Singh et al. (1983), APROSC (1991), HMGN (1999), DSCWM (2004), and DSCWM (2005).

Bioengineering in Flash Flood Risk Management

Bioengineering can be used in various ways to reduce flash flood risk. It can be used to stabilize slopes and thus reduce the risk of landslides and debris flows occurring. It can be used to increase infiltration, to form structures to temporarily capture and store runoff, and to lower the velocity of runoff, all of which hinder the formation of flash floods after cloudbursts. And it can be used to change the flow pattern of rivers downstream in order to reduce the impact of floods that do occur. Bioengineering is often used in combination with structural techniques, either to reinforce structures or as a complementary approach to increase the overall impact of the measures.

Bioengineering techniques to control slope failure phenomena

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

- mechanical reinforcement,
- controlling erosion,
- increasing the infiltration ratio,

- reducing runoff, and
- soil moisture adjustment.

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).

Erosion control. 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.

Soil infiltration. 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.

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.

Soil moisture adjustment. Soil moisture is a key factor in slope stability. Vegetation can directly influence soil moisture through interception and evapotranspiration. 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 evapotranspiration, 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.

Choice of techniques. Different bioengineering techniques are used to control erosion and slope failure in different parts of the world. The techniques suitable for a particular area should be selected on the basis of availability of resources, site condition, and required function. Table 3 shows the appropriate bioengineering techniques for controlling different types of landslide and debris flow hazards. Details of the techniques are given in the latter part of this chapter.

Bioengineering to reduce the volume and velocity of runoff

High runoff can directly cause development of a flash flood from a small catchment following a heavy localized rainfall event. The aim of bioengineering in this case is to slow and trap the runoff in order to reduce the rate of outflow from the catchment. Appropriate techniques include palisades, grassed water ways, brush layering, bamboo fencing, wattle fencing, and similar measures.

River training

The impact of a flash flood can be reduced by measures designed to direct and reduce the speed of the flood wave in the river downstream. These measures are a part of so-called 'river training' techniques, which are undertaken to improve a river and its banks in order to change the waterway pattern and reduce the velocity of flow, hinder erosion, reduce transportation of sediment, and guide flood waves into a less destructive path. The most common river training measures involve construction of physical structures such as banks and spurs (described in Chapter 6). However, used alone, these techniques may have a marked negative effect on the environment and landscape, as well as being expensive. Bioengineering techniques used alone or in combination with physical measures offer a low-cost approach that is easily implemented by local communities and provides an environmentally friendly environment for local flora and fauna.

Table 3: 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 Stone pitching and planting of trees, shrubs, and grass slip Bamboo fencing with live poles, planting and seeding grass Terracing and planting with bamboo, trees, shrubs, grass Live peg fence, wild shrubs, live check dams 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)
	Slumping	
	Planar sliding	
	Shear failure	
	Cut and fill area at deep and shallow-rooted landslide (<3 m depth)	
	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 grass
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

*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.

Source: DWIDP/JICA 2004a

The use of bioengineering techniques alone is mainly confined to river bank stabilization. By their nature, river banks provide a good environment for growth of vegetation. Left alone, banks usually have dense vegetation as the river provides nutrients in the form of silt and water to support growth. If vegetation is sufficient, both on the bank and in the river bed, it can stabilize the bank, lessen erosion, reduce the speed of flowing water, and reduce scouring by a flood wave. Where vegetation has been reduced or removed, it can be replaced by carefully selected planting of appropriate species to achieve the desired effect. Structures formed from a combination of dead and living plant material can also be used to guide the river course and prevent flood surges entering into settlements and farmland. The plants can provide additional benefits for the local population like fodder, fruit, and firewood, but this is secondary to the protective function.

As in slope protection, bioengineering can involve building a structure such as a fence to provide immediate protection, but using living branches that will take root and become an increasingly strong barrier. It can also involve a combination of dead and live vegetation, with a framework made of bamboo or timber, intertwined with living plants to grow and strengthen the structure. A good example is that of a permeable protection wall constructed out of bamboo porcupines (see river training chapter) intertwined with living plants to form a 'green wall'. Placed in the water or in regularly flooded areas of the bank, these structures trap silt in which they slowly become embedded, creating a strong stable self-sustaining bank with bamboo reinforcement held together by roots and vegetation.

In general, bioengineering is used in combination with physical techniques in river training rather than on its own. It is highly recommended as a means of reducing the impact of physical measures on the local ecology and landscape, and also for providing long-term strengthening of structures such as embankments.

Common Bioengineering Techniques in the Hindu Kush Himalayas

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 Hindu Kush Himalayan region.

Bamboo fencing

Bamboo fencing can be used to prevent soil creep or surface erosion on a slope (Figures 7 and 8), to hinder gully extension, particularly in seasonal water channels, and to control flood waves along a river bank. Live bamboo pegs can be used for the main posts so that the whole structure becomes rooted. The growing bamboo can be further interleaved between the posts (as in a wattle fence) to increase the strength of the fence. Shrubs and grasses are planted on the upper side of the fence to hold small soil particles. The main purpose is to trap loose sediments on the slope, to improve the conditions for growing vegetation, and to reduce the surface runoff rate.

Figure 7: Sketch of bamboo fencing

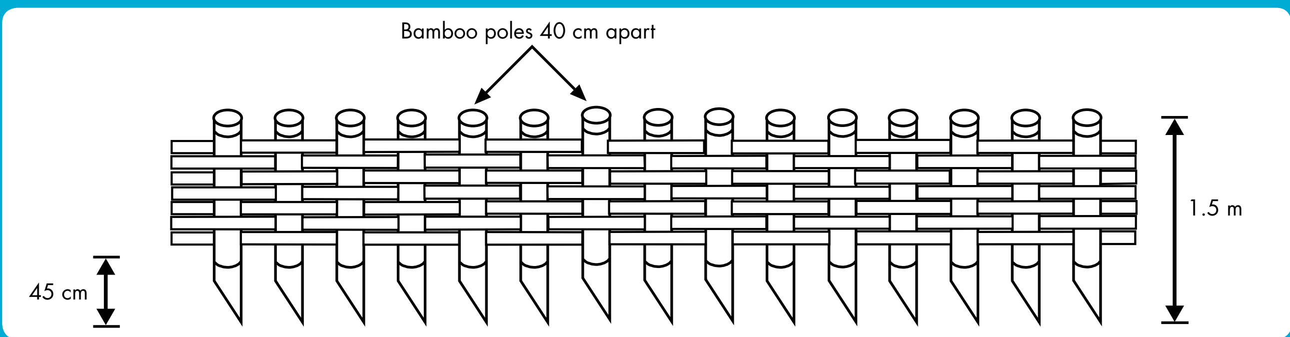


Figure 8: Bamboo fencing on a slope – the posts (pegs) are live bamboo that will sprout to provide foliage (left); detail showing live bamboo peg with sprouting leaves (right)

Source: DWIDP

Materials

- Live bamboo pegs or strong bamboo poles about 1.5 m long and 10–15 cm in diameter
- Digging tools
- Seeds or plants of grasses or shrubs

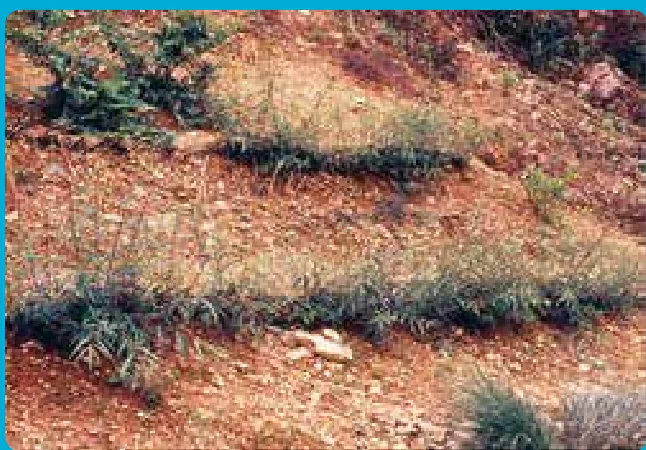
Installation

1. Starting from the base of the slope, mark the line for the fence with string.
2. Dig a long pit about 45–50 cm deep along the contour of the slope for each line of fencing.
3. Insert a row of bamboo poles or pegs 40 cm apart into the pit and back fill the pit to stabilize the poles.
4. Weave split bamboo or branches in and out between the poles to form a semi-solid face.
5. Plant small grasses and/or shrubs along the upper side of the fence.
6. Regular maintenance is important to ensure longevity of the fence. Any broken sections should be replaced immediately.

Brush layering

In brush layering, live cut branches are interspersed between layers of soil to stabilize a slope against shallow sliding or erosion. Fresh green cuttings are layered in lines across the slope (Figures 9 and 10). As the roots grow, they anchor and reinforce the upper soil layers (up to 2 m depth), and the foliage helps to catch debris (Howell 1999, cited in Lammeranner et al. 2005). Some toe protection structures such as a wattle fencing, fiberschine, or rock riprap may be required to support brush layering.

Figure 9: Brush layering

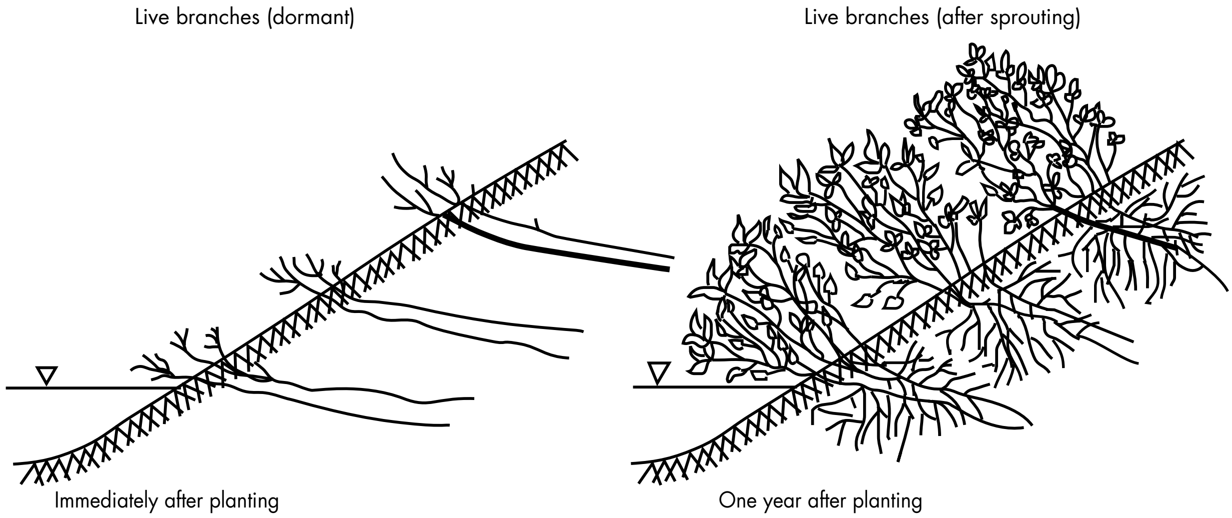


Source: Keshar Man Sthapit

Materials

- Branches of different age and diameter cut from rooting woody plants of different species (e.g., willow, alder, *populus* spp., *garuga* spp., Malabar nut [*Justicia adhatoda*], mulberry, five-leaved chaste tree [*Vitex negundo*]). Branches should be at least 1 m long and 4 cm in diameter

Figure 10: Brush layering



- Mixed plants of different easily growing species, both rooted and freshly cut
- Shovels or other digging tools
- Measuring tape and string line to calculate and mark the surface

Installation

1. Mark lines across the slope to be planted at intervals of 0.5–1.0 m upwards from the base. The slope should have an inclination of at least of 10–20%. Dig a small channel along the line by hand or machine.
2. Cut fresh branches with a right angle at the top and 45° angle at the bottom. If possible, cut the branches on the same day that they are to be planted. Ensure branches are at least 1 m long with a mixture of different species. This will allow the root system to penetrate deeper into the soil, giving greater chances of survival and producing mixed vegetation.
3. Place branches in the dug terrace, with only ¼–⅕ of their length protruding (Figure 10).
4. Place rooted and unrooted plants of species that grow easily 0.5–1.0 m apart among the layers of branches.
5. Regular supervision and care is needed until the branches are fully rooted.
6. The pre-monsoon season is good for installing brush layering. If the site is moist, installation can be done in any season.

Brush mattress

A brush mattress is a layer of interlaced live branches placed on a bank face or slope, often with a live fascine and/or rock at the base (Figures 11 and 12). The aim is to provide a living protective covering to an eroding bank to hinder erosion, to reduce the river velocity along the bank, and to accumulate sediment. The mattress is generally constructed from live stakes, fascines, and branches from species that root easily, but can be made from any brushy and woody branches to provide immediate and effective protection. A layer of biodegradable material such as loosely woven jute can be placed under the mat on steep slopes to increase stability if the soil is very loose. The mattress that is formed protects the surface of the bank until the branches can root and native vegetation becomes established.

Materials

- Live branches 2–3 m long and approximately 2.5 cm in diameter
- Fascine bundles
- Live and/or dead wooden stakes
- Digging tools (shovel)

Figure 11: Cross-section of brush mattress

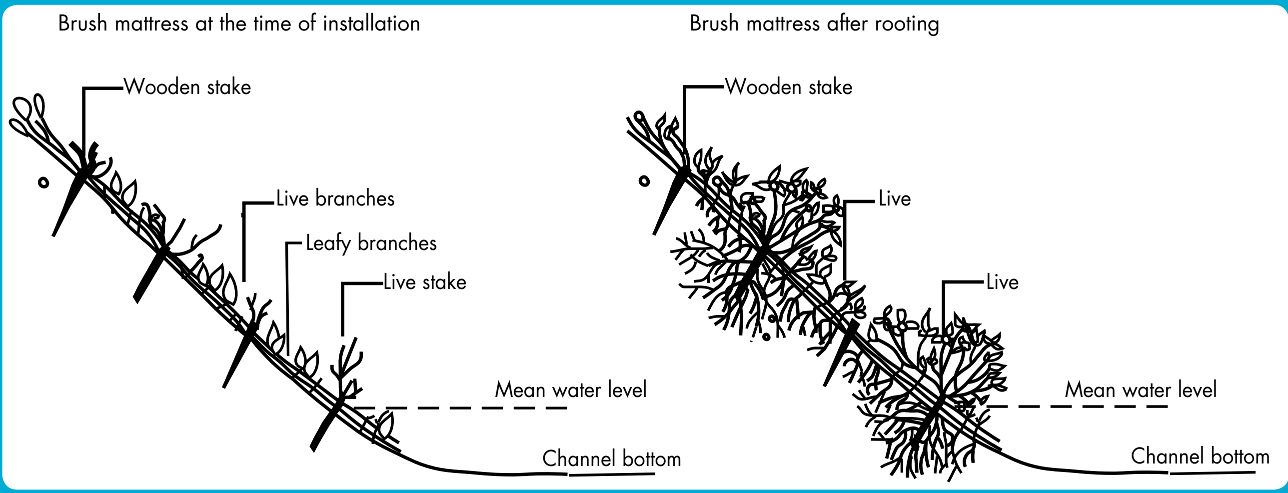


Figure 12: Installing brush mattress

Source: © Urban Creeks Council

Installation

1. Prepare the site by clearing away large debris and other materials.
2. If desired, cover the slope with a layer of biodegradable material, e.g., jute netting, to provide extra stability.
3. Dig a horizontal trench 20–30 cm deep at the toe of the bank or slope.
4. Lie the cuttings flat on the graded slope in an overlapping crisscross pattern with the root ends pushed into the soil in the trench to below the water level and the growing tips placed at a slight angle in the direction of the stream flow (if on a stream bank) or parallel to the slope.
5. Branches should be placed at a density of approximately 4 branches every 15 cm.
6. Pound wooden stakes between the branches into the soil to half their length and about 1 m apart.
7. Wrap wire around the stakes and over the branches as tightly as possible.
8. Pound the wooden stakes further in to tighten the wire and press the branches down onto the slope.
9. Push live stakes into the ground between the wooden stakes.
10. Place bundles of fascines along the trench at the base of the slope over the bottom of the branches and cover with soil, leaving the tops slightly exposed.
11. Fill any voids around and in between the branches with loose soil (from the trench) to promote rooting.
12. Periodic maintenance is required to ensure the mattress is securely tied to the slope.

Fiberschine

(adapted from Bentrup and Hoag 1998)

Fiberschine is a roll of material made from coconut fibre used to form a toe protection structure on a slope and to trap any sediment derived from erosion. The most common use is to stabilize the base of a stream bank or shoreline, but it can also be used in slope stabilization to support other measures such as brush layering. Live cuttings from herbaceous plants are planted together with the fiberschine; by the time the fiberschine decomposes, the vegetation will have stabilized the stream bank or slope. Fiberschine can usually be installed throughout the year, but the high water season should be avoided along streams. The following describes installation along a stream bank. The method can be adapted for use on a slope.

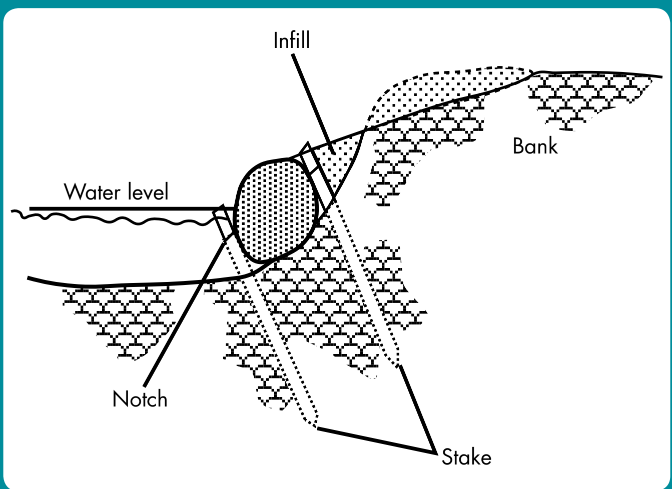
Materials

- Fiberschine roll
- Wedge-shaped wooden stakes 60–90 cm long
- Twine or wire
- Herbaceous wetland plants or willow twigs

Installation

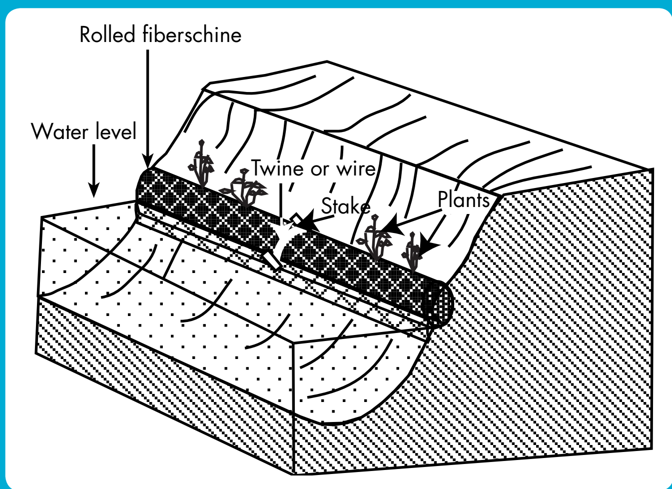
1. Determine the length of the treatment area and obtain the necessary amount of fiberschine.
2. Place a roll of fiberschine along the toe of the stream bank at the level of the low flow line with approximately half the roll below the water line and half above. Place additional rolls of fiberschine along the bank for the extent of the treatment area. Tie the ends of adjacent fiberschine rolls together with strong twine.
3. Secure the fiberschine on both sides with wedge-shaped wooden stakes 60–90 cm) long at 1.5 m intervals. Cut a 7.5–10 cm deep notch in each stake about 12.5 cm from the top. Secure each pair of stakes together by binding around the notches. Drive the stakes in so that the twine is secured against the top of the fiberschine (Figures 13 and 14).
4. Key the ends of the fiberschine into the bank to prevent the flow from entering behind it and protect the ends with something hard such as rock to prevent scouring.
5. Backfill behind the fiberschine by knocking down the top of the stream bank onto the fiberschine.
6. Plant herbaceous wetland plants or willows into and behind the fiberschine at approximately 15–30 cm intervals.

Figure 13: Securing the fiberschine



Source: Modified from Bentrup and Hoag et al. 1998

Figure 14: Fiberschine used to reinforce a river bank



Source: Modified from Bentrup and Hoag et al. 1998

Jute netting

Jute netting is a useful way of stabilizing steep slopes of 35–80° where it is difficult to establish vegetation (Figure 15). Locally available woven jute net is used as a form of armour on the slope and low growing grass is planted through the holes. The technique is often used in South Asia to reduce landslides along roads. The aim is to protect the bare slope from rain splash erosion, to improve the condition of the site, and to enable vegetation to become established by retaining soil moisture and increasing infiltration.

Materials

- Woven jute net
- Digging tools
- Sledgehammer
- Live wood pegs
- Grass seed or small-rooted tufts of grass

Installation

1. Trim the slope so that it is even and clear away any hanging masses or depressions.
2. Spread fertile soil on the bare slope.
3. Mulch with straw or other soft vegetation.
4. Start laying netting along a line above the slope to be covered, secure by hammering wooden pegs through the net at 0.3 m intervals.
5. Unroll the net down the slope and fix by hammering live wood pegs through it at intervals of 0.5–1.0 m.
6. Continue until the whole slope is covered by netting.
7. Sow grass seed or plant small grass clumps through the netting diagonally at a spacing of 10cm by 10cm over the entire area.
8. Regular supervision and care is needed until the grass is fully grown.

Figure 15: Jute netting on a cut slope

Source: DWIDP

Figure 16: Newly constructed live crib wall made of bamboo (left) and live crib wall on a slope (right)

Source: Madhav Dhakal

Live crib wall

A crib wall is a box structure made of interlocking struts (either logs or precast structures made of concrete, recycled polymers, or other material) and back-filled with boulders, soil, or similar. They are mainly used to stabilize steep banks and protect them against undercutting, for example a stream bank or the side of a cutting made for a road, and are also a useful method for stabilizing the toe of a slope. However, they are only effective where the volume of soil to be stabilized is relatively small.

In a live crib wall, live branches and well-rooted plants are placed between interlocking logs where they can grow and develop a root network that further strengthens the wall (Figure 16). If needed, the anchor and cross logs can be held together with nails or bolts. Vegetated crib walls provide immediate protection, and their effectiveness increases over time as the vegetation grows. Once the plants become established, the vegetation gradually takes over the structural functions of the wooden supports (Gray and Sotir 1996 cited in Lammeranner et al. 2005). Crib walls should be installed at an angle of 10–15° towards the slope to increase stability. Green willow branches can be used to ensure a quick outcome.

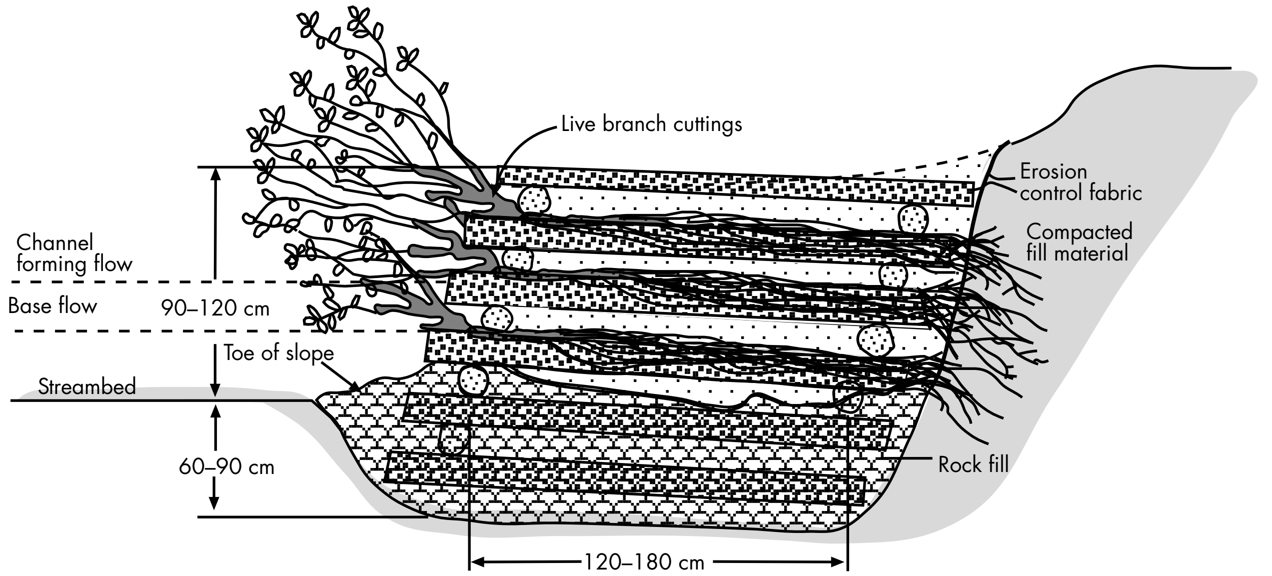
Materials

- Live branches 1–6 cm in diameter and long enough to reach from the front to the back of the structure with an overhang at both ends.
- Logs, timber, or bamboo 1–2 m long
- Steel reinforcing bars
- Excavator or digging tools (shovels), rakes, sledgehammers, knife, measuring tape, level instruments
- Rock and soil

Installation

1. Excavate an area 1–2 m wide along the toe of the bank (stream bank or toe of a landslide) to a level around 1 m below the surface and fill with rock (Figure 17).
2. Place a series of large logs on the rock end to end along two lines marking the front and back of the wall.
3. Place smaller logs perpendicular to and towards the ends of the large logs from front to back of the wall to form the bottom layer of a box-like structure. Allow an overhang of about 15 cm in each direction. The logs can be fixed together with metal bars and nails.
4. Place a layer of live willow (or other) cuttings from front to back of the wall between the logs, and protruding over the front logs and extending into the slope behind the back logs.
5. Cover the branches with a layer of rock and soil and press down to fill the box.
   (Steps 4 and 5 can also be carried out in reverse order.)

Figure 17: Section view of live crib wall installed along a river bank



Source: Adapted from ODNR n.d.a

6. Continue for as many layers as needed to reach the desired height, alternating layers of soil and cuttings and logs and ending with soil. Each successive course of logs parallel to the bank should be set back by 15–20 cm from the log beneath.
7. To ensure success, the upstream and downstream sections should be well-secured to the bank to prevent undercutting.

Live fascines

A fascine is a bundle of sticks or brushwood used in construction, generally to strengthen an earthen structure, fill ditches, or make a path across uneven or wet terrain. Live fascines are bundles of live branches intended to grow and produce roots. They can be placed in shallow trenches on a stream bank to reduce erosion across the bank and increase soil stability (Figure 18). The rooted branches protect the toe of the stream bank from erosion and improve infiltration. Properly placed, the bundles can also trap debris and sediment. Live fascines can also be used to reinforce slopes and increase drainage and infiltration. They are installed perpendicular to the slope in dug trenches or in existing gullies and rills. The optimum spacing depends on the steepness of the slope, usually 4 m intervals for slopes of less than 30° and 2 m intervals for slopes of 30–45°. They are most effective on soft cut slopes or slopes with consolidated debris. Draining effects can be seen as soon as the fascines are established (Schiechtl and Stern 1992, cited in Lammeranner et al. 2005).

Figure 18: Installing live fascine

Source: Madhav Dhakal

Materials

- Live branches of rooting plants of different species 3–5 cm in diameter and 50–100 cm or more long
- Live wooden stakes ready to sprout 3–6 cm in diameter and 50–100 cm long
- Dead wooden stakes 3–6 cm in diameter and 50–75 cm long
- Digging tools
- Jute or coir string or wire to bind the fascines

Installation

1. Prepare the site by clearing away loose material and protrusions and firmly infill any depressions (Figure 19).
2. Mark the lines along which fascines are to be installed. The lines should follow the contours, or be at a desired angle or along rills and at intervals of 2–4 m up the slope (2 m for slopes of 30°–45°; 4 m for slopes of less than 30°).
3. Excavate trenches approximately 10 cm deep and 20–40 cm wide along the marked lines starting from the bottom of the slope and working upwards.
4. Bind 4–8 live branches into bundles (fascines) using string or wire.
5. Place the fascines lengthwise in the trenches.
6. Drive live or dead stakes directly through the fascines every metre or so flush with the top of the fascines, and where the bundles connect.
7. Drive live stakes into the soil immediately below the fascines, protruding about 7 cm above the fascine.
8. Backfill the trench with moist soil to the side of the fascine, but allow the top of the fascine to show.
9. Riprap (see next chapter) can be used to stabilize the toe of the slope and prevent scouring.

Palisades

A palisade is a fence or wall made from wooden stakes or tree trunks. Palisades were used historically as a defensive structure. In slope protection, palisades are barriers made from live wood cuttings or bamboo installed across a slope following the contour in order to trap debris moving down the slope, to armour and reinforce the slope, and to increase the infiltration rate. Palisades are used to prevent the extension of deep, narrow gullies and the erosion of V-shaped rills (Figure 20) by forming a strong barrier which stabilizes the gully floor and traps material moving downwards (Lammeranner et al. 2005). They are also effective on steep landslide or debris slopes. Palisades can be used on a wide range of sites with slopes of up to about 60°.

Materials

- Stakes made from cuttings of rooting plants of different species 3–5 cm in diameter and 30–50 cm long
- Cross beam
- Gabion wire
- Digging tools such as crowbars and shovels

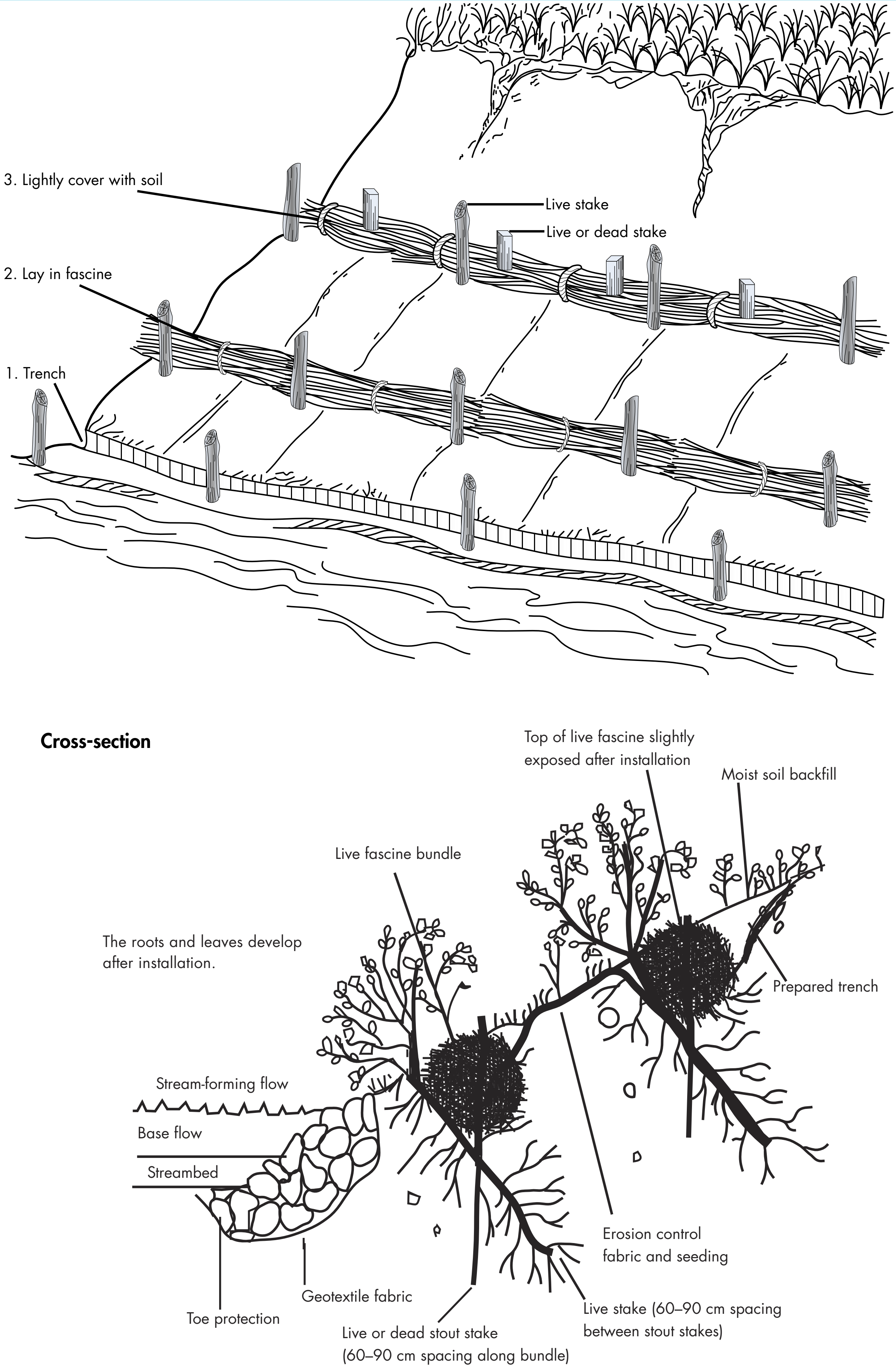
Installation

1. Installation should start from the top of the slope and work down.
2. Clean or trim the site, remove unnecessary irregularities of slope and loose material.
3. Mark the places to be planted. Palisades should be spaced at intervals of about 2 m down a slope of less than 30° and 1 m down a slope of 30–60°.
4. Make holes with the help of a pointed bar or crowbar for planting the cuttings.
5. Trim the top of the cuttings at a right angle to the stem and the bottom at an angle of 45°.
6. Place at least two-thirds of the length of the cutting into the hole and pack the soil around it.
7. Tie the stakes with pieces of gabion wire to a cross beam which is anchored in the sides of the gully and protected by pegs at either end.
8. On steep gullies and rills, support the palisade by placing a layer of stone and soil in front of and below the structure (Figure 20).
9. Regular inspection is necessary throughout the year. Broken stakes should be repaired and strengthened to encourage vegetation to develop.
10. Thinning might be required after a few years.

Wattle fence

A wattle fence is made by weaving flexible branches or vines between posts, rather like a large basket. A live wattle fence is constructed out of live branches which will root and continue to grow and strengthen the fence. The main purpose of wattle fences is to catch debris moving down a slope and to reinforce and modify the slope. Different

Figure 19: Live fascine installation on a river bank



Source: Adapted from ODNR n.d.b

Figure 20: Palisades

Source: Madhav Dhakal

kinds of grass (e.g., broom grass and napier grass) and tree species can also be planted along the fence. Wattle fences are useful in small shallow short slides as well as for river bank protection if combined with other measures such as brush layering, live pegs, and rock riprap (Figure 21).

Materials

- Sharpened stakes from plants 1 m long and 4–6 cm in diameter
- Shorter stakes 0.5 m long and 3–4 cm in diameter
- Long and flexible woody cuttings from plants which can root easily
- Jute or coir string or wire to bind
- Digging tools

Installation

1. Prepare the site by clearing all loose material and protrusions.
2. Mark lines along contours on the slope where the fences are to be installed. Fences should be spaced at intervals of about 4–5 m down the slope, depending on the site and slope angle.
3. Dig holes at 1 m intervals along the lines for the stakes.
4. Insert 1 m long stakes in the holes and place two 0.5 m long stakes at equal distances between the long stakes. Both long and short stakes should protrude about 20–30 cm.
5. Dig out a trench at least 15 cm deep along the contour between the stakes.
6. Place the cuttings with their lower ends in the trench, and bend them down along the line of the fence. Firm the soil back into the trench. Weave the cuttings in and out between the stakes one above another to fill in the fence area.
7. If desired, add soil above the wattle fence for planting tree and grass seedlings and cuttings.
8. Regular supervision and maintenance is necessary, including weaving the branches in and out as they grow.

Figure 21: Wattle fence used for river bank protection

Source: Sundar Kumar Rai