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South – South Experience Exchange

Trust Fund TF011068

Transfer of Pakistan's Experience in Soil Bioengineering for Slope Stabilization to Timor-Leste

A vegetated concrete block and a vegetated soft gabion wall constructed on rural road in Pakistan

Field Guide on Soil Bioengineering for Slope Stabilization in Timor-Leste

World Bank Office, Dili, Timor-Leste.
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1. Introduction

Soil Bioengineering is a useful and effective technology for slope stabilization and soil conservation. Soil bioengineering is defined as *"the use of living plant materials to construct structures that perform an engineering function".* The technology is now widely used for slope stabilization and soil conservation in many countries that experience slope instability. The Pakistan Forest Institute tested the technology at several places in Pakistan between 1987 and 1989 on a small scale. The technology was scaled up for slope stabilization and integrated watershed management in affected areas (from the 2005 earthquake) under the UNDP supported "Environmental Recovery Programme for the Earthquake affected Areas".

The technology is simple, low cost, and effective, requires little to no maintenance, is environmentally friendly, and sustainable. The technology has been used in Pakistan for slope stabilization on Kaghan Road (Balakot to Mahandri), Silk Road (Battagram to Thakot) and Jhelum Valley Road (Muzaffarabad to Chakothi) under World Bank financed projects and Neelum Valley Road under an Asian Development Bank (ADB) financed project. Now the technology is being used extensively for slope stabilization throughout mountainous areas of Pakistan by both Government and Non-Government Organizations.

Under the South – South Experience Exchange Trust Fund (TF011068) a technical assistance (TA) project entitled, "Transfer of Pakistan's Experience of Soil Bioengineering for Slope Stabilization to Timor-Leste" was implemented during January and February, 2012. The TA included an awareness workshop on the important role soil bioengineering can play in slope stabilization, training on soil bioengineering for slope stabilization for the officers of the Directorate of Roads, Bridges and Flood Control and the Directorate of Forestry (both held in Timor-Leste), and preparation of a Field Guide on Soil Bioengineering for Slope stabilization for Timor-Leste for future guidance of the field officers and other relevant practitioners and stakeholders.

Necessary information about local tree and grass species suitable for soil bioengineering was collected during the visit to Timor-Leste, including establishing the most suitable season for conducting soil bio-engineering activities. The "Field Guide on Soil Bioengineering for Slope Stabilization" will be useful for the technical staff of the Directorate of Roads, Bridges and Flood Control and the Directorate of Forestry, as well as international and local NGOs for the application of soil bioengineering for slope stabilization on roads and for other soil conservation activities in Timor-Leste.

As bamboo, coconut and other palms are abundant in Timor-Leste; soil bioengineering applications are designed in such a way that bamboos and palm leaves can be used in soil bioengineering structures to make them more economical. The Field Manual includes a description of different soil bioengineering structures suitable for slope stabilization, gully and river bank erosion control in Timor-Leste.

The material in this field guide is derived from the publication "Field Manual on Slope Stabilization" published by UNDP, Pakistan, and may be accessed on the UNDP Pakistan website; http://undp.org.pk under 'training materials'.

2. Soil Bio-Engineering Structures for Slope Stabilization

Soil bioengineering structures used for slope stabilization include retaining walls, check dams and mechanical barriers for fixing loose soil on landslides and fill slopes. In addition to slope stabilization, soil bioengineering structures are also used to control gully and river bank erosion. Gullies commonly occur on landslides and fill slopes if treatment is not given in time and landslides are also triggered by undercutting from river and channel erosion.

2.1 Retaining Walls

Soil bioengineering retaining walls are effective in stabilizing slips and small landslides. Different types of soil bioengineering retaining walls have been used for stabilizing landslides in different parts of the world. Among these, the most common soil bioengineering retaining walls are vegetated soft gabions, geo-textiles and timber crib walls. In Pakistan the vegetated soft gabion walls and live brushwood retaining walls were constructed on a large scale in earthquake affected areas and have proved effective and economical for small landslides. The vegetated soft gabion and live brushwood retaining walls are also combined with gabion, stone masonry and concrete walls to reduced cost of engineering structures for slope stabilization. The selection of the type of bioengineering retaining wall for a particular site depends on the availability of the material required at the particular site and for the favored construction method.

2.1.1 Vegetated Soft Gabion Retaining Wall

This retaining structure utilizes empty used bags of synthetic fiber or jute, generally available in the market at cheap rates. The ruble cleared from the toe of the landslide is used for filling the bags for the construction of vegetated soft gabion walls. The filled bags are used as building blocks like bricks to construct the retaining wall (Figure 1). The foundation is excavated at the toe of the landslide by removing the debris. The first layer of bags is placed length wise across the length of the retaining wall. A 15cm thick soil layer is placed on the bags and branches of the living woody plants and rooted seedlings are placed above the soil layer in such a way that their basal (butt) ends reaches the mother soil of the slope. The soil is placed on the brush-hedge layers and compacted well. Above the brush layer another layer of bags is placed width wise by giving a step of 20-35cm. The soil from the upslope is scrapped for filling the space behind the bags and compacted properly. A second layer of brush layer treatment is given above the bags as explained above. The process is repeated till the required height of the retaining wall is reached. After rooting and sprouting, thick vegetation is established at the toe of the landslide (Photo 1a, 1b and 1c). By the time the synthetic bags rot the vegetation is established and the slope is stabilized permanently.

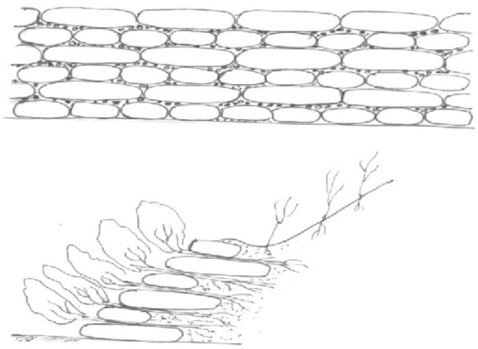


Figure 1. Schematic diagram of vegetated soft gabion

Photo 1a - Vegetated soft gabion wall at time of construction

Photo 1b - Vegetated soft gabion retaining wall, four months after construction

Photo 1c - Vegetated soft gabion Wall, two years after establishment

2.1.2 Live Brushwood Retaining Wall

For establishing live brushwood retaining walls, poles of tree species such as *Marmele sp. (Amare fuik), Jatropha sp., Cordia spp. and Ficus spp.* are driven at the toe of a small landslide at 1m spacing across the toe of the slope. The length of the poles should be 1.5m (minimum). Brushwood bundles having 15cm diameter from any tree, bush or grass species available near the site are prepared and placed along the uphill side of the poles. Coconut or palm leaves along with their stalks are the best suited material for this purpose. The soil is pushed from the upslope and firmly packed behind the brushwood bundles or coconut leave stalks. After attaining 30cm height, brush layering treatment is carried out by using the brushwood of trees species with high growth. The placed brushwood is covered with soil which is then compacted. Only 10cm length of the tail ends of the brushwood is projected out of the brushwood wall. Brushwood bundles or palm leaves are again placed above brush layer treatment and the soil is filled as described above. The second layer of brushwood is placed and the process is repeated till the top of the poles is reached (Photos 2, 3 and 4). If the pole is less than the required height of the retaining wall, another live brush retaining wall is established after giving a step of 1m. The poles and the fresh brushwood used in brush layers quickly sprout, creating a live vegetation retaining wall. By the time the dead brushwood bundles rot the vegetation will be established fully. Additionally, the live brushwood wall is productive in providing fodder and fuel wood.

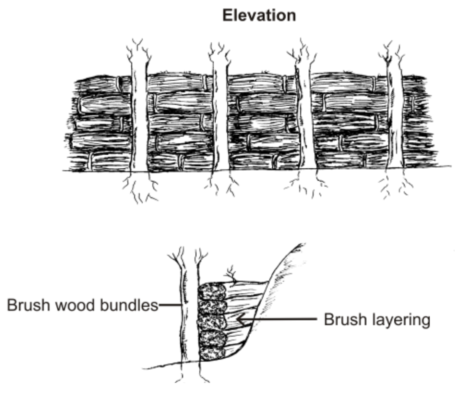


Figure 2 - Schematic Diagram of a Live Brushwood Retaining wall

Photo 2 - Live brushwood retaining wall constructed by the participants of the training on soil bioengineering Timor-Leste

Photo 3 - Newly constructed live brushwood retaining wall.

Photo 4 - Sprouted live brushwood retaining wall

2.1.3 Vegetated Geo-.textile Retaining Wall

Geo-textile rolls are used for constructing vegetated geo-textile retaining walls. Coconut fiber and jute is also used for weaving the biodegradable geo-textile sheets. After removing the debris from the toe of landslide the geo-textile sheet is spread across a width of 1.5m. The remaining portion of the sheet is rolled and kept at the outer edge. The soil is pushed down from the cut slope and placed over the sheet and compacted well. The depth of the soil over the sheet is kept at 1m and its outer face is given a batter of 1 (horizontal):8 (vertical). The remaining roll of the sheet is overlapped on the compacted soil towards the cut slope. It is better to sow seeds of native grasses on outer face of the soil before covering it with the sheet. A 20cm thick layer of soil is placed on the sheet and covered with a 1.6m long brushwood layer extending it beyond the overlapped sheet to ensure adequate rooting takes place. A thin soil layer is placed over the brush layer and compacted before placing another geo-grid sheet with the same procedure as described above. At each layer a step of 35cm is given (Figure 3). The brushwood sprouts in the wet season. The roots reinforce the soil and make it strong to resist the shearing forces working on it. In Timor-Leste vegetated geo-textile walls could be constructed with sheets made from coconut fiber.

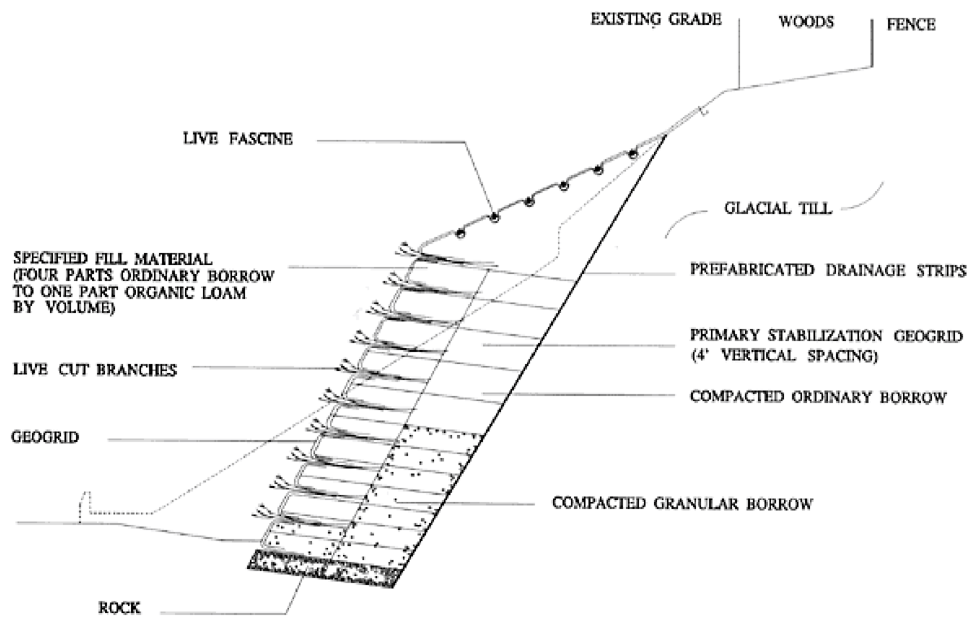


Figure 3 - Schematic diagram of a geo-textile retaining wall

2.1.4 Vegetated Timber Crib Wall

Crib walls should be built from round poles or square timber held together by nails or bolts. Crib walls are placed at an angle of no more than 1:8 (horizontal: vertical) inclining toward the upslope. Wooden crib walls should not be higher than 3m. For construction of the wall, the first row of footers is placed in touch with the cut slope and parallel to it. The second row is placed at 1.5m distance parallel to the first row. The length of the footers depends on the available length of the poles. The headers are 1.5-2m long and are placed across the footers at 2m distance. During the crib wall construction, branches of living plants should be placed in the open spaces between the poles in such a way that less than 10cm length protrude from the wall. When the fill material is damped into openings between the poles, large hollow spaces should be avoided to ensure that the branches are in touch with the soil and will root properly.

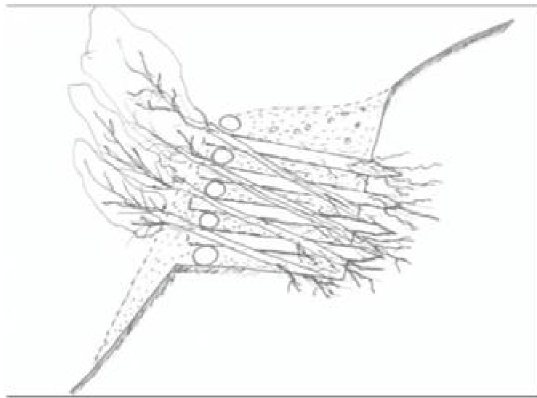


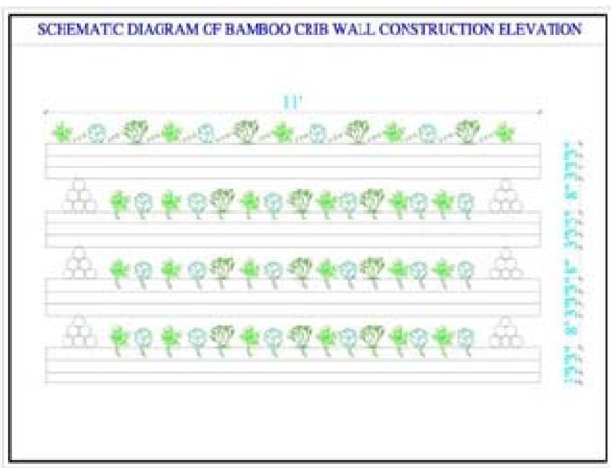
Figure 4 - Schematic diagram of vegetated timber crib wall

Photographs 5,6 and 7 - Examples of vegetated timber crib walls used in India and Pakistan

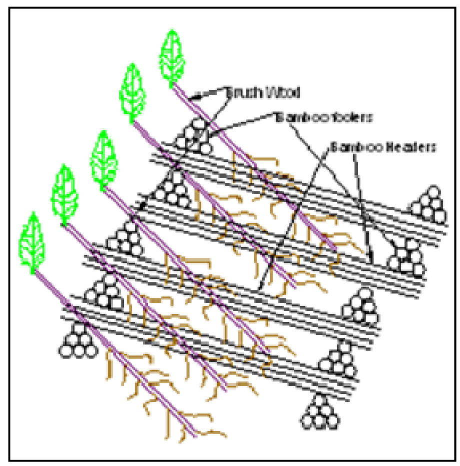
The basal ends of the branches should reach into the soil behind the crib wall. The fill material should contain enough fine grained material to permit vegetation growth (Photographs 5, 6, and 7). In forested areas if the poles are available free of cost then timber crib walls are economical. Over time the timber degrades and vegetation is properly established. The established plants reinforce the soil and help drain the slopes quite effectively.

2.1.5 Vegetated Bamboo Crib Wall

In Timor-Leste bamboo grows naturally, is found in abundance and can be used for vegetated bamboo crib wall construction. The diameter of bamboo poles is small, therefore six bamboo poles can be bundled together as shown in Figure 5 to increase the height of bamboo headers and footers so that brush layering treatment has an adequate vertical spacing. The procedure for the construction of a vegetated bamboo crib wall is the same as that for a vegetated timber crib wall. The only difference is that instead of timber logs, bamboo bundles are used. A bamboo bundle is made by placing three bamboo poles in the bottom layer, two bamboo poles in the second layer by fitting them into the depressions between the three bamboo poles, while a final bamboo pole is placed at the top as shown in Figure 5. The bundle is tied with steel wire. The procedure for brush layering treatment and filling with soil is the same as explained for Timber Crib Wall construction above.



Elevation



Cross-section

Figure 5 - Schematic diagram of Bamboo Crib wall

2.1.6 Vegetated Bamboo Retaining Wall

In tropical countries, bamboo is extensively used for construction of retaining walls, check dams and terraces. In Timor-Leste vegetated bamboo retaining walls can be economical for use as retaining structures for stabilizing landslides. For vegetated bamboo walls, fresh poles may be cut from the tree species which can easily root and sprout. Poles should be 1.5m long and 6-10cm in diameter. Debris is first removed at the toe of landslide and the poles are driven in a line at 1m spacing close to the cut face of the landslide, at least 0.5m deep and fixed properly. Then four to five bamboo poles are paced horizontally behind the fixed poles one above the other and soil filled in the space between the bamboo and the cut face of the landslide. The soil is properly compacted and tender branches of the same trees species from which the poles are prepared placed above the wall with basal ends directed towards the mother soil of the landslide. The length of the branches should fit the available space between the landslide cut face and the bamboo wall. Only 10cm tail ends of branches should protrude from the bamboo wall. The bamboo wall is completed by filling soil in the space between the landslide and bamboo wall. After a vertical interval of another 40cm, a brush layering treatment is given (as explained above) and the bamboo wall is extended until the top of the vertical poles is reached. The branches are covered with a layer of soil and bamboo is placed above the branches along the fixed poles to complete the wall.

A bench (terrace) is constructed above the bamboo structure and a new wall is then constructed above the bench following the same procedures described above (Figure 6 and Photo 8).

A row of seedlings of fast growing trees is planted on the bench (terrace) so developed above the vegetated bamboo wall.

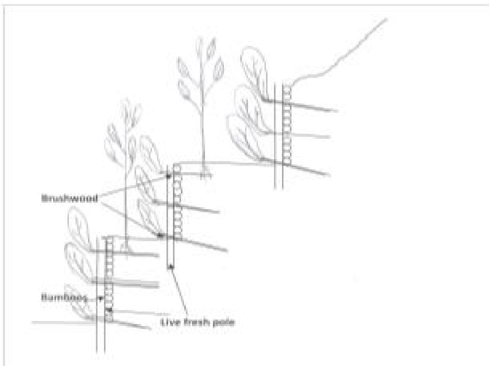


Figure 6 - Schematic diagram of Vegetated Bamboo wall

Photo 8 - Vegetated bamboo Retaining wall constructed by training participants in Timor-Leste.

2.2 Fixation of Loose Soil on Landslides and Fill Slopes

Different soil bioengineering techniques are used for fixing the soil before planting the slope. All the techniques serve the same purpose of developing live mechanical barriers to stop rill and gully formation due to surface runoff and soil movement. The techniques are described below.

2.2.1 Brush Wattles (Fascines)

Brush wattle treatment is the placing of bundles of brushwood in prepared trenches and burying them across the slope at regular contour intervals resulting in a lightly terraced slope. All work starts at the base of the slope. Wattles are constructed by the laying of fresh brushwood in alternate directions to form a bundle 25cm in diameter. The bundles are compressed tightly and firmly tied with flexible tender branches or string. On the lower side of the trenches 0.5m long pegs are driven into soil up to their two third lengths at 1m spacing. The brushwood bundles are placed in the trenches along the uphill side of the pegs allowing the fringe ends to overlap. Few small pegs are also driven through the centre of the brushwood bundles for fixing them tightly in the trenches. The bundles are partially covered with excavated soil and are pressed by walking over them so that soil penetrates into the bundle. The branches get roots and sprout in the rainy season and ultimately a hedge is established across the slope. The fresh pegs are also rooted and sprouted. The wattle fascines also act as drains from the slope. On the fill slopes the wattle alignment should be horizontal but on the landslides the wattles should be oriented with gentle slope for proper drainage of runoff and seepage from the landslide area (Figure 7 and Photo 9).

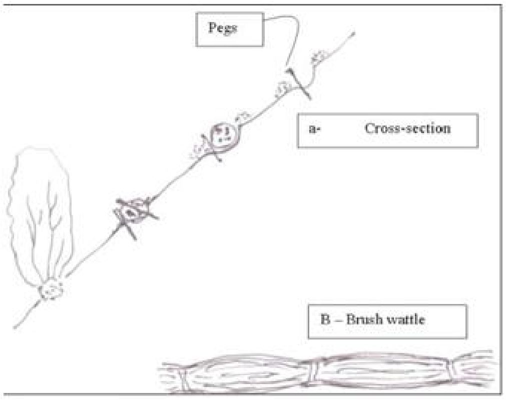


Figure 7 - Schematic diagram of brush wattles

Photo 9 - Sprouted brush wattles of poplar

2.2.2 Brush Layering

Brush layering is useful on steep slopes to take advantage of reduced slope angle. An 80cm wide bench having reverse slope is excavated at the base of the slope. The brushwood is placed side by side on the bench with the tail ends facing outward, with a 10cm overhang. The branches are placed in slanting and criss-cross fashion to have maximum length of the branches in the soil for deep rooting. The brush layering is started from the base of the slope. A similar terrace is developed at 3-4m distance above the treated terrace. The soil excavated from the new terrace moves down due to gravity on the lower terrace treated with the brushwood. The brushwood is covered with soil falling from the upper terrace. The soil is compacted as it falls down. The process is repeated until the entire slope is treated. After rooting and sprouting a thick hedge is established, which serves as a permanent mechanical barrier against runoff (Figure 8 and Photo 10).

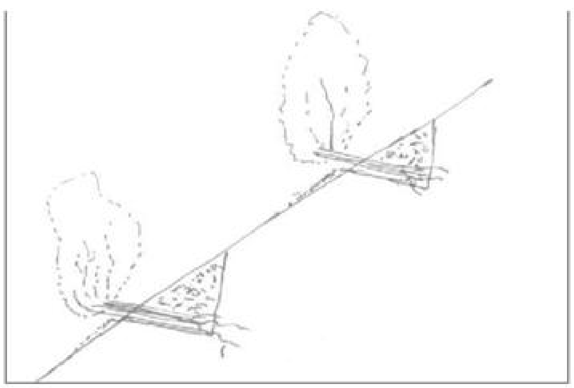


Figure 8 - Schematic diagram of brush layering

Photo 10 - Newly sprouted brush layering

2.2.3 Hedge Layering

The hedge layering treatment is similar to the brush layering treatment with the difference that only rooted seedlings of tree species suitable for the area are placed at close spacing instead of brushwood. The treatment procedure is the same as described for brush layering treatment.

2.2.4 Brush Hedge Layering

The procedure for brush-hedge layering treatment is also the same as described for brush layering above with the only difference that along with placement of brushwood, rooted seedlings of species suitable for the area are also placed at 30cm spacing. It ensures the establishment of the live hedges (Photos 11 and 12).

Photo 11 - Brush and hedge layering

Photo 12 - Brush-hedge layering with hedges

2.2.5 Brushwood Fences

For establishing brushwood fences, trenches are excavated along the slopes. Fresh pegs 0.5m in length are prepared from the branches of tree species that allow vegetative propagation. Pegs are driven in the center of the trenches at 1m spacing. Fresh flexible branches of *Marmele sp. (Amare fuik), Jatropha sp., Cordia spp. and Ficus spp. a*re used for weaving fences around the pegs. The flexible branches are woven around the fixed pegs alternately as is done for preparing baskets (Figure 9). The height of the fences should be 30cm. The fences are covered with soil on the upside slope. The pegs and the fences covered with soil are rooted and sprouted and as a result live hedges are established. The brushwood fence is effective as a mechanical barrier from the time it is established (Photos 13a and 13b).

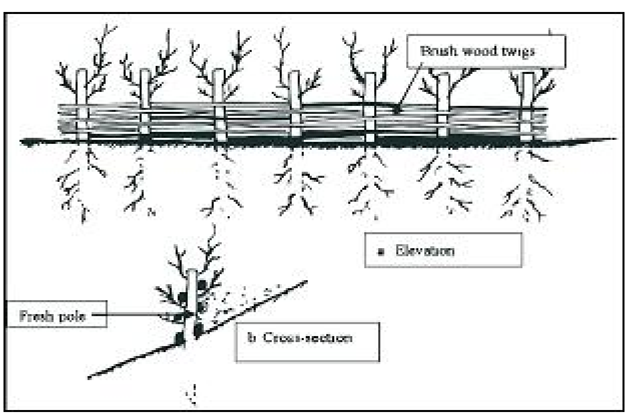


Figure 9 - Schematic diagram of brush fences

Photo 13a - Landslide treated with brush fences

Photo 13b - Same landslide two years after treatment

2.2.6 Semi-Dead Fences with Live Hedges

For establishing semi-dead fences with hedges, brushwood of any species readily available can be used for establishing the fences with the fresh pegs of willow. A row of pegs is driven at one meter interval in horizontal lines on the fill slopes but at a smooth angle on landslides.

On the uphill side of the pegs, dead brushwood bundles are placed and cross pegs are driven to keep the bundles in place. A trench is excavated on the uphill side of the brush bundles. Tufts of *Penesetum purpurium*, Napier grass, *Saccharum spp.* and other local bunch-forming grasses are planted. Sowing or planting of *Leucanea leucocephala and Calendra sp.* can also be carried out in the trench for establishing live hedges. The fresh pegs will root and sprout and keep the dead fence intact. By the time dead brushwood rots, live hedges of grass or tree species are established and act as mechanical barrier.

2.2.7 Hedges

Slopes, which are not too steep, can be stabilized by establishing hedges of grasses (Photos 17 and 18). Various bunches forming grasses can be planted on the contour to establish hedges on the fill-slopes and landslides which act as mechanical barriers. Selection of grass species can be made according to the climatic conditions of the site. In Timor-Leste *Penesetum purprium*, *Sachaarum spp*. and *Arundo donax* are naturally growing in abundance along Dili to Ainaro road and other parts of Timor-Leste. The stumps of these grasses can be used for establishment of hedges on landslides and fill slopes.

Photos 17 & 18 - Hedges of Arundo donax established in northern mountain areas of Pakistan

2.2.8 Sodding

For sod treatment, 30-40cm square slabs of local grasses are excavated from the pastures with their soil & root system intact. The grass sods are placed in the shallow trenches excavated along the contour or in a checker board fashion on the slopes (Figure 10; Photo 19, 20, and 21). The sods are placed as such that at least 8-10cm of their upper portion is raised above the slope surface. The sods are pressed enough to keep them well in touch with the soil below for the easy penetration of the root system. As the sods are already established natural grasses, there is no chance of their failure. The sod treatment acts as live mechanical barrier as in case of other bio-engineering structures (Photos 20 and 21). It is necessary to use the local grasses because of their suitability and adaptability to the local climatic and soil conditions. Spacing for sod treatment is also kept the same as for other bio-engineering structures. Planting of fast- growing suitable tree species is carried out in the spaces between the sod treatments.

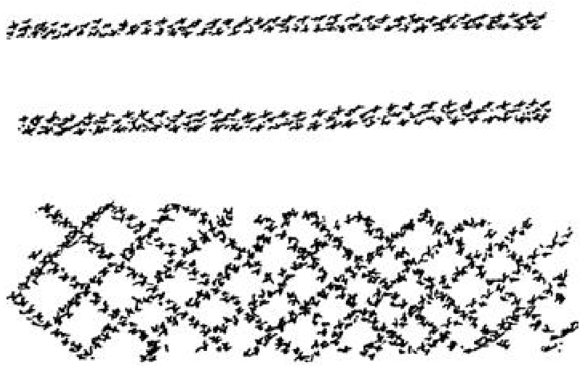


Figure 10 - Schematic Diagram of Sodding

Photo 19 - Sodding treatment in Timor-Leste

Photos 20 and 21 - Sodding treatment parallel & checker board fashion in Pakistan

3. Gully Erosion Control Structures

Soil bioengineering structures have also been used for gully erosion control both at gully head and gully bottom.

3.1 Gully Head Erosion Control Structure

Gully head is the top point of the gully from where it enlarges upward following each runoff event. Controlling the gully head erosion is important because it engulfs the productive land above.

3.1.1 Gully Head Erosion Control with Sodding

Gully head erosion is effectively controlled through the soil bioengineering techniques such as sod and brush layer treatments (Figure 11).

The first step for gully head erosion is to convert the steep cut into smooth and gentle slope all around the gully head cut. The soil all around the gully head up to 1.5 to 2 times the height of the head cut is cut & pushed down into the gully head cut to make the slope gentle. The depth of the soil cut should be equal to the thickness of the sod to be used for treatment. Soil is also excavated from the gully bottom on the lower side of the gully head and moved up and used for preparing smooth slope around the gully head. The depth of the soil excavation in the gully bottom should be equal to the thickness of the sod to be used later. Square grass sods are excavated from a nearby area, where possible. The sods are placed on the smooth slopes of the gully head and prepared in such a way that the surface of the sod is level with the soil surface around the gully head and in level with the gully bottom. After completing the treatment the sods are pressed well so that the roots of the sods are well in touch with the mother soil. The small spaces between the sods and the surrounding soil may be filled with sand and loose soil and planted with grass tufts so that there is no undercutting by the runoff water below the sod treatment. It is better to plant the native trees around sod treated area (Photo 22).

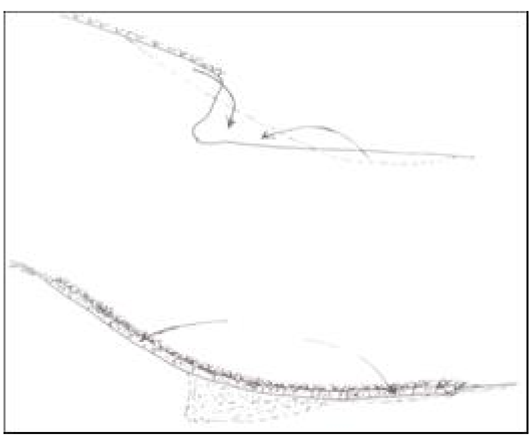


Figure 11 - Schematic diagram of gully head sodding

Photo 22- Sodding treatment of gully head

3.1.2 Gully Head Erosion Control with Brushwood

The process of conversion of a steep gully head cut into gentle slope is the same as described above for sod treatment. To construct the brush layering treatment, trenches are excavated at 1m intervals across the gully head. One to one and a half meter long fresh brushwood branches are cut and spread with their butt (basal) ends embedded in the lowest trench and refilled with excavated soil. The second layer of brushwood layer is carried in the upper trench and overlaps the tail ends over the lower brush layer treatment. The process is completed following the same procedure till the whole gully head is treated.

Pegs are driven at 0.5m intervals over the brush layers. The number of peg rows depends on the number of brush layers. Strings or wires are tied tightly with pegs close to the brush layer. The pegs are driven further down to keep the brushwood compressed and in contact with the soil. The upper 35cm wide round edge of the gully slope is treated with sod in such a way that the upper surface of the sod is level with the surrounding soil surface. The space between the sod and surrounding soil is packed with loose soil to avoid undercutting by the run off. Planting is done around the gully plug and on the sides of the gully.

3.2 Gully Bottom Erosion Control

For controlling gully bottom erosion, check dams are commonly constructed. Different types of check dams are constructed such as loose stone, gabion, masonry or concrete check dams. For small gullies, in addition to engineering structures, soil bioengineering structures can be very effective, particularly on landslides and/or fill slopes.

3.2.1 Live Brushwood Check Dams

Live brushwood check dams should be constructed with live poles and brushwood during the rainy season in Timor-Leste. Before construction of a check dam, a 35cm wide and 25cm deep foundation (key) is excavated across the streambed and its banks. For the construction of live brushwood check dams, freshly cut wooden poles of tree species with fast growth and with a 10cm diameter are driven in the trench at 30-50cm distance across the gully. The length of the poles is decided according to the depth of the gully to be treated. The poles are driven into the soil about half a meter deep in a line across the gully. The branches removed from the poles are used for the construction of the check dam wall (Photos 13 and 14).

Two types of live brushwood check dams can be constructed; single row post and double row posts brushwood check dams. Single row post check dams are less expensive and need less brushwood. If, however, the brushwood is available in sufficient quantity then double row post check dams may be constructed. At the time of fixing the poles some of the branches of the same species used for preparation of poles are placed longitudinally at the stream bed with their butt ends fixed with poles and covered with soil before constructing the brushwood check dam. After sprouting the treatment will serve as apron and protect the soil from the water falling over the check dam spillway.

Photos 23 & 24 - Newly constructed live brushwood check dams and after six months of construction

Flexible branches are used in the construction of the check dam. The butt (basal) ends of the branches are placed in the trench in the banks layer by layer and covered with soil. The branches are then moved alternately around the poles as is done in the case of weaving baskets. The placement of the butt ends of the branches in the banks, and then covering with soil, layer by layer, results in a brushwood wall with raised sides having a depression in the center. The branches buried in the banks of gullies get rooted and all of the branches used in the check dam wall are sprouted. The fresh poles driven in the soil in the foundation trench are also rooted ending up with live vegetated check dams with a spillway in the center. Live brushwood check dams are useful in landslides because the weight of the brushwood used in the construction of check dams is nominal as compared to a loose stone check dam. The poles used in the brushwood check dams get rooted and are useful in fixing the soil material as is the case with general planting on the landslide area. As the brushwood check dams are porous they will be useful in conserving the soil but water will flow down without adding moisture in the slide area.

3.2.2 Palisades

For establishing the vegetated palisades, first a cross wooden pole is placed horizontally across the gully and anchored into the banks of the gully firmly by excavating trenches into the banks. The function of the cross beam is to give support to the poles planted in the trench above the cross pole across the gully. At the bottom of the gully, brush layer treatment is given for the establishment of a live apron. Fresh poles are driven into the ground side by side across the gully on the upstream side of the fixed crossbeam and in touch with it (Figure 12, Photos 25a and 25b). Two thirds of the total pole length should remain above the ground. The poles are then fastened to a crossbeam with the help of a flexible willow branch or a string. Soil is excavated from the upstream side and placed on the upstream of the palisade for rooting and sprouting.

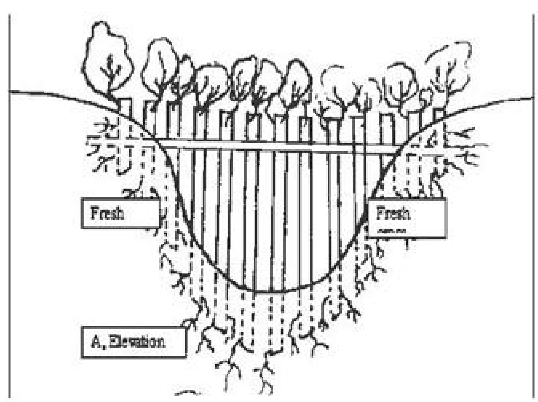


Figure 12 - Schematic Diagram of a Palisade

Photo 25a - A newly constructed palisade

Photo 25b - Sprouted Palisade in monsoon season

3.2.3 Vegetated Pole Check Dams

Vegetated pole check dams are constructed on landslides and in gullies in forested areas where poles are readily available and stone is not. The vegetated pole check dams are established by placing the poles across the gully with brush layering treatment. The poles are placed across the gully by fixing their ends in the trenches dug out in the banks of the gully. After fixing the first pole freshly cut brushwood of suitable species capable of vegetated growth are placed above the pole with their butt ends directed upstream and their tail ends projected over the pole. Only 10-20cm tail ends are projected from the pole. Butt ends are covered with soil taken from upstream. After brush layering, another pole is placed above the brush layer by fixing both ends in the banks. Above the pole, brush layering treatment is given as described above. The third pole is placed above the second pole and again brush layering treatment is given. A gap of 20cm is given between the poles by placing stone above the pole ends in the banks. Depending on the depth of the gully, a fourth pole can be placed with the brushwood treatment on both sides leaving the central 1.5m space for a spillway. Two poles are placed in a slanting position from the banks to touch the point with a distance of one fourth of the total length of the pole check dam. This gives the shape of a trapezoidal spillway. After the sprouting of the brushwood, a vegetated pole check dam is established (Photo 26a and 26b).

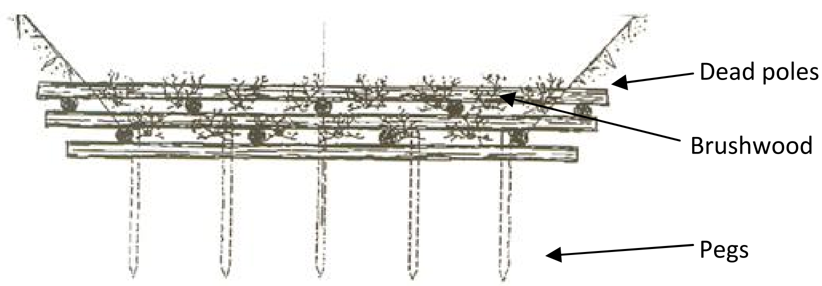


Figure 13 - Schematic Diagram of Vegetated Pole Check Dam

Photo 26a & Photo 26b - Vegetated pole check dam at time of construction and after 8 months

3.2.4 Vegetated Pole/Brushwood Check Dams

In the construction of live brushwood check dams more manual work is involved in weaving the fresh tender brushwood in the shape of baskets, therefore the cost of establishment is comparatively high. Secondly, if workers do not properly embed the butt-ends of the brushwood in the gully banks, then the sprouting of the brushwood is impaired. In forested areas, both palisades and vegetated pole check can be constructed but in areas where pole wood is to be procured, both palisades and the vegetated pole check dams are expensive to construct. To make the vegetated pole check dams economical, dead brushwood can be used along with cross poles to construct the vegetated pole/brushwood check dams (Photos 27a and 27b).

Photo 27-a & 27-b - Vegetated pole/brushwood check dams at the time of construction and eight months after construction

3.2.5 Vegetated Bamboo Check Dams

Vegetated Bamboo Check Dams can be constructed with the same procedure as for vegetated pole check dams. A vegetated bamboo check dam was constructed by the participants of the training on soil bioengineering at a north coastal road location in Timor-Leste (Photo 28). Two to four fresh poles of tree species with high growth rates are driven in a line across the gully. Key trenches are excavated into both banks for fixing the bamboo poles. Bamboo poles are then cut according to the width of the gully and the length of the excavated trenches on both banks. Before starting the construction of a check dam a brush layer is placed at the bottom of the check dam and bamboo sections are placed across the gully behind the poles and inserted into the banks. After placing four bamboo sections, a brush layer treatment is applied and the brushwood is covered with excavated soil from upstream of the gully. This treatment is repeated to complete the check dam. Two or more bamboo sections are placed on both sides for free board, leaving a 50% length in the center for the spillway. A brush layer is provided on both sides of the free board.

Photo 28 - Vegetated bamboo check dam under construction by the participants of training in Timor-Leste

3.2.6 Vegetated Palm Frond Check Dams

In Timor-Leste, the leaf stock of coconut and other palms (fronds) can serve as excellent material for the establishment of check dams for the replacement of a vegetated pole check dam. The same procedure can be adopted for the establishment of vegetated palm frond check dams as for vegetated pole check dams described in section 3.2.4. The only difference is that instead of wooden poles, palm fronds along with their stock can be placed for supporting the brush layers. The palm fronds have a large span - enough to provide a vertical interval of 30-40cm for each brush layering treatment. The length of frond stocks is also 2 meters, therefore, gullies less than 2m width are suitable for treatment with vegetated palm frond check dams.

3.2.7 Vegetated Soft Gabion Check Dams

The vegetated soft gabion check dams can be constructed with the same procedure as that of vegetated soft gabion walls except they are established in the gullies just like other check dams. After excavation of the foundation, freshly cut brushwood of suitable plant species which can be propagated with cuttings is placed in the foundation and covered with a 15cm layer of soil. After sprouting, this acts as an apron. The first layer of debris filled bags can be placed on the brush layer leaving their outer ends (15cm) uncovered. The bags are covered with a 7-15cm thick layer of soil before placing another brushwood layer over bags, after leaving a step of 20-30cm width. The process is repeated to reach he required height. The free board is given on both of the sides leaving a spillway according to design criteria. At least two layers of bags and brushwood are used for the free board on both of the sides of the check dam (Photos 29a and29b).


Photos 29a and 29b - Vegetated soft gabion check dams at the time of construction and six months after construction

3.2.8 Live Sills

Live sills are established by using hedges of tough grasses or bushes which can resist water erosion and prevent scouring of the stream bed. The simplest form is the establishment of hedges across the stream by planting tufts of grasses like *Vetiver* and *Saccharum* species in shallow and narrow trenches excavated across the stream bed and packed with soil. For the second type, stones are placed in the trench on the downstream side of the grass tufts to make the live sills stronger. In the absence of stones at the site, soil filled bags can also be placed in the excavated trench along with planting of grasses. The tough grasses can resist the water flow; being flexible they bend with the water flow and therefore do not divert the flow towards banks. The live sills are not only useful in stopping the scouring of the gentle sloping streams but also contribute to siltation of the stream bed and encourage natural regeneration in the stream bed.

3.2.9 Vegetated Loose Stone Check Dams

Loose stone check dams are commonly used for gully erosion control. However, vegetated check dams are generally considered to be more effective; the addition of brush layers acts like a reinforcing layer similar to a concrete slab inserted in a stone masonry wall.

The procedure for the construction of vegetated loose stone check dams is the same as for simple loose check dam construction, with the only difference being the addition of fresh brush layers at 0.5m vertical intervals. The length of the brushwood should be large enough to extend at least half a meter upstream and 10cm downstream of the completed check dam wall. Basal ends of the brushwood should be directed upstream. The brush layering treatment may also be given in the free board. The brush layering in the foundation will act as apron for the check dam (Photos 30a and Photo 30b). The soil may be filled behind the check dam to cover the extended brushwood for rooting. The soil should be taken from upstream of the check dam which will increase space for expected siltation from storm runoff.

It is better to drive freshly cut small size poles (1.5m long with 5-10cm diameter) adjacent to the check dam wall on the downstream side. The poles after rooting and sprouting make the check dam much stronger.

Photo 30a and 30b - Vegetated loose stone check dam at time of construction and four month after construction

4. Soil Bioengineering Structures for Stream Bank Erosion Control

Two types of engineering structures are used for river bank erosion control, retaining walls and spurs. The engineering retaining walls and spurs can be gabion, stone masonry, Portland Cement Concrete (PCC) and Reinforced Cement Concrete (RCC) structures. The use of bioengineering in retaining walls and spurs to replace or complement the aforementioned structure types is described below. If the landslides are triggered because of bank cutting by rivers and streams, then river bank control structures are needed.

4.1 Retaining Walls

4.1.1 Live Brushwood Retaining Wall

Live brushwood retaining walls can be used for treating small stream bank cuttings. The procedure for the construction of vegetated brushwood retaining walls for erosion control is the same as for live brushwood retaining walls for landslide control.

4.1.2 Vegetated Loose Stone Retaining Wall

Loose stone retaining walls can be strengthened by reinforcing with brush layering at 60cm intervals along the height of the wall. The brushwood from tree species which can root and sprout such as *Marmele sp. (Amare fuik), Jatropha sp., Cordia spp. and Ficus spp.* may be used for brush layering. Rooted seedlings may also be placed along with the brushwood. The procedure for the construction of vegetated loose stone for river bank erosion control is the same as described earlier for vegetated loose stone retaining walls for landslides.

4.2 Spurs

Bioengineering spurs can be of three types; live spurs, vegetative soft gabion spurs and vegetated loose stone spurs.

4.2.1 Live Spurs

Live spurs are suitable for small streams with low flows. The live spurs may be complemented with gabion or PCC spurs to reduce the cost of the bank erosion control. The live spurs may be constructed during the rainy season (from December to March) in Timor-Leste. Two rows of poles of tree species having the adequate rooting and sprouting ability are driven at spacing of 40-50cm at an angle of 35-45° with the bank. A minimum half meter key is inserted into the bank. Holes are made with help of an iron bar and hammer and then timber poles are driven into the holes and are further hammered down to at least half a meter into the ground. The spacing of the poles in the rows should be 50cm. The poles should be firmly fixed by filling sand and soil mixture around the poles, tampered down with an iron bar. The space between the two rows of poles is filled with dead brush (palm fronds etc). The top of the compacted brushwood wall is capped with stone. If stones are not available, poles are tied with a string in a zigzag pattern to keep the brushwood in place. Small pegs of the same tree species are driven around the spur walls. Rooted seedlings of water resistant tree species such as *Arundo donax* are planted on both sides of the live spurs that have been established. The poles and pegs will root and sprout in the rainy season. Stones are placed on both sides of the planted seedlings, with large size stones anchored at the tip of the brushwood spur.

The brushwood wall will resist the hydraulic pressure of the stream flow during the first few years. The rooted poles will be strong enough to keep the brushwood intact. The seedlings will grow and result in permanent thick hedges on both sides of the dead brushwood spur.

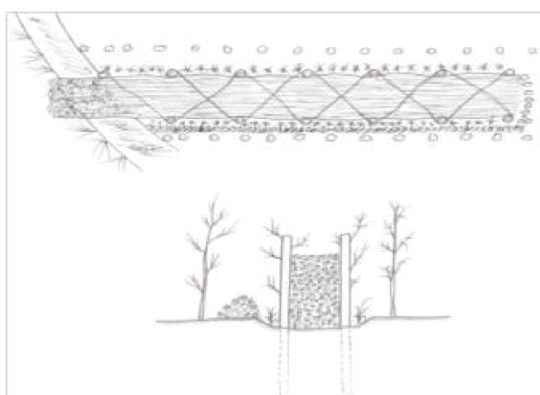


Figure 13 - Schematic diagram of live spur (plan above, cross-section below)

Photo 31a - Newly Constructed Live Spurs

Photo 31b - Newly Constructed Live Spur

4.2.2 Vegetated Soft Gabion Spurs

The vegetated soft gabion spurs can be established with the procedure described above with the difference being that debris filled bags can be used in place of brushwood. The bags will be effective during the first two years and the vegetation on both sides of the gabion wall will be become permanent live spurs with passage of time.

4.2.3 Vegetated Loose Stone Spurs

The vegetated loose stone spurs can also be established with the same procedure as that described for live spurs. The loose stone wall can be constructed following the principle of gabion spurs but on both sides of the loose stone walls, vegetation treatment may be given as described for live spurs. The vegetation will strengthen the loose stone wall after its establishment.

4.3 Revetments

Revetment consists of stone pitching to protect the banks from the wave action of water. The banks can be protected with vegetation treatment such as live brushwood revetment and sod treatment combined with planting of cutting and seedlings.

4.3.1 Live Brushwood Revetment

The banks are given a smooth slope before brushwood treatment. Brushwood of tree species which can root and sprout may be cut in the rainy season (December to March) in sections of 1-1.5m length. A trench is excavated at 1m from the top of the bank. Butt ends of the brushwood are placed in the trench and spread on the upslope side. A second trench is excavated below the first trench at 1m distance and parallel to the first one. A second layer of brushwood treatment is applied which overlaps the tail ends above the upper brushwood layer. The brushwood treatment is continued until the bottom of the stream is reached. Pegs of freshly cut branches of the same species from which the brushwood is taken are driven in rows at 1m intervals. The pegs are tied with to the brushwood with strings and hammered down to keep the brushwood in close contact with soil for rooting and sprouting. In the rainy season, a mat of vegetation will be established which is strong enough to protect the bank from erosion.

4.3.2 Sod Revetment with Plant Cuttings and Seedlings

The smooth slope of a bank can also be treated with sod. In between sods, cuttings of suitable tree species capable of vegetative growth and seedlings of other tree species can be planted. This treatment will be stronger than the brushwood revetment. The base of the banks treated with sod and brushwood can be further reinforced with a vegetated stone wall, if stones are available; otherwise a live brushwood wall may be constructed.

5. Recommendations for Bioengineering Implementation

Soil bioengineering structures, recommended for use in Timor-Leste, are typically constructed and established by using living plant material - particularly endemic tree and grass species. Therefore it is very important that the Forest Department of Timor-Leste be involved in the implementation of the soil bioengineering applications for road slope stabilization and erosion control in Timor-Leste.

For road rehabilitation works to be implemented under the World Bank funded Road Climate Resilience Project (RCRP) for the Dili -Ainaro corridor, bioengineering measures will be included to stabilize slopes and prevent soil erosion. These works will be implemented as part of road rehabilitation contracts between the Directorate of Roads, Bridges and Flood Control of the Ministry of Infrastructure and civil contractors.

For the execution of soil bioengineering works and related activities, the contractor could consider sub-contracting the bioengineering component to the Forest Department. Alternatively, the Forest Department could be provided funds (as part of the Bank-funded project) to manage the implementation, and provide training to the contractors in prescribed soil bioengineering measures.

However, to date, only basic training has been provided to staff at DRBFC as well as the Directorate of Forestry, and on this basis, supervision of the soil bioengineering activities will be needed by an experienced specialist during the first 2-3 months of contract implementation period. This will help ensure that bioengineering measures are properly constructed and established. The contractor is expected to engage a suitably qualified individual to oversee the works.

It is recommended that the Directorate of Forestry assign a staff member(s) to supervise the works alongside the consultant to acquire additional training and gain experience in implementing soil bioengineering. The Directorate of Forestry would be well placed to perform supervision activities on future projects where bioengineering is being implemented. It is intended that this manual for soil bioengineering applications in Timor-Leste would be used as reference material and a training guide by the contractors and the relevant Government agencies.

6. Suitable Tree Species for Landslide Stabilization in Timor-Leste

6.1 Tree Species Suitable for Soil Bioengineering in Timor-Leste

Botanical Name	Common Name
Ficus benjamina	*Ai hali timir rahun*
Ficus virens	
Ficus drupacea	
Ficus racemosa	*Ai gun*
Hibiscus tiliaceus	*Ai fau*
Pterocarpus indicus	*Ai na*
Erythrina variegata	*Ai dik*
Grevia breviflora	*Ai Klenok*
Cordia monica	*Ai Nunan*
Inocarpus edulis	*Ai Kaen*
Pipturus argenteus	*Ai Rame*
Rhus sppp.	
Cliricidea sepium	*Gamal*
Planchonia careya	
Baringtonia racemosa	*Ai Kakasa*
Sterculia holtzei	*Ai kmitaen*
Timonius timon	*Ai katimu*
Antarius tonxicaria	*Aius manu hir*
Euroschinus falcatus	
Melodorum sp.	*Ai amare*
Mutinggia calabura	*Sereja*
Ceiba petantera	*Ai lele*
Melachia umbelatum	*Ai Donu*
Cordia dichotoma	*Nunan karau*
Marmele sp.	*Amare fuik*
Jatropha sp.	

6.2 Suitable fast growing Tree Species, for planting on landslide affected areas

Botanical Name	Common Name
Ficus benjamina	*Ai Hali timir rahun*
Ficus virens	
Ficus drupacea	
Ficus racemosa	*Ai gun*
Hibiscus tiliaceus	*Ai fau*
Pterocarpus indicus	*Ai na*
Erythrina variegata	*Ai dik*

Pipturus argenteus	*Ai Rame*
Cliricidea sepium	*Gamal*
Sterculia holtzei	*Ai kmitaen*
Antarius tonxicaria	*Aius manu hir*
Euroschinus falcatus	
Melodorum sp.	*Ai amare*
Mutinggia calabura	*Sereja*
Ceiba petantera	*Ai lele*
Melachia umbelatum	*Ai Donu*
Cordia dichotoma	*Nunan karau*
Gamilina arborea	*Gamelina*
Tecoma grandis	*Ai teka*

6.3 Suitable Grasses and Brushes for Hedges

Botanical Name
Leucanea leucocephalla
Calendera sp.
Vitiverus spp (Vitiver)
Saccharum sp.
Penesetum pedicelatum
Penesetum purpureum
Panicum repens
Panicum argyrostachym

6.4 Suitable Species for Coastal Areas for Beach Protection

Botanical Name	Common Name
Cordia subcordata	
Thespesia populnoides	
Baringtonea asiatica	
Hibiscus tiliaceus	*Ai fau*
Calophyllum inaphyllum	*Ai Too*
Baringtonea racemosa	*Ai kamanasa*
Tamarindus indicus	*Ai Sukaer*
Pandanus tectorius	*Hedan*
Pemphis acidula	
Guetarda speciosa	
Ochroaia oppositfolia	
Cerbera mangas	

7. Glossary of Terms

Bioengineering: Bioengineering (including biological systems engineering) is the application of concepts and methods of biology to solve real-world problems related to the life sciences and/or the application thereof, using engineering's own analytical and synthetic methodologies and also its traditional sensitivity to the cost and practicality of the solution(s) arrived at. In this Field Guide, the term has been used for soil bioengineering.

Brush Hedge Layering: The use of live brushwood mixed rooted seedlings for the reinforcement of soil on landslides to develop hedges is termed brush hedge layering.

Brush layering: The use of live brushwood for reinforcement of soil on landslides and fill slopes to develop hedges is called brush layering.

Brushwood: The term brushwood in this Field Guide refers to fresh live branches of tree or bushes which can root and sprout and may be used in different soil bioengineering structures.

Brushwood Fences: Brushwood fences in this Field Guide refers to the development of fences by weaving tender branches of tree species around the live pegs driven along the contour to fix loose soil on the landslides and fill slopes.

Brush Wattle construction: Brushwood bundles of fresh branches of tree (or bush) species which can root & sprout are placed in trenches for creating hedges along the contour on landslides and fill slopes to fix the loose soil and act as drains. Such treatment is called brush wattle construction.

Check dam: Check dams are walls constructed in gullies and small narrow channels with a spillway to reduce the velocity of water and thereby controlling channel erosion.

Contour Lines: Contour lines are lines having equal height above sea level and are often included on topographical maps.

Crib Walls: Crib walls are gravity retaining walls, constructed from interlocking pre-cast concrete components or timber planks/logs. They are filled with free draining material and earth backfill to eliminate the hazards of hydrostatic pressure building up behind the wall. Concrete crib walls are low cost, of open web construction, and can be quickly and inexpensively erected. Mostly brush hedge layering treatment is applied to make the crib walls more affective in giving extra strength to wall in case of landslides and also are more aesthetically pleasing.

Concrete Crib Walls: The concrete crib walls are constructed by using pre-cast concrete components (headers and footers /stretchers).

Erosion: Erosion is the displacement and transport of soil particles by water and/or wind.

Earth Slump: Earth slump is the movement of land down the slope due to gravitational force along with vegetation and other objects with little to no distortion.

Fascine: Brush wattles and fascine are synonyms.

Fill slope: The loose soil pushed down the slopes from the road or any other earthwork place is called a fill slope. It is loose soil without vegetation cover and is vulnerable to rill and gully erosion.

Footer (Stretchers): The footers or stretchers are the components of the crib walls placed parallel to the landslide at the toe. These may be of concrete, timber or steel members of specified length.

Gabion: The GI wire crate boxes filled with stones are called Gabions. Gabion are typically used in the construction of retaining walls, check dams and spurs.

Gabion Retaining wall: Retaining walls constructed with stone placed GI wire crates (gabions).

Gabion Check dam: Check dams constructed with stone placed GI wire crates (gabions).

Gabion Spur: Spurs constructed with stone placed GI wire crates (gabions).

Geo-textile: Geo-textiles are permeable fabrics which, when used in association with soil, have the ability to separate, filter, reinforce, protect or drain. Reference in this Field Guide is for sheets used in constructing vegetated geo-textile retaining walls.

Gully: Gully is a channel which has formed on a slope. It is the advanced stage of rill erosion.

Gully head: Gully head is the upper end of the gully.

Gully Erosion: Erosion caused by gullies is gully erosion.

Header: Headers are the components of crib walls which are placed at right angle to a landslides toe and footers (stretchers) are placed parallel to a landslide. In the plan of the crib walls the only ends of the header can be seen while the footers are visible lengthwise in plan.

Hedges: Hedges are thick rows of grasses or bushes established along the contours on the landslides and fill slopes to prevent rill and gully formation.

Hedge layering: The establishment of hedges through developing small terraces and embedding rooted seedlings is called hedge layering.

Landslide: Mass movement of consolidated or unconsolidated material along the slope due to gravitational force is called mass erosion or landslide.

Landslip: A landslide small in size and of shallow depth.

Live brushwood retaining wall: A retaining wall established by using live posts in front and dead brushwood or grass stocks for loose soil retention with brush layering at every 0.3-0.4m vertical interval is called live brushwood retaining wall.

Live brushwood check dam: Live brushwood check dams are established by fixing fresh poles across the small gullies and weaving a basket with fresh tender branches of tree species having the quality of vegetative propagation and burying their butt ends in the narrow trenches in the banks for rooting and sprouting.

Live spur: Live spurs are established through live plant material to stop bank erosion.

Palisade: Palisade is a kind of bioengineering check dam established by fixing live poles across the gully with support of cross beam fixed in the banks.

PCC Structures: PCC structures are engineering structures by using Portland cement concrete (mixture of cement, sand and stone crush). PCC structures can be retaining walls, spurs and check dams.

RCC Structures: Reinforced Cement Concrete (RCC) structures are engineering structures by adding steel bars in concrete to make it strong. RCC structures can be retaining walls, spurs and check dams.

Retaining walls: Retaining walls are constructed on the down side of the roads. Retaining walls at the toe of landslides and landslips are constructed to resist landslide mass pressure and to stabilize the landslide.

Revetment: Revetment is established by placement of brushwood or stones on the river bank to protect the earthen slopes from wave action.

Rill Erosion: Rill erosion is the removal of soil by concentrated water flows running through little streamlets. Rill erosion refers to the development of small, ephemeral concentrated flow paths, which function as both sediment source and sediment delivery systems.

Semi-dead Fences with live hedges: Semi-dead fences are established by using live pegs with dead stocks of grasses with planting of stumps or sowing to establishing hedges behind fences.

Sod: Sod is mat forming grass like lawn grass. In this Field Guide **s**od refers to a block of natural grass taken out along with roots and soil.

Sodding: Treatment of slope with parallel lines or checker board fashion of sods is called sodding.

Soft Gabion: The bags of jute or any synthetic material used for filling the debris or soil and using them for constructing the retaining walls with brush layering treatment are called soft gabion.

Soil Bioengineering: The use of living plant material to construct structures which serve some engineering purpose is called soil bioengineering such as vegetated soft gabion walls, vegetated timber crib walls, live brushwood check dams, vegetated pole check dams, palisades, brush layering, fences etc.

Spur: Spurs are structures constructed along the stream or river banks at a certain angle to redirect the water flow towards the center of the stream is called spur. Spurs can be of gabion, loose stone concrete, RCC or live spur.

Stone masonry wall: Walls constructed with stones with cement, sand mixtures.

Stone Pitching: Stone pitching is the placement of stones on the surface of slopes or ditches to stop surface erosion.

Timber Crib walls: Timber crib is the crib wall in which its components (Header & footer) are wooden.

Trench: A ditch dug out on the land surface for any purpose is called a trench.

Vegetated Geo-textile Retaining: Biodegradable geo-textile sheets are used in building retaining walls by using live brushwood treatment between each layer of earth packed geo-textile sheet. The brush layering after rooting and spouting reinforce the retaining wall.

Vegetated Loose stone retaining wall: Dry stone masonry wall treated with live brush layering at regular interval of 0.5m.

Vegetated Loose Stone Check Dam. Loose stone check dams treated with live brush layering at regular vertical intervals.

Vegetated Pole Check Dam: Check dams constructed with poles treated with brush layering.

Vegetated Soft Gabion Wall: Vegetated soft gabion walls are constructed at the toe of small landslides and as retaining and breast walls of the roads by using the debris filled jute or synthetic bags as building material and treated with brush layering alternately with bag layers. The bags are placed alternately across and lengthwise at every layer of the wall as in case of bricks.

Wattles: Wattles in this Field Guide refers to bundles of fresh brushwood placed in the trenches excavated on the slopes for brush wattle or fascine treatment.

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Document Information

Pictures on the cover page are vegetated soft gabion walls eight months after construction in KPK province Pakistan.

The picture on the back page is a group photograph of the participants of the training on soil bioengineering on February, 3, 2012, on the north coastal road near Maubara, Timor-Leste.

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Group photograph of the participants at the practical training session on February 3rd 2012 - North Coastal road (near Maubara, Timor-Leste)