



# Study of Soil Bio-engineering for Slope Stabilization and Site Restoration

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**Abstract:** Soil bioengineering is the use of living plant materials to construct structures that perform some engineering function. Often, soil bioengineering is used to treat sites where surface stability and erosion problems arise. The use of plants for soil erosion protection and slope stabilization has a long practice. Old methods with rocks and plants, erections of timber have been used over the past eras. Recently these old soil conservation and stabilization methods have been rediscovered and improved. Methods such as wattle fences and modified brush layers form small retaining walls that can be used to support failing slopes or to reduce slope angles and allow other vegetation to be established. Biotechnical engineering methods have become part of geotechnical and hydraulic engineering and have helped to link the gap between classical engineering disciplines, land use management, landscape architecture and biological sciences. In this assessment, the different uses of plants in geotechnical and hydraulic engineering design are presented. The core of this analysis is a complete overview of the most important biotechnical construction techniques used for soil erosion protection and slope stabilization. Methods, construction procedure, and the major advantages and disadvantages of these biotechnical methods are discussed. Considerations about construction and maintenance costs conclude in this review.

**Keywords:** Soil erosion protection, slope stabilization, geotechnical engineering, biotechnical construction method.

## I. INTRODUCTION

Soil bioengineering can provide an effective means of treating sites where steep slopes and soil instability are causing revegetation problems. Soil bioengineering is the use of living plant materials to perform some engineering role, from simple erosion control with grass and legume seeding or more complex slope stabilization with willows and other plants (Schiechtel, 1980). Soil bioengineering techniques can be used to revegetate steep slopes, to treat seepage zones and to control surface erosion (Gray and Leiser, 1982). Soil bioengineering can also be used in construction to provide soil reinforcement and as living retaining walls (wattle fences) and live reinforced earth walls.

Soil bioengineering techniques fit well with ecological restoration and the successional reclamation model developed by Polster, (1989). Successional reclamation seeks to reintegrate the disturbed site into the natural successional processes that would serve to vegetate the site eventually. By investigating how natural revegetation systems stabilize natural disturbances (Polster and Bell, 1980; Straker, 1996), methods designed to stabilize anthropogenic troubles can be developed. Different species such as those that are found on naturally disturbed sites are used to construct soil bioengineering structures. Characteristics of these species such as the ability to root from cuttings, continued growth following burial and the ability to grow under harsh conditions all serve to make these plants useful for soil bioengineering.

## II. PLANT MATERIALS FOR SOIL BIOENGINEERING

Different woody species are of particular importance in the development of bioengineering systems. This group of plants represents the successional bridge between the herbaceous initial colonizers (seeded grasses and legumes) of a disturbed site and later seral types and thus plays a key role in successional development of the site. Different woody species perform important roles in the natural restoration of damaged sites such as stabilization, erosion protection and as wildlife browse. Different woody species are often related with rhizobia, which fix nitrogen, and thus help to improve the nutritional status of a site (Binkley et al. 1982).

Stem cuttings of many species can be used for bioengineering although willows and cottonwood are most effective. Cuttings should be collected while the plant is inactive. Cutting woody vegetation in the fall and winter results in the maximum amount of growth. Carbohydrate assets are at their highest level in the plants at this time of year. This allows the cutting to provide fresh growth in the spring without the benefit of further photosynthesis. Cutting woody plant stems in the fall and winter permits all of this stored energy to be used in the growth of new roots and shoots during the spring and early summer. New roots and shoots on the cuttings develop either from buds that develop in the axils of the leaves (axillary buds), or from other tissues in a process termed dedifferentiation. Buds arising from these are termed "adventitious" buds (Hartmann and Kester, 1975). Axillary buds result in the



growth of new roots and shoots from sites where there were leaves on the plant in the past. Adventitious buds result in the growth of new roots and shoots from either axillary locations or from other areas on the plant such as the cut end of the cutting. In some species, such as willows, which are very easy to root and widely used for soil bioengineering, preformed (latent) bud initials are formed as the stem develops in the beginning. These species have a variety of adaptations, which allow them to function well in bioengineering systems. The presence of preformed bud initials is one such adaptation, and allows these plants to regrow effectively from cuttings and after being buried.

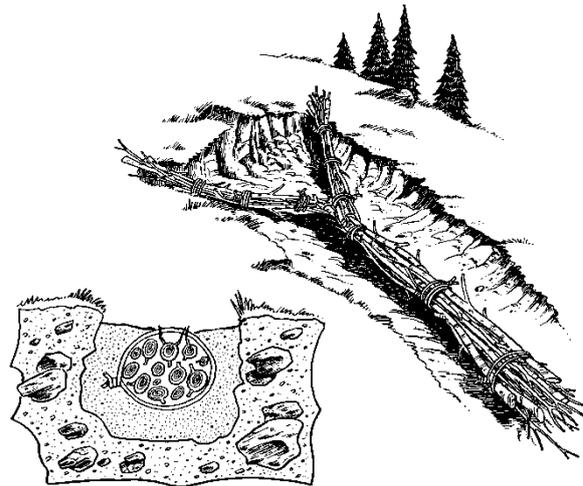
Cuttings, which are collected from healthy, moderately rapidly growing parent plants, will perform better than those collected from decadent, senescent stems although the tips of stems should be avoided. Marchant and Sherlock (1984) reports that cutting material with a low nitrogen / high carbohydrate asset will root better than exceptionally vigorous, "sappy" wood. Local logging sites, power lines, pipelines, railroad and road rights-of-way often provide ideal sites for the collection of cuttings as these areas are often maintained in an early seral state. Permission from the landowner must be obtained prior to collecting cuttings from any site. In the case of Crown Land, local Ministry of Forests officers can provide advice on appropriate locations for the collection of cuttings. Care must be taken in the collection of cuttings to avoid environmentally sensitive sites such as stream banks or areas of heavy ungulate use. Direct planting of root cuttings may be used for the establishment some species. Although the collection and use of root cuttings is significantly more difficult than using stem cuttings, there are cases (e.g. aspen) where root cuttings provide the best results and stem cuttings are not effective. As with stem cuttings, healthy, moderately rapidly growing roots that are one half to one centimetre in diameter will work best. These should be collected during the dormant period of the parent plant when the parent plant has stored food reserves contained in the roots. Collections should be made well before any flushing of the parent plant in the spring. Collection of root cuttings during clearing operations can provide an efficient means of collecting large quantities of suitable roots. Root cuttings should be 5 to 15 cm long and at least 0.25 cm in diameter. Root cuttings must be planted with the proximal end (end towards the parent plant) up, or horizontally. Root cuttings should be planted 2.5 to 7.5 cm deep. Root cuttings should be kept moist and planted at the restoration site as soon as weather conditions allow.

### III. SOIL BIOENGINEERING METHODS FOR WATER MANAGEMENT

#### Live Pole Drains

Live pole drains (Figure 1) are constructed of bundles of living cuttings and are used to provide stability to sites

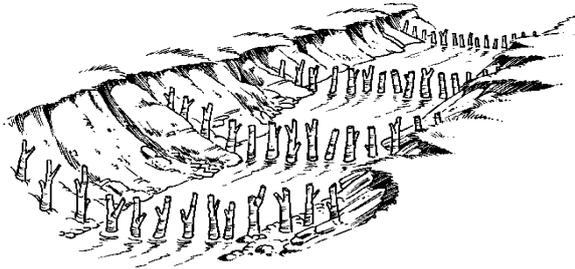
where excess soil moisture results in soil instabilities. The bundles of cuttings are placed in shallow trenches in such a manner that they intersect and collect the moisture. The bundles are then lightly buried with local materials, taking care to avoid over-burial. Careful trimming of the cuttings is not required, although the bundles should be as tight as possible and twigs with leaf buds should be removed. The plants used to form the bundles sprout and grow, with the moisture continuing to drain from the lower end. The growth from the live pole drains forms the initial cover on the seepage site, allowing other species to invade. As with other bioengineering systems, live pole drains must be designed to suit the specific conditions of the site. A variety of different shapes can be used for the drains depending on the site conditions. A "Y" pattern of the drains can be used to collect moisture from a diffuse seepage zone while a linear pattern can be used where a discrete seepage site exists. The objective in design of the drains is to collect all of the moisture and to get it to drain away as quickly as possible.



**Figure 1.** Live pole drains can be used to stabilize slumping soils. This view shows the layout of live pole drains in a slump with the covering soils removed for clarity. The section shows a typical covering. Some twigs from the bundles should be left above ground.

### IV. LIVE SILT FENCES

Live silt fences (Figure 2) are used to reduce sediment movement on low gradient streams. Where live gully breaks can be used on very steep gullies and seasonal streams, and live bank protection can be used on larger streams and rivers, live silt fences are used on smaller streams with lower gradients. The live silt fences are simply rows of cuttings stuck into the streambed to slow water velocities and cause sediments to be deposited. The rows of cuttings trap floating debris that further slows water velocities. Once the cuttings grow, the water flows between the stems of the growing cuttings, creating a brushy, swampy area characteristic of natural seepage areas and small streams.



**Figure 2.** Live silt fences can be used to provide a willow coppice in small streams and ditches. They act by slowing the velocity of the water and allowing sediments to settle out. The cuttings can be either in single rows (as shown) or multiple rows in each band.

**Live Bank Protection**

Live bank protection (Figure 3) can be used to stabilize stream banks that may have become destabilized by debris torrents or other disturbances. Live bank protection can be very useful in stabilizing roadside ditches and culvert inlets and outfalls.



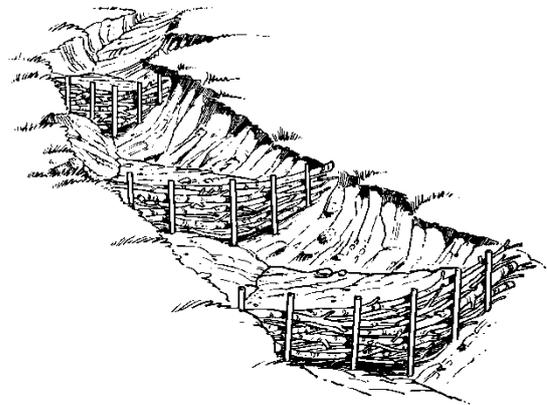
**Figure 3.** Live bank protection can be used to control erosion on the outside of curves. The backfill has been removed in these drawings for clarity. Typically, the undercut bank would be re-sloped to backfill be structures.

Live bank protection structures are typically located on the bends of streams with the upstream ends located at the tangent point between opposing curves. The ends should be tucked well into the bank to avoid "catching" the flow and causing more erosion. The structures are backfilled with local materials, taking care to avoid large cobbles and boulders that will tend to be dry in the summer. The growth of the live bank protection structures provides a cover of riparian vegetation along the streams.

**Live Gully Breaks**

Live gully breaks (Figure 4) are used in gullies to control water flow and the initiation of debris disturbing. Where gully torrents originate from minor collapses of gully sidewalls, live gully breaks can assist in reducing the potential for torrents to initiate. The live gully breaks must be established high in the channel where torrents are initiated. Live gully breaks can be helpful in the revegetation and stabilization of gullies that have already experienced debris torrents by providing sites where

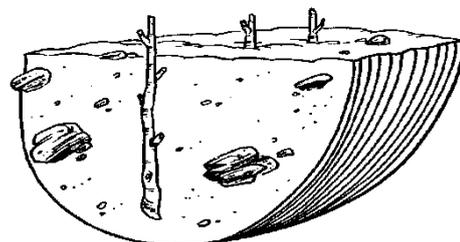
materials may be trapped and where vegetation can become established. As with any bioengineering system, live gully breaks will strengthen with age.



**Figure 4.** Live gully breaks act to slow the velocity of water movement down a gully and thus to trap sediments.

**Live Staking**

Live staking (Figure 5) is perhaps the simplest form of bioengineering. Live staking is simply the use of living cuttings to stabilize slumping materials or to "pin" sods to a slope. Live staking is particularly useful in flowing silty materials where the growth of the roots will serve to bind the unstable materials and prevent further flows. The cuttings used in live staking should be inserted into the soil so that at least 3/4 of the length of the cutting is underground. On drier sites, 7/8 of the length should be inserted. The cuttings should be a minimum of 40 cm long and at least 2 cm in diameter at the tip. Cuttings need not be planted vertically (as shown) but can be slipped into the soil diagonally, as long as the cutting will remain moist over most of its length. Cuttings should be planted with the distal(top) end up. The spacing between cuttings will vary depending on the materials, but can be as little as 10 cm. On flowing silts, spacing of about 20 cm work well.



**Figure 5.** Live staking is a simple method of establishing different woody vegetation. It can be effectively used on "flowing" silts and to establish riparian vegetation along streams.

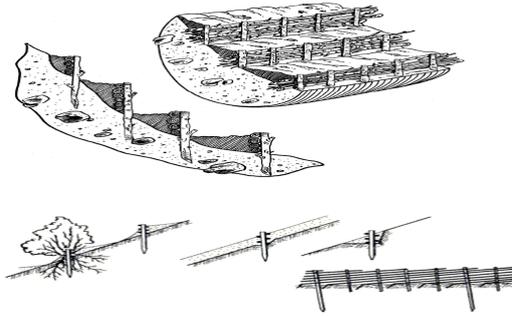
**V. BIOENGINEERING METHODS FOR STEEP SLOPES**

**Wattle Fences**

Wattle fences (Figure 6) are short retaining walls built of living cuttings. The living cuttings used to make the walls



sprout and grow, further strengthening the structure. Wattle fences are used where site moisture conditions will allow the living cuttings on the face of the fence to sprout and grow. Sites where fine textured soils can provide ample summer moisture or where seepage of groundwater provides moisture are suitable for wattle fence installations.



**Figure 6.** Wattle fences are short retaining walls constructed of living cuttings. They are used to provide slopes, which will support plant growth where over steepened slopes are preventing plant establishment. The section shows the effects of steeper slopes on wattle fence spacing.

Chestnut pegs (length: 1m, diameter 4-5 cm) driven into the soil (depth 50-70 cm) according to the contour lines every 1 meter. Between these pegs (every 20 cm) shorter of living material (diameter 2-3 cm, length 60 cm) are driven in (depth 30cm) and strong rods of sprouting material (such as rods of Salix, Platannas) are woven around them.

The ends of the woven rods are struck into the soil (depth 10 cm every 10 cm between them).

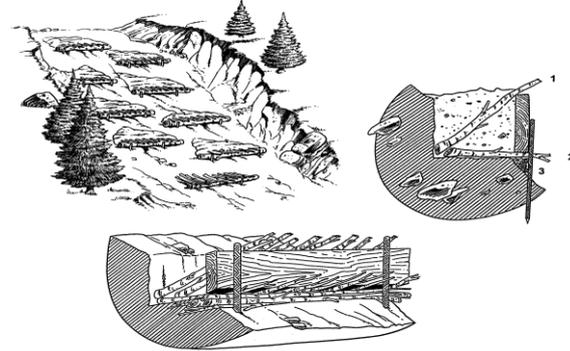
The construction is placed in part of the internal surface of slope (distance 30 -50 cm). The part between slope and construction filled with excavations products or surface soil of slope. In that way stabilize and suitable flat surfaces created for planting. (Figure 6).

While used extensively in the past, they are rarely constructed any longer because of their high labour costs and the danger of erosion of fine material from behind the fence.

**Modified Brush Layers**

Modified brush layers (Figure 7) are the brush layer (see below) supported on a short, small (2 m in length) log or board. The use of a log or board for support of the brush layer provides the added advantage that the small terrace that is created can serve to "catch" rolling rocks rather than allowing them to roll down the slope, gathering speed and damaging vegetation. Although the log or board will eventually rot, the cuttings will, by that time, have grown to the point where they are stabilizing the slope. The cuttings that are used in the brush layer will grow into a wall of plants that will serve to trap rocks and soil and prevent movement of materials down the slope. Modified

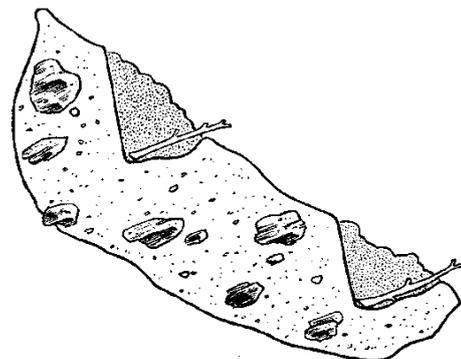
brush layers can be used on sites that would be too dry for effective wattle fence growth but where some form of additional support is needed for stabilization of the slopes.



**Figure 7.** Modified brush layers can be built with either a log or a board for support. They should be staggered across a slope so that material rolling down the slope doesn't have a chance to get going before it is caught. The detail shows a modified brush layer prior to backfilling, while the section shows the normal backfill which creates a bit of a bench.

**Brush Layers in a Cut**

Brush layers in a cut (Figure 8) are horizontal rows of cuttings (50 to 100 cm long) buried in the cut (in-situ materials) slope. Brush layers are constructed by digging a bench across the slope and placing the cuttings in a layer on the bench with the tips sticking out with at least seven eighths of the cutting underground. Brush layers in a cut are built from the bottom of the slope so that the second bench excavation can be used to backfill the first and so on up the slope. Brush layers in cuts add little to the stability of the cut as no significant bench is created by the brush layer as in a modified brush layer and the cuttings are not deep enough to provide substantial mechanical stability as in brush layer in fill. The wall of plant materials can act to control movement of materials from the slopes and can assist in maintenance of a road where falling materials are a problem. Modified brush layers (see above) are easier to build and provide more immediate stabilization than brush layers in a cut.



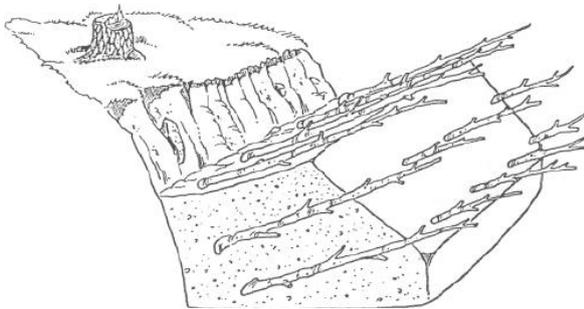
**Figure 8.** Brush layers in a cut can provide a row of living plant materials and assist in preventing movement of surface materials.



**VI. BIOENGINEERING METHODS FOR SOIL REINFORCEMENT**

**Brush Layers in Fill**

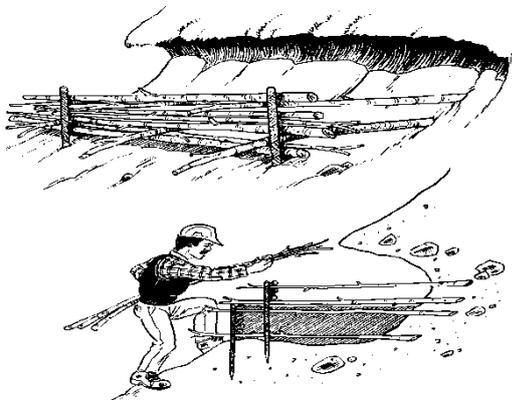
Brush layers in fill (Figure 9) are also horizontal rows of cuttings buried in a fill such as a pulled back road. Brush layers in fills are particularly useful where new roads are being built or where roads are being deactivated. In either case, brush layers can be used to strengthen the fill material. In some cases, fill materials must be placed on steep (1.5 : 1 or greater) angles due to the geometry of the site. In these cases, cuttings (1.5 to 5 m long) can be inserted into the fills as they are constructed. These increase the shear resistance of the soil and can assist in preventing circular failures.



**Figure 9.** Brush layers in fill can act to reinforce the fill material. Full length cuttings can be used and can be expected to root along their entire length.

**Live Reinforced Earth Walls**

Live reinforced earth walls (LaREWs) are a combination of wattle fences and brush layers that can be used to treat overhanging cuts and other slope cavities. Where piping has caused the cavity, live pole drains can be used in combination with LaREWs to treat the slope. Figure shows the typical design for LaREWs.



**Live Staking of Sod**

Establishment of a healthy grass and legume cover in cut and fill slopes is a requirement of road construction under the Forest Practices Code. However, in some cases, the cover that is established may tend to "peel" off of the slope. In these cases, live staking (see above) can be used

to hold the sod in place and to provide a diversity of rooting depths. This will prevent the development of a slip surface below the sod. The length of the cuttings used in live staking of sods will vary depending on the depth of rooting. However, lengths of 40 to 50 cm should be considered as a minimum. Live staking of sods can provide an effective solution to slipping turf mats.

**VII. CONCLUSION**

Bioengineering can be an effective tool for the treatment of landslides and unstable slopes. Treatments are somewhat economical and can provide important benefits in terms of reduced maintenance, reduced erosion and enhanced stability. As living systems, bioengineering systems need little or no maintenance and continue to strengthen over the years. Bioengineering can provide a useful bridge between traditional engineering treatments and normal seeding work. Bioengineering can be a useful addition in the recovery of forest sites.

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