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Chapter 18 Soil Bioengineering for Upland Slope Protection and Erosion Reduction

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Cover: Live plant cuttings are installed (top photo) on upland slopes to provide soil reinforcement and reduce surface erosion. The bottom photo shows the slope after 1 year. (Photos: Robbin B. Sotir & Associates)

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Preface

Chapter 18, Soil Bioengineering for Upland Slope Protection and Erosion Reduction is one of the 18 chapters of the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) Engineering Field Handbook, previously referred to as the Engineering Field Manual. Other chapters that are pertinent to, and should be referenced in use with, chapter 18 are:

Chapter 1: Engineering Surveys
Chapter 2: Estimating Runoff
Chapter 3: Hydraulics
Chapter 4: Elementary Soils Engineering
Chapter 5: Preparation of Engineering Plans
Chapter 6: Structures
Chapter 7: Grassed Waterways and Outlets
Chapter 8: Terraces
Chapter 9: Diversions
Chapter 10: Gully Treatment
Chapter 11: Ponds and Reservoirs
Chapter 12: Springs and Wells
Chapter 13: Wetland Restoration, Enhancement, or Creation
Chapter 14: Drainage
Chapter 15: Irrigation
Chapter 16: Streambank and Shoreline Protection
Chapter 17: Construction and Construction Materials

This is the first revision of chapter 18. The science of soil bioengineering is rapidly evolving and improving; therefore, additions to and modifications of this chapter will be made as necessary.

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Chapter 18 Soil Bioengineering for Upland Slope Protection and Erosion Reduction

650.1800 Introduction

(a) Purpose and scope

Chapter 18 provides field personnel with a guide for soil bioengineering intended primarily for upland slope protection and erosion reduction. It describes characteristics, principles, design, and construction techniques of soil bioengineering. Two approaches to soil bioengineering techniques are presented: woody vegetative systems and woody vegetative systems combined with simple structures. Woody vegetative systems are emphasized. Vegetative plantings and vegetated structures are discussed cursorily to help distinguish them from soil bioengineering techniques.

This chapter is national in scope and should be supplemented with regional and local information. Soil bioengineering measures, such as live cribwalls and brushlayering, are relatively complex and must be tailored carefully to specific soil and site conditions. The contents of this chapter are not directly applicable to massive erosion problems or complex shallow slope failure problems. Additional background on specific designs and sample calculations are available in other sources (Gray, et.al. 1982).

Planning and design of soil bioengineering systems generally require a team of experts. Therefore, the scope of this chapter reflects the interdisciplinary nature of soil bioengineering.

(b) Background

Soil bioengineering, in the context of upland slope protection and erosion reduction, combines mechanical, biological, and ecological concepts to arrest and prevent shallow slope failures and erosion. Basic approaches to upland slope protection and erosion control can be divided into two general categories: living and nonliving (table 18–1). Frequently, living and nonliving measures are combined to form a system.

The **living approach**, which uses live plant materials, can be further divided into two specific categories: vegetative plantings and soil bioengineering. Vegetative plantings are conventional plantings of grasses, forbs, and shrubs used to prevent surface erosion. Soil bioengineering utilizes live plant parts to provide soil reinforcement and prevent surface erosion (fig. 18–1). In soil bioengineering systems, the installation may play the major structural roles immediately or may become the major structural component over time.

Live staking, live fascines, brushlayers, branchpacking, and live gully repair are soil bioengineering techniques that use stems or branch parts of living plants as initial and primary soil reinforcing and stabilizing material. When these vegetative cuttings are placed in the ground, roots develop and foliage sprouts. The resulting vegetation becomes a major structural component of the soil bioengineering system.

Live cribwalls, vegetated rock gabions, vegetated rock walls, and joint plantings are soil bioengineering techniques that use porous structures with openings through which vegetative cuttings are inserted and established. The inert structural elements provide immediate resistance to sliding, erosion, and washout. As vegetation becomes established, roots invade and permeate the slope, binding it together into a unified, coherent mass. Over time, the structural elements diminish in importance as the vegetation increases in strength and functionality.

Nonliving approaches use rigid constructions, such as surface armoring, gravity retaining walls, and rock buttresses. Vegetation can be used in conjunction with nonliving structures to create vegetated structures. Vegetation enhances the structures and helps reduce surface erosion, but usually does not provide any major reinforcement benefits.

(c) Integrated planning and design requirements

Soil bioengineering combines biological elements with engineering design principles. The requirements for both must be considered when planning and designing the measures presented in table 18–1. For example, engineering requirements may dictate highly compacted soil for fill slopes, while plants prefer relatively loose soil. Using a sheep's foot roller for compaction is a solution that would integrate biological and engineering requirements because it compacts the soil, but also allows plant establishment in resulting depressions in the slope. Differing needs can generally be integrated through creative approaches and occasional compromises in planning and design.

(d) Applications

The soil bioengineering techniques in this document are generally appropriate for immediate protection of slopes against surface erosion, shallow mass wasting, cut and fill slope stabilization, earth embankment protection, and small gully repair treatment. Appropriate application of specific measures are discussed in detail in Section 650.1803, Construction techniques and materials.

Other situations where soil bioengineering measures can be employed are not discussed in this chapter. These situations include dune stabilization, wetland buffers, reservoir drawdown areas where plants can be submerged for extended periods, and areas with highly toxic soils. Properly designed and constructed soil bioengineering measures have also been employed with considerable success in stabilizing shorelines and streambanks. This topic is addressed in EFH, Chapter 16, Streambank and Shoreline Protection.

Table 18–1 Approaches to upland slope protection and erosion control

	Category	Examples	Appropriate uses	Role of vegetation
LIVING	**Vegetative plantings**			
	Conventional plantings	Grass seedlings Transplants Forbs	Control water and wind erosion. Minimize frost effects.	Control weeds. Bind & restrain soil. Filter soil from runoff. Intercept raindrops. Maintain infiltration. Moderate ground temperature.
	Soil bioengineering			
	Woody plants used as reinforcement, as barriers to soil movements, & in the frontal openings or interstices of retaining structures.	Live staking Live fascine Brushlayer Branchpacking Live cribwall Live gully repair Vegetated rock gabion Vegetated rock wall Joint planting	Control of rills & gullies. Control of shallow (translational) mass movement. Filter sediment. Improved resistance to low to moderate earth forces.	Same as above, but also reinforce soil, transpire excess water, & minimize downslope movement of earth masses. Reinforce fill into monolithic mass. Improve appearance and performance of structure.
NONLIVING	**Vegetated structures**			
	Inert structures with vegetative treatments.	Wall or revetment with slope face planting. Tiered structures with bench planting.	Control erosion on cut & fill slopes subject to scour & undermining.	Stop or prevent erosion & shallow sloughing on or at the slope face above the toe.
	Rigid construction	(see Chapter 6, Structures, of the Engineering Field Handbook).		

Figure 18–1 Soil bioengineering provides soil reinforcement and reduces surface erosion (Robbin B. Sotir & Associates photos)

Figure 18–1a Eroding fill slope

Figure 18–1b Measures being installed

Figure 18–1c Installation 1 year later

650.1801 Characteristics of soil bioengineering systems

Soil bioengineering uses particular characteristics of vegetative components and integrates specific characteristics of structures with vegetation. The resulting systems and their components have benefits and limitations that need to be considered prior to selecting them for use.

(a) Vegetative components

(1) Herbaceous species

Herbaceous vegetation, especially grasses and forbs, offers long-term protection against surface (water and wind) erosion on slopes. It provides only minor protection against shallow mass movement. Vegetation helps to prevent surface erosion by:

- Binding and restraining soil particles in place
- Reducing sediment transport
- Intercepting raindrops
- Retarding velocity of runoff
- Enhancing and maintaining infiltration capacity
- Minimizing freeze-thaw cycles of soils susceptible to frost

Herbaceous species are almost always used in conjunction with soil bioengineering projects to add protection against surface erosion.

(2) Woody species

More deeply rooted woody vegetation provides greater protection against shallow mass movement by:

- Mechanically reinforcing the soil with roots
- Depleting soil-water through transpiration and interception
- Buttressing and soil arching action from embedded stems

Live fascines, for example, provide many of these protective functions. They are fabricated from woody species, such as shrub willow or shrub dogwood, into sausage-like bundles, which are placed with the stems oriented generally parallel to the slope contour. This method of placement and orientation would not be used in slope reinforcement. Live fascines serve to dissipate the energy of downward moving water by trapping debris and providing a series of benches on which grasses, seedlings, and transplants establish more easily. Portions of the live fascines also root and become part of the stabilizing cover. Live fascines provide an immediate increase in surface stability and can further improve soil stability to depths of 2 to 3 feet as roots develop.

In the case of brushlayering, live branches or shoots of such woody species as shrub willow, dogwood, or privet are placed in successive layers with the stems generally oriented perpendicular to the slope contour, as shown in figure 18–1. This orientation is the optimal direction for maximum reinforcing effect in a slope. Brushlayering can improve soil stability to depths of 4 to 5 feet.

(b) Structural components

Properly designed and installed structures help to stabilize a slope against shallow mass movement and protect the slope against rill and gully formation. Structures also play a critical role in the establishment of vegetation on steep slopes or in areas subject to severe erosion. They may make it possible to establish plants on slopes steeper than would normally be possible. Structures stabilize slopes during the critical time for seed germination and root growth. Without this stabilization, vegetative plantings would fail during their most vulnerable time.

(1) Materials

Structures can be built from natural or manufactured materials. Natural materials, such as earth, rock, stone, and timber, usually cost less, are environmentally more compatible, and are better suited to vegetative treatment or slight modifications than are manufactured materials. Natural materials may also be available onsite at no cost.

Some structures are comprised of both natural and manufactured materials. Examples include concrete cribwalls, steel bin walls, gabion walls or revetments, welded wire or polymeric geogrid walls, and reinforced earth. In these cases steel and concrete mostly provide rigidity, strength, and reinforcement, whereas stone, rock, and soil provide mass. These types of

structures have spaces that are often planted with herbaceous or woody vegetation.

(2) Retaining structures
A retaining structure of some type is usually required to protect and stabilize steep slopes. Low retaining structures at the toe of a slope make it possible to grade the slope back to a more stable angle that can be successfully revegetated without loss of land at the crest. Structures are generally capable of resisting much higher lateral earth pressures and shear stresses than vegetation.

(3) Grade stabilization structures
Grade stabilization structures are used to control and prevent gully erosion. A grade stabilization structure reduces the grade above it and dissipates the excess energy of flowing water within the structure itself. Debris and sediment tend to be deposited and trapped upstream of the structure. This, in turn, permits establishment of vegetation behind the structure, which further stabilizes the ground. Grade stabilization structures may range from a series of simple timber check dams to complex concrete overfall structures and earth embankments with pipe spillways.

Gully control provides a good example of the integration of structures and vegetation. Structural measures may be required in the short term to stabilize critical locations. The long-term goal is to establish and maintain a vegetative cover that prevents further erosion. This goal is seldom realized unless the severe gully conditions can be altered immediately. Vegetation alone, for example, will rarely stabilize gully headcuts because of the concentrated water flow, overfalls, and pervasive forces that promote gully enlargement in an unstable channel system. Initially, the vegetation and the structure work together in an integrated fashion. The ultimate function of these structures, however, is to help establish vegetation which will provide long-term protection.

(c) Attributes and limitations

Soil bioengineering measures should not be viewed as a panacea or solution for all slope failure and surface erosion problems. Soil bioengineering has unique attributes, but is not appropriate for all sites and situations. In certain cases, a conventional vegetative treatment (e.g., grass seeding and hydro mulching) works satisfactorily at less cost. In other cases, the more appropriate and most effective solution is a structural retaining system alone or in combination with soil bioengineering.

The following specific attributes and limitations should be considered before applying a soil bioengineering technique:

(1) Environmental compatibility
Soil bioengineering systems generally require minimal access for equipment and workers and cause relatively minor site disturbance during installation. These are generally priority considerations in environmentally sensitive areas, such as parks, woodlands, riparian areas, and scenic corridors where aesthetic quality, wildlife habitat, and similar values may be critical (fig. 18–2).

(2) Cost effectiveness
Field studies have shown instances where combined slope protection systems have proven more cost effective than the use of either comparative vegetative treatments or structural solutions alone. Where construction methods are labor intensive and labor costs are reasonable, the combined systems may be especially cost effective. Where labor is either scarce or extremely expensive, however, soil bioengineering systems may be less practical than structural measures. This can be offset by the time of year (fall and winter) when other construction work is slow.

Using indigenous materials accounts for some of the cost effectiveness because plant costs are limited to labor for harvesting, handling, and direct costs for transporting the plants to the site.

(3) Planting times
Soil bioengineering systems are most effective when they are installed during the dormant season, usually the late fall, winter, and early spring.

Constraints on planting times or the availability of the required quantities of suitable plant materials during allowable planting times may limit the usefulness of soil bioengineering methods.

(4) Difficult sites
Soil bioengineering is often a useful alternative for small, highly sensitive, or steep sites where the use of machinery is not feasible and hand labor is a necessity.

However, rapid vegetative establishment may be difficult on extremely steep slopes.

The usefulness of soil bioengineering methods may be limited by the available medium for plant growth, such as rocky or gravelly slopes that lack sufficient fines or moisture to support the required plant growth. In addition, soil-restrictive layers, such as hardpans, may prevent required root growth.

The biotechnical usefulness of vegetation would be limited on slopes that are exposed to high velocity water flow or constant inundation.

(5) Harvesting local plant material

Appropriate vegetation is often obtained from local stands of willows and other suitable species. This stock is already well suited to the climate, soil conditions, and available moisture and is a good candidate for survival. While harvesting may often help a beneficial species proliferate, reliance on the use of local plant materials and gathering in the wild could result in short supplies or unacceptable depletion of site vegetation. Some localities may have prohibitions against gathering native plants, and materials must be purchased from commercial sources.

Figure 18–2 Newly established installation provides multiple functions and values (Robbin B. Sotir & Associates photo)

(6) Biotechnical strengths
Soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. In some instances, the primary role of the structural component is to give the vegetation a better chance to become established. It has been shown in slope reconstruction projects that soil bioengineering systems can withstand heavy rainfalls immediately after installation. Even if established vegetation dies, the plant roots and surface residue may continue to play an important protective role during reestablishment.

(7) Maintenance requirements
Once vegetation is well established on a soil bioengineering project, usually within one growing season, it generally becomes self-repairing by regeneration and growth and requires little maintenance. However, a newly installed soil bioengineering project will require careful periodic inspections until it is established. Established vegetation is vulnerable to trampling, drought, grazing, nutrient deficiencies, toxins, and pests, and may require special management measures at times.

650.1802 Basic principles and design considerations

(a) Basic principles of soil bioengineering

The basic principles that apply to conventional soil erosion control also apply in general to soil bioengineering. These principles are mostly common sense guidelines that involve planning, timing, and minimizing site disturbance as well as the design of individual measures themselves. Applicable principles can be summarized as follows:

(1) Fit the soil bioengineering system to the site
This means considering site topography, geology, soils, vegetation, and hydrology. Avoid extensive grading and earthwork in critical areas and perform soil tests to determine if vigorous plant growth can be supported. At a minimum, collect the following information:

(i) Topography and exposure

- Note the degree of slope in stable and unstable areas. Also note the presence or lack of moisture. The likely success of soil bioengineering treatments can best be determined by observing existing stable slopes in the vicinity of the project site.
- Note the type and density of existing vegetation in areas with and without moisture and on slopes facing different directions. Certain plants grow well on east-facing slopes, but will not survive on south-facing slopes.
- Look for areas of vegetation that may be growing more vigorously than other site vegetation. This is generally a good indicator of excess moisture, such as seeps and a perched water table, or it may reflect a change in soils.

(ii) Geology and soils

- Consult SCS geologists about geologic history and types of deposits (colluvium, glacial, alluvium, other).
- Note evidence of past sliding. If site evidence exists, determine whether the slide occurred along a deep or shallow failure surface. Leaning or deformed trees may indicate previous slope movement or downhill creep. In addition to site evidence, check aerial photos, which can reveal features that may not be apparent from a site visit.
- Determine soil type and depth. Use the soil survey report, if available, or consult SCS soil scientists.

(iii) Hydrology

- Determine the drainage area associated with the problem area. Note whether water can be diverted away from the problem area.
- Determine the annual precipitation. Are there concentrated discharges?
- Calculate peak flows or mean discharge through the project area.
- If a seep area was noted, locate the source of the water. Determine whether the water can be intercepted and diverted away from the slope face.

(2) Retain existing vegetation whenever possible

Vegetation provides excellent protection against surface erosion and shallow slope failures. Soil bioengineering measures are designed to aid or enhance the reestablishment of vegetation.

(3) Limit removal of vegetation

- Limit cleared area to the smallest practical size
- Limit duration of disturbance to the shortest practical time
- Remove and store existing woody vegetation that may be used later in the project
- Schedule land clearing during periods of low precipitation whenever possible

(4) Stockpile and protect topsoil

Topsoil removed during clearing and grading operations can be reused during planting operations.

(5) Protect areas exposed during construction

Temporary erosion and sediment control measures can be used.

(6) Divert, drain, or store excess water

- Install a suitable system to handle increased and/or concentrated runoff caused by changed soil and surface conditions during and after construction.
- Install permanent erosion and sediment control measures in the project before construction is started if possible.

(b) Design considerations

(1) Earthwork

Typically, sites require some earthwork prior to the installation of soil bioengineering systems. A steep undercut or slumping bank, for example, requires grading to flatten the slope for stability. The degree of flattening depends on the soil type, hydrologic conditions, geology, and other site factors.

(2) Scheduling and timing

Planning and coordination are needed to achieve optimal timing and scheduling. The seasonal availability of plants or the best time of year to install them may not coincide with the construction season or with tight construction schedules. In some cases, rooted stock may be used as an alternative to unrooted dormant season cuttings.

(3) Vegetative damage to inert structures

Vegetative damage to inert structures may occur when inappropriate species or plant materials that exceed the size of openings in the face of structures are used. Vegetative damage does not generally occur from roots. Plant roots tend to avoid porous, open-faced retaining structures because of excessive sunlight, moisture deficiencies, and the lack of a growing medium.

(4) Moisture requirements and effects

The backfill behind a stable retaining structure has certain specified mechanical and hydraulic properties. Ideally, the fill is coarse-grained, free-draining, granular material. Excessive amounts of clay, silt, and organic matter are not desirable. Free drainage is essential to the mechanical integrity of an earth-retaining structure and also important to vegetation,

which cannot tolerate waterlogged soil conditions. The establishment and maintenance of vegetation, however, usually requires the presence of some fines and organic matter in the soil to provide adequate moisture and nutrient retention. In many instances, these biological requirements can be satisfied without compromising engineering performance of the structure. With cribwalls, for example, adequate amounts of fines or other amendments can be incorporated into the backfill. Gabions can be filled with rock and soil drifted into them to facilitate growth of vegetation. Woody vegetative cuttings can be placed between the baskets during filling and into the soil or backfill beyond the baskets. The needs of plants and the requirements of structures must be taken into account when designing a system.

650.1803 Construction techniques and materials

(a) General considerations

Soil bioengineering measures have certain requirements and capabilities. Plant species must be suitable for the intended use and adapted to the site's climate and soil conditions. Consult a plant materials specialist about available cultivars to ensure that appropriate species are used. Species that root easily, such as willow, are required for such measures as live fascines, brushlayer, and live staking or where unrooted stems are used with structural measures. Table 18–2 is a general listing of plant species used in soil bioengineering. A more complete list of plant species is an appendix to Chapter 16, Streambank and Shoreline Protection, of the Engineering Field Handbook.

Table 18–2 Soil bioengineering plant species

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Acer negundo Boxelder	N, NE	Common	Excellent	Tree	Fibrous, mod. deep, spreading, suckering	Poor to fair
Alnus rubra Red alder	NW	Very common	Excellent	Medium tree	Shallow, spreading, suckering	Poor to fair
Baccharis glutinosa Water wally	W	Common	Very good	Medium shrub	Fibrous	Good
Baccharis halimifolia Eastern baccharis	S, SE	Common	Very poor	Medium shrub	Fibrous	Good
Baccharis pilularis Coyotebrush	W	Very common	Good	Medium shrub	Fibrous	Good
Baccharis viminea Mule fat	W	Very common	Very good	Medium shrub	Fibrous	Good

Table 18–2 Soil bioengineering plant species—Continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Betula papyrifera Paper birch	N, E, & W	Common	Good	Tree	Fibrous shallow	Poor
Betula pumila Low birch	N, E, & W	Common	Very good	Medium shrub	Fibrous	Poor
Cornus amomum Silky dogwood	N, SE	Very common	Very good	Small shrub	Shallow fibrous	Very good
Cornus racemosa Gray dogwood	NE	Common	Very good	Med-small shrub	Shallow fibrous	Good
Cornus rugosa Roundleaf dogwood	NE	Common	Very good	Med-small shrub	Shallow fibrous	Fair-good
Cornus sericea ssp. stolonifera Red osier dogwood	N, NE, & NW	Very common	Very good	Med-small shrub	Shallow	Very good
Crataegus Sp. Hawthorn	SE	Uncommon	Good	Sm. dense tree	Tap root	Fair
Elaeagnus commutata Silverberry	N. Cent.	Very Common	Poor	Small tree	Shallow fibrous	Fair-good
Ligustrum sinense Chinese privet	S, SE	Common	Fair-good	Medium shrub	Shallow spreading	Good
Lonicera involucrata Black twinberry	E	Common	Poor-fair	Large shrub	Shallow fibrous	Good
Physocarpus capitatus Pacific ninebark	NW, W	Common	Fair	Large shrub	Fibrous	Good
Physocarpus opulifolius Common ninebark	NE	Common	Good	Medium shrub	Shallow lateral	Fair-good
Populus angustifolia Narrowleaf cottonwood	W	Common	Good	Tree	Shallow	Very good
Populus balsamifera ssp. trichocarpa Black cottonwood	NW	Common	Good	Tree	Shallow fibrous	Very good

Table 18–2 Soil bioengineering plant species—Continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Populus deltoides Eastern cottonwood	MW, E	Very common	Good	Large tree	Shallow fibrous suckering	Very good
Populus fremontii Fremont cottonwood	SW	Very common	Good	Tree	Shallow fibrous	Very good
Populus tremuloides Quaking aspen	NW	Very common	Good	Large tree	Shallow suckering	Fair
Robinia pseudoacacia Black locust	NE	Common	Very poor	Tree	Shallow	Good
Rubus allegheniensis Allegheny blackberry	NE	Very common	Very good	Small shrub	Fibrous	Good
Rubus spectabilis Salmonberry	SW	Very common	Good	Small shrub	Fibrous	Good
Rubus strigosus Red raspberry	N, NE, & W	Very common	Very good	Small shrub	Fibrous	Good
Salix amygdaloides Peachleaf willow	N, S	Common	Good	Very large shrub	Shallow to deep	Very good
Salix bonplandiana Pussy willow	W & MW	Very common	Good	Medium shrub	Fibrous	Very good
Salix eriocephala ssp. ligulifolia Erect willow	NW	Common	Good	Large shrub	Fibrous	Very good
Salix exigua Coyote willow	NW	Fairly common	Good	Medium shrub	Shallow suckering	Good
Salix gooddingii Goodding willow	SW	Very common	Good	Large shrub Small tree	Shallow to deep	Excellent
Salix hookeriana Hooker willow	NW	Common	Good	Large shrub Small tree	Fibrous dense	Very good
Salix humilis Prairie willow	N, NE	Very common	Good	Medium shrub	Fibrous spreading	Good

Table 18–2 Soil bioengineering plant species—Continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Salix interior Sandbar willow	N, SE	Common	Good	Large shrub	Shallow to deep	Very good
Salix lasiolepis Arroya willow	W	Common	Good	Large shrub	Fibrous	Very good
Salix lemmonii Lemmon willow	W	Common	Good	Medium shrub	Fibrous	Very good
Salix lucida Shining willow	N, NE	Very common	Good	Med-large shrub	Fibrous spreading	Very good
Salix lucida ssp. lasiandra Pacific willow	NW	Very common	Good	Large shrub Small tree	Fibrous	Very good
Salix lutea Yellow willow	W	Very common	Good	Med-large shrub	Fibrous	Very good
Salix nigra Black willow	N, SE	Very common	Good	Large shrub Small tree	Shallow to deep	Excellent
Salix purpurea Purpleosier willow	N, S, E, & W	Very common	Very good	Medium shrub	Shallow	Very good
Salix scouleriana Scouler's willow	NE	Very common	Good	Large shrub Small tree	Shallow	Very good
Salix sitchensis Sitka willow	NW	Common	Good	Very large shrub	- - -	Very good
Salix X cotteti Dwarf willow	N, S, E, & W	Uncommon	Good	Small shrub	Shallow	Very good
Salix discolor Pussy willow	N, NE	Very common	Good	Large shrub	Shallow fibrous spreading	Very good
Sambucus canadensis American elderberry	NE, SE	Very common	Very good	Medium shrub	Fibrous	Good
Sambucus cerulea Blue elderberry	W	Common	Very good	Medium shrub	Fibrous	Poor

Table 18–2 Soil bioengineering plant species—Continued

Name	Location	Availability	Habitat value	Size/form	Root type	Rooting ability from cuttings
Sambucus racemosa Red elderberry	NW	Common	Good	Medium shrub	- - -	Good
Sambucus racemosa ssp. pubens Scarlet elder	NE	Common	Very good	Medium shrub	Deep laterals	Fair-good
Spiraea alba Meadowsweet spirea	N, E	Common	Good	Small dense tree	Dense shallow lateral	Fair-good
Spiraea douglasii Douglas spirea	NW	Common	Fair	Dense shrub	Fibrous suckering	Good
Spiraea tomentosa Hardhack spirea	NE	Common	Good	Small shrub	Dense shallow	Fair
Symphoricarpos albus Snowberry	N, NW, & E	Common	Good	Small shrub	Shallow fibrous suckering	Good
Viburnum alnifolium Hubbiebush viburnum	NE	Fairly common	Good	Large shrub	Shallow fibrous	Good
Viburnum dentatum Arrowwood viburnum	E	Common	Good	Medium shrub	Shallow fibrous	Good
Viburnum lentago Nannyberry viburnum	S, SE	Fairly common	Good	Large shrub	Shallow	Fair-good

Rooted plants and vegetative cuttings are living materials and must be handled properly to avoid excess stress, such as drying or exposure to heat. They must be installed in moist soil and be adequately covered. The soil must be compacted to eliminate or minimize air pockets around the buried stems. If soils are not at or near moisture capacity, the installation must be delayed unless deep and regular irrigation can be provided during and following installation.

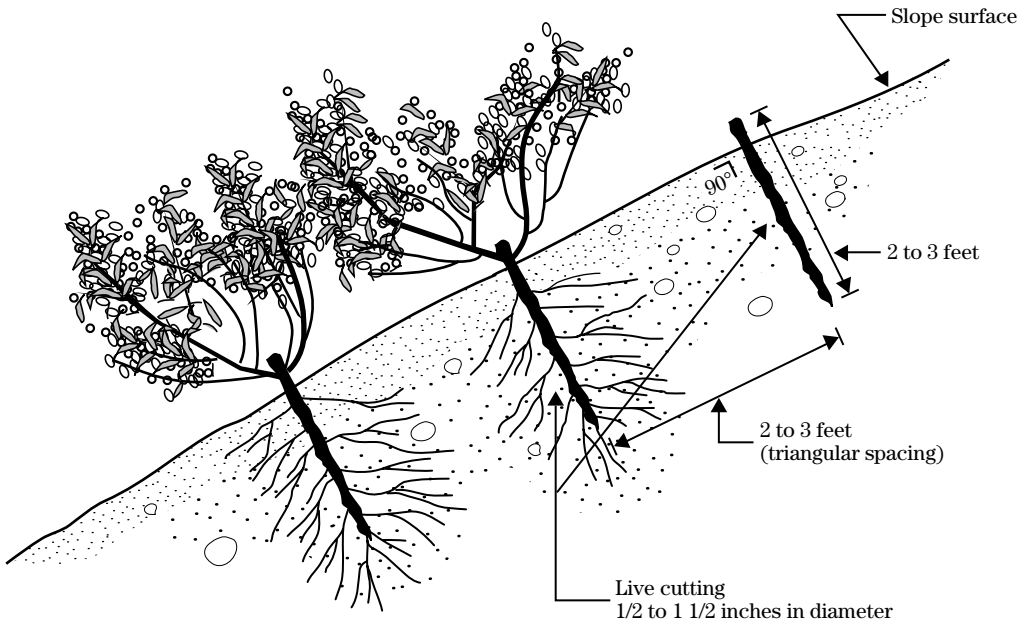
Installation of soil bioengineering systems is best accomplished in the late fall at the onset of plant dormancy, in the winter as long as the ground is not frozen, or in early spring before growth begins. In some cases installation after initial spring growth may be successful if extreme care is used, but the risks of failure are high. Summer installation is not recommended. Rooted plants can be used, but they are sometimes less effective and more expensive.

All installations should be inspected regularly and provisions made for prompt repair if needed. Initial failure of a small portion of a system normally can be repaired easily and inexpensively. Neglect of small failures, however, can result in the failure of large portions of a system.

Properly designed and installed vegetative portions of systems will become self-repairing to a large extent. Periodic pruning and replanting may be required to maintain healthy and vigorous vegetation. Structural elements, such as cribwalls, rock walls, and gabions,

Figure 18–3 Live stake installation

Cross section
Not to scale



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

may require maintenance and/or replacement throughout their life. Where the main function of structural elements is to allow vegetation to become established and take over the role of slope stabilization, the eventual deterioration of the structures is not a cause for concern.

(b) Soil bioengineering techniques

The following describes soil bioengineering techniques. Their applications, effectiveness, and construction guidelines are also presented.

(1) Live stake

(i) Description—Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground (fig. 18–3). If correctly prepared and placed, the live stake will root and grow (fig. 18–4).

A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Most willow species root rapidly and begin to dry out a slope soon after installation. This is an appropriate technique for repair of small earth slips and slumps that frequently are wet.

Figure 18–4 Top growth and root development of a 7-month-old live stake (Robbin B. Sotir & Associates photo)

(ii) Applications and effectiveness:

- A technique for relatively uncomplicated site conditions when construction time is limited and an inexpensive method is necessary.
- May be used for pegging down surface erosion control materials.
- Enhances conditions for natural invasion and the establishment of other plants from the surrounding plant community.
- Can be used to stabilize intervening area between other soil bioengineering techniques, such as live fascines.

(iii) Construction guidelines

Live material sizes—The cuttings are usually 1/2 to 1 1/2 inches in diameter and 2 to 3 feet long, as shown in figure 18–5. For final size determination, refer to the available cutting source. Figure 18–6 shows a rooted, healthy live stake.

Live material preparation

- The materials must have side branches cleanly removed and the bark intact.
- The basal ends should be cut at an angle for easy insertion into the soil. The top should be cut square.
- Materials should be installed the same day that they are prepared.

Figure 18–5 A prepared live stake (note angled basal end and flat top end) (Robbin B. Sotir & Associates photo)

Installation

- Tamp the live stake into the ground at right angles to the slope. The installation may be started at any point on the slope face.
- The live stakes should be installed 2 to 3 feet apart using triangular spacing. The density of the installation will range from 2 to 4 stakes per square yard.
- The buds should be oriented up.
- Four-fifths of the length of the live stake should be installed into the ground and soil firmly packed around it after installation.
- Do not split the stakes during installation. Stakes that split should be removed and replaced.
- An iron bar can be used to make a pilot hole in firm soil. Drive the stake into the ground with a dead blow hammer (hammer head filled with shot or sand).

Figure 18–6 A live stake that has rooted and is demonstrating healthy growth (Robbin B. Sotir & Associates photo)

(2) Live fascine

(i) Description—Live fascines are long bundles of branch cuttings bound together into sausage-like structures (fig. 18–7).

When cut from appropriate species and properly installed with live and dead stout stakes, they will root and immediately begin to stabilize slopes. They should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow face sliding. This system, installed by a trained crew, does not cause much site disturbance (fig. 18–8)

(ii) Applications and effectiveness

- An effective stabilization technique for slopes.
- Protects slopes from shallow slides (1 to 2 foot depth).
- Immediately reduces surface erosion or rilling.
- Suited to steep, rocky slopes, where digging is difficult.
- Capable of trapping and holding soil on the face of the slope, thus reducing a long slope into a series of shorter slopes.
- Enhances vegetative establishment by creating a microclimate conducive to plant growth.

(iii) Construction guidelines

Live materials—Cuttings must be from species, such as young willows or shrub dogwoods, that root easily and have long, straight branches.

Live material sizes and preparation

- Cuttings tied together to form live fascine bundles vary in length from 5 to 30 feet or longer, depending on site conditions and limitations in handling.
- The completed bundles should be 6 to 8 inches in diameter, with all of the growing tips oriented in the same direction. Stagger the cuttings in the bundles so that tops are evenly distributed throughout the length of the uniformly sized live fascine.
- Live stakes should be 2 1/2 feet long in cut slopes and 3 feet long in fill slopes.

Figure 18–7 Fabrication of a live fascine bundle (Robbin B. Sotir & Associates photo)

Figure 18–8 A live fascine system (Robbin B. Sotir & Associates photos)

Figure 18–8a During installation (note size and depth of trench to size of live fascine bundle)

Figure 18–8b Three months after installation

Inert materials—String used for bundling should be untreated twine.

Dead stout stakes used to secure the live fascines should be 2 1/2-foot long, untreated, 2 by 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length. Only new, sound, unused lumber should be used, and any stakes that shatter upon installation should be discarded (fig. 18–9).

Installation

- Prepare the live fascine bundles and live stakes immediately before installation.
- Beginning at the base of the slope, dig a trench on the contour just large enough to contain the live fascine. The trench will vary in width from 12 to 18 inches, depending on the angle of the slope to be treated. The depth will be 6 to 8 inches, depending on the individual bundle's final size.
- Place the live fascine into the trench.
- Drive the dead stout stakes directly through the live fascine every 2 to 3 feet along its length. Extra stakes should be used at connections or bundle overlaps. Leave the top of the stakes flush with the installed bundle.
- Live stakes are generally installed on the downslope side of the bundle. Drive the live stakes below and against the bundle between the previously installed dead stout stakes. The live stakes should protrude 2 to 3 inches above the top of the live fascine. Place moist soil along the sides of the live fascine. The top of the fascine should be slightly visible when the installation is completed (fig. 18–10).

Next, at intervals on contour or at an angle up the face of the bank, repeat the preceding steps to the top of the slope (table 18–3). When possible, place one or two rows over the top of the slope.

Long straw or similar mulching material should be placed between rows on 2.5:1 or flatter slopes, while slopes steeper than 2.5:1 should have jute mesh or similar material placed in addition to the mulch.

Figure 18–9 A dead stout stake

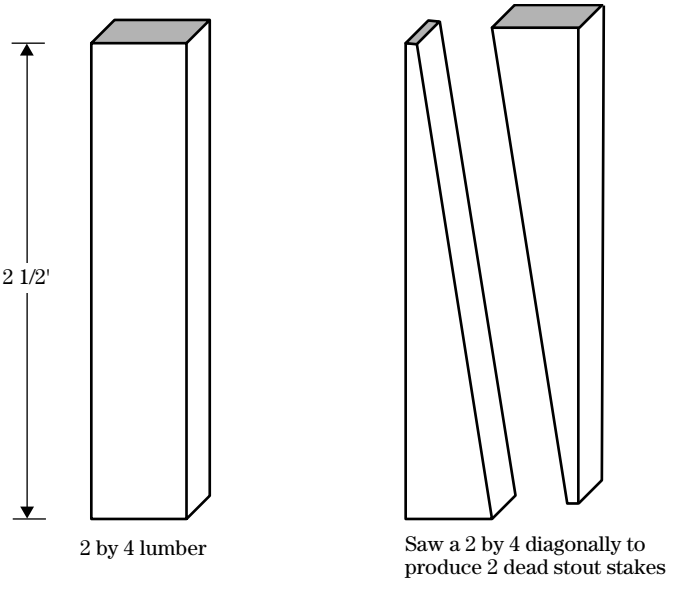
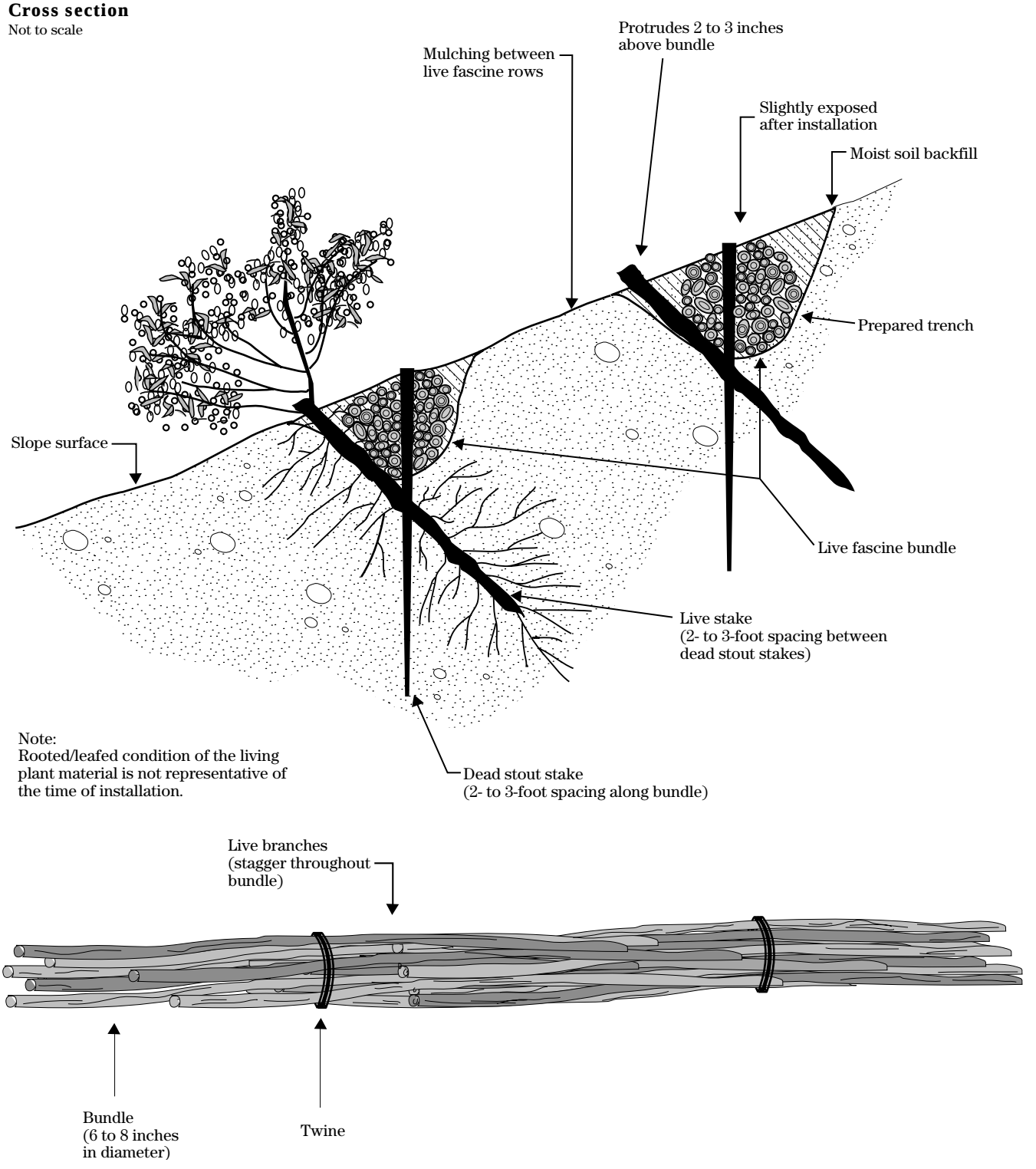


Table 18–3 Live fascine installation guidelines

Slope	Slope distance between trenches (ft)	Maximum slope length (ft)
1:1 to 1.5:1	3 – 4	15
1.5:1 to 2:1	4 – 5	20
2:1 to 2.5:1	5 – 6	30
2.5:1 to 3:1	6 – 8	40
3.5:1 to 4:1	8 – 9	50
4.5:1 to 5:1	9 – 10	60

Figure 18–10 Live fascine details



(3) Brushlayer

(i) Description—Brushlayering is somewhat similar to live fascine systems because both involve the cutting and placement of live branch cuttings on slopes. The two techniques differ principally in the orientation of the branches and the depth to which they are placed in the slope. In brushlayering, the cuttings are oriented more or less perpendicular to the slope contour (fig. 18–11). The perpendicular orientation is more effective from the point of view of earth reinforcement and mass stability of the slope.

Brushlayering consists of placing live branch cuttings in small benches excavated into the slope. The benches can range from 2 to 3 feet wide. These systems are recommended on slopes up to 2:1 in steepness and not to exceed 15 feet in vertical height. Brushlayer branches serve as tensile inclusions or reinforcing units. The portions of the brush that protrude from the slope face assist in retarding runoff and reducing surface erosion.

(ii) Applications and effectiveness—Brushlayers perform several immediate functions in erosion control, earth reinforcement, and mass stability of slopes:

- Breaking up the slope length into a series of shorter slopes separated by rows of brushlayer.
- Reinforcing the soil with the unrooted branch stems.
- Reinforcing the soil as roots develop, adding significant resistance to sliding or shear displacement.
- Providing slope stability and allowing vegetative cover to become established.
- Trapping debris on the slope.
- Aiding infiltration on dry sites.
- Drying excessively wet sites.
- Adjusting the site's microclimate, thus aiding seed germination and natural regeneration.
- Redirecting and mitigating adverse slope seepage by acting as horizontal drains.

(iii) Construction guidelines

Live material sizes—Branch cuttings should be 1/2 to 2 inches in diameter and long enough to reach the back of the bench. Side branches should remain intact for installation.

Installation

- Starting at the toe of the slope, benches should be excavated horizontally, on the contour, or angled slightly down the slope, if needed to aid drainage. The bench should be constructed 2 to 3 feet wide.
- The surface of the bench should be sloped so that the outside edge is higher than the inside (fig. 18–12).
- Live branch cuttings should be placed on the bench in a crisscross or overlapping configuration.
- Branch growing tips should be aligned toward the outside of the bench.
- Backfill is placed on top of the branches and compacted to eliminate air spaces. The brush tips should extend slightly beyond the fill to filter sediment.
- Each lower bench is backfilled with the soil obtained from excavating the bench above.
- Long straw or similar mulching material with seeding should be placed between rows on 3:1 or flatter slopes, while slopes steeper than 3:1 should have jute mesh or similar material placed in addition to the mulch.
- The brushlayer rows should vary from 3 to 5 feet apart, depending upon the slope angle and stability (table 18–4).

Table 18–4 Brushlayer installation guidelines

Slope	Slope distance between benches Wet slopes (ft)	Dry slopes (ft)	Maximum slope length (ft)
2:1 to 2.5:1	3	3	15
2.5:1 to 3:1	3	4	15
3.5:1 to 4:1	4	5	20

Figure 18–11 A brushlayer system (Robbin B. Sotir & Associates photos)

Figure 18–11a During installation

Figure 18–11b Two years after installation

Figure 18–12 Installing a brushlayer (Robbin B. Sotir & Associates photos)

Figure 18–12a Bench being prepared for a brushlayer

Figure 18–12b Placing live branch cuttings (Note crisscross configuration)

(4) Branchpacking

(i) Description—Branchpacking consists of alternating layers of live branch cuttings and compacted backfill to repair small localized slumps and holes in slopes (fig. 18–13).

(ii) Applications and effectiveness

- Effective in earth reinforcement and mass stability of small earthen fill sites.
- Produces a filter barrier, reducing erosion and scouring conditions.
- Repairs holes in earthen embankments other than dams where water retention is a function.
- Provides immediate soil reinforcement.

(iii) Construction guidelines

Live material—Live branch cuttings may range from 1/2 inch to 2 inches in diameter. They should be long enough to touch the undisturbed soil at the back of the trench and extend slightly from the rebuilt slope face.

Inert material—Wooden stakes should be 5 to 8 feet long and made from 3- to 4-inch diameter poles or 2 by 4 lumber, depending upon the depth of the particular slump or hole.

Figure 18–13 A branchpacking system being installed (Robbin B. Sotir & Associates photo)

Installation

- Starting at the lowest point, drive the wooden stakes vertically 3 to 4 feet into the ground. Set them 1 to 1 1/2 feet apart.
- A layer of living branches 4 to 6 inches thick is placed in the bottom of the hole, between the vertical stakes, and perpendicular to the slope face (fig 18–14). They should be placed in a crisscross configuration with the growing tips generally oriented toward the slope face. Some of the basal ends of the branches should touch the back of the hole or slope.
- Subsequent layers of branches are installed with the basal ends lower than the growing tips of the branches.
- Each layer of branches must be followed by a layer of compacted soil to ensure soil contact with the branch cuttings.
- The final installation should match the existing slope. Branches should protrude only slightly from the filled face.
- The soil should be moist or moistened to insure that live branches do not dry out.

The live branch cuttings serve as tensile inclusions for reinforcement once installed. As plant tops begin to grow, the branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or holes, while roots spread throughout the backfill and surrounding earth to form a unified mass (fig. 18–15). Branchpacking is not effective in slump areas greater than 4 feet deep or 5 feet wide.

Figure 18–14 Branchpacking details

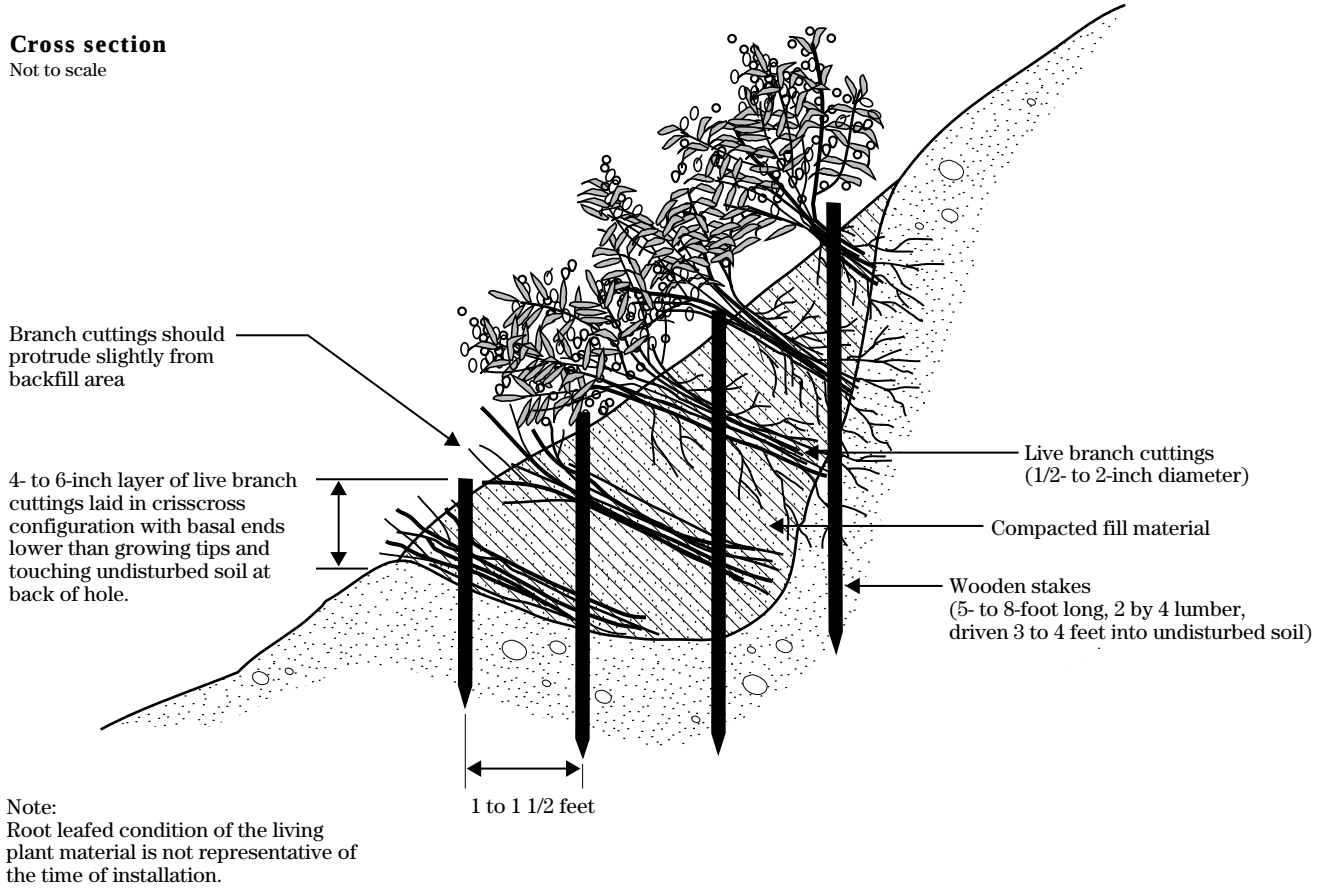


Figure 18–15 Completed branchpacking system (Robbin B. Sotir & Associates photos)

Figure 18–15a Newly installed system

Figure 18–15b One year after installation

(5) Live gully repair

(i) Description—A live gully repair utilizes alternating layers of live branch cuttings and compacted soil to repair small rills and gullies. Similar to branchpacking, this method is more appropriate for the repair of rills and gullies.

(ii) Applications and effectiveness

- The installed branches offer immediate reinforcement to the compacted soil and reduce the velocity of concentrated flow of water.
- Provides a filter barrier that reduces rill and gully erosion.
- Limited to rills or gullies which are a maximum of 2 feet wide, 1 foot deep, and 15 feet long.

(iii) Construction guidelines

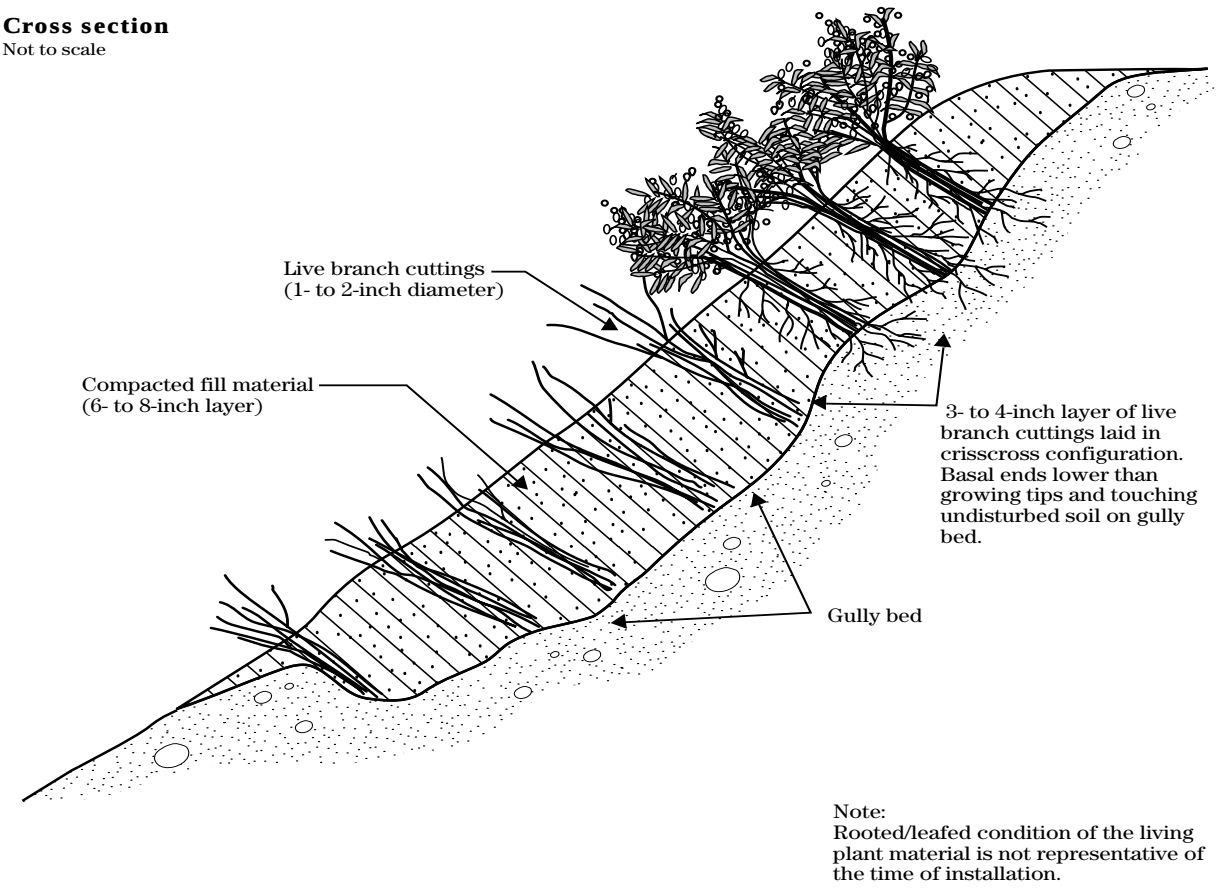
Live material sizes—Live branch cuttings may range from 1/2 inch to 2 inches in diameter. They should be long enough to touch the undisturbed soil at the back of the rill or gully and extend slightly from the rebuilt slope face.

Inert materials—Fill soil is compacted in alternate layers with live branch cuttings.

Installation

- Starting at the lowest point of the slope, place a 3- to 4-inch layer of branches at lowest end of the rill or gully and perpendicular to the slope (fig. 18–16).

Figure 18–16 Live gully repair details



- Cover with a 6- to 8-inch layer of fill soil.
- Install the live branches in a crisscross fashion. Orient the growing tips toward the slope face with basal ends lower than the growing tips.
- Follow each layer of branches with a layer of compacted soil to ensure soil contact with the live branch cuttings.

(6) Live cribwall

(i) Description—A live cribwall consists of a hollow, box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings which root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (fig. 18–17).

(ii) Applications and effectiveness

- This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Not designed for or intended to resist large, lateral earth stresses. It should be constructed to a maximum of 6 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a more vertical structure is required.
- Provides immediate protection from erosion, while established vegetation provides long-term stability.
- Should be tilted back or battered if the system is built on a smooth, evenly sloped surface.
- May also be constructed in a stair-step fashion, with each successive course of timbers set back 6 to 9 inches toward the slope face from the previously installed course.

Figure 18–17 A live cribwall being installed (Robbin B. Sotir & Associates photo)

(iii) Construction guidelines

Live material sizes—Live branch cuttings should be 1/2 to 2 inches in diameter and long enough to reach the back of the wooden crib structure.

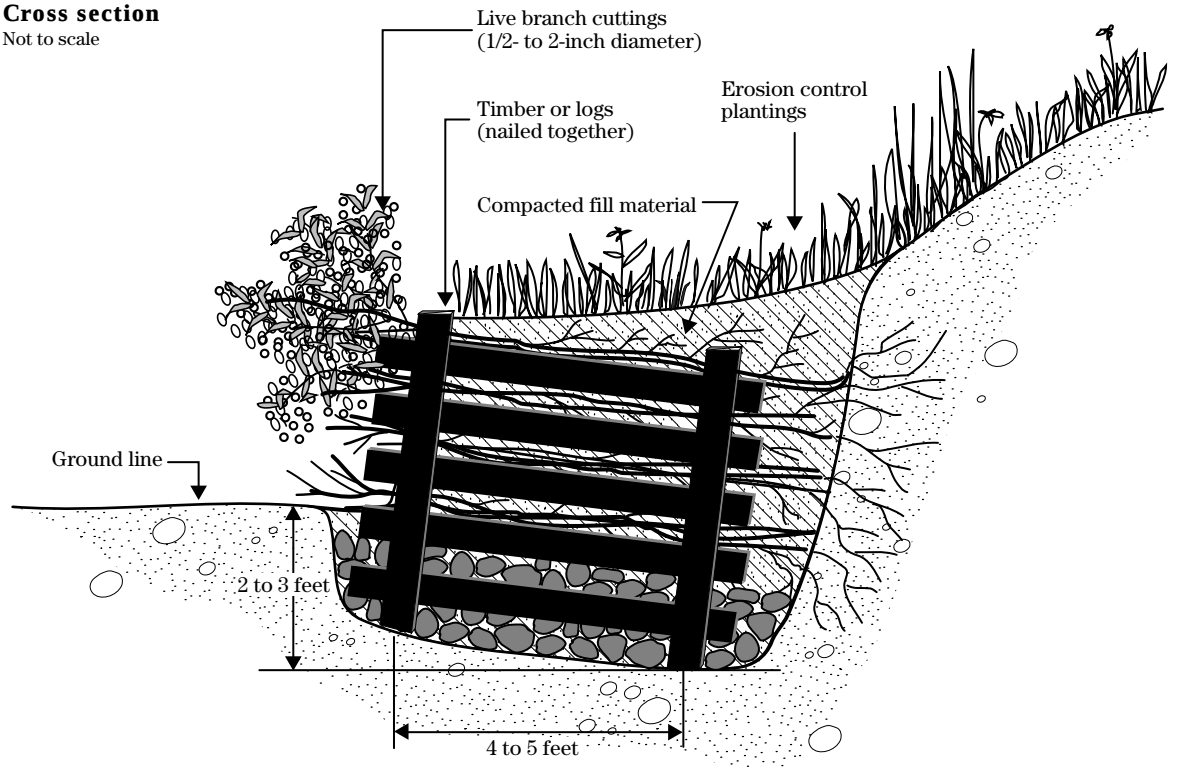
Inert materials—Logs or timbers should range from 4 to 6 inches in diameter or dimension. The lengths will vary with the size of the crib structure.

Large nails or rebar are required to secure the logs or timbers together.

Installation

- Starting at the lowest point of the slope, excavate loose material 2 to 3 feet below the ground elevation until a stable foundation is reached.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.
- Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4 to 5 feet apart and parallel to the slope contour.
- Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course to overhang the front and back of the previous course by 3 to 6 inches.
- Each course of the live cribwall is placed in the same manner and nailed to the preceding course with nails or reinforcement bars.
- When the cribwall structure reaches the existing ground elevation, place live branch cuttings on the backfill perpendicular to the slope; then cover the cuttings with backfill and compact.
- Live branch cuttings should be placed at each course to the top of the cribwall structure with growing tips oriented toward the slope face. Follow each layer of branches with a layer of compacted soil to ensure soil contact with the live branch cuttings. Some of the basal ends of the live branch cuttings should reach to undisturbed soil at the back of the cribwall with growing tips protruding sightly beyond the front of the cribwall (fig. 18–18).

Figure 18–18 Live cribwall details



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

(7) Vegetated rock gabions

(i) Description—Vegetated gabions begin as rectangular containers fabricated from a triple twisted, hexagonal mesh of heavily galvanized steel wire. Empty gabions are placed in position, wired to adjoining gabions, filled with stones and then folded shut and wired at the ends and sides. Live branches are placed on each consecutive layer between the rock-filled baskets. These will take root inside the gabion baskets and in the soil behind the structures. In time the roots consolidate the structure and bind it to the slope (fig. 18–19).

(ii) Applications and effectiveness

- This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Not designed for or intended to resist large, lateral earth stresses. It should be constructed to a maximum of 5 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a more vertical structure is required.

(iii) Construction guidelines

Live material sizes—Branches should range from 1/2 to 1 inch in diameter and must be long enough to reach beyond the back of the rock basket structure into the backfill.

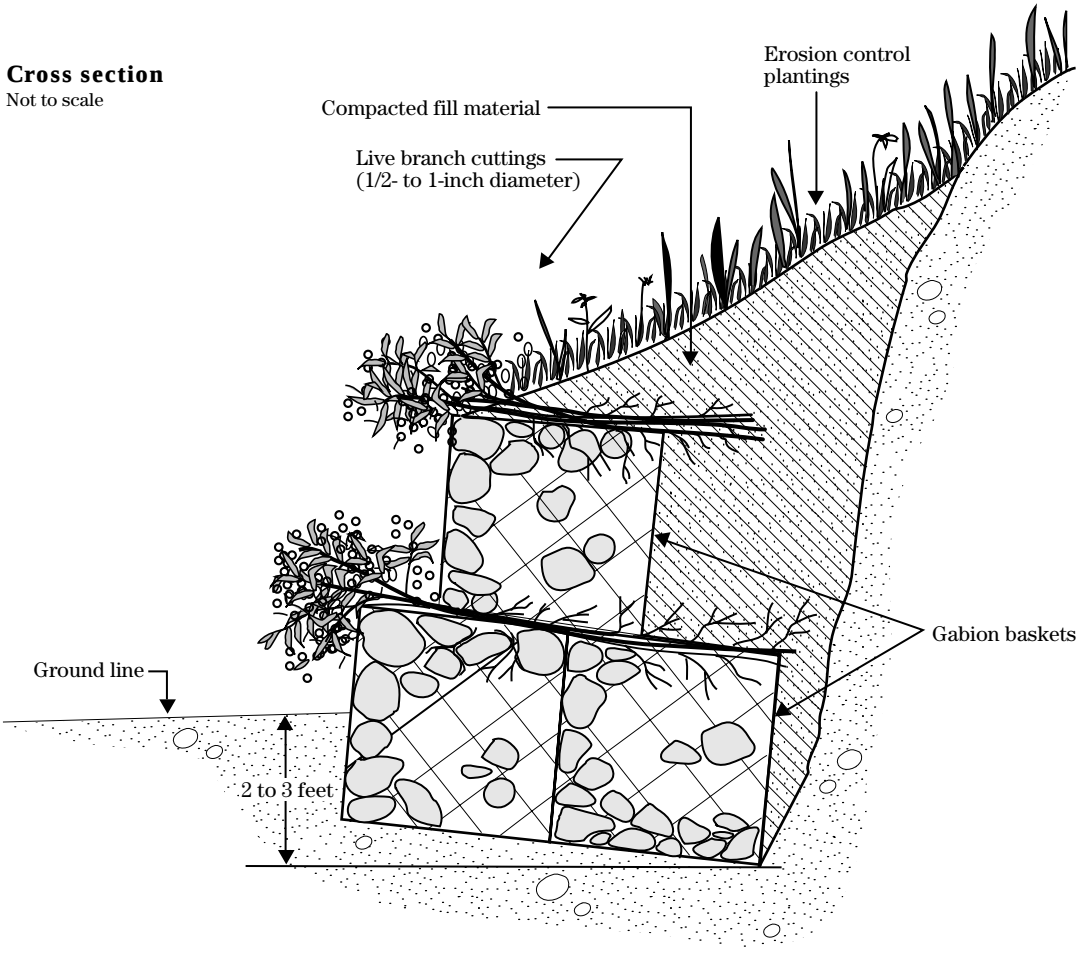
Inert materials—Inert material requirements include wire gabion baskets and rocks to fill the baskets.

Figure 18–19 An established vegetated rock gabion system (H.M. Schiechtl photo)

Installation

- Starting at the lowest point of the slope, excavate loose material 2 to 3 feet below the ground elevation until a stable foundation is reached.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure. This will provide additional stability to the structure and ensure that the living branches root well.
- Place the fabricated wire baskets in the bottom of the excavation and fill with rock.
- Place backfill between and behind the wire baskets.
- Place live branch cuttings on the wire baskets perpendicular to the slope with the growing tips oriented away from the slope and extending slightly beyond the gabions. The live cuttings must extend beyond the backs of the wire baskets into the fill material. Place soil over the cuttings and compact it.
- Repeat the construction sequence until the structure reaches the required height (fig. 18–20).

Figure 18–20 Vegetated rock gabion details



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

(8) Vegetated rock wall

(i) Description—A vegetated rock wall is a combination of rock and live branch cuttings used to stabilize and protect the toe of steep slopes. Vegetated rock walls differ from conventional retaining structures in that they are placed against relatively undisturbed earth and are not intended to resist large lateral earth pressures.

(ii) Applications and effectiveness

- This system is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Useful where space is limited and natural rock is available.

(iii) Construction guidelines

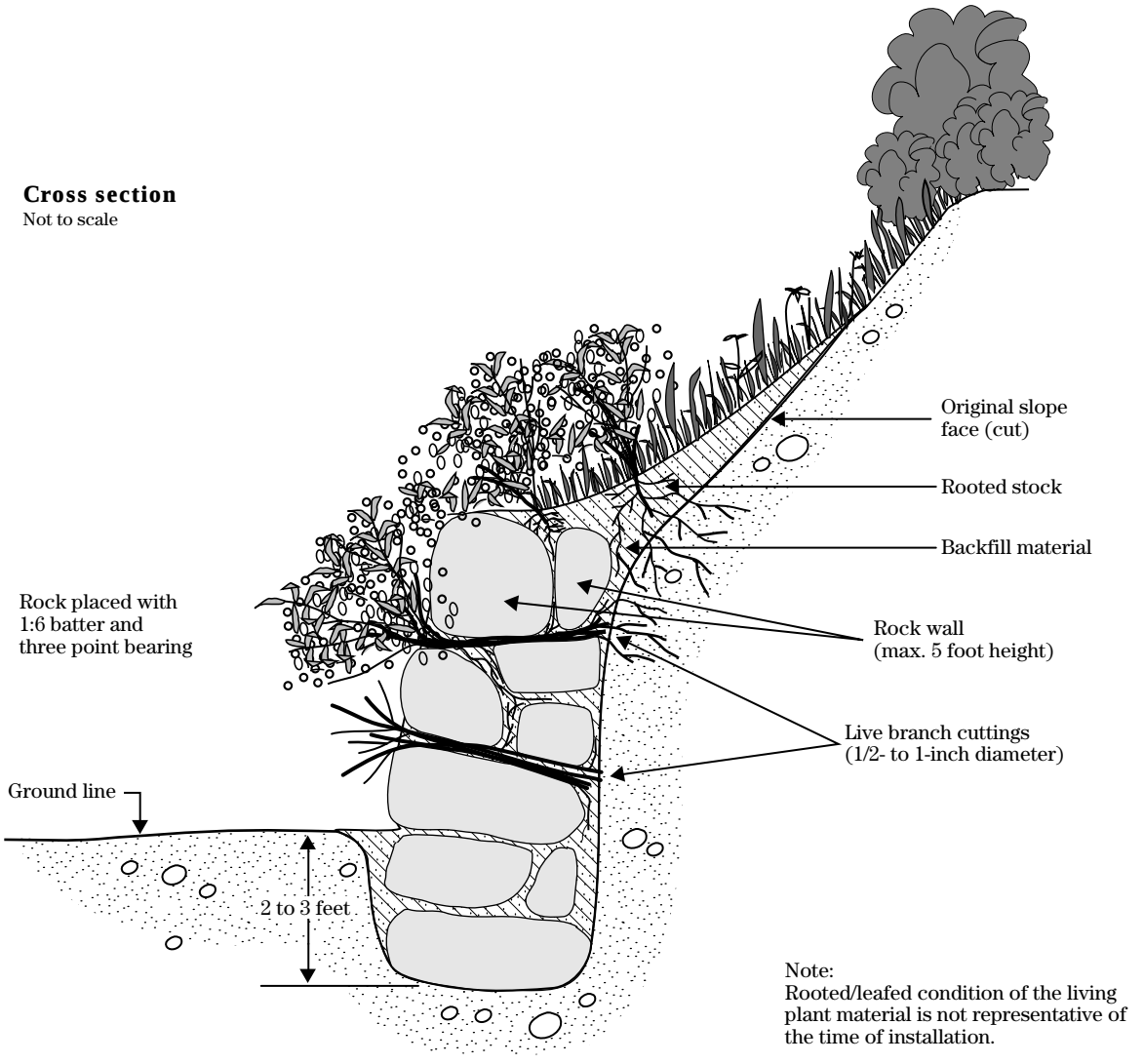
Live material sizes—Live cuttings should have a diameter of 1/2 to 1 inch and be long enough to reach beyond the rock structure into the fill or undisturbed soil behind.

Inert materials—Inert materials consist of rocks and fill material for the wall construction. Rock used should normally range from 8 to 24 inches in diameter. Larger boulders should be used for the base.

Installation

- Starting at the lowest point of the slope, remove loose soil until a stable base is reached. This usually occurs 2 to 3 feet below ground elevation. Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure.
- Excavate the minimum amount from the existing slope to provide a suitable recess for the wall.
- Provide a well-drained base in locations subject to deep frost penetration.
- Place rocks with at least a three-point bearing on the foundation material or underlying rock course. They should also be placed so that their center of gravity is as low as possible, with their long axis slanting inward toward the slope if possible.
- When a rock wall is constructed adjacent to an impervious surface, place a drainage system at the back of the foundation and outside toe of the wall to provide an appropriate drainage outlet.
- Overall height of the rock wall, including the footing, should not exceed 5 feet.
- A wall can be constructed with a sloping bench behind it to provide a base on which live branch cuttings can be placed during construction. Live branch cuttings should also be tamped or placed into the openings of the rock wall during or after construction. The butt ends of the branches should extend into the backfill or undisturbed soil behind the wall.
- The live branch cuttings should be oriented perpendicular to the slope contour with growing tips protruding slightly from the finished rock wall face (fig. 18–21).

Figure 18–21 Vegetated rock wall details



(9) Joint planting

(i) Description—Joint planting or vegetated riprap involves tamping live cuttings of rootable plant material into soil between the joints or open spaces in rocks that have previously been placed on a slope (fig. 18–22). Alternatively, the cuttings can be tamped into place at the same time that rock is being placed on the slope face.

(ii) Applications and effectiveness

- Used where rock riprap is required.
- Roots improve drainage by removing soil moisture. Over time, they create a living root mat in the soil base upon which the rock has been placed. The root systems of this mat help to bind or reinforce the soil and to prevent washout of fines between and below the rock units (fig. 18–23).

(iii) Construction guidelines

Live material sizes—The cuttings must have side branches removed and bark intact. They should range in diameter from 1/2 inch to 1 1/2 inches and be sufficiently long to extend into soil below the rock surface.

Installation

- Tamp live branch cuttings into the openings of the rock during or after construction. The butt ends of the branches should extend into the backfill or undisturbed soil behind the riprap.
- Orient the live branch cuttings perpendicular to the slope with growing tips protruding slightly from the finished face of the rock (fig. 18–24).

Figure 18–22 A newly established joint planting stake (H.M. Schiechtl photo)

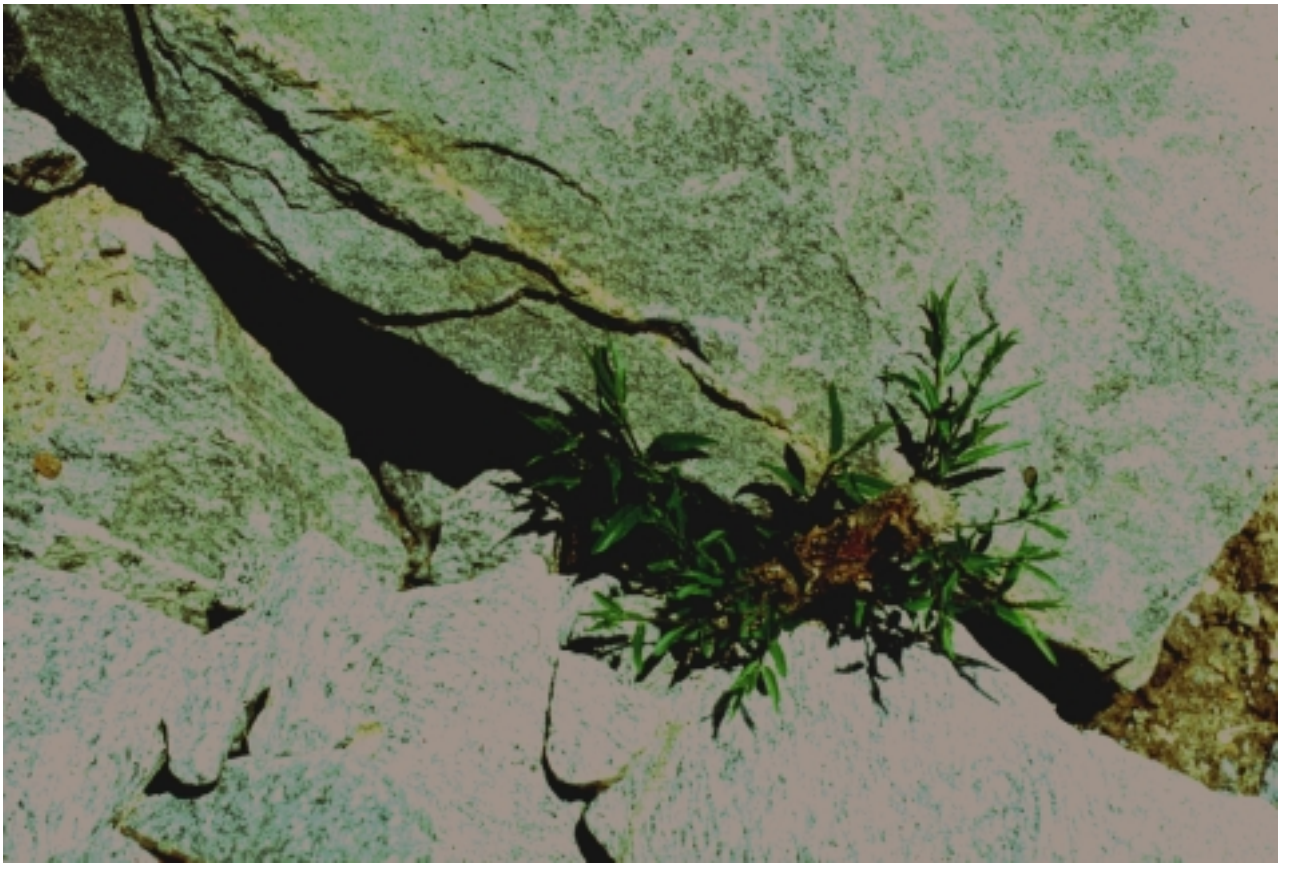


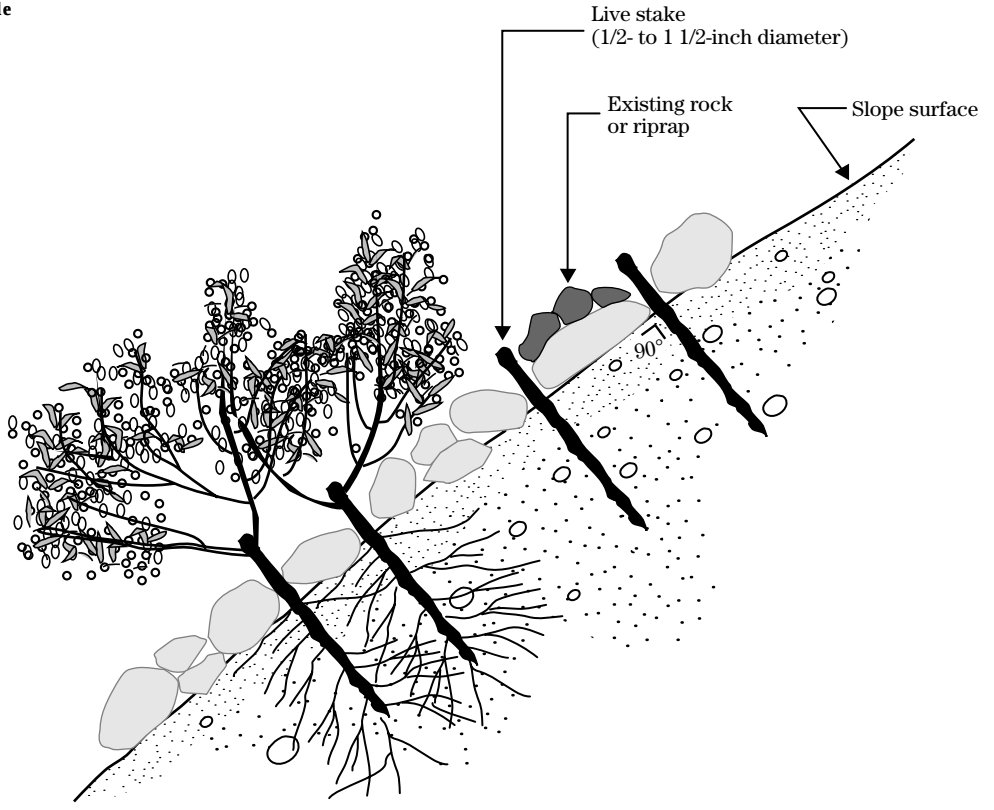
Figure 18–23 Roots improve drainage by removing soil moisture (Robbin B. Sotir & Associates photos)

Figure 18–23a Root system 7 months after installation

Figure 18–23b Joint planted area after 2 years of growth

Figure 18–24 Joint planting details

Cross section
Not to scale



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

(c) Soil bioengineering materials

(1) Locating and selecting plant materials

(i) Commercial sources—Commercially grown plant materials are suitable sources of vegetation for use in soil bioengineering systems; however, it is necessary to allow adequate lead time for their procurement and delivery.

The SCS Plant Materials Program has selected superior cultivars of willows, dogwoods, and other species, which have been evaluated in soil bioengineering systems and are being produced commercially. The most desirable species and cultivars to use can be determined from specifications for critical area stabilization for each state.

The information on plant tolerances in table 18–5 should be used in selecting species appropriate for adverse site conditions. Plant materials specialists are closely involved with the testing of plants and can assist with up-to-date information on cultivar adaptation.

Table 18–5 Plant tolerance

Name	Location	Availability	Tolerance to deposition 1/	Tolerance to flooding 2/	Tolerance to drought 3/	Salt tolerance 4/
Acer negundo Boxelder	N, NE	Common	High	High	High	Medium
Alnus rubra Red alder	NW	Very common	High	Medium	Low	Low
Baccharis glutinosa Water wally	W	Common	Medium	High	Medium	Low
Baccharis halimifolia Eastern baccharis	S, SE	Common	Medium	High	Medium	Medium
Baccharis pilularis Coyotebrush	W	Very common	Medium	Medium	High	Medium
Baccharis viminea Mule fat	W	Very common	High	High	High	Medium
Betula papyrifera Paper birch	N, E, & W	Common	Medium	Medium	Medium	Medium
Betula pumila Low birch	N, E, & W	Common	Low	– – –	– – –	Low
Cornus amomum Silky dogwood	N, SE	Very common	Low	Medium	Medium	Low

See footnotes at end of table.

Table 18–5 Plant tolerance — Continued

Name	Location	Availability	Tolerance to deposition 1/	Tolerance to flooding 2/	Tolerance to drought 3/	Salt tolerance 4/
Cornus racemosa Gray dogwood	NE	Common	Medium	Medium	High	Low
Cornus rugosa Roundleaf dogwood	NE	Common	– – –	– – –	– – –	– – –
Cornus sericea ssp. stolonifera Red osier dogwood	N, NE, & NW	Very common	Low	High	Medium	Low
Crataegus Sp. Hawthorn	SE	Uncommon	Medium	Low	High	Low
Elaeagnus commutata Silverberry	N. Cent.	Very Common	High	Low	High	Medium
Ligustrum sinense Chinese privet	S, SE	Common	High	Medium	Medium	Low
Lonicera involucrata Black twinberry	E	Common	Medium	Medium	Low	Low
Physocarpus capitatus Pacific ninebark	NW, W	Common	Low	Medium	Low	Low
Physocarpus opulifolius Common ninebark	NE	Common	Low	Medium	Medium	Medium
Populus angustifolia Arrowleaf cottonwood	W	Common	Medium	Medium	High	Medium
Populus balsamifera ssp. trichocarpa Black cottonwood	NW	Common	Medium	Medium	Medium	Medium
Populus deltoides Eastern cottonwood	MW, E	Very common	Medium	High	Medium	Low
Populus fremontii Fremont cottonwood	SW	Very common	Medium	Medium	Medium	Medium

See footnotes at end of table.

Table 18–5 Plant tolerance — Continued

Name	Location	Availability	Tolerance to deposition 1/	Tolerance to flooding 2/	Tolerance to drought 3/	Salt tolerance 4/
Populus tremuloides Quaking aspen	NW	Very common	Medium	Low	Medium	Medium
Robinia pseudoacacia Black locust	NE	Common	Medium	Low	High	High
Rubus allegheniensis Allegheny blackberry	NE	Very common	Medium	Medium	Medium	Low
Rubus spectabilis Salmonberry	SW, NW	Very common	Medium	Medium	Medium	Low
Rubus strigosus Red raspberry	N, NE, & W	Very common	Medium	Low	Medium	Low
Salix exigua Coyote willow	NW	Fairly common	High	High	Medium	Low
ssp. interior Sandbar willow	N, SE	Common	High	High	Low	High
Salix amygdaloides Peachleaf willow	N, S	Common	High	High	Low	High
Salix bonplandiana Pussy willow	W & MW	Very common	Medium	Medium	Low	– – –
Salix eriocephala ssp. ligulifolia Erect willow	NW	Common	High	High	Medium	Low
Salix gooddingii Goodding willow	SW	Very common	High	Medium	Medium	Low
Salix hookeriana Hooker willow	NW	Common	High	High	Low	Medium
Salix humilis Prairie willow	N, NE	Very common	Medium	Medium	High	Low
Salix lasiolepis Arroya willow	W	Common	High	High	Medium	Low

See footnotes at end of table.

Table 18–5 Plant tolerance — Continued

Name	Location	Availability	Tolerance to deposition 1/	Tolerance to flooding 2/	Tolerance to drought 3/	Salt tolerance 4/
Salix lemmonii Lemmon willow	W	Common	High	High	Medium	Low
Salix lucida Shining willow	N, NE	Very common	Medium	Medium	Medium	Low
ssp. lasiandra Pacific willow	NW	Very common	High	High	Low	Low
Salix lutea Yellow willow	W	Very common	Medium	Medium	Medium	Low
Salix nigra Black willow	N, SE	Very common	High	High	Medium	Medium
Salix purpurea Streamco	N, S, E, & W	Very common	High	High	Medium	Low
Salix scouleriana Scoulers willow	NE	Very common	High	High	Medium	Low
Salix sitchensis Sitka willow	NW	Common	High	Medium	Medium	Low
Salix X cotteti Bankers willow	N, S, E, & W	Uncommon	High	High	Medium	Low
Salix discolor Red willow	N, NE	Very common	High	High	High	Medium
Sambucus cerulea Blueberry elderberry	W	Common	Medium	Medium	Medium	Low
Sambucus canadensis American elderberry	NE, SE	Very common	High	Medium	Medium	Low
Sambucus racemosa Red elderberry	NW	Common	Medium	Low	Medium	Low
ssp. pubens Scarlet elder	NE	Common	Medium	Medium	Medium	Low

See footnotes at end of table.

Table 18–5 Plant tolerance — Continued

Name	Location	Availability	Tolerance to deposition 1/	Tolerance to flooding 2/	Tolerance to drought 3/	Salt tolerance 4/
Spiraea alba Meadowsweet spirea	N, E	Common	Low	Medium	Medium	– – –
Spiraea douglasii Douglas spirea	NW	Common	Medium	Medium	Medium	Low
Spiraea tomentosa Hardhack spirea	NE	Common	Medium	Medium	Medium	Medium
Symphoricarpos albus Snowberry	N, NW, & E	Common	Low	Low	High	High
Viburnum alnifolium Hubbiebush viburnum	NE	Fairly common	– – –	– – –	– – –	– – –
Viburnum dentatum Arrowwood viburnum	E	Common	Medium	Medium	Medium	Low
Viburnum lentago Nannyberry viburnum	S, SE	Fairly common	Medium	Low	Medium	Low

1/ Tolerance to deposition—Regrowth from shallow coverage by soil (stream deposits, soil slips). High, Medium, or Low ability for regrowth.

2/ Tolerance to flooding:
- High—severely damaged after 10 to 30 days of flooding.
- Medium—severely damaged after 6 to 10 days of flooding.
- Low—severely damaged after 1 to 5 days of flooding.

3/ Tolerance to drought—Resistance to drought (relative to native vegetation on similar sites) is High, Medium, or Low.

4/ Salt tolerance—Tolerance (relative to salt tolerant native vegetation on similar sites) is High, Medium, or Low.

(ii) Harvesting indigenous species—Correctly selected indigenous species harvested from existing stands of living woody vegetation are the preferred soil bioengineering materials. The use of indigenous live materials requires careful selection, harvesting, handling, and transporting. They should result in plants that have deep and strong root systems, are relatively inexpensive, are usually effective, and can be installed quickly.

Live plant materials can be cut from existing native or naturalized stands found near the project site or within practical hauling distance. The source site must contain plant species that will propagate easily from cuttings. Cuttings are normally 1/2 to 2 inches in diameter and range in length from 2 to 6 feet.

Chain saws, bush axes, loppers, and pruners are recommended for cutting living plant material. Safety precautions must be followed when using these tools. Onsite plant material should be harvested with great care. In some places a large area can be cut, but other sites require selective cutting. Cuts should be made at a blunt angle, 8 to 10 inches from the ground, to assure that the source sites will regenerate rapidly and in a healthy manner. The harvesting site should be left clean and tidy. Remnant materials that are too large for use in soil bioengineering projects should be chipped or left in piles for wildlife cover. A site may be needed again for future harvesting and should be left in a condition that will enhance its potential for regeneration.

Binding and storage—Live cuttings should be bundled together securely at the collection site for easy loading and handling and for protection during transport. Side branches and brushy limbs should be kept intact.

Transporting—The bundles of live cuttings should be placed on the transport vehicles in an orderly fashion to prevent damage and facilitate handling. They should be covered with a tarpaulin during transportation to prevent drying and additional stress.

Handling—Live cuttings should arrive on the job site within 8 hours of harvest and should be installed immediately. This is especially critical when the ambient temperature is 50 °F or above.

Live cuttings not installed on the day they arrive should be promptly placed in controlled storage conditions and protected until they can be installed. When in storage, the cuttings must receive continuous shade, must be sheltered from the wind, and must be continuously protected from drying by being heeled into moist soils or stored in uncontaminated water. All live cuttings should be removed from storage and used within 2 days of harvest.

(2) Installing plant materials

(i) Timing—Installation of live cuttings should begin concurrently with earth moving operations if they are carried out during the dormant season. All construction operations should be phased together whenever possible. The best time for installation of soil bioengineering systems is during the dormant season, which generally occurs from September to March throughout most of the United States. Each geographic area has a specific dormant season within this broad range, and yearly variations should be taken into account.

(ii) Planting medium—Soil bioengineering projects ideally use onsite stockpiled topsoil as the planting medium of choice. Gravel is not a suitable material for use as fill around live plant materials. Soil bioengineering systems need to be installed in a planting medium that includes fines and organic material and is capable of supporting plant growth. Muddy soils that are otherwise suitable should not be used until they have been dried to a workable moisture content. Heavy clays should be mixed with organic soils to increase porosity. Select soil backfill does not need to be organic topsoil, but it must be able to support plant growth.

Soil samples of the onsite materials should be taken prior to installation of live woody cuttings. Soil samples should also be taken of all fill materials that are brought to the site prior to use. Nutrient testing by an approved laboratory should include analyses for a full range of nutrients, metal contents, and pH. The laboratory reports should also include recommended fertilizer and lime amendments for woody plant materials.

All fill soil around the live vegetative cuttings should be compacted to densities approximating the surrounding natural soil densities. The soil around plants should be free of voids.

(3) Quality control

Maintaining quality control throughout installation and maintenance operations will ensure a successful soil bioengineering project. The following guidelines are recommended:

(i) Pre-construction

- Select plant species for conformance to requirements.
- Locate and secure source sites for harvesting live cuttings or commercial procurement.
- Define construction work area limits.
- Fence off sites requiring special protection.
- Complete and inspect the following preparations:
  - — Layout
  - — Excavation, systems excavation
  - — Bench size, shape, angle
  - — Preparation of site; i.e., clearing, grading, and shaping
  - — Disposal of excess gravel, soil, and debris
  - — Depth of excavation
  - — Vegetation to be removed/preserved
  - — Stockpiling of suitable soil and/or rock

(ii) Construction

- Inspect each system component, at every stage, for the following:
  - — Angle of placement and orientation of the live cuttings
  - — Backfill material/rock and stone material
  - — Fertilizer, method and quantity applied
  - — Lime, method and quantity applied
  - — Preparation of trenches or benches in cut and fill slopes
  - — Staking
  - — Pruning
  - — Stock handling and preparation
  - — Soil compaction
  - — Watering
- Ensure that proper maintenance occurs during and after installation.
- Inspect daily for quality control.
  - — Check all cuttings; remove unacceptable material and use fresh stock for replacement installations.
  - — Continuously check all items in the preconstruction and construction inspection lists.
  - — Inspect the plant materials storage area when it is in use.

(4) Establishment period

(i) Interim inspections—Inspections should be made after the soil bioengineering measures have been installed. The following schedule is recommended:

- Inspect biweekly for the first 2 months. Inspections should note insect infestations, soil moisture, and other conditions that could lead to poor survivability. Immediate action, such as the application of supplemental water, should be taken if conditions warrant.
- Inspect monthly for the next 6 months. Systems not in acceptable growing condition should be noted and, as soon as seasonal conditions permit, should be removed from the site and replaced with materials of the same species and sizes as originally specified.
- Needed reestablishment work should be performed every 6 months during the initial 2-year establishment period. This will usually consist of replacing dead material.
- Extra inspections should always be made during periods of drought or heavy rains. Damaged sections should always be repaired immediately.

(ii) Final inspection—A final inspection should be held 2 years after installation is completed. Healthy growing conditions should exist.

- Healthy growing conditions in all areas refer to overall leaf development and rooted stems defined as follows:

  Live stakes ---------- 70%-100% growing
  Live fascines ---------- 20%-50% growing
  Live cribwall ---------- 30%-60% growing
  Brushlayers ---------- 40%-70% growing
  Branchpacking ---------- 40%-70% growing
  Live gully repair ---------- 30%-50% growing
  Vegetated rock wall ------ 50%-80% growing
  Vegetated gabion --------- 40%-60% growing
  Joint planting ---------- 50%-70% growing
- Growth should be continuous with no open spaces greater than 2 feet in linear systems. Spaces 2 feet or less will fill in without hampering the integrity of the installed living system.

(5) Maintaining the system

After inspection and acceptance of the established system, maintenance requirements should be minor under normal conditions. Maintenance generally consists of light pruning and removal of undesirable vegetation. Heavy pruning may be required to reduce competition for light or stimulate new growth in the project plantings. In many situations, installed soil bioengineering systems become source sites for future harvesting operations. The selective removal of vegetation may be required to eliminate undesirable invading species that should be cut out every 3 to 7 years.

More intensive maintenance will sometimes be required to repair problem areas created by high intensity storms or other unusual conditions. Site washouts should be repaired immediately. Generally, reestablishment should take place for a 1-year period following construction completion and consist of the following practices:

- Replacement of branches in dead unrooted sections
- Soil refilling, branchpacking, and compacting in rills and gullies
- Insect and disease control
- Weed control

Gullies, rills, or damaged sections should be repaired through the use of healthy, live branch cuttings preferably installed during the dormant season. The repair should use the branchpacking system for large breaks and the live gully repair system for breaks up to 2 feet wide and 2 feet deep. If the dormant season has passed, the use of rooted stock may be considered.

(d) Vegetated structures

Vegetated structures consist of either low walls or revetments (concrete or rock and mortar) at the foot of a slope with plantings on the interposed benches. A structure at the foot of a slope protects the slope against undermining or scouring and provides a slight buttressing effect. In the case of low walls, it allows regrading of the slope face to a more stable angle without excessive retreat at the crest. Vegetation planted on the crest of the wall and the face of the slope protects against erosion and shallow sloughing. In the case of tiered structures, the roots of woody plants grow into the soil and backfill within the structure, binding them together. The foliage in front covers the structure and enhances its appearance.

These systems are not soil bioengineering structures, as their plant materials represent little or no reinforcement value to the structure.

(1) Low wall/slope face plantings

(i) Description—A low retaining structure at the foot of a slope makes it possible to flatten the slope and establish vegetation. Vegetation on the face of the slope protects against both surface erosion and shallow face sliding (fig. 18–25).

(ii) Materials and installation—Several basic types of retaining structures can be employed as low walls. The simplest type is a gravity wall that resists lateral earth pressures by its weight or mass. The following types of retaining structures can be classified as gravity walls:

- Masonry and concrete walls
- Crib and bin walls
- Cantilever and counterfort walls
- Reinforced earth and geogrid walls

In addition, each of these can be modified in a variety of ways to fit nearly any condition or requirement. A low wall with vegetated slope is shown in figure 18–26. For further discussion of standard engineering design requirements and specifications see National Engineering Handbook, section 6.

Figure 18–25 A low wall with plantings above

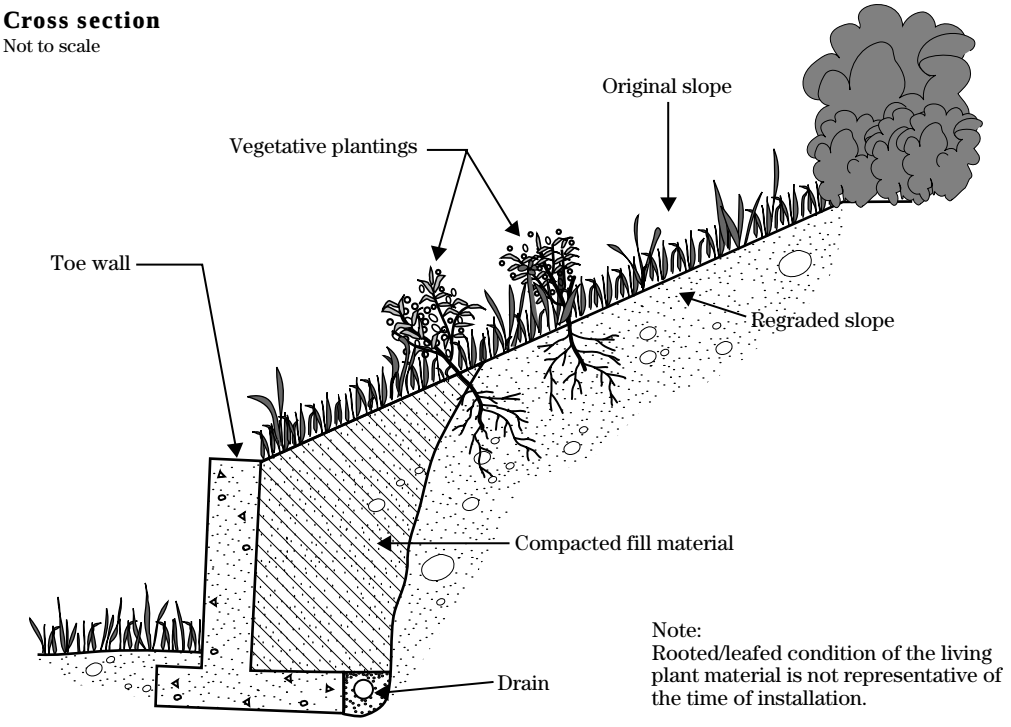


Figure 18–26 Low wall at the base of a slope with vegetation on face of slope (Donald H. Gray photo)

(2) Tiered wall/bench plantings

(i) Description—An alternative to a low wall with face planting is a tiered retaining wall system. This alternative effectively allows vegetation to be planted on slopes that would otherwise be too steep. Shrubs and trees planted on the benches screen the structure behind and lend a more natural appearance while their roots permeate and protect the benches.

Virtually any type of retaining structure can be used in a tiered wall system. A tiered wall system provides numerous opportunities for adding vegetative values on steep slopes and embankments (fig. 18–27).

(3) Cribwalls with plantings

(i) Description—A cribwall is a structure formed by joining a number of cells together and filling them with soil, gravel, or rock to furnish strength and weight. In crib structures, the members are essentially assembled "log cabin" fashion. The frontal, horizontal members are termed stretchers; the lateral members, headers.

The frontal spaces between the stretchers in conventional cribwalls provide openings through which vegetative cuttings can be inserted and established in the crib fill (fig. 18–28).

Figure 18–27 A tiered wall with bench plantings (Donald H. Gray photo)

Figure 18–28 Cribwall systems with face plantings (Donald H. Gray photos)

Figure 18–28a Tiered cribwall system with trees and shrubs planted on benches

Figure 18–28b Open-front concrete cribwall with plantings in openings

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Coppin, N.J., D.L. Barker, and I. Richards. 1990. Use of vegetation in civil engineering. Butterworths, Sevenoaks, Kent, England.

Fridl, W.F., and P.E. Demetrious. 1982. Biotechnical bank stabilization. Public Works.

Gray, D.H. 1991. Proceedings: Workshop on biotechnical stabilization. The University of Michigan.

Gray, D.H., A.T. Leiser, and C.A. White. 1980. Combined vegetative-structural slope stabilization. Amer. Assoc. Civil Eng., Vol. 50, No. 1, pp. 82-85.

Gray, D.H., and A.T. Leiser. 1982. Biotechnical slope protection and erosion control. Van Nostrand Reinhold, New York, NY. Krieger Pub. Co., Melbourne, FL.

Gray, D.H., and R. Sotir. 1992. Biotechnical stabilization of a highway cut slope. J. Geotechnical Eng. Amer. Assoc. Civil Eng., Vol. 118, No. 9.2.

Gray, D.H., and R. Sotir. 1992. Biotechnical stabilization of cut and fill slopes. Proceedings, ASCE-GT spec. conf. on slopes and embankments. Berkeley, CA.

Hynson, J.R., P.R. Adamus, J.O. Elmer, and T. Dewan. 1983. Environmental features for levee projects. U.S. Army Corps of Eng., Wash., DC, Tech. Rep. E-83.

Kraebel, C.J. 1936. Erosion control on mountain roads. USDA Circ. No. 380, 43 pp.

Kropp, A. 1989. Biotechnical stabilization of a debris flow scar. Proceedings, XX Intl. Erosion Control Assoc. Conf., Vancouver, BC, pp. 413-429.

Lake, D.W., and J.A. Dickerson. 1989. Cost effective biotechnical slope protection trials in New York. Amer. Soc. Agric.Eng. Pap. No. 892654. 1989 Intl. ASAE meeting, New Orleans, LA.

Reid, G. 1969. How to hold up a bank. A.S. Barnes and Co., New York, NY.

Schiechtl, H.M. 1980. Bioengineering for land reclamation and conservation. The Univ. Alberta Press, Edmonton, Canada.

Smoltczyk, U., and K. Malcharek. 1983. Living sheets on steep slopes. Proceedings, 2nd Intl. Conf. on Geotextiles, Vol. 2, Las Vegas, NV, pp. 253-257.

United States Navy. 1991. Soil bioengineering major gully washout repair, Silverhill Airfield, Baldwin County, AL, Naval Civil Eng. Lab., Port Hueneme, CA.

Glossary

Batter The angle of the front face of a retaining structure with respect to a vertical plane.

Bench A horizontal surface or step in a slope.

Buttressing Lateral restraint provided by earth or rock masses and embedded structural columns, such as piles and well-rooted tree trunks.

Brushlayer Live branch cuttings laid in crisscross fashion on benches between successive lifts of soil.

Concrete cribwall A hollow, structural wall formed out of perpendicular and interlocking concrete beams.

Cut face The open, steep face of an excavated slope.

Cutting A branch or stem pruned from a living plant.

Crib structure A hollow structure constructed of mutually perpendicular, interlocking beams or elements.

Dead stout stake A 2 by 4 timber that has been cut into a specific shape and length.

Face planting Planting live cuttings and other vegetation in the frontal openings of retaining structures.

Gabion A wire mesh basket filled with rock that can be used in multiples as a structural unit.

Grade stabilization The maintenance of a gentle, noneroding gradient on a watercourse or land surface. This is usually accomplished by means of structural measures or by regrading (lengthening) the slope.

Gravity retaining walls Retaining structures that resist lateral earth forces and overturning primarily by their weight.

Grid wall A lattice or grid-like array of timbers that are fastened or anchored to a slope. The grid spaces are filled with topsoil and then seeded or planted.

Joint planting The insertion of live branch cuttings between openings or interstices of rocks, blocks, or other inert armor units and into the natural ground.

Lateral earth pressure The horizontal pressure exerted by soil against a retaining structure.

Live cribwall A hollow, structural wall formed out of mutually perpendicular and interlocking members, usually timber, in which live cuttings are inserted through the front face of the wall into the crib fill and/or natural soil behind the wall.

Live branch cuttings Living, freshly cut branches of woody shrub and tree species that propagate from cuttings embedded in the soil.

Live fascines Bound, elongated sausage-like bundles of live cut branches that are placed in shallow trenches, partly covered with soil, and staked in place to arrest erosion and shallow mass wasting.

Live stake Cuttings from living branches that are tamped or inserted into the earth. The stakes eventually root and leaf out.

Mass movement The movement of large, relatively intact masses of earth and/or rock along a well defined shearing surface as a result of gravity and seepage.

Mass wasting See "Mass movement."

Reinforced earth Strengthening of a soil fill by utilizing tensile inclusions, such as metal strips, woody fibers, wire mesh, or fabric.

Shallow mass movement Near-surface sliding or movement of earth and/or rock masses usually along planar failure surfaces parallel to the slope face.

Slope flattening Reduction in slope angle by excavation and regrading in order to achieve a more stable slope.

Soil arching Restraint of soil movement through an opening or gap as a result of transfer of shear stress from the deforming (or moving) soil mass to adjacent stationary (nonyielding) portions of the soil.

Soil bioengineering Use of live, woody vegetative cuttings to repair slope failures and increase slope stability. The cuttings serve as primary structural components, drains, and barriers to earth movement.

Steel bin wall Hollow wall sections constructed of steel that are bolted together and filled with rock or gravel to serve as a gravity retaining wall.

Stepped-back reinforced wall A reinforced earth retaining wall in which successively higher portions of the wall are set back from the front in stepped fashion.

Surface armoring Placement of an armor layer, composed of rock, brush matting, gabion mattresses, stabilized earth, etc., on the ground surface.

Tiered retaining wall structures Retaining structures in which successively higher portions of the structure are set back from the front in stepped fashion. Crib, gabion, and reinforced earth walls can be erected in this fashion.

Toe wall A low, structural wall erected at the toe or base of a slope to provide support and protect against undermining.

Undermining The removal of lateral support at the base of a slope by scour, piping erosion, or excavation.

Vegetative cuttings Live, cut stems and branches of plants that will root when embedded or inserted in the ground.

Vegetated earth buttress An earthen mass placed against the base or toe of the slope to improve stability. Vegetation can be planted on the face of the buttress or introduced into the buttress in the form of brushlayers.

Vegetative measures The use of live cuttings, seeding, sodding, and transplanting in order to establish vegetation for erosion control and slope protection work.

Vegetated rock gabions See "Vegetated structures."

Vegetated rock walls See "Vegetated structures."

Vegetated structures A retaining structure in which living plant materials, cuttings, or transplants have been integrated into the structure.

Vegetated structural revetments Porous revetments, e.g., a gabion mattress or riprap, into which live plants or cuttings can be placed or inserted.