

PAP-546

HYDRAULIC MODEL STUDY ASWAN HIGH DAM
POWER STATION POWER TUNNEL INTAKES
OPERATING WITH A RESERVOIR WATER SURFACES
AT OR BELOW ELEVATION 155 METERS ABOVE M.S.L.

by

P. L. Johnson

**RECOMMENDATIONS FOR BIOENGINEERING
STABILIZATION OF FIVE SITES
ON HARLAND CREEK, MISSISSIPPI**

Submitted To:

**COMMANDER
U.S. ARMY CORPS OF ENGINEERS
WATERWAYS EXPERIMENT STATION**

by

**Dr. Chester C. Watson
Dr. Steven R. Abt
Mr. Christopher I. Thornton**

**CIVIL ENGINEERING DEPARTMENT
COLORADO STATE UNIVERSITY**

November 1994

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1. Introduction

The objective of this research is to develop a data base for performance of bioengineering sites within the Demonstration Erosion Control (DEC) watersheds. Five bioengineering sites have been selected in coordination with Vicksburg District and Waterways Experiment Station (WES) personnel. These sites have been surveyed and conceptual designs for bioengineering have been prepared by the Principal Investigators. This report contains background information concerning design, construction, and inspection of bioengineering techniques, typical drawings for bioengineering techniques, and a topographic survey of each site.

1.1 Authorization

This research has been authorized through a Broad Agency Announcement Contract, No. DACW39-94-K-0015. Technical coordination at WES has been through Mr. Dave Derrick, Mr. Tom Prokefke and Mr. Nolan Raphelt. Dr. Phil Combs has provided technical assistance and review for the Vicksburg District.

1.2 Background

Bioengineering is a branch of engineering in which live plants and plant parts are used as building material for erosion control and landscape restoration in contrast to conventional engineering in which only dead materials are used (Schiechtl, 1980). Bioengineering combines mechanical, biological, and ecological concepts to arrest and prevent shallow slope failures and to control erosion.

Bioengineering of stream bank stabilization in the United States has lagged behind progress in engineering of riprap features. This may be the result of uncertainty in using plants as a construction material. Bioengineered bank stabilization can be less costly to construct than riprap, and may be a better engineering solution considering aesthetic and ecological benefits.

Much of the following discussion has been taken directly from Chapter 18, Soil Bioengineering for Upland Slope Protection and Erosion Reduction (SCS, 1992). A complete listing of references used is contained in the bibliography at the conclusion of the text. The techniques and practices have been taken from the literature, and have been modified, in some cases, by experience with riprap and willow pole techniques. Application of the techniques to the highly unstable Yazoo Basin DEC streams should be considered experimental; however, some success should be expected.

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

2. Characteristics of Bioengineering Systems

Bioengineering uses particular characteristics of vegetative components and integrates specific characteristics of structures with vegetation. The resulting systems have benefits and limitations that need to be considered prior to selection for use.

2.1 Vegetative components

Herbaceous vegetation, especially grasses and forbs, offers long-term protection against surface erosion on slopes, and 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 and impinging flow
- Enhancing and maintaining infiltration capacity
- Minimizing freeze-thaw cycles of soils susceptible to frost

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

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

- Structurally reinforcing the soil with additional root mass
- Depleting soil-water through transpiration and interception
- Buttrressing and soil arching action from embedded stems

Live fascines, for example, provide many of these protective functions. Fascines are fabricated from woody species, such as willow or privet, into sausage-like bundles, which are placed with the stems oriented generally parallel to the slope contour. Live fascines serve to dissipate the energy of 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.

Brushlayering consists of live branches or shoots of such woody species as shrub willow, dogwood, or privet that are placed in successive layers with the stems generally oriented perpendicular to the slope contour. Brushlayering can improve soil stability to depths of 4 to 5 feet.

2.2 Structural components

Properly designed and installed structures help to stabilize a 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. Structural components 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 the most vulnerable time.

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 on site at minimal or 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 wood vegetation.

Low retaining structures at the toe of a slope allow the slope to be graded 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.

2.3 Attributes and limitations

Bioengineering measures should not be viewed as a panacea or solution for all bank 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) may work satisfactorily at less cost. In other cases, the more appropriate and most effective solution is a structural retaining system such as a heavy stone toe, either alone or in combination with soil bioengineering.

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.

Field studies (SCS, 1992) have shown examples where combined slope protection systems have proven more cost effective than the use of either 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, bioengineering systems may be less practical than structural measures. Using indigenous

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

Bioengineering systems are most effective when installed during the dormant season, usually the late fall, winter, and early spring. This often coincides with the time that other construction work is slow. Constraints on planting times or the availability of the required quantities of suitable plant materials during allowable planting times may limit the cost effectiveness of bioengineering methods.

The usefulness of bioengineering methods may be limited by the available medium for plant growth, such as rocky or gravel banks 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. Usefulness of vegetation would be limited on banks that are exposed to high velocity water flow or constant inundation.

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. Furthermore, some localities have prohibitions against gathering native plants, and materials must be purchased from commercial sources.

Soil bioengineering systems 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.

After vegetation is well established on a bioengineering project, usually within one or two growing seasons, regeneration and growth of the vegetation results in only minimal maintenance. However, a newly installed bioengineering project will require careful periodic inspections until it is established. Unestablished vegetation is vulnerable to trampling, drought, grazing, nutrient deficiencies, toxins, and pests, and may require special management measures at times.

3. Basic principles of bioengineering

The basic principles that apply to bioengineering are mostly common sense guidelines that involve planning, timing, and minimizing site disturbance rather than the design of individual measures themselves.

3.1 Fit the bioengineering system to the site

Consider 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:

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 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. Shading, moisture and inundation, and aspect may affect plant mortality.
- Look for areas of vegetation that may be growing more vigorously than other site vegetation as a good indicator of excess moisture or a change in soils.

Geology and soils

- Consult geologists about geologic history and types of deposits (colluvium, glacial, alluvium, etc.).
- Note evidence of past sliding. If evidence of sliding 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 an SCS soil survey report, if available, or consult soil scientists.

Hydrology

- Determine the site hydrology in relation to gulling problems. Use the procedure similar to drop pipe design. Note whether water can be diverted away from the problem 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.

Retain existing vegetation whenever possible

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

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

Stockpile and protect topsoil

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

Protect areas exposed during construction

- Temporary erosion and sediment control measures can be used.

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.

3.2 General design considerations

(1) Earthwork

Sites may require some earthwork prior to the installation of bioengineering systems. A steep undercut or slumping bank, for example, may require 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 plants 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.

Installation of bioengineering systems is best accomplished in late fall at the onset of plant dormancy, in the winter as long as the ground is not frozen, or in spring before growth occurs. Summer installation is not recommended. Rooted plants can be used, but are expensive and are sometimes less effective.

(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

Backfill behind a stable retaining structure has certain specified mechanical and hydraulic properties. Ideally, the fill is a 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 saturated 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.

(5) Species Selection

Species that root easily, such as willow, are required for bioengineering techniques such as fascines, willow poles, brush layer, and live staking.

(6) Handling

Rooted plants and vegetative cuttings are living materials that must be handled properly to avoid excess stress caused by drying or exposure to heat. Materials must be installed in moist soil and adequately covered. Compaction of the soil to eliminate air pockets around buried stems is essential. If soils are not at or near moisture capacity, regular irrigation may be required.

(7) Inspection

All installations should be regularly inspected and provisions for prompt repair should be made if needed. Repair can usually be made easily and cost effectively. Neglect or small failures can result in total system failure.

3.3 Bioengineering Techniques

The following techniques are typical bioengineering methods that can be adapted for bioengineering bank stabilization in the Vicksburg District. The success in applying each of these techniques to the severe bank erosion found along some streams in the District is untried and should be considered experimental. Application, effectiveness, and guidelines are presented in the following paragraphs.

(1) Live Stake

Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground as shown in Figure 3.1. 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 a slope soon after installation. This is an appropriate technique for repair of small earth slips and slumps that frequently are wet.

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 putting down surface erosion control materials.
- Enhances conditions for natural invasion and 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.

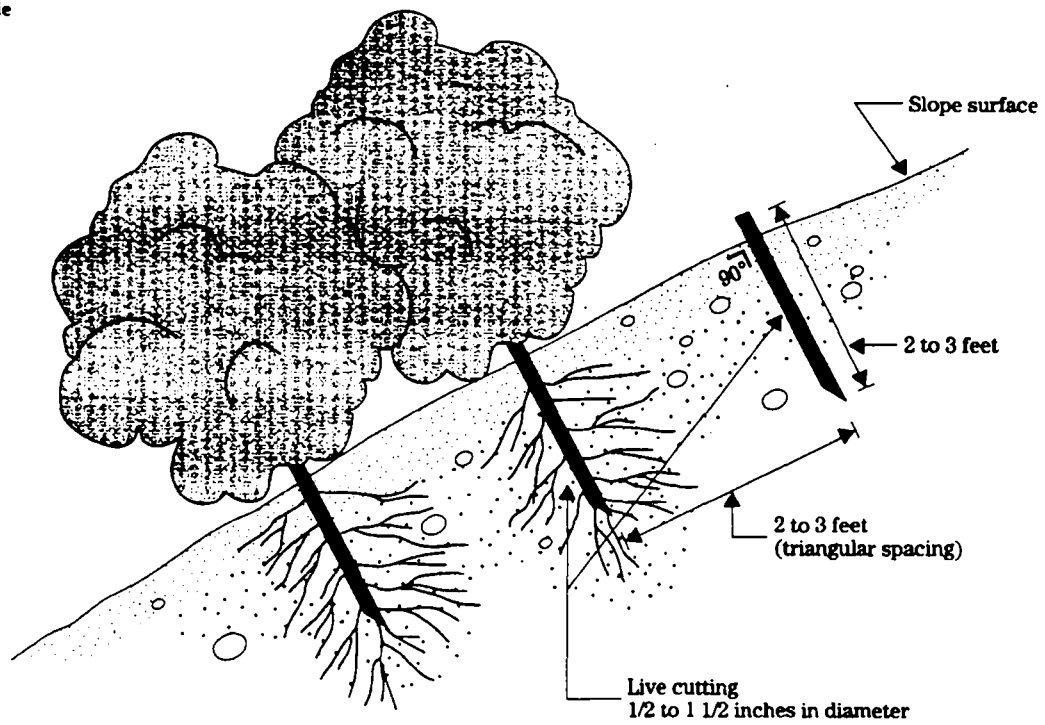
Construction guidelines

Live material sizes - Willow cuttings are usually ½ to 1½ inches in diameter and 2 to 3 feet long. Final size determination, can be made at the available cutting source.

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 as gathered.

Cross section
Not to scale



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

Figure 3.1 Live staking installation (after SCS, 1992)

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.
- Four-fifths of 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 or small auger 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), or a wooden mallet to avoid damage to the live stake.

(2) Live Fascine

Live fascines are long bundles of branch cuttings bound together into sausage-like structures, as shown in Figure 3.2. When cut from an appropriate species and properly installed with live and dead stout stakes, rooting will occur and begin to stabilize slopes. Fascines should be placed in shallow contour trenches, as shown in Figure 3.3. This system, installed by a trained crew, should not cause much site disturbance. Fascines placed at an angle to the contour can act as drains on wet slopes.

Applications and effectiveness

- An effective stabilization technique for slopes, and may be suitable for toe protection.
- 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.

Construction guidelines

Live materials - Cuttings must be from species, such as young willows, privet, or river birch, which root easily and have long, straight branches.



Figure 3.2 Live fascine can be quickly assembled on site (after SCS, 1992)

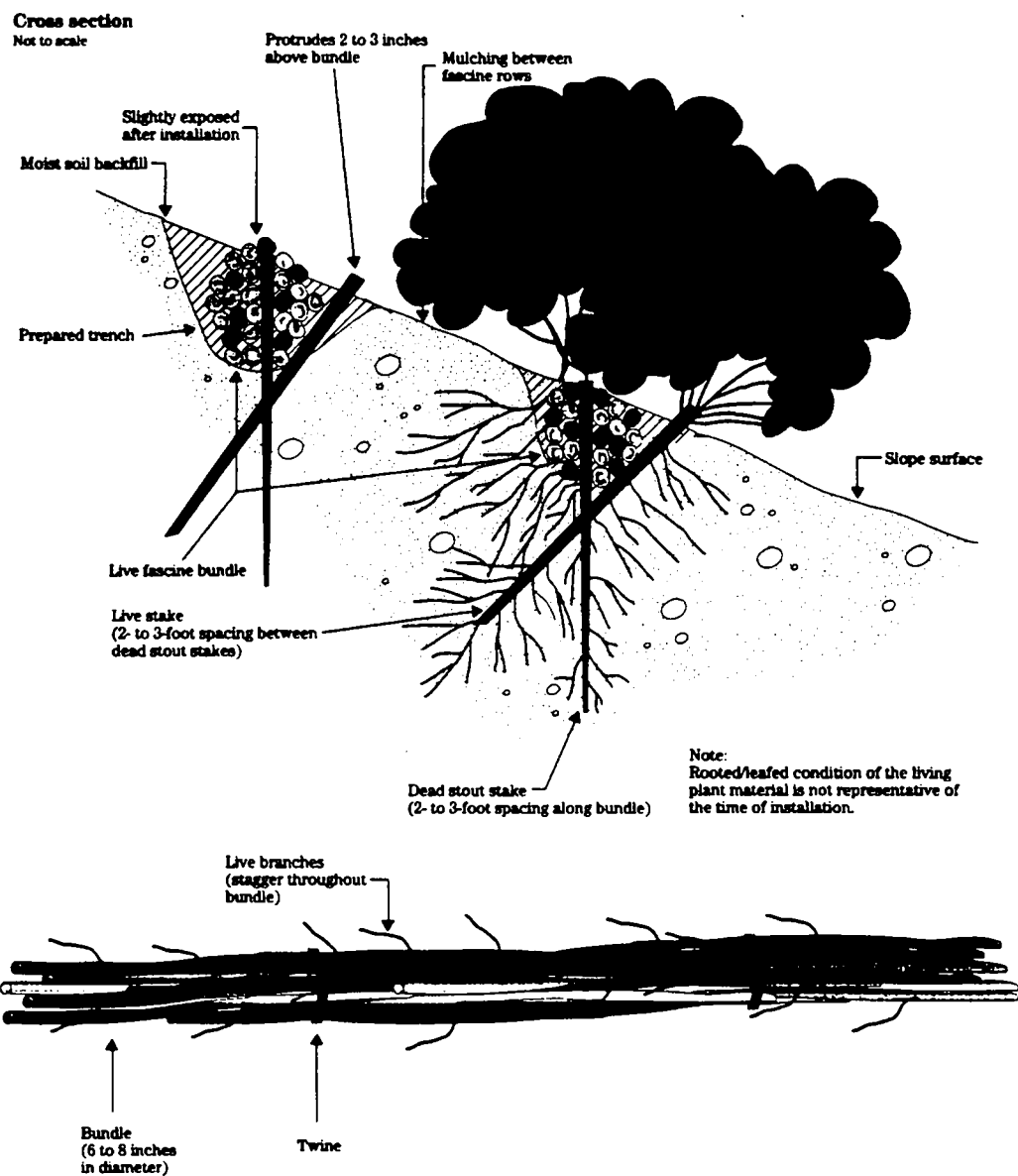


Figure 3.3 Live fascine instalation (after SCS, 1992)

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. Assemble the bundles on X-frames using trimmed willow poles branches or tops.
- 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 2½ feet long in cut slopes and 3 feet long in fill slopes.

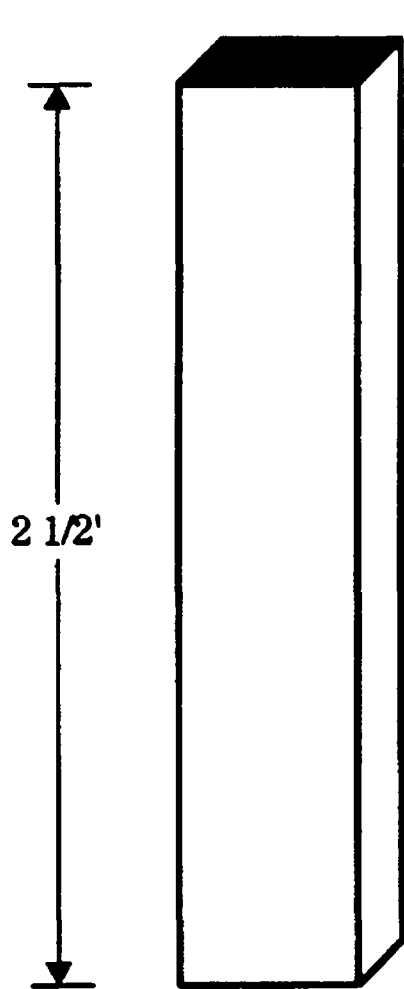
Inert materials - String used for bundling should be untreated twine. Dead stout stakes used to secure the live fascines should be 2½-foot long, untreated, 2 by 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length, as shown in Figure 3.4. Only new, sound, unused lumber should be used, and any stakes that shatter upon installation should be discarded.

Installation

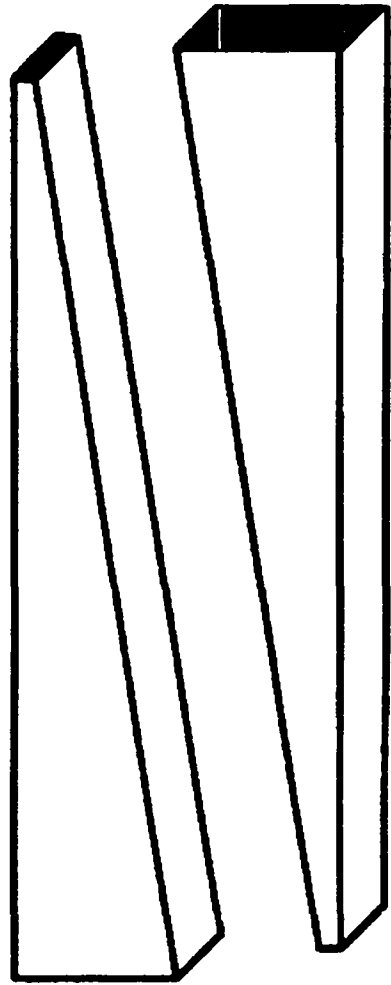
- Prepare the live fascine bundles and live stakes immediately before installation.
Beginning at the base of the slope, dig a trench on the contour just large enough to contain the live fascine. The trench will vary in width from 12 to 18 inches, depending on the angle of the slope to be treated. The depth will be 6 to 8 inches, depending on the individual bundle 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.
- Fascines can be installed at intervals on the contour up the slope to resist erosion. Installations angled downslope provide drainage routes for slopes with excess water.

(3) Brushlayer

Brushlayering is somewhat similar to live fascine systems as 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, as shown in



2 by 4 lumber



Saw a 2 by 4 diagonally to produce 2 dead stout stakes

Figure 3.4 Dead stout stakes are useful in securing plant materials (after SCS, 1992)

Figure 3.5. 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 exceeding 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.

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 microclimate of the site, thus aiding seed germination and natural regeneration.
- Redirecting and mitigating adverse slope seepage by acting as horizontal drains.

Construction guidelines

Live material sizes - Branch cuttings should be ½ 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 in 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.
- Live branch cuttings should be sloped so that the outside edge is higher than the inside.
- 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.

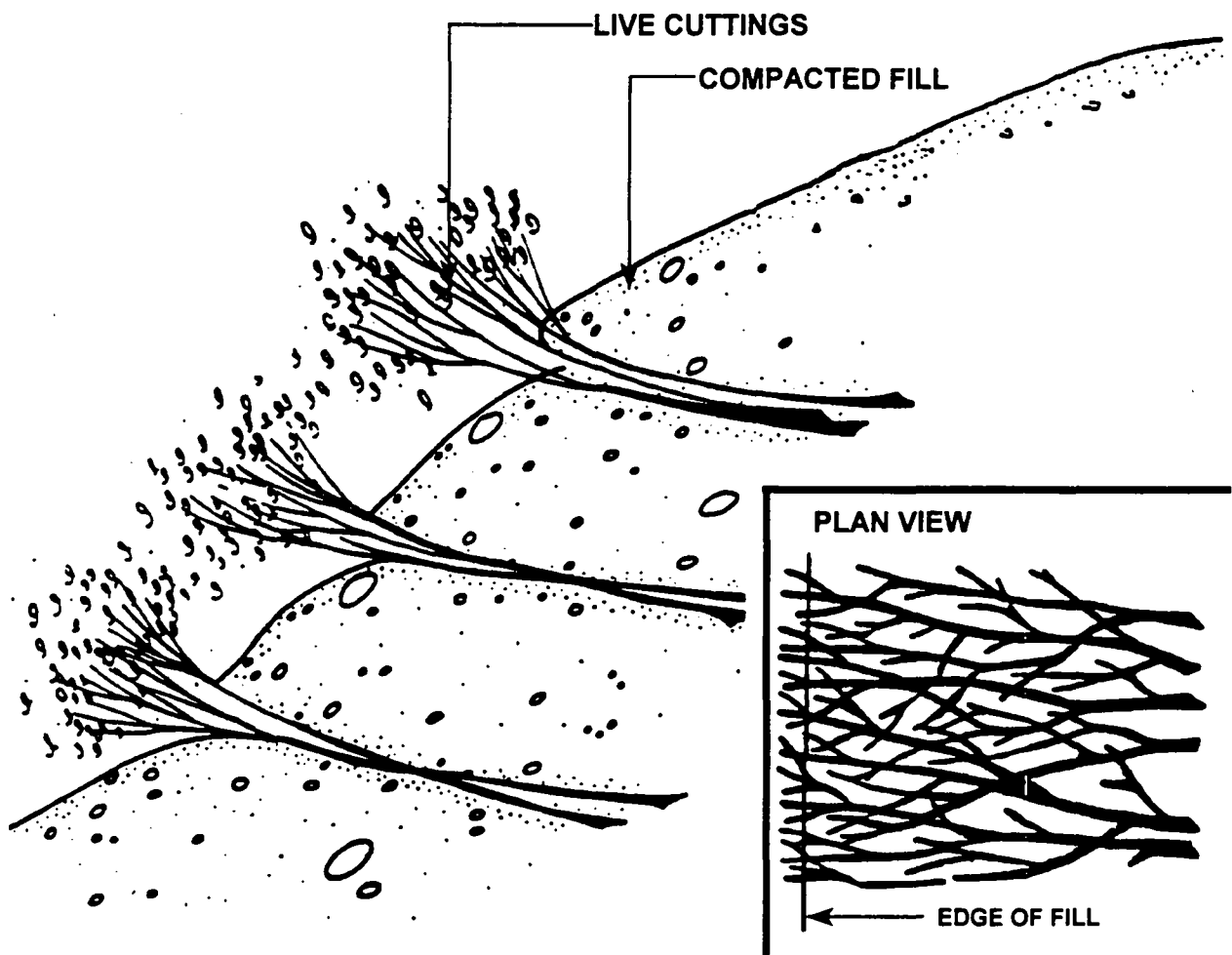


Figure 3.5 Brushlayering is an effective method for increasing slope stability

- Each lower bench is backfilled with the soil obtained from excavating the bench above.
- Long straw or similar mulching material should be used with seeding and should have jute mesh or similar material applied in addition to the mulch.
- The brushlayer rows should vary from 3 to 5 feet apart, depending upon the slope angle and stability.

(4) Branchpacking

Branchpacking consists of alternating layers of live branch cuttings and compacted backfill to repair small localized slumps and holes in banks, as shown in Figure 3.6.

Applications and effectiveness

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

Provides immediate soil reinforcement.

Construction guidelines

Live material-Live branch cuttings may range from ½ 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.

Wooden willow poles should be 5 to 8 feet long and from 3 to 6 inches in diameter, depending upon the depth of the particular slump or hole.

Installation

- Starting at the lowest point, install the willow poles on 3-foot centers. •A layer of living branches 4 to 6 inches thick is placed in the bottom of the hole, between the vertical willow poles. Branches should be placed in a crisscross configuration with the growing tips generally oriented away from 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.

Cross section
Not to scale

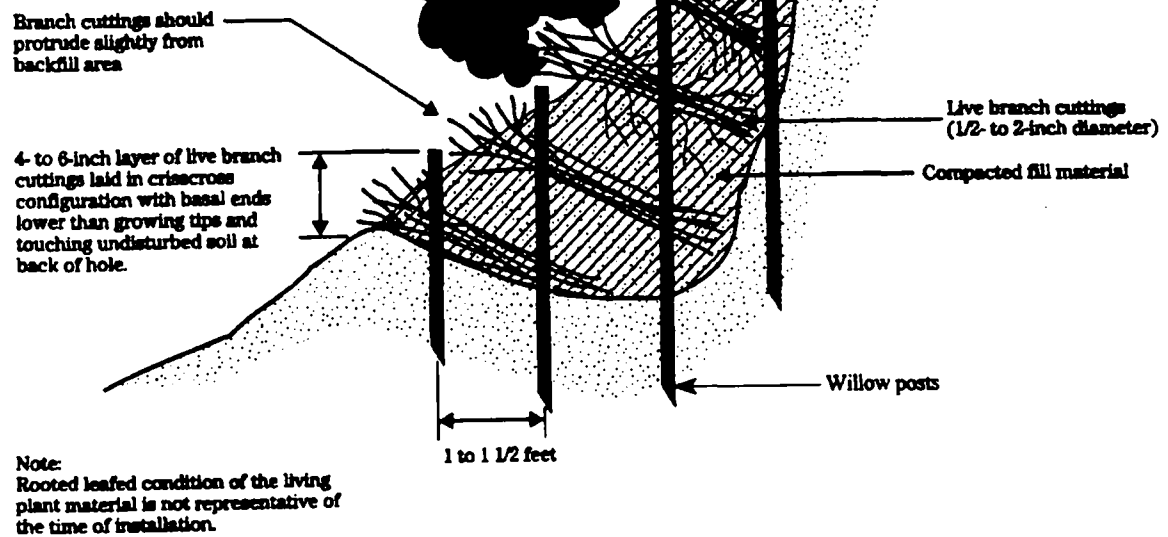


Figure 3.6 Branchpacking can be used to fill gullies or bank irregularities (after Schietle, 1980)

- The soil should be kept 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. Branch packing may be effective in preparing stream bank gullies.

(5) Live cribwall

A live cribwall consists of a hollow, box-like interlocking arrangement of untreated log members. Construction using live willow members assembled in log-cabin fashion, together with willow posts (Section 9), as shown in Figure 3.7, provides a very effective bioengineered structure. 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. After the live cuttings root and become established, the developing vegetation gradually takes over the structural functions of the wood members.

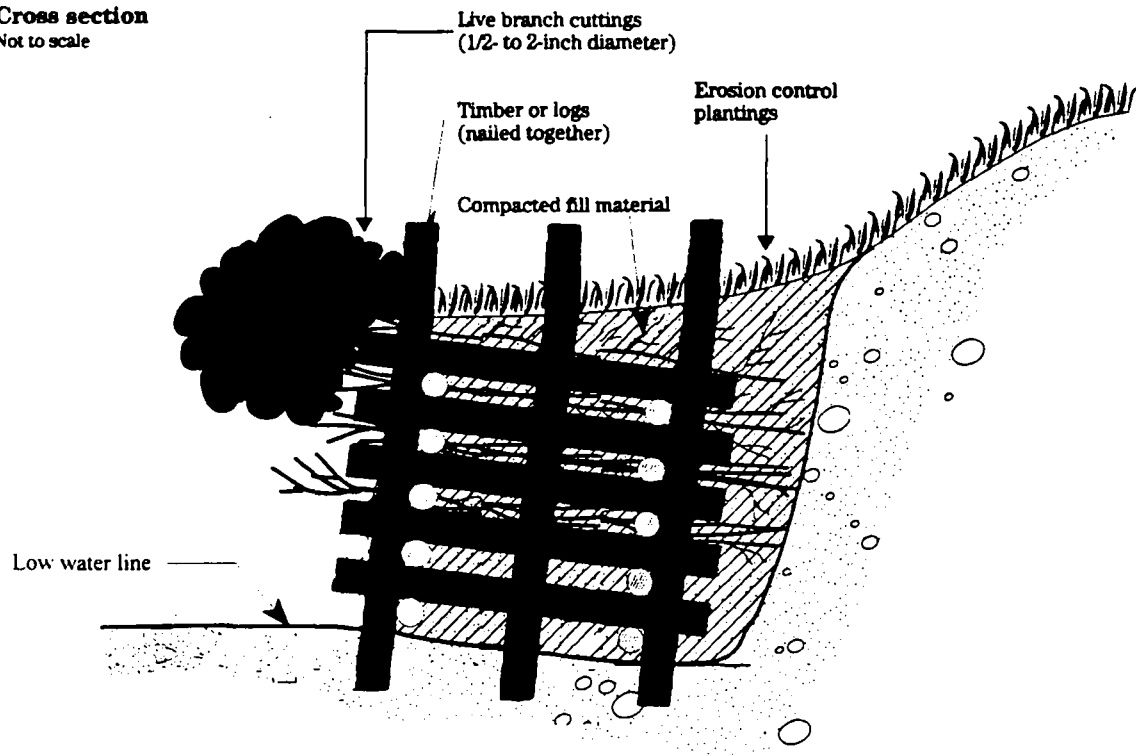
Applications and effectiveness

- 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 steepness.
- Not designed for or intended to resist large, lateral earth stresses. It should be constructed to a maximum of 4 feet in overall height.
- 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.

Construction guidelines

Live material sizes-Live branch cuttings should be ½ to 2 inches in diameter and long enough to reach the back of the wooden crib structure. Willow poles should be installed in accordance with the guidelines given in Section 9. Large nails or rebar are required to secure the logs or timbers together.

Cross section
Not to scale



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

Figure 3.7 A live cribwall using live willow posts and cross members

Installation

- Install three rows of willow poles on 2- to 3-foot centers.
- Starting at the lowest point of the slope, excavate loose material between the poles until a stable foundation is reached.
- Excavate the back of the stable foundation 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, against and inside of the lower and higher row of willow poles.
- Place the next course of logs or timbers at right angles 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.
- Live branch cuttings should be placed at each course to the top of the cribwall structure with growing tips extending out of the cribwall. Following each layer of branches with a layer of compacted soil to ensure soil contact with the live branch cuttings. Cuttings should reach to undisturbed soil at the back of the cribwall with growing tips protruding slightly beyond the front of the cribwall.

(6) Vegetated rock gabions

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, as shown in Figure 3.8. 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.

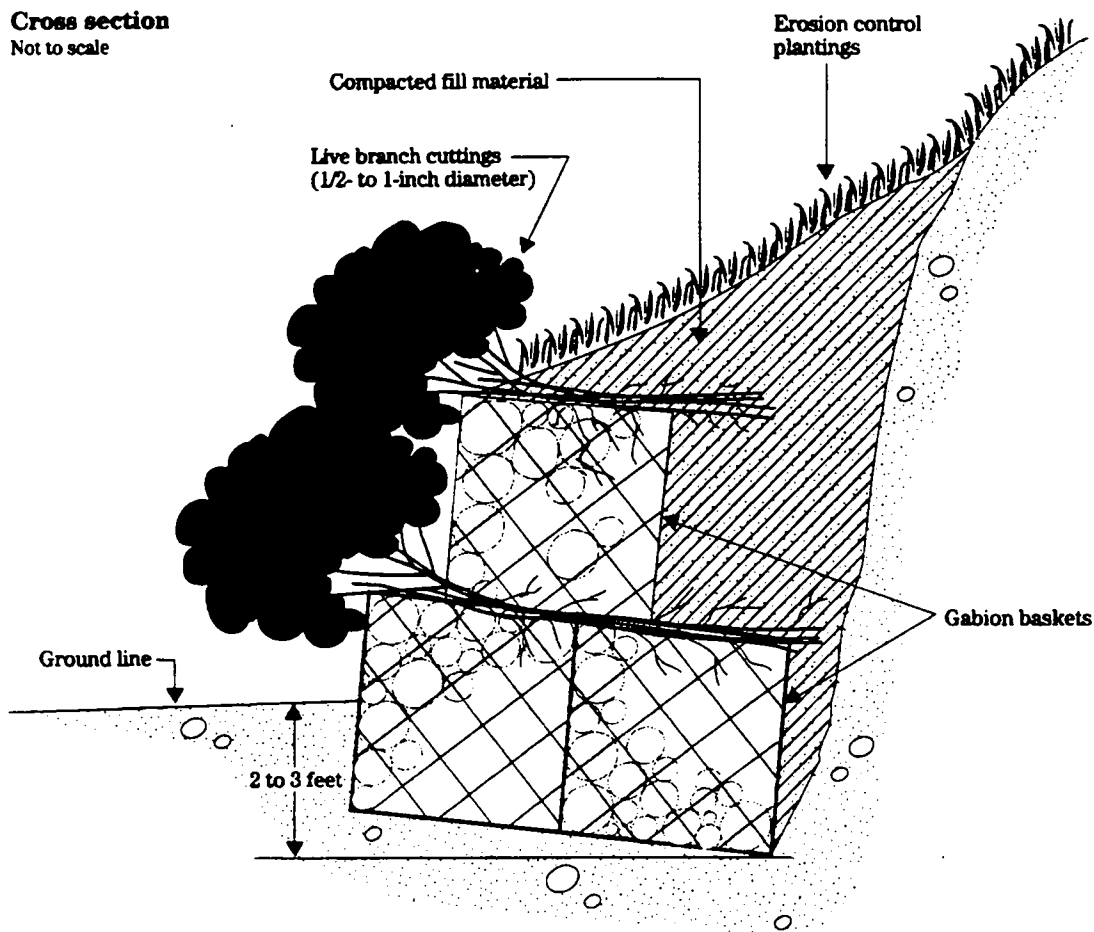
Applications and effectiveness

- 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 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.

Construction guidelines

Live material sizes-Branches should range from ½ to 1 inch in diameter and must be long enough to reach beyond the back of the rock basket structure into the backfill.

Cross section
Not to scale



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

Figure 3.8 Vegetated gabions (after SCS, 1992)

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

- Starting at the lowest point of the slope, excavate loose material 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.

Installation

- Place the fabricated wire basket 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 and compact soil over the cuttings and compact.
- Repeat the construction sequence until the structure reaches the required height.

(7) Vegetated Toe Riprap

Vegetated toe riprap is a combination of rock and live branch cuttings used to stabilize and protect the toe of steep slopes, as shown in Figure 3.9. Vegetated riprap is not intended to resist large lateral earth pressures, and is for primary use in resisting impinging flow.

Applications and effectiveness

- This system is appropriate at the toe of a slope to resist erosion and to establish vegetation.

Construction guidelines

Live material sizes-Live cuttings should have a diameter of ½ to 1 inch and be long enough to reach beyond the rock structure into the fill or undisturbed soil behind.

Inert materials - Standard 1 ton/L. F. riprap toe materials.

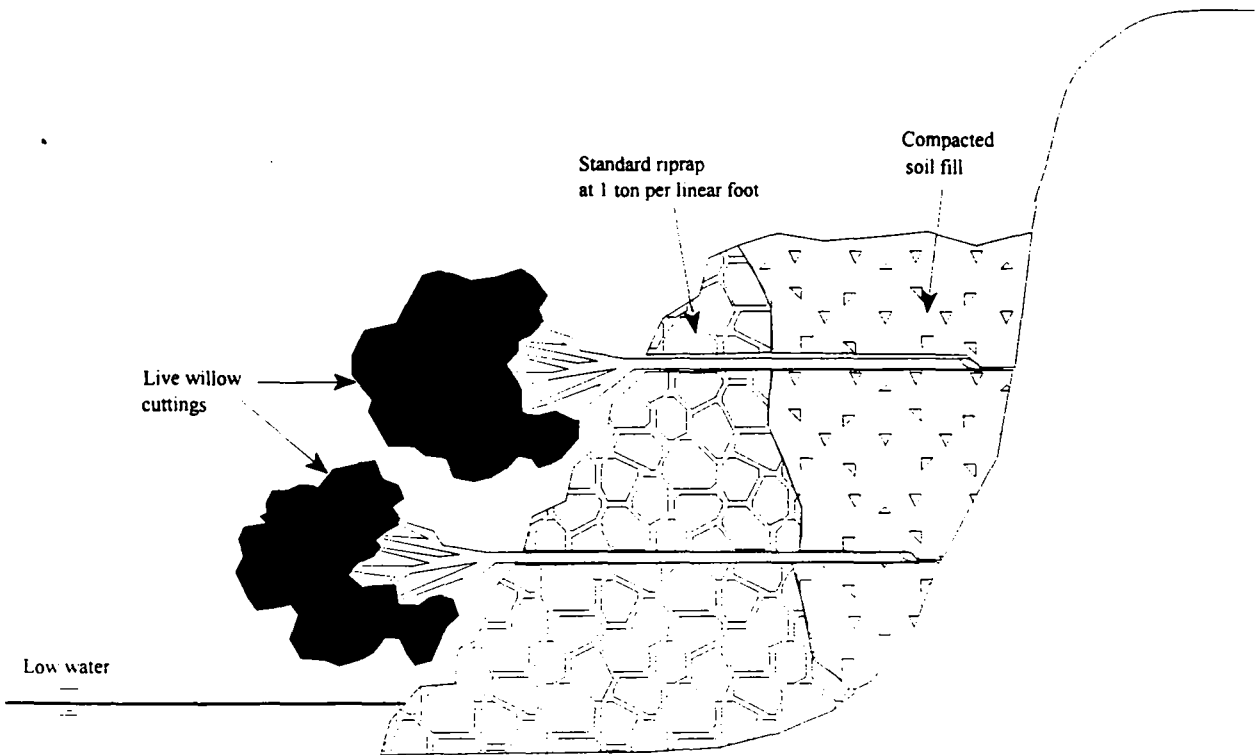


Figure 3.9 Vegetated toe riprap

Installation

- A third of the toe riprap should be placed and then a layer of live willow branch cuttings. This layer should be covered with a layer of soil of 4 to 6 inches thickness followed by another layer of riprap, a layer of soil and branches, followed by a final layer of riprap. The top of fill material behind the riprap should slope gently toward the stream to prevent ponding behind the stone, which can inhibit vegetation.
- The live branch cuttings should be oriented perpendicular to the slope contour with growing tips protruding slightly from the finished rock wall face.

(8) Joint planting

Joint planting or vegetation 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, as shown in Figure 3.10. Alternatively, the cuttings can be tamped into place at the same time that rock is being placed on the slope face.

Applications and effectiveness

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

Construction guidelines

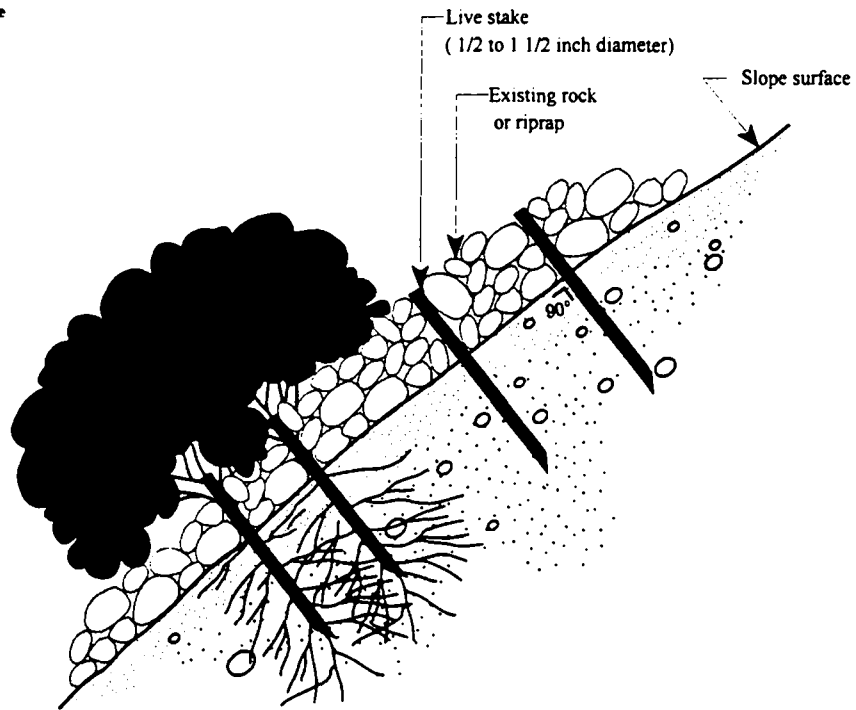
Live material sizes-The cuttings must have side branches removed and bark intact. They should range in diameter from ½ inch to 1½ inches and be sufficiently long to extend into soil below the rock surface.

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.
- An iron bar may be required to establish an opening within the riprap.

(9) Willow Posts

Cross section
Not to scale



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

Figure 3.10 Joint planting (after SCS, 1992)

(9) Willow Posts

Willow posts are a basic departure from the other methods presented. Willow poles are installed vertically, whereas the emphasis for the other methods is to construct in horizontal layers, as shown in Figure 3.11. Basically, the willow post technique consists of harvesting sections of trunk 10- to 12-feet in length and 3- 6-inches in diameter after the tree is dormant, and inserting the pole into augured holes 6- to 8-feet deep spaced at regular intervals along an eroding stream bank. Although others have historically used similar techniques, Mr. Don Roseboom of the Illinois State Water Survey can be considered the originator of the modern willow pole technique. The method has been presented in "Streambank Stabilization Training," an instruction manual (Roseboom, 1993). Abraham and Derrick (1993), have also utilized this technique.

Applications and effectiveness - Willow poles perform several immediate and long-term functions in erosion control, earth reinforcement, and mass stability of slopes:

- Stream banks are strengthened by soil arching and by pinning of possible failure surfaces
- Depletion of soil-water by transportation
- Mechanically reinforcing the soil strength by root growth
- Retarding stream velocity impinging against the bank

- Providing a micro-climate for colonization by other species
- Trapping debris and soil blocks from upslope failures
- Providing a sound anchor for other bioengineering techniques (such as fascines) placed along the toe of the bank, crib wall support, or use of large woody debris attached at the water edge.

Construction guidelines

Live material sizes-Willow posts should be taken from trunk sections of willow trees with branches removed. Post diameter should be a minimum of 3 inches at the butt end. Minimum post length should be 10 feet.

Installation

- Posts should be planted in augured holes at least 8 feet in depth.
- Post holes should be backed-filled to insure that no voids exist and that the post is fully in contact with the soil and the butt is in contact with the bottom of the post hole.
- The holes will be augured in a grid spacing of 3 feet on centers, i.e., between rows and between posts in a single row. An 8-inch diameter auger is recommended.
- No more than 4 feet of the post should be above ground following installation.

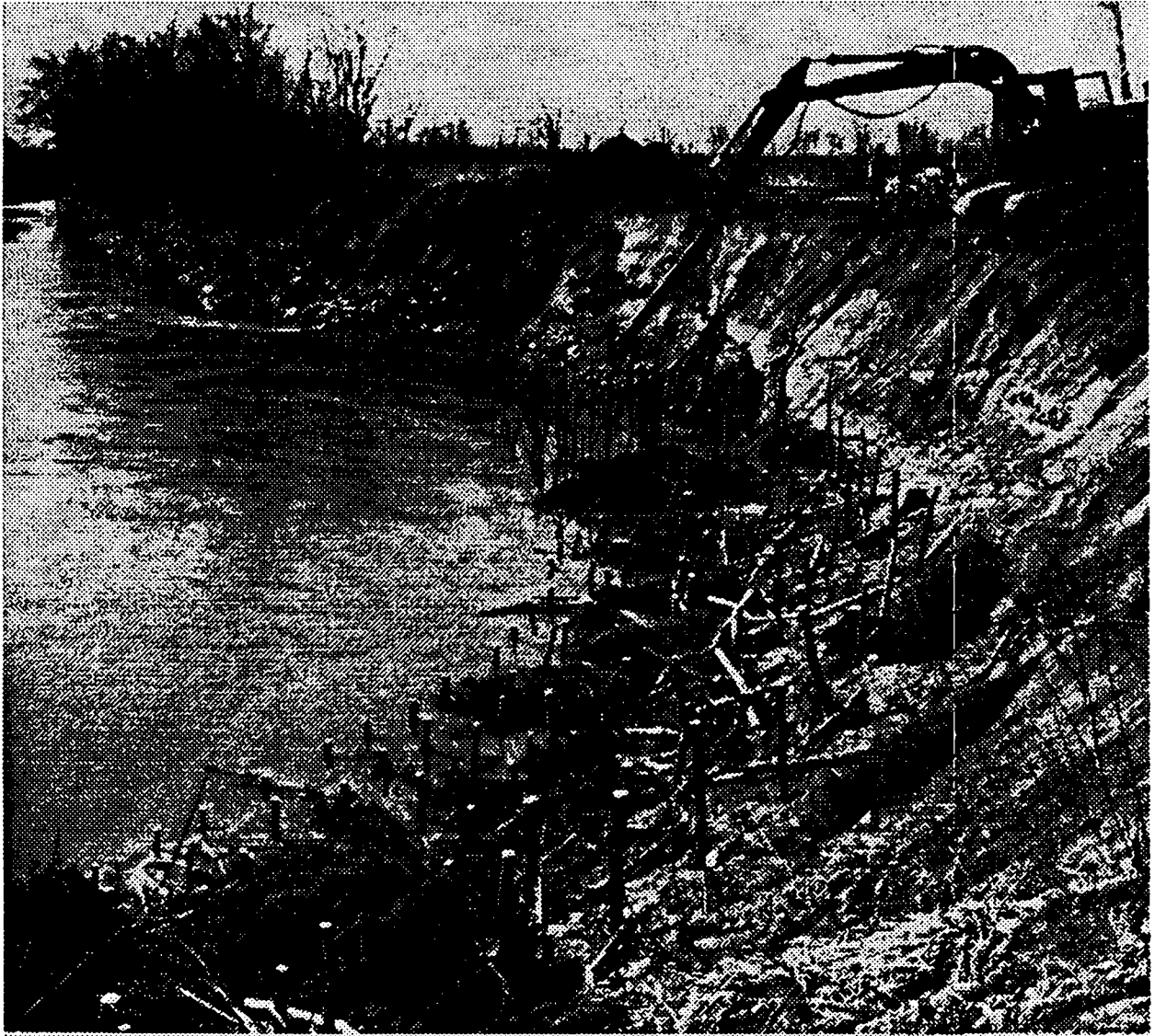


Figure 3.11 Willow posts installation (after Roseboom, 1992)

- Native willows in good condition and with bark relatively undamaged should be used. Bark should not be damaged during installation.
- Posts should be harvested during the dormant season, soaked in water, and planted within 48 hours
- Tops of the posts should be marked during harvest to insure planting right-side-up
- Grass seeding of the site is required following installation

3.4 Soil bioengineering materials

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 procurement and delivery.

The SCS Plant Material Program has selected types of willows, dogwoods, and other species, which have been evaluated in bioengineering systems and are being produced commercially. The most desirable species and types can be determined from specifications for critical area stabilization. Table 3.1 lists eight types for the southeast United States. As shown, Black willow and Sandbar willow are ranked the highest for rooting ability and tolerance of deposition and flooding.

The information on plant tolerances 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 type adaptation.

Correctly selected indigenous species harvested from existing stands of living woody vegetation are the preferred bioengineering materials. The use of indigenous live materials requires careful selection, harvesting, handling, and transporting. The use of indigenous species 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 ½ to 2 inches in diameter and range in length from 2 to 10 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 potential for regeneration.

Table 3.1 Plant Suitability Ranking for Southeastern Streams (SCS, 1992)

Name	Availability	Habitat value	Size/form	Root type	Rooting ability from cutting	Tolerance to disposition ¹	Tolerance to flooding ²	Tolerance to drought ³
<i>Baccharis halimifolia</i> Eastern baccharis	Common	Very poor	Small-med shrub	Fibrous	Fair-good	Medium	High	Medium
<i>Cornus amomum</i> Silky dogwood	Very Common	Very good	Small Shrub	Shallow fibrous	Very Good	Low	Medium	Medium
<i>Crataegus Sp.</i> Hawthorn	Uncommon	Good	Sm. dense tree	Top root	Fair	Medium	Low	High
<i>Ligustrum sinense</i> Chinese privet	Common	Fair-good	Small-med. shrub	Shallow fibrous	Good	High	Medium	Medium
<i>ssp. interior</i> Sandbar willow	Common	Good	Large shrub	Shallow to deep	Fair-good	High	High	Low
<i>Salix nigra</i> Black willow	Very common	Good	Large shrub Small tree	Shallow to deep	Excellent	High	High	Medium
<i>Sambucus canadensis</i> American elderberry	Very common	Very good	Medium shrub	Fibrous	Good	High	Medium	Medium
<i>Viburnum lentago</i> Nannyberry viburnum	Fairly common	Good	Large shrub	Shallow	Fair-good	Medium	Low	Medium

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.

Live cuttings should be bundled together securely at the collection site for easy loading and handling and for protection during transport. Side branches and brush limbs should be kept intact. The bundles of live cuttings should be placed on the transport vehicles in an orderly fashion to prevent damage and facilitate handling. Materials should be covered with a tarpaulin during transportation to prevent drying and additional stress.

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 installation. When in storage, the cuttings must receive continuous shade, be sheltered from the wind, and 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.

3.5 Installing plant materials

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. Installation of live cuttings should begin concurrently with earth moving operations if carried out during the dormant season. All construction operations should be phased together. Each geographic area has a specific dormant season within this broad range, and yearly variations should be taken into account.

Soil bioengineering projects ideally utilize onsite stockpiled topsoil as the planting medium. Gravel is not a suitable material for use as fill around live plant materials. Bioengineering systems need to be installed in a planting medium that included fines and organic material and is capable of supporting plant growth. Muddy soils that are otherwise suitable should not be used until 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 site areas should be seeded following construction activities.

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.

3.6 Quality control

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

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 such as special habitat or areas of cultural significance.
- 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

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.

Establishment period

Interim inspections-Inspections should be made after the 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 or insect spraying, 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.

Final inspection-A final inspection should be held 2 years after the installation is completed.

- 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
Willow Posts	60-80% 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.

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 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 occasionally 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 2-year period following the completion of construction 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 elapsed, the use of rooted stock may be considered.

4. Recommended Experimental Bioengineering Treatment for Five Harland Creek Sites

Surveys were made of five sites along Harland Creek proposed for bioengineering bank stabilization were conducted in June, 1994. Based on the surveys, site visits by the Principal Investigators, and the information compiled in the previous chapters, a combination of bioengineering treatments were developed. A preliminary version of this report was given to Waterways Experiment Station and Vicksburg District for review in September, 1994. Office review was conducted by both groups, and Mr. Tom Prokefke and Mr. David Derrick participated in a field review of the proposed construction in October, 1994. The recommendations of the District and WES are incorporated in the experimental bioengineering treatments, and are presented in the following sections. Plan and cross section drawings are furnished with this report, and are also available in AutoCad format. All elevations should be considered as local datum, and stationing is referenced to the drawings.

4.1 Site No. 1

A plan view contour drawing and two sheets of cross section drawings are provided. The recommended plan is to construct a vegetated toe riprap along the toe of the left bank beginning at approximate section 3+50 and continuing upstream to approximate section 7+00. The constructed vegetated toe riprap will tie between riprap placed at the county road bridge (Section 3+50) and longitudinal toe riprap placed by the Vicksburg District (Section 7+00). Construction details for vegetated toe riprap are given in Section 3.3(7). Landward of the vegetated toe riprap, two rows of willow posts, Section 3.3(9), will be installed at a spacing of 3 feet on center. The top of fill should slope at approximately 1 vertical on 2 horizontal to prevent ponding behind the stone. All disturbed areas should be seeded in accordance with standard criteria.

4.2 Site No. 2

A plan view and a sheet of cross section drawings are provided for Site No. 2. The recommended plan is to construct a crib wall as described in Section 3.3(5) from approximate Section 0+00 to approximate Section 1+50. The crib wall will tie smoothly between two existing sections of longitudinal stone toe dikes. Willow posts, necessary to construct the crib wall, are described in Section 3.3(9). The crib will be 9 feet in thickness, consisting of three cells of 3 feet in thickness as measured from streamside to landward side using 4 rows of willow posts installed at 3 feet on center. The primary alignment of the crib is the streamside face, which must smoothly tie from the upstream to the downstream existing longitudinal riprap toe. If the streamside alignment does not permit a full thickness of 9 feet without excavating the existing bank, the thickness of the crib may be decreased to no less than 3 feet. The crib thickness will, in all cases, occupy from the streamside alignment to the existing bank up to a maximum thickness of 9 feet. The crib will be constructed up to an elevation of 192 feet, approximately 6 feet in height. Total height is measured from the streamside.

The crib will be filled with riprap up to 6 inches above the approximate low water surface elevation, the stream side cell will be filled with burlap bags of soil, and alternating layers of soil

and branches will be used to fill the remaining cells up to the total height. Bags will be placed in the streamside cell to allow branches to protrude through the riprap and overhang the stream.

Two additional rows of willow posts will be installed landward of the live crib, and fill will be placed to the elevation of the top of the crib and sloped as shown on the drawings. All disturbed or fill areas will be seeded in accordance with standard criteria.

4.3 Site No. 3

Drawings, in 5 sheets provide planview and cross sections of Sites 3, 4, and 5. At Site No. 3, four rows of willow posts will be installed on the right bank beginning at Section 0+00 and continuing upstream to approximate Section 3+00, tying into the existing upstream longitudinal stone toe. Willow posts, Section 3.3(9), will be installed at a spacing of 4 feet on center. The lower row of willow posts will be placed approximately 1 foot above low water surface elevation. A willow fascine, Section 3.3(2), will be installed on the landward side of the first row.

Riverward of the first row, downed willow trees with limbs and with butt pointed upstream will be anchored along the toe of the bank and cabled to the first row of willows. Trees must be brushy, at least 12 feet in length, and with a butt diameter of 6-12 inches. Trees must be overlapping by at least 3 feet, and each tree will be anchored to at least two willow posts at a spacing of approximately 6 feet using steel cable and cable clamps. The trunk of the tree should be in contact with the stream bottom.

The point bar attached to the left bank will be excavated to provide a channel approximately matching the upstream Section 3+00 dimensions. All disturbed bank areas in Site 3 will be seeded in accordance with standard criteria.

4.4 Site No. 4

A vegetated toe riprap, Section 3.3(7), will be installed at Site No. 4. The downstream extent of the vegetated riprap toe will tie into the existing longitudinal riprap toe at approximate Station 6+75, and will continue upstream to approximate Section 11+00. The upstream extent of the vegetated toe riprap is the unstable slide area, which begins at approximately Section 11+00. The slide area appears to be very unstable, and no excavation or vehicle traffic should be permitted on the site.

Landward of the vegetated toe riprap, branchpacking, as explained in Section 3.3(4), will be installed. The branchpacking will tie from the elevation of the fill landward of the riprap to the right top bank. If the slope of the branchpacking fill required to match the top bank is greater than 1 vertical on 2 horizontal, the branchpacking will be placed at 1 on 2 up to the intersection with the existing bank. Intervals between vegetation composed of willow and privet branches, will be no more than 3 feet vertically. A combination of willow and privet branches will be used in the branchpacking. A debris pile along the left bank at approximate Station 6+00 to 7+00 will be

removed from the stream. All disturbed or fill areas will be seeded in accordance with standard criteria.

4.5 Site No. 5

Site No. 5 is adjacent and upstream of Site No. 4, and comprises the unstable slide area and the right bank upstream of the slide to the upstream right bank point bar. The point bar begins at approximate Section 14+00. Five rows of willow posts, Section 3.3(9), will be installed at a spacing of 3 feet on center into the loose material at the toe of the slide, beginning approximately 1 foot above the low water elevation. A crib wall, Section 3.3(5), will be installed upstream of the slide area and continue upstream to approximate Section 14+00. Three rows of willow posts will be used in installation of the crib, for a crib thickness of 6 feet. The crib will be filled using riprap up to the low water surface elevation, and with alternating layers of willow branches and soil up to a total height of 6 feet. Soil in the streamside cell will be contained in burlap bags to resist erosion of the soil. The five rows of willow posts on the slide area will tie smoothly between the downstream vegetated riprap toe of Site No. 4 and the upstream crib.

The slide area is very unstable. No excavation of the slide exception for augering the post holes should be permitted. All fill areas should be seeded in accordance with standard criteria.

5. Recommended Construction Phasing

In accordance with Section 3.6, Quality Control, a recommendation is made that the construction should be phased in three phases: Phase 1 would be Initial Construction, Phase 2 would be the first year of the Establishment Period, and Phase 3 would be the second year of the Establishment Period. The establishment period for two years permits replacement of dead or damaged plant materials, spraying for insect infestations, or other undesirable conditions. A plan for planting a diverse mix of woody vegetation will be presented following construction. This plan is recommended for installation during Phase 2 construction. Local maintenance would be expected after the final inspection that is recommended at two years following the initial construction.

A schedule for inspection of the sites is included in Section 3.6. The Principal Investigators suggest that provisions be made for their inspections on at least a 6 month interval. This preliminary report will be finalized following construction at the sites, reporting on the progress up through early Spring, 1995.

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