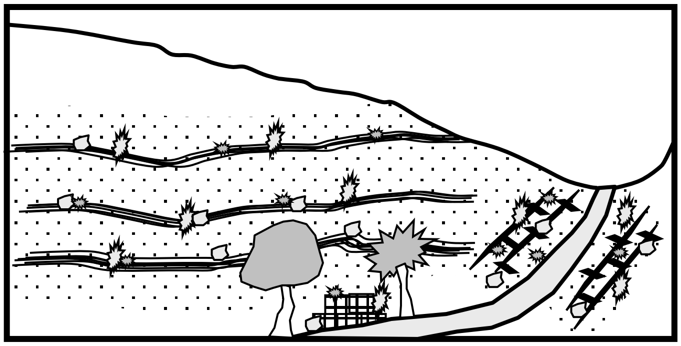
ACTIVITY: Bank Stabilization and Soil Bioengineering	ES – 20



Targeted Constituents

● Significant Benefit ◗ Partial Benefit ○ Low or Unknown Benefit

● Sediment	○ Heavy Metals	○ Floatable Materials	○ Oxygen Demanding Substances	
○ Nutrients	○ Toxic Materials	○ Oil & Grease	○ Bacteria & Viruses	○ Construction Wastes

Description

Provide slope stabilization, protection, vegetative cover and erosion reduction through the use of woody vegetation structures alone or in combination with simple retaining structures. This practice is likely to create a significant reduction in sediment.

Suitable Applications

- Protection of steep slopes against surface erosion and shallow mass wasting.
- Protection of earth embankments and for repairs of small gullies.
- Along streambanks and other channels that are experiencing erosion. Any work along a stream or within a stream must be approved by the Tennessee Department of Environment and Conservation (TDEC) prior to construction.
- Wherever trees, shrubs and dense non-landscaped vegetation may be desired.

Approach

At some locations it is very difficult to establish vegetation. Steep slopes that are subject to weather from prevailing storm patterns are a primary example. It is difficult to plant trees and shrubs on a steep slope in order to establish a stable ground cover. Streambanks are also subject to erosion and severe stresses, for which grass and other vegetation may not be sturdy enough. The techniques in this BMP are generally for slope stabilization; design of stream habitats and vegetation is a lengthy subject for which expert advice and extensive regulatory review is needed.

Bank and slope stabilization can be accomplished using woody materials that are placed in an alternative manner other than planting in a specially prepared hole using nursery stock (as in ES-10, Trees, Shrubs and Vines). The use of native plant materials can also be accomplished using live roots, branches and cuttings. Traditionally willow plants have been used near streams, due to quick sprouting and growth characteristics.

Bank stabilization and soil bioengineering can be incorporated into a standard retaining wall design such as a crib wall or gabion wall by adding live branches and cuttings. A retaining wall is an engineered structure with calculated loads and stresses that are used in material selection and design. Retaining walls must be designed by a professional engineer in accordance with stability calculations, by examining all possible combinations of live loads and dead loads. Adding vegetation to a retaining wall may or may not affect structural stability in the future. A project designer should carefully consider all potential issues of retaining walls during conceptual design.

Site Considerations

- Observe surrounding slopes for types of vegetation, vegetation density and overall plant health. Also observe the directions that nearby slopes are facing. For instance, some plantings generally do better on an eastern exposure and do not survive in a southern exposure. Plant health is a good indicator of soil types and conditions (including moisture).
- Make geologic observations of project site and nearby slopes, noting soil types and any types of failure such as sliding or rotating. Look for groundwater or wet soils. Consider potential freeze/thaw conditions that may contribute to slope failure.
- Retain existing vegetation whenever possible. Limit removal of vegetation by keeping the cleared area to the smallest practical size, limiting duration of the surface disturbance, and retaining existing woody vegetation for future planting.
- Stockpile and protect topsoil removed during clearing. Protect areas exposed during construction with temporary erosion and sediment control practices.

General Installation Techniques

- Grade or terrace a slope in order to eliminate possible failure by sliding or rotating. Flatten slopes to reduce potential slumping or undercutting from stormwater flows.
- Installation of bank stabilization methods is best accomplished in late fall at onset of plant dormancy. Plants that are not dormant are less likely to survive. Bank and slope stabilization plantings will not typically take full effect in slowing erosion for at least a year. Temporary or permanent grass seeding may be necessary.
- Keep fresh cuttings and branches moist. Store in a cool place away from direct sunlight. Backfill soil material should have sufficient fine soils and proper drainage depending on the type of vegetation selected. Soil may need lime or slow-release fertilizer in moderate amounts in order to support vegetation.

Live Stakes

Live stakes are the insertion of live, rootable vegetative cuttings into the ground. Live stakes are an appropriate technique for repair of small earth slumps that are frequently wet. Or they can be used to supplement other types of bank stabilization plantings. Live stakes can also be installed through existing riprap or other aggregate materials, allowing a stabilized riprap location to eventually have natural vegetation.

Live stakes are usually 0.5 to 1.5 inches in diameter and approximately 2 to 3 feet in length. Typical spacing is 2 to 3 feet apart. The basal end (or root) is cut to an angled point for easy insertion. The top should be cut square. Willow branches have historically been specified for use as live stakes and are well-suited to the purpose. Other types of tree branches may be selected, depending on soil type and available moisture conditions, such as ash, alder, elm or dogwood.

Gently tamp the live stake into the ground at right angles to the slope. Approximately 80 percent of the live stake length should be installed into the ground. Pack soil firmly around live stake after installation. Do not split the stakes during installation; stakes that split should be removed and replaced. An iron bar can be helpful in establishing a pilot hole for the live stake.

Live Fascine Bundles

A fascine is defined as a bundle of sticks or branches, tied together and used for a definite purpose such as preparing a primitive house, fort, or other structure. A live fascine is defined as a bundle containing live branch cuttings bound together into sausage-like structures, and then placed to provide slope stability or prevent erosion.

Live branch cuttings should be from species that easily root and have long, straight branches. Cuttings are tied together to form live fascine bundles that vary in length from 5 to 30 feet, 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.

Both live stakes and dead stakes are used to install fascine bundles. Stakes should be at least 2.5 feet long on cut slopes and at least 3 feet long on fill slopes. Dead stakes can be constructed from untreated 2x4 lumber with a minimum length of 2.5 feet. A diagonal cut across the 2x4 lumber will assist in creating stakes quickly.

Prepare the live fascine bundles and live stakes immediately before installation.

Begin at the base of the slope and work upwards. Dig a trench along a level contour just deep enough to contain the live fascine bundle. A typical trench size is 12 to 18 inches across and also 6 to 8 inches deep. Place the live fascine bundle into the trench.

Drive dead stakes directly through the bundle every 2 to 3 feet to securely fasten it. Extra stakes should be used at connections and overlaps. Leave the top of 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 as shown in Figure ES-20-1. Place straw or similar mulching material between rows. Slopes steeper than 3:1 may need erosion control matting or some type of mesh to prevent erosion. Recommended maximum slope lengths for live fascine bundles are:

Slope (H:V)	Maximum slope length
1 : 1 to 1.5 : 1	15 feet
1.5 : 1 to 2 : 1	20 feet
2 : 1 to 2.5 : 1	30 feet
2.5 : 1 to 3 : 1	40 feet
3 : 1 and flatter	50 feet

A willow mattress (also called a brush mattress) is similar to a fascine roll. Willow branches and cuttings are formed into a layered arrangement approximately 4 to 6 inches thick and then tied with twine or string. Excavate an anchor trench along the bottom of the willow mattress to a depth of 3 inches, to prevent downhill sliding. Loosen the subgrade soil throughout the mattress installation location; add lime and slow-release fertilizer as needed. A willow mattress is anchored onto a slope by using dead stout stakes and twine. Place 4 to 6 inches of fertile soil upon the willow mattress and tamp firmly.

Branchpacking

Branchpacking (a descriptive name for this method) consists of alternating layers of live branch cuttings and compacted backfill to create bank stabilization vegetation. It is often used to repair small localized slumps, gully washouts, or other small areas where the slope needs to be stabilized. Branchpacking can also be adapted as a method for planting an entire slope (see description below for brushlayering).

Live branch cuttings may range from 1/2 inch to 2 inches in diameter. Cuttings should be long enough to touch the undisturbed soil at the back of the trench. Wooden stakes (typically made from 2x4 lumber, untreated) are 5 feet or longer, depending on the depth of the hole and field conditions. Starting at the lowest point, drive the wooden stakes vertically 3 to 4 feet into the ground, at a typical spacing of 1 to 2 feet apart.

Place a 6-inch layer of live branch cuttings in the bottom of the hole or trench, between the vertical stakes and perpendicular to the slope face (as shown in Figure ES-20-2). Cuttings should be placed in a crisscross configuration with the growing tips generally oriented toward the slope face. Most branch basal ends should touch the back of the hole or slope. Each layer of branches is followed by a layer of compacted soil, typically 6 to 8 inches thick, to ensure soil contact with the branch cuttings. Final grade should match the existing slope, and branches should protrude slightly from the filled face. The soil should be moist so that the live branch cuttings do not dry out.

Branchpacking may not be effective in slumped areas or gullies which are greater than 5 feet wide. Examine the slope closely to determine the cause of slumped areas and gullies. Wet soils, inadequate drainage, excessive stormwater runoff or other site conditions may require additional solutions.

Brushlayering is a variation of branchpacking suitable for gentle slopes with only a moderate potential for erosion. The live branch cuttings are oriented perpendicular (up and down) to the slope level contours, installed in a trench or cut slope, and then covered with soil as before. The difference is that the soil for each downhill trench comes from the next excavated trench immediately uphill. The presence of branch cuttings in the soil will limit the amount of compaction that can be obtained on a slope, so that additional erosion control measures may be necessary. Straw mulch, temporary seeding, jute mesh and erosion control mats may be necessary, particularly for slopes steeper than 3:1. Avoid slopes steeper than 2:1 and generally limit slope lengths to 20 feet or less.

Vegetated Crib Wall

A crib wall is a hollow, box-like, interlocking arrangement of structural members to create a retaining wall. A retaining wall is an engineered structure, with calculated loads and stresses used for the material selection and design. Crib walls made from prefabricated metal or reinforced concrete beams can be designed as very tall retaining walls that can handle large surcharge loads and traffic impacts; these types of crib walls must be designed by a professional engineer. Crib walls are filled with compacted soil or gravel, with provisions for subsurface drainage.

Adding vegetation may or may not affect structural stability of a retaining wall in the future. It would certainly affect large structural crib walls, but should not impact small crib walls such as the type shown in Figure ES-20-3 for a relatively short height using untreated logs or timber. The structure is filled with suitable backfill material and layers of live branch cuttings which will root inside the crib structure and extend upward into the slope or outward into the wall face. This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe.

Live branch cuttings should be long enough to reach the back of the wooden crib structure. Logs or timbers are usually 6 inches in diameter or thickness. Large nails or rebar are required to secure the logs or timbers together. Place foundation of wall 2 to 3 feet below grade, as shown on Figure ES-20-3.

Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4 to 5 feet apart. Place the second 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. Repeat course in same manner and nail to the preceding course with nails or reinforcement bars. When the crib wall structure reaches the existing ground elevation, place live branch cuttings on the backfill perpendicular to the slope. Then cover the branch cuttings using fertile soil as backfill and compact firmly.

Vegetated Gabion Wall

A gabion is a wire basket, usually galvanized or with plastic coating, designed to hold and retain rock, riprap, aggregate, etc. The wire baskets come in standard rectangular sizes with one or more compartments. A typical gabion has triple-twisted, hexagonal mesh with openings of 1 inch more or less, depending on the type of rock that is being retained. Empty gabions are usually delivered to the project site flat, assembled and then placed into position, wired to adjoining gabions, filled with stones and then folded shut and wired at the ends and sides.

Gabion walls can be used as a designed retaining wall, with certain estimated properties and the ability to resist surcharged loads. Gabion walls which are over 4 feet tall or which are located in critical areas need to be designed by a professional engineer. Follow gabion manufacturer's recommendations and design guidelines in designing a gabion wall.

Since a gabion wall does not contain soil as part of its structure, the live branch cuttings are typically extended through the gabions to the backfilled soil behind the wall (as shown on Figure ES-20-4). Live branches are placed on each consecutive layer between the rock-filled baskets. Eventually the roots will take hold in the backfilled soil and will also help to consolidate the structure and bind it to the slope.

Vegetated Rock Wall

A vegetated rock wall can be constructed to take advantage of live cuttings to stabilize a very low embankment or at the base of a gentle slope. The rock wall can constructed with or without mortar, depending on the types of rocks and the skill of the rock masons involved. Additional erosion control measures such as straw mulch, temporary seeding, jute mesh and erosion control mats may be necessary. A retaining wall over 4 feet high must be designed and analyzed by a professional engineer, particularly in applications which could endanger health or property.

Live cuttings should be long enough to reach the undisturbed soil behind the wall. Rock sizes normally range from 8 to 24 inches in diameter, with larger boulders used for the base. Excavate and construct a stable foundation 2 to 3 feet below existing grade as shown on Figure ES-20-5. Drainage considerations may require weepholes or other methods to remove moisture and to prevent frost damage. Provide subsurface drainage if the water table is above the wall foundation, or if the retaining wall is adjacent to impervious surfaces such as parking lot.

Place rocks with at least three contact points bearing on the layer below. Place rocks so that the center of gravity is as low as possible, with the long axis slanting inward toward the slope if possible.

Limitations

- Streams and streambanks should not be disturbed or modified unless permission is granted by the City of Knoxville Engineering Department and TDEC. Permits must be obtained from TDEC prior to any work within or along any stream.
- Constraints on planting times or availability of suitable plant materials during the

allowable planting times may limit soil bioengineering methods.

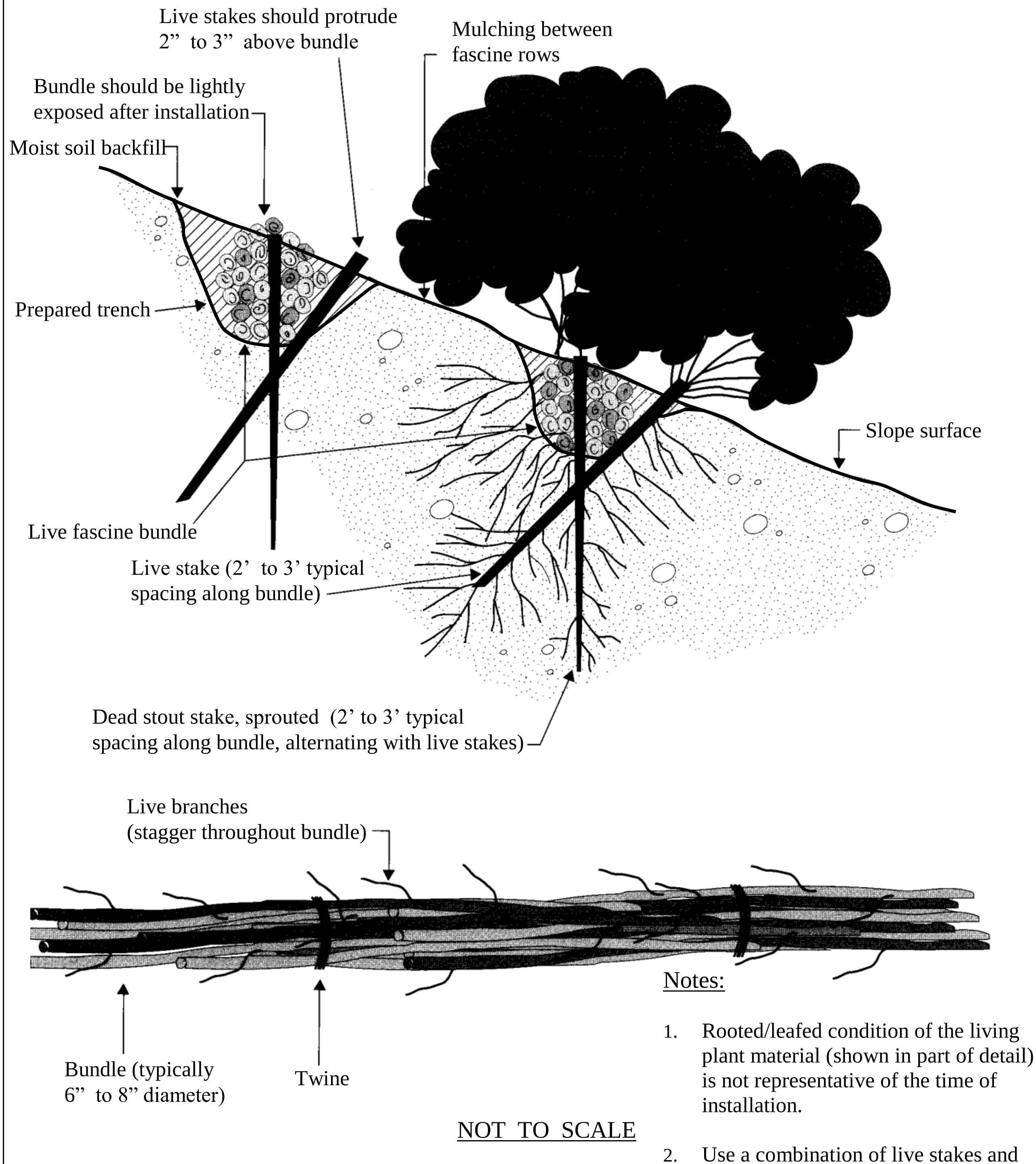
- Rapid vegetative establishment may be difficult on extremely steep slopes. Rocky or gravelly slopes can lack sufficient fines or moisture for plant growth.
- Soil bioengineering and bank stabilization methods takes considerable time and effort to accomplish. Other methods, such as hydroseeding and the use of erosion control mats, may be much cheaper and quicker.

Maintenance

- During the two weeks of the establishment period, inspect cuttings daily and replace any dead vegetation with fresh stock. Inspect biweekly for the first 2 months, looking for insect infestations, inadequate soil moisture, and other conditions that could lead to poor survivability. Take immediate action to remedy any site conditions as warranted.
- Inspect monthly for the next 22 months. Extra inspections should be conducted during periods of drought or heavy rains. Systems which are 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. Repair damaged sections immediately.
- Final inspection – A final inspection should be held 2 years after installation is completed. Healthy growing conditions include assessment of overall leaf development and the rooted stems. Growth should be continuous with no open spaces more than 2 feet. The following list has a typical rate for each type of planting, particularly when good techniques and preparation have been used.

  Live stakes ----------------------------- At least 75% growing
  Live fascines --------------------------- At least 50% growing
  Branchpacking (repairs) ------------- At least 50% growing
  Vegetated crib wall ------------------- Approx 50% growing
  Vegetated gabion wall ---------------- Approx 50% growing
  Vegetated rock wall ------------------- Approx 50% growing

References **30, 82, 124, 141, 155, 162, 167, 179** (see BMP Manual Chapter 10 for list)



Notes:

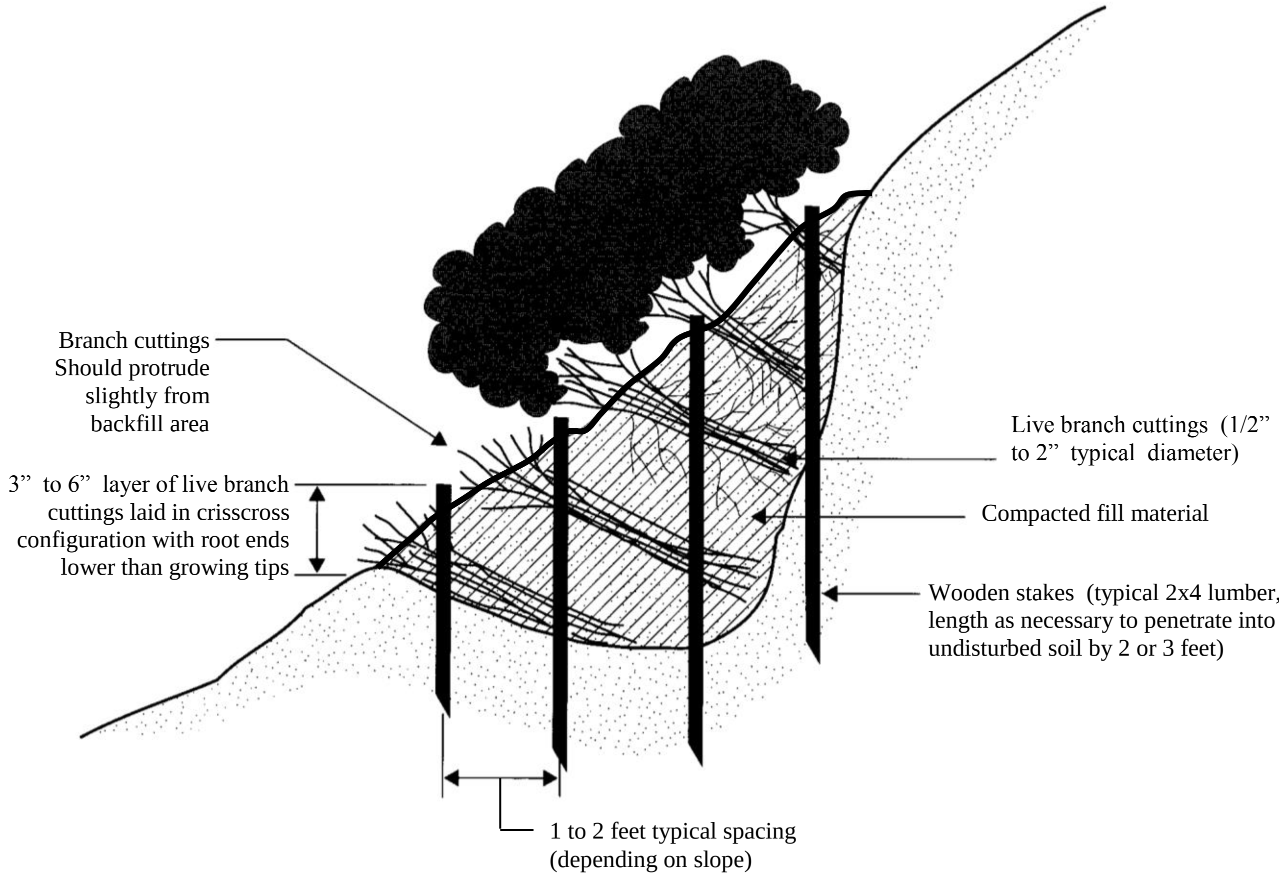
1. Rooted/leafed condition of the living plant material (shown in part of detail) is not representative of the time of installation.
2. Use a combination of live stakes and dead stakes to anchor fascine bundles.

Figure ES-20-1
Live Fascine Details

Notes:

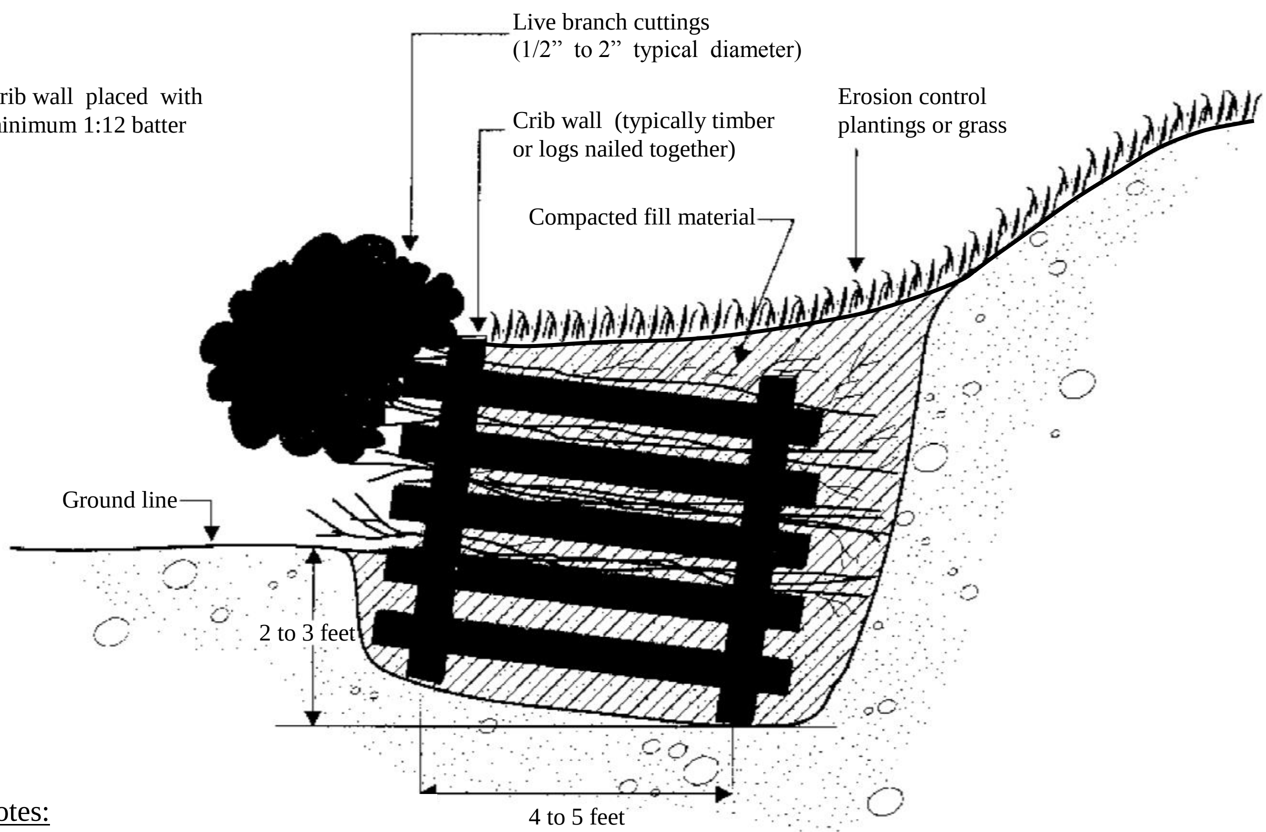
1. Rooted/leafed condition of the living plant material (shown in part of detail) is not representative of the time of installation.

2. Branchpacking locations are typically for small repairs of a slope or gully. Carefully examine site conditions to determine cause of needed repair, such as wet soils or excessive stormwater runoff, before conducting repairs.



NOT TO SCALE

Figure ES-20-2
Branchpacking Details



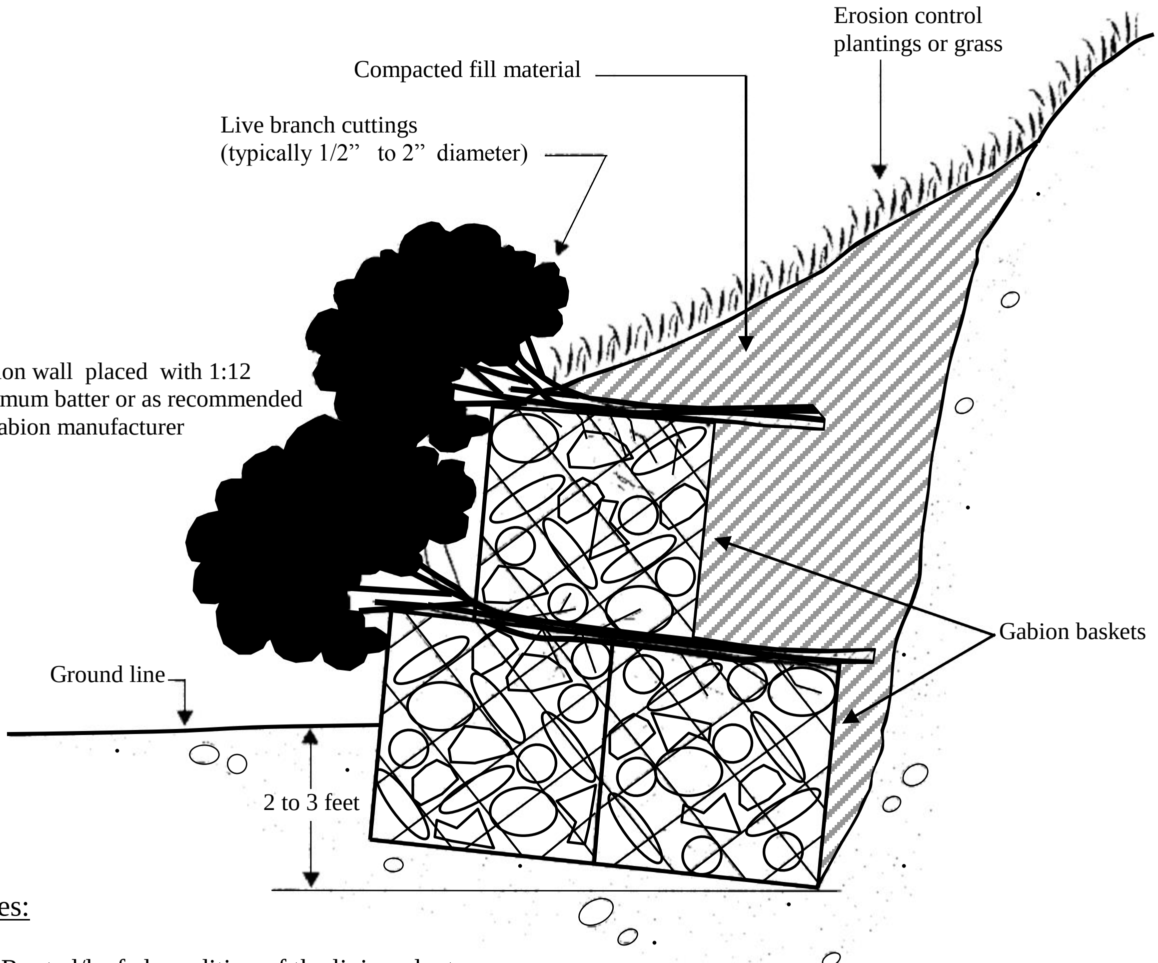
Notes:

1. Rooted/leafed condition of the living plant material (shown in part of detail) is not representative of the time of installation.

2. Crib walls are typically an engineered structure with calculated loads and stresses used in the material selection and design. Adding vegetation to the crib wall may or may not affect structural stability. Consult a professional engineer for walls at the base of steep slopes. Retaining walls over 4' high must be designed by a professional engineer.

NOT TO SCALE

Figure ES-20-3
Vegetated Cribwall



Notes:

1. Rooted/leafed condition of the living plant material (shown in part of detail) is not representative of the time of installation.

2. Gabion walls are typically an engineered structure with calculated loads and stresses used in the material selection and design. Adding vegetation to the gabion wall may or may not affect structural stability. Consult a professional engineer for walls at the base of steep slopes. Retaining walls over 4' high must be designed by a professional engineer.

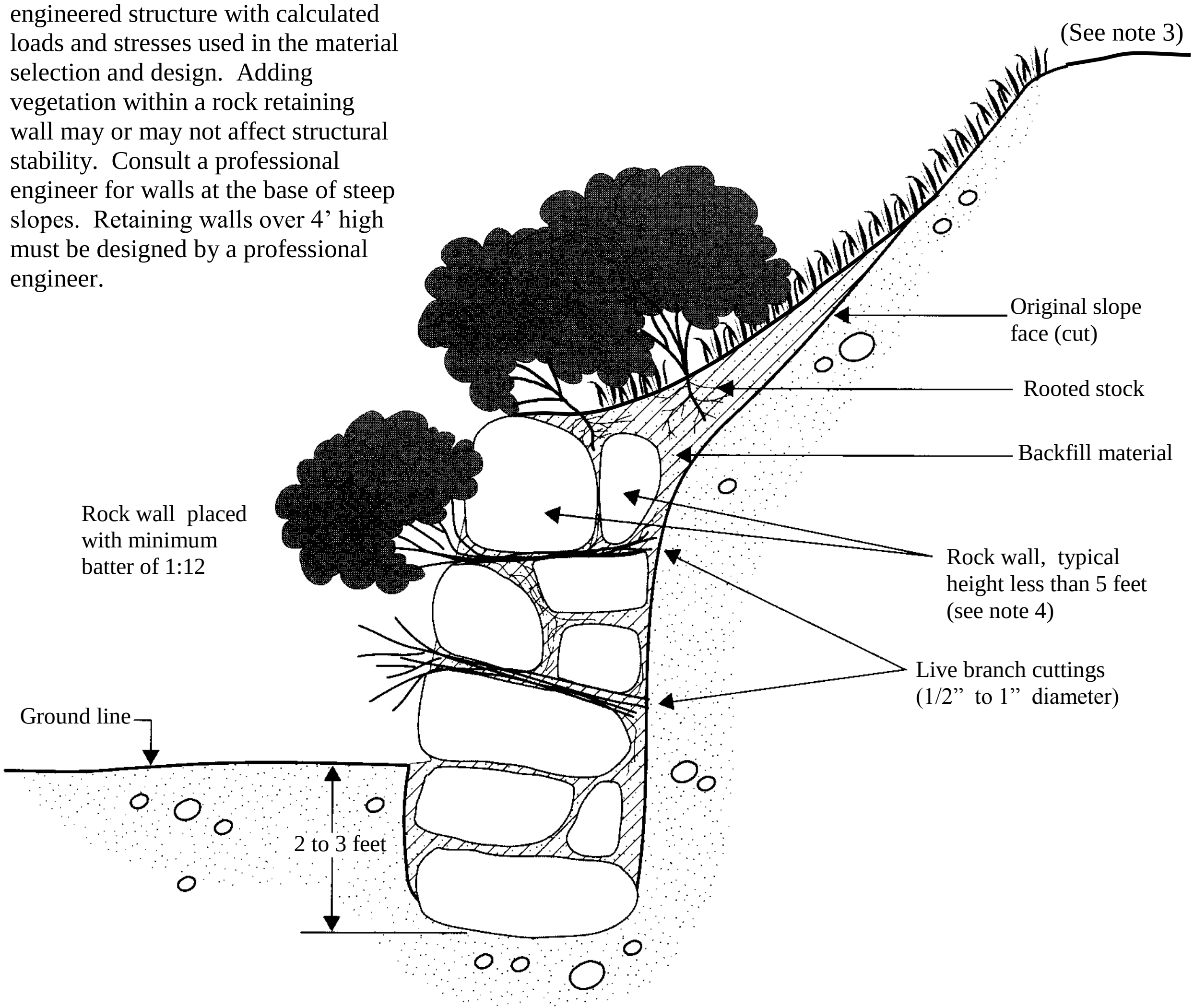
NOT TO SCALE

Figure ES-20-4
Vegetated Rock Gabion

Notes:

1. Rooted/leafed condition of the living plant material (shown in part of detail) is not representative of the time of installation.

2. Retaining walls are typically an engineered structure with calculated loads and stresses used in the material selection and design. Adding vegetation within a rock retaining wall may or may not affect structural stability. Consult a professional engineer for walls at the base of steep slopes. Retaining walls over 4' high must be designed by a professional engineer.



3. Limit height of slope and types of surcharged loads (such as buildings or traffic) above vegetated rock wall.

NOT TO SCALE

4. Rock wall may be constructed with or without mortar. Subsurface drainage (such as a gravel drainage layer or weep holes) should be considered in design.

Figure ES-20-5
Vegetated Rock Wall