3.3.2.2 Bioengineered Soil Bank Stabilization

Source: TNWRRC

Definition and Purpose

Soil bioengineering is defined as the use of living and nonliving plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment. These techniques incorporate natural and readily available plant materials such as root wads, coconut fiber rolls, and rock or log vanes to direct stream flow away from eroding banks and stabilizing the bank.

Appropriate Applications

Bioengineered soil bank stabilization is appropriate anywhere repair or protection from erosive forces on the banks is needed. This could be along straightened channels, in urbanized watersheds, exposed streambanks, or where highly erosive flows have been observed or are anticipated. Native vegetation is the preferred method of bank stabilization. However, when vegetation cannot provide adequate stabilization, bioengineered methods are favored.

Limitations and Maintenance

Bioengineered soil stabilization measures must be affixed in place so they cannot become dislodged migrate downstream. Continual repair or maintenance may be incurred if the stabilization practice is under-designed and cannot withstand the shear forces in which it is subjected. This can be costly and more impactful than initially designing a more stable option. Any implemented practice must not reduce the hydraulic capacity of the stream.

Installing bioengineered soil bank protection in jurisdictional waters requires additional permits, such as an ARAP, and therefore, both the conditions of the CGP and ARAP must be followed. A Section 404 permit from USACE may also be required. If the proposed bioengineered soil bank protection is to be completed in a TVA reservoir, a TVA 26a permit may also be necessary. Local permitting may be required in addition to state and federal permitting requirements. Consider the criteria and conditions of the necessary permits during the planning stages of the project and EPSC plans.

Planning and Design Considerations

When selecting the best-suited bioengineered technique, it is important to have a clear understanding of the ecological systems in adjacent areas. Plant selection and the techniques used will play an initial role in site stabilization and, ultimately, serve as the foundation for the ecological restoration of the site. Long-term establishment and health of herbaceous, woody vegetation is critically important to the physical and biological functions of streams. See Section 3.3.2.1 Bank Protection for the different planting zones within the riparian buffer zone.

Bioengineered soil bank stabilization is especially useful as a transition between conventional, inert bank stabilization and natural downstream banks. Abrupt transitions from projects, such as conventional riprap, to natural channel linings are often prone to scour. Established bioengineered soil treatments can act to protect and reinforce the transition and reduce the possibility of washouts and flanking (NRCS, 2007). Combinations of vegetative and structural protection can often be used in place of most structural measures. As with structural measures, start and end all combined methods along stable reaches of the stream.

Cellular confinement matrices are commercially available products comprised of heavy-duty polyethylene and formed into a honeycomb-shaped matrix. The product is flexible to conform to irregular surfaces and the honeycombs can be filled with soil, sand, gravel, or cement. When soil is filled into the honeycombs, it is usually ideal to plant vegetation in addition. Install all cellular confinement systems according to manufacturer specifications.


Source: Yee (2012)

Live cribwalls are a bioengineered technique that consists of a hollow, box-like interlocking arrangement of untreated logs or timber. They are appropriate to use at the base of a slope where a low wall may be required to stabilize the toe and reduce steepness. They are also appropriate where space is limited, and a vertical structure is required. The live walls are natural materials, thereby promoting environmental sustainability and allowing for the growth of plants within their structure, which can help with long-term bank stability. Cut live branches one-half to two inches in diameter. Construct the crib from logs or timbers from four to six inches in diameter or width. Branch lengths will vary depending on crib size. Starting at the lowest point of the slope, excavate loose material two to three 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. Place the first course of logs or timbers at the front and back of the excavated foundation, approximately four to five feet apart and parallel to the slope contour (Figure 3.3.2.2-A). Place the next set of logs or timbers orthogonal to the slope on top of the previously set timbers. Place each set of timbers in the same manner and affix them to the preceding set. Place live branch cuttings on the top of each cribwall structure with growing tips oriented outward. Backfill the cribwall, compact the soil for good root-to-soil contact, and apply seed and mulch.

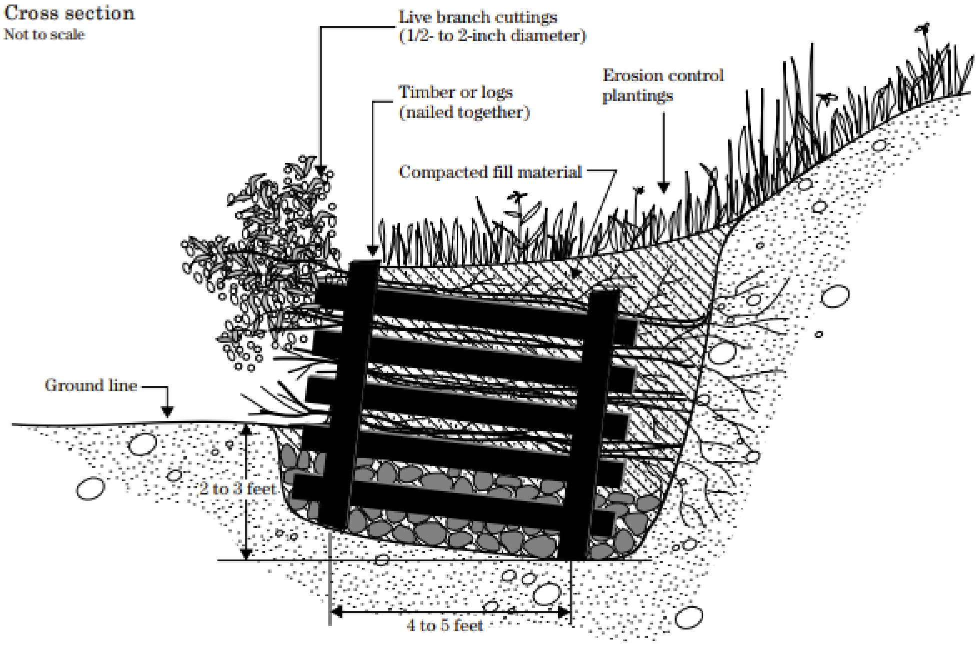


Figure 3.3.2.2-A: Live cribwall details. Source: NRCS (1996, 2021).

The Tennessee Cedar Revetment is a bioengineered soil bank technique that combines small, locally harvested eastern red cedar trees with 700-gram coir matting to form a flexible, interlocking structure that traps sediment and protects eroding banks. Constructed with cedar branches as the internal framework and encased in coir matting, each revetment unit is typically 10 feet long and 14 to 22 inches in diameter, forming a sturdy, yet flexible structure that conforms to the streambank. This method is most suitable for small to medium-sized streams with active erosion but where heavy equipment access is limited or undesirable, especially in forested areas where preserving vegetation is a priority. Installation begins downstream, using duckbill anchors and aircraft cables to tightly secure each revetment into the bank, layering them in overlapping sequences to prevent water from getting behind the structure. Revetments may be stacked in multiple rows depending on bank height and are often paired with rock toes or vanes for added protection. Once in place, the coir matting filters suspended sediment while the cedar adds structure, creating a new, reinforced bank that supports natural revegetation. Tennessee Cedar Revetments offer a cost-effective, minimally invasive, and volunteer-friendly alternative to conventional erosion control, with a proven track record of durability and ecological compatibility in Tennessee streams (Gregg & McFadden).

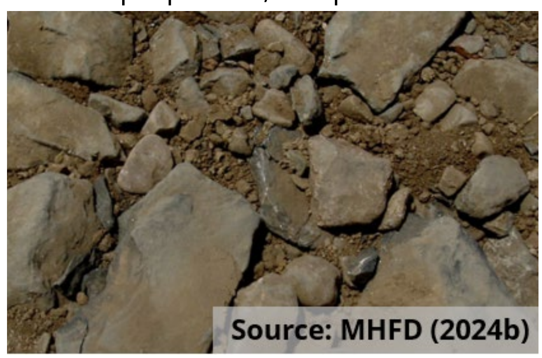
Source: Gregg & McFadden

Soil riprap is a bioengineered soil technique that mixes conventional riprap with natural soil or topsoil. The ideal mixture is two-thirds conventional riprap and one-third soil, which fills the voids between the angular stone. Mix the materials to a uniform consistency with a front-end loader or excavator. Prior to installation, ensure that the subgrade is excavated to the proper depth to account for the soil riprap upon placement and subsequent compaction. Because the soil fills the void spaces, erosion due to piping is not a concern, and therefore an underlying geotextile or bedding material is not necessary, as with conventional riprap. As the soil riprap is installed, ensure it is compacted such that the angular stone forms interlocking compartments to hold the soil in place. Additionally, ensure there are no excessively large pockets of soil, which may indicate weak spots. Once installed, all void spaces should be adequately filled

Source: MHFD (2024a)

and compacted by visual inspection. For some projects, an additional layer of topsoil may be added to the top of the soil riprap profile to provide a more suitable growing medium. This practice is particularly useful where aesthetics are important, as vegetation will effectively hide the riprap (MHFD, 2024a). Ensure the soil and conventional riprap are stored separately onsite, as pre-mixed compositions that are not compacted may allow the soils to migrate downward, resulting in a nonuniform matrix.

Void-filled riprap is a soil bioengineered technique that consists of a composition of conventional riprap, cobbles, gravels, sands, and onsite (or natural) soils. The materials in void-filled riprap will form a dense, interlocking composition that more naturally mimics natural stream flow compared to soil riprap or conventional riprap. Thus, this practice is ideal where continual and/or larger flows are anticipated. Using a front-end loader or excavator, mix an initial test batch of all void-filled riprap materials until a uniform consistency is achieved. Make note of the ratio of materials used such that the test batch can either be recreated or amended. Amending material proportions should be done during this initial test batch such that the finalized ratios most accurately resemble natural riffle material. Prepare the subgrade and place the void-filled riprap in the same manner as soil riprap. Ensure that the mixing and placement of the void-filled riprap results in some of the larger riprap flush and visible on the surface, with other materials organized to minimize the voids. Before compacting, inspect the void fillings. It may be necessary to add bedding or cobbles to the surface and "wash it in" with a high-pressure hose to fill any voids. After which, compacting can occur. These techniques ensure stability such that the void fillings are locked in place and cannot be eroded away or migrate downwards (MHFD, 2024b). Lastly, ensure void-filling materials are stored separately on-site similar to soil riprap.


Source: MHFD (2024b)

Vegetated gabions are a bioengineered soil technique that combines layers of live branches and gabions (Section 3.3.2.1). This practice is appropriate at the base of a slope where a low wall is required to stabilize the toe of the slope and reduce its steepness. It is not designed to resist large lateral earth stresses. Ideal use is where space is limited and a more vertical structure is required. Keep the overall height, including the footing, less than five feet. Cut live branches one-half to one inch in diameter and long enough to reach beyond the rock basket structure into


Source: TDOT

the backfill. Starting at the lowest point of the slope, excavate loose material two to three feet below the ground elevation until a stable foundation is reached (Figure 3.3.2.2-B). Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability and ensure rooting. Place the wire baskets in the bottom of the excavation and fill with stone. Backfill between and behind the wire baskets. Place live branch cuttings on the wire baskets orthogonal to the slope, with the growing tips oriented away from the slope and extending slightly beyond the gabions. Root ends must extend beyond 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.

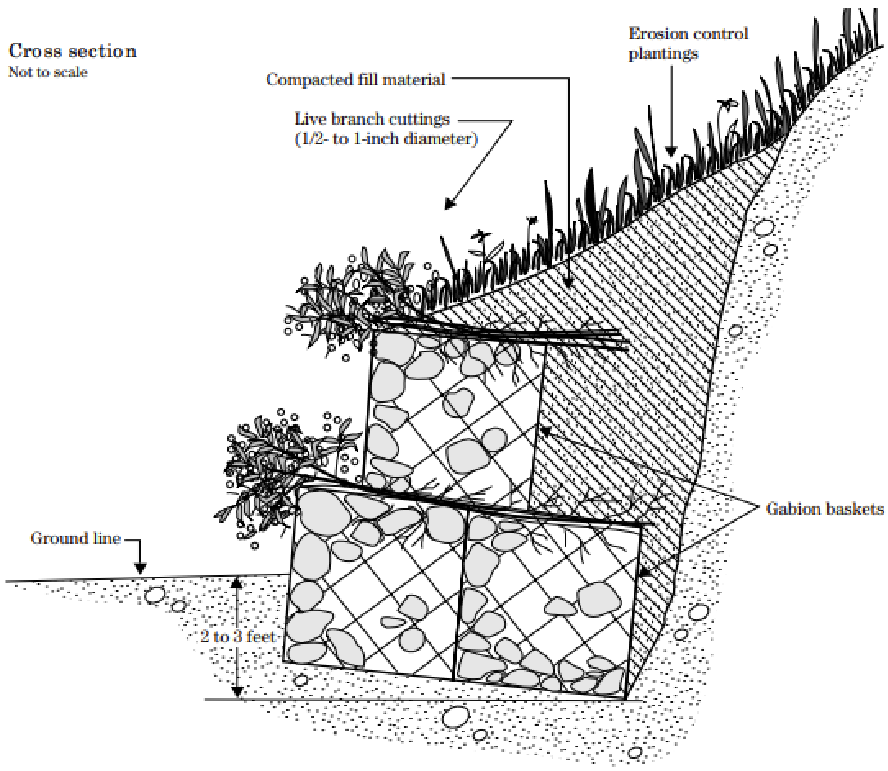


Figure 3.3.2.2-B: Vegetated gabion details. Source: NRCS (1996).

Joint plantings, sometimes referred to as vegetated riprap, are a bioengineered soil technique that involves tamping live cuttings into soil between the joints or open spaces in conventional riprap that is already set in place. Joint planting is ideal where riprap is required. This technique aids in soil moisture removal, preventing soil from washing out below the riprap, and in slope stability. Cut live branches one-half to one and one-half inches in diameter and long enough to extend into the soil below the riprap. Remove side branches from cuttings while leaving the bark intact. Tamp live branch cuttings into riprap void spaces during or after construction. Ensure the root ends extend into the soil beyond the riprap (Figure 3.3.2.2-C). Mechanical probes may be needed to create pilot holes for the live cuttings. Place cuttings orthogonal to the slope with growing tips protruding from the finished face of the riprap.

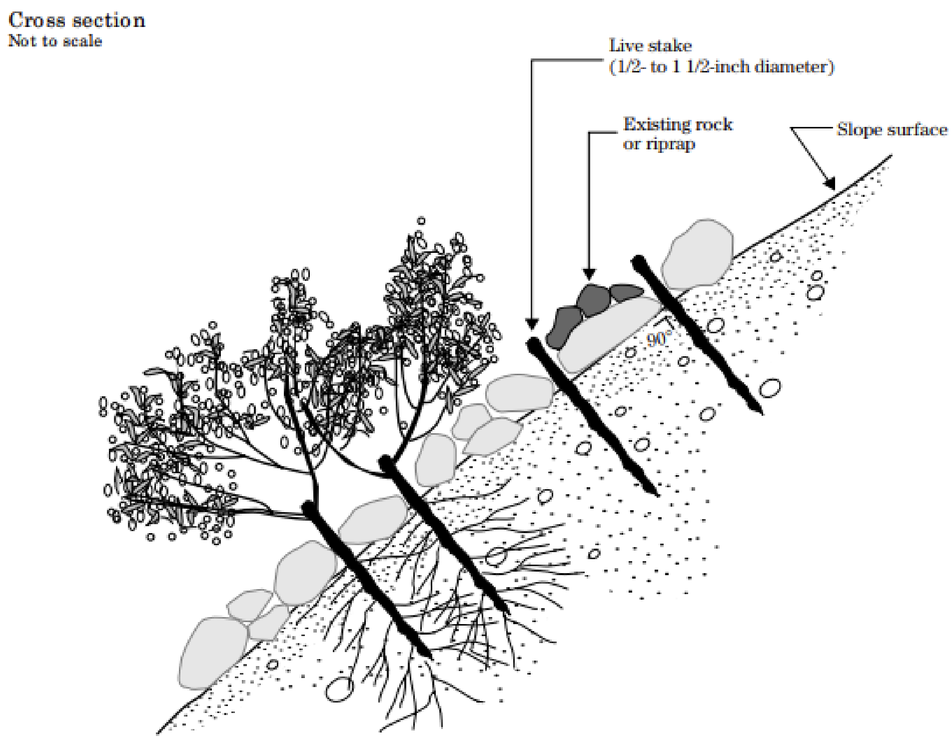


Figure 3.3.2.2-C: Joint planting details. Source: NRCS (1996).

Vegetated mechanically stabilized earth walls are soil retaining bioengineered structures designed to stabilize steep slopes while incorporating vegetation to improve environmental benefits. These walls use a porous fascia and tensile inclusions (reinforcements) integrated into the soil to distribute loads and resist lateral forces. Two common types are geocell systems and wrapped soil systems, each utilizing different materials for the fascia and reinforcements. Geocells contain soil and vegetation, with perforated cells allowing for root growth, while wrapped soil systems use geosynthetic fabric to hold compacted soil layers and support vegetation. The design of these vegetated mechanically stabilized earth walls requires careful consideration of factors such as slope, wall height, material selection, and geotechnical analysis. These walls can be constructed with various slopes, typically ranging from nearly vertical to 1H:1V, and may incorporate vegetation through seeding or live cuttings, depending on the project's needs. A key concern is ensuring the stability of the structure, particularly with respect to shear stresses and erosion protection. Walls are often reinforced with a stone toe to prevent undermining from scour. The structure must be engineered to handle external forces such as overturning, sliding, and soil pressure while ensuring proper drainage and vegetation growth. Design details are presented in Figure 3.3.2.2-D. Consult geotechnical experts when necessary, as factors such as shear stresses, erosion protection, and reinforcement placement are crucial for stability.

Source: TDOT

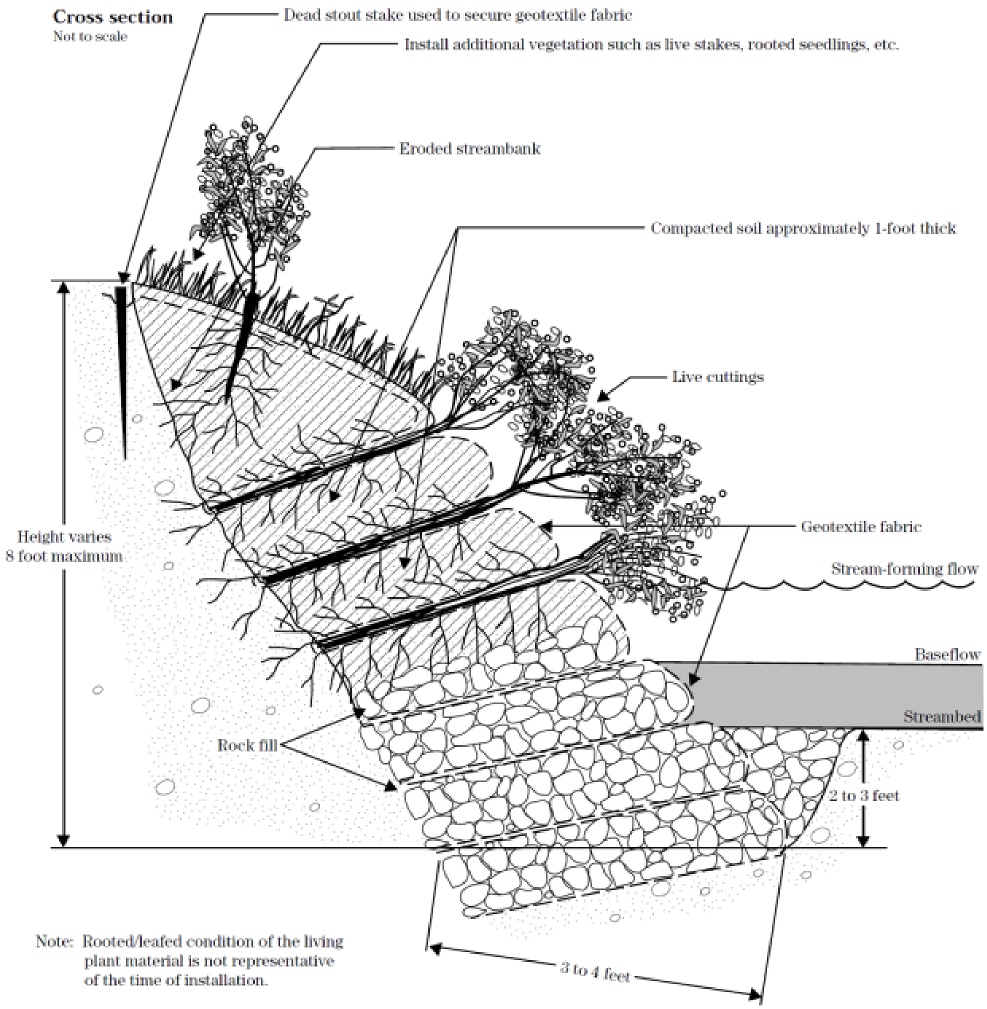


Figure 3.3.2.2-D: Design details of mechanically stabilized earth walls. Source: NRCS (1996).

Geotextile containments are bioengineered soil techniques that are relatively novel and commercially available products. The containment systems vary broadly in design within manufacturers and from manufacturer to manufacturer because of their broad applicability on bank slopes, lake perimeters, coastlines, dunes, etc. Typically, geotextile containments are to be staked below the finished grade at both the top and bottom of the bank. Containments can be filled with eroded sediment, soil fill, etc., and planted to ensure long-term stability. Refer to manufacturer specifications on stake material, stake spacing, alternative tie-down methods, tensile strengths, etc. All geotextile containments must in installed according to such specifications.

Soil bioengineering techniques use live, woody vegetative cuttings to increase slope stability. It can either be a woody vegetation system alone or a woody vegetation system combined with simple inert structures. Beyond structural benefits, these systems enhance riparian habitats, improve water quality, and offer aesthetic and ecological advantages (ALSWCC, 2018). Native plant species that root easily, such as willow, are ideal for soil bioengineering projects. Use plants that are well-suited to the conditions of each site and sourced locally, either from natural stands or reputable nurseries. However, careful consideration must be given to local wildlife interactions, as some species may pose challenges. For example, in west Tennessee, beavers are particularly drawn to willows, often undermining their effectiveness in stabilizing streambanks by causing additional erosion. When harvesting plant materials, cuttings can range from one-half to two inches in diameter and two to six feet in length, depending on project needs. To ensure regrowth, cut plants at a blunt angle, leaving an eight- to ten-inch trunk above the ground. Once harvested, cuttings are to be bundled, stripped of side branches, and kept moist to preserve viability. Careful handling during transport is essential to prevent damage and drying. It is ideal for cuttings to be delivered to the construction site within eight hours of harvest and installed immediately, particularly in temperatures above 50°F. If short-term storage is necessary, submerge cuttings in water or place them in moist, shaded soil to maintain their integrity for up to two days. For successful establishment, install cuttings during the dormant season, typically from late September to March. Soil conditions must support healthy plant growth, with compacted backfill ensuring proper contact between cuttings and the soil to eliminate air pockets. Thoughtful planning and careful handling of plant materials are essential for a resilient, long-lasting bioengineered streambank. Common slope stability techniques include live staking, live fascines, brushlayering, branchpacking, and brushmattresses.

Live staking is a slope stability technique that involves inserting and tamping live, rootable vegetative cuttings directly into the ground. As these stakes establish, they develop a dense root mat that binds soil particles, reinforces streambanks, and extracts excess moisture, making them particularly effective for stabilizing wet areas and repairing small earth slips. This method is cost-effective, quick to install, and can be used to secure surface erosion control materials or enhance vegetation colonization. Proper preparation includes removing side branches while keeping the bark intact, cutting the bottom end at an angle for easier insertion, and ensuring that the buds face upward. Stakes, typically one-half to one and one-half inches in diameter and two to three feet long, are spaced two to three feet apart in a triangular pattern, with four-fifths of each stake embedded in the soil (Figure 3.3.2.2-E). In firm ground, a pilot hole can be made with an iron bar, and stakes can be driven in using a dead blow hammer. To ensure effectiveness, compact the soil tightly around each stake, and replace any split or damaged stakes.

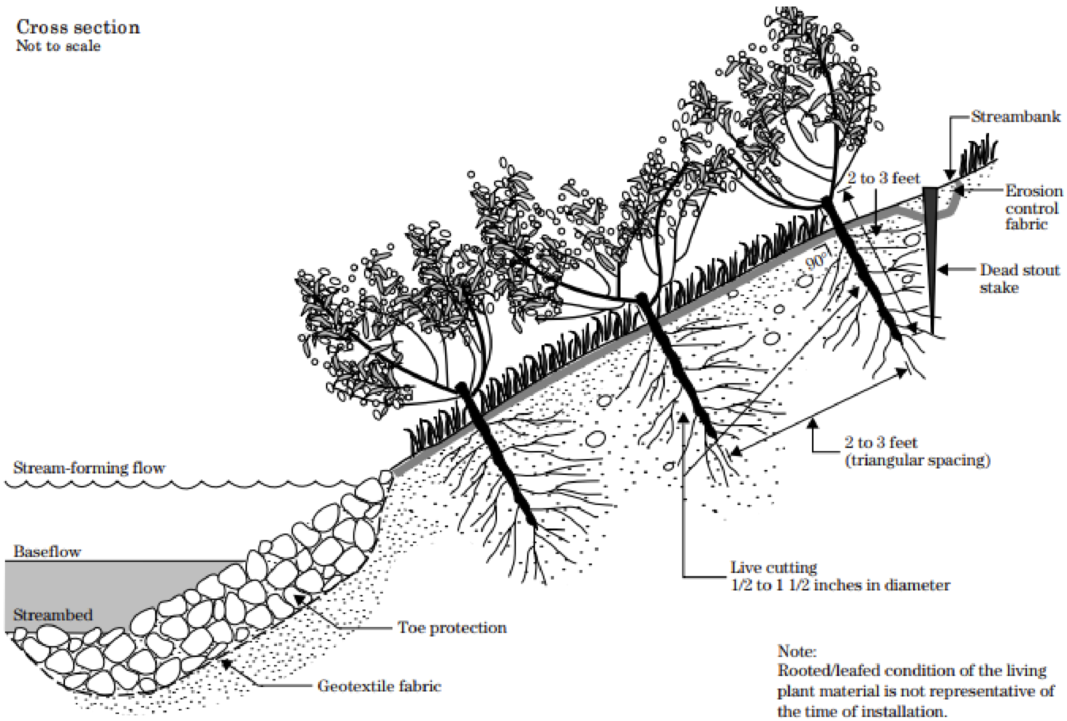


Figure 3.3.2.2-E: Live staking details. Source: NRCS (1996).

Live fascines are a slope stability technique involving cylindrical bundles of branch cuttings strategically placed in shallow trenches that can be ideal for steep or rocky slopes. These structures create a series of shorter slopes that minimize surface runoff and prevent shallow sliding. Typically composed of easily rootable species like young willows or shrub dogwoods, fascines also enhance drainage and encourage the natural colonization of vegetation. When properly installed, they provide immediate surface protection while gradually integrating into the landscape, reinforcing soil stability, and fostering plant growth. Construction involves tying cuttings into bundles, usually six to eight inches in diameter and five to 30 feet long, ensuring that growing tips align in one direction. The bundles are placed in trenches dug along the contour of the slope, secured with untreated twine and dead stout stakes driven at regular intervals. Live stakes are positioned downslope to promote additional root development (Figure 3.3.2.2-F). Proper soil contact is essential, with moist soil packed around the bundles, leaving them slightly exposed to facilitate rooting. Erosion control materials such as jute mesh or coconut netting may be added between rows for extra reinforcement. Over time, the fascines trap sediment, stabilize the soil, and create a microclimate conducive to long-term vegetation establishment.

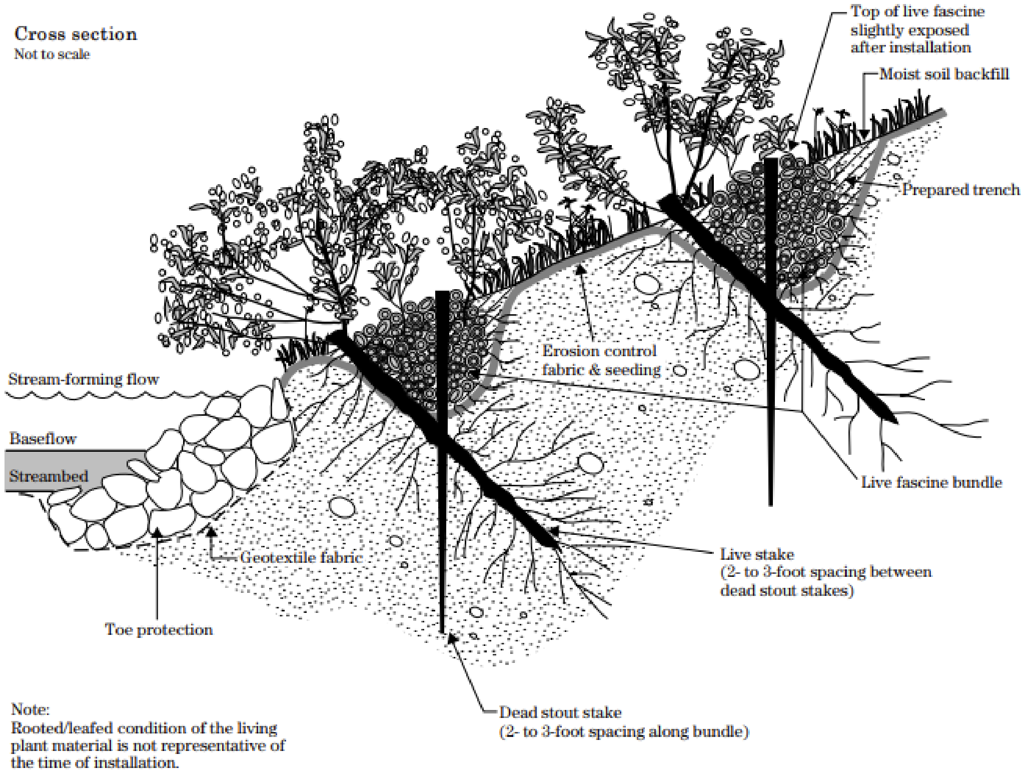


Figure 3.3.2.2-F: Live fascine details. Source: NRCS (1996, 2021).

Brushlayering is a slope stabilization technique that involves embedding live branch cuttings into excavated benches on a slope to provide stability and erosion control. Unlike live fascine systems, brush layering positions the cuttings perpendicular to the slope contour, allowing the protruding branch ends to disrupt surface runoff and reduce erosion. This method is particularly effective on slopes up to 2H:1V in steepness but no more than 15 feet in vertical height. The process begins at the toe of the slope, where horizontal benches, typically two to five feet wide, are excavated on contour or slightly angled downward to facilitate drainage. The benches are sloped inward to direct water away from the slope face. Branch cuttings, ideally from species that root easily, such as willows or shrub dogwoods, are arranged in

overlapping or crisscrossed patterns with their basal ends embedded in the back of the bench. A layer of soil, sourced from the next upslope bench, is placed over the root ends, compacted to remove air pockets, and built up in six to eight-inch lifts until the desired thickness is achieved. Ensure the growing tips of the cuttings extend beyond the slope face to help trap sediment and aid vegetation establishment. This technique provides immediate soil reinforcement through the unrooted stems while offering long-term stabilization as the cuttings take root and develop into mature vegetation. The live stems act similarly to geotextiles, increasing frictional resistance and preventing shallow slides. Brushlayering also serves multiple ecological functions, including breaking up long slopes into smaller segments to slow surface runoff, trapping debris, adjusting microclimates for seed germination, and redirecting slope seepage. On slopes with a gradient of 3H:1V, long straw or similar mulch can be applied between brush layers, while steeper slopes require additional reinforcement with jute mesh or other erosion control materials. Over time, the rooted branches integrate into the slope, enhancing stability, improving infiltration, and fostering the natural regeneration of vegetation.

Branchpacking is a slope stability technique that involves layering live branches with compacted soil to repair small slumps or holes in slopes. This method is particularly effective for reinforcing earth in small fill sites where erosion control and mass stability are needed. Typically used on areas no deeper than four feet and no wider than five feet, branchpacking relies on the mechanical reinforcement provided by both the branches and wooden stakes. The process begins by driving wooden stakes, ranging from five to eight feet in length, vertically into the ground at one to one and a half foot intervals. The lowest point of the slump is treated first. A layer of live branches, about three to six inches thick, is placed between the stakes, with their growing tips extending slightly beyond the face of the slope, while the root ends touch the undisturbed soil at the back of the hole. Each layer of branches is followed by a layer of compacted soil to ensure close contact between the cuttings and the backfill. This alternating process continues until the hole is completely filled, and the final installation blends seamlessly with the natural slope (Figure 3.3.2.2-G). Branchpacking provides immediate reinforcement to the soil while promoting long-term stability as the live cuttings take root and establish vegetation. The protruding branches serve to slow surface runoff, trap debris, and reduce the risk of shallow slides by increasing friction within the slope. Over time, as the branches develop into rooted plants, they enhance the slope’s resistance to shear displacement and further strengthen the embankment. This technique is not suitable for repairing larger slumps but is highly effective for stabilizing minor earth movements and maintaining slope integrity. To maximize effectiveness, keep the soil moist throughout the installation to prevent drying of the live cuttings and properly trim the terminal buds to encourage lateral sprouting.

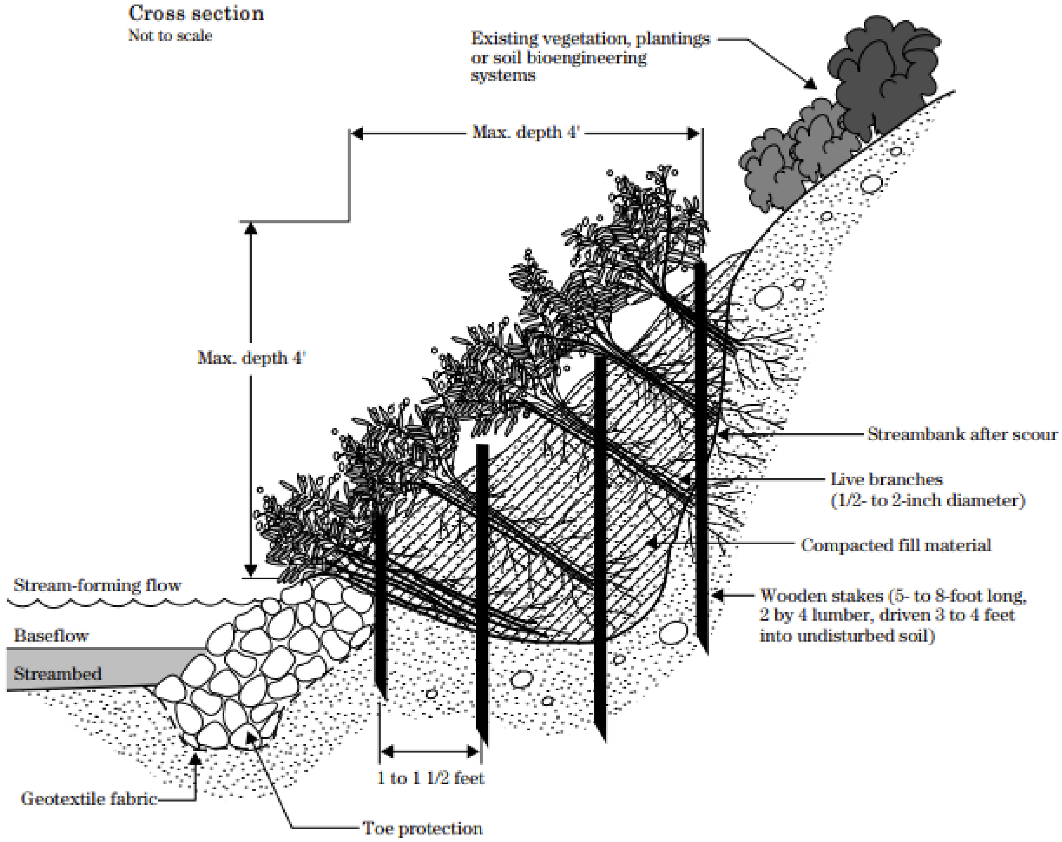


Figure 3.3.2.2-G: Branchpacking details. Source: NRCS (1996, 2021).

A brushmattress is a slope stability technique that integrates live stakes, live fascines, and branch cuttings to stabilize streambanks. Installed from the base of the slope upward, it provides immediate erosion control, making it particularly useful for steep, fast-flowing streams. Beyond structural reinforcement, it captures sediment during floods, rapidly restores riparian vegetation, and fosters conditions for native plant colonization, enhancing streamside habitat. The construction of a brushmattress requires flexible branches, typically six to nine feet long and about one inch in diameter, secured with untreated twine and wire. Installation begins by grading the unstable bank to a gradual slope, followed by excavating a trench at the base to anchor the vegetation. Live and dead stout stakes are driven into the slope in a uniform grid to secure the brush layer, with live fascines placed over the basal ends of the branches (Figure 3.3.2.2-H). Thin layers of soil are added between the branches to encourage rooting while leaving the surface slightly exposed. This method not only reinforces the streambank but also accelerates ecological recovery, blending natural function with long-term stability.

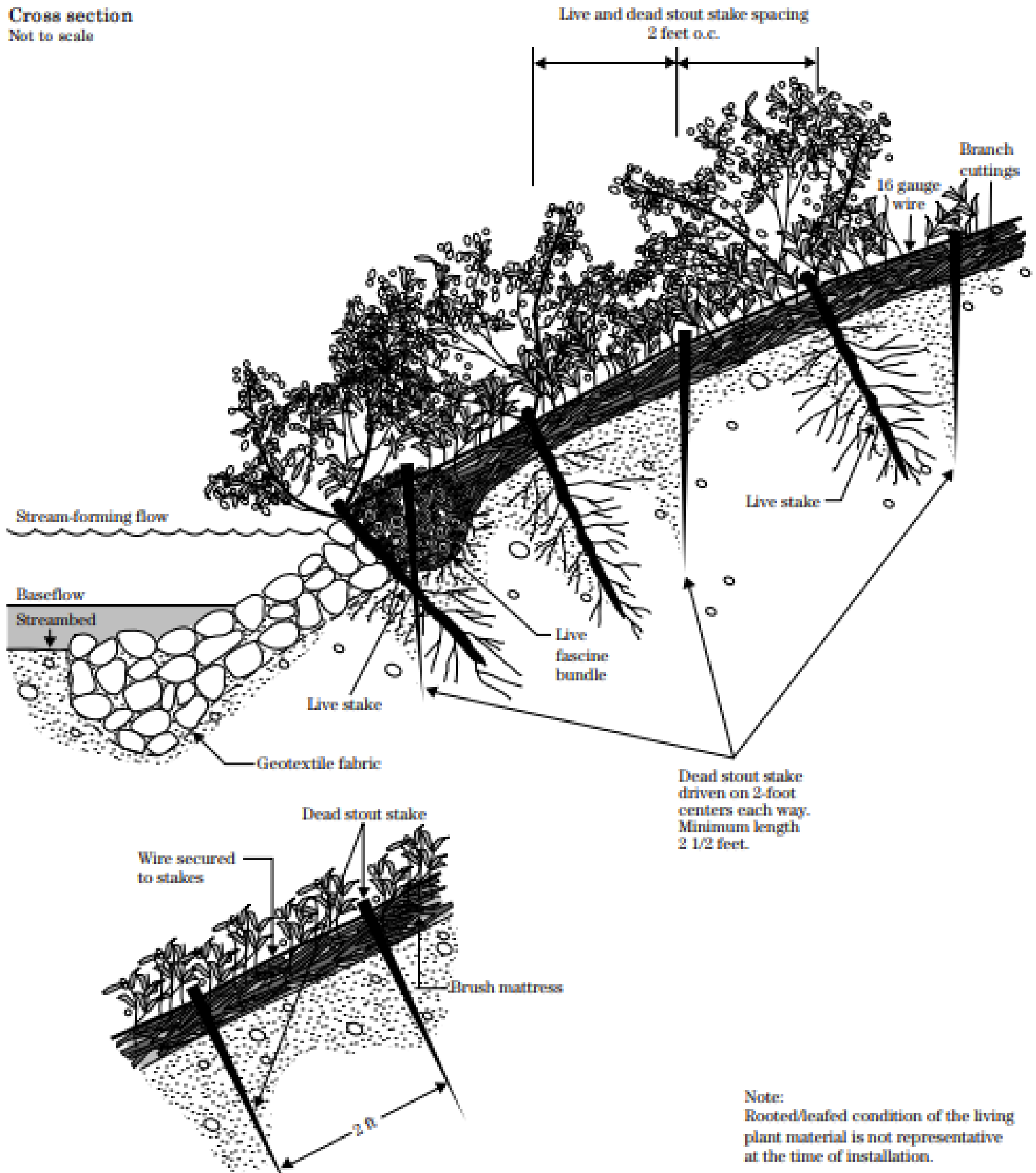


Figure 3.3.2.2-H: Brushmattress details. Source: NRCS (1996).

Designers are referred to NRCS (1996, 2021) for additional bioengineered soil bank stability and slope stability techniques if none of the presented material herein are suitable or desirable for specific project constraints. Though less commonly implemented, other techniques presented in the referenced material are allowable for use in construction sites with coverage under the Tennessee CGP.

Example Application

-Example courtesy of TDOT-

Given:

A channel bank approximately 6 feet high and 50 feet long is experiencing bank stability problems. The stream has a bedrock channel bed, and hydraulic analysis indicated that the channel velocity in the 50-year flood event is 7.23 ft/s.

Determine:

The quantity of vegetated gabions for this project.

Solution:

Utilizing the Geotechnical Engineering Section in TDOT, it has been determined that sufficient structural integrity can be achieved by stacking two rows of gabions to form a near-vertical wall. To meet the 6-foot height of the channel bank, it is determined that the wall should be constructed with 3 × 3 × 6 ft gabion baskets. Further, lateral stability will be ensured by cutting a shallow groove into the exposed basket to serve as a foundation for the gabion wall.

Based on the hydraulic analysis for the 50-year event, it is determined that machined riprap Class B would be required (Tables 3.3.2.1-A and 3.32.1-C). Although the velocity appears somewhat high for the structure of gabions, it is anticipated that the presence of vegetation along the structure will reduce flow velocities and thus prevent abrasions on the wire coatings.

Each layer of the wall will be constructed by placing 3 x 3 x 6-foot gabions end to end. Thus, 9 gabions will provide a length of 54 ft, and an additional gabion will be placed to provide a sufficient length of erosion protection past the end of the curved section of the channel alignment (60ft). Thus, the wall will contain 20 gabions, each with a volume of 54 ft^3 for a total volume of 1080 ft^3 or 40 cubic yards. The geotextile will be placed across the top and down the inside face of the wall. In order to provide additional protection against the piping of fill through the wall, an additional length of 3 ft will be placed on the bedrock at the toe of the wall to form an apron. Thus, the total surface area of the geotextile may be computed as:

$$A = W \times L = (3 + 6 + 3) \times 60 = 720 \text{ ft}^2 = 80.0 \text{ square yards.}$$

-Example courtesy of TDOT-

Given:

Vegetated riprap is proposed on a 200-foot reach of a small stream. The stream has a bottom width of 5 feet and 1.5H:1V side slopes. Hydraulic analysis of the stream for the channel-forming discharge yields a flow depth of 2.5 feet and a velocity of 3.7 ft/s. The hydraulic analysis for the 50-year event yields a flow velocity of 5.66 ft/s.

Determine:

The quantity of vegetated riprap for this project.

Solution:

Based on the hydraulic analysis for the 50-year event, it is determined that machined riprap Class B would be required (Tables 3.3.2.1-A and 3.3.2.1-C). Based on TDOT standard specifications, the minimum depth of the riprap layer should be 2.5 feet.

The height along the slope over which riprap is to be installed will be equal to 1.5 times 2.5 feet, which is 3.75 feet. The quantity of vegetated riprap for each side of the channel can be determined by computing the required volume of riprap as follows:

$$V = H \times D \times L = 3.75 \times 2.5 \times 200 = 1875 \text{ ft}^3$$

Thus, the total volume for both sides of the channel will be $3750 \text{ ft}^{3,}$ which can be divided by 27 to determine the final quantity of 139 cubic yards.

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