Vegetated Reinforced Soil Slope Streambank Erosion Control

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May 2003

Complexity	Environmental Value	Cost
Low Moderate High	Low Moderate High	Low Moderate High

OVERVIEW

The vegetated reinforced soil slope (VRSS) soil bioengineering system is an earthen structure made from living, rootable, live-cut, woody plant material branches, bare root, tubling or container plant stock in conjunction with rock, geosynthetics, geogrids, and/or geocomposites (Figure 1). The VRSS system is useful for the immediate repair or prevention of deeper failures providing a structurally sound system with soil reinforcement, drainage and erosion control typically on steepened slope sites where space is limited. In the VRSS system, the living cut branches and plants are expected to grow (performing additional soil reinforcement functions via the roots and surface protection via the top growth).

Live vegetation in the VRSS is typically installed from just above the baseflow elevation and up the face of the reconstructed streambank, acting principally to protect the bank through immediate mechanical soil reinforcement and confinement, drainage, and, in the toe area, with rock. The VRSS system extends below the depth of scour, typically with rock. Rock is useful in improving infiltration and supporting the riparian zone. The internal systems such as rock, live cut branches, geosynthetics, geogrids, and geocomposites can also be configured to act as drains that redirect and/or collect internal bank seepage and transport the water to the stream via a rock toe. (Figures 2-7).

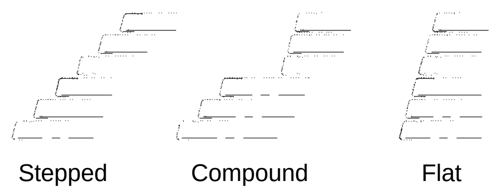

Figure 1. Illustrations of VRSS system frontal configurations

Figure 2. Constructing a VRSS structure rock toe protection and slope drainage

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Figure 3. Constructing the VRSS soil wrapped reinforcement layer

Figure 4. Installing live-cut branch vegetation on the prepared wrapped terrace

Figure 5. Installed rooted vegetation on the prepared terrace

Figure 6. A VRSS structure immediately after construction

Figure 7. Established VRSS structures

The VRSS structure benefits fisheries habitat by providing food and overhanging cover, offering protection from predators, and lowering water temperatures at the edge of the stream. Stone used at the base of the VRSS structure produces substrates suited for an array of aquatic organisms. Some of these organisms adapt to living on and within the rocks and some attach to the leaves and stems. The leaves and stems may also become food for shredding varieties of macroinvertebrates. The VRSS structure can improve water quality, avian, herptile, and mammalian habitat, and aesthetics.

Plants within the VRSS structure may be selected to provide color, texture, and other attributes that add a pleasant, natural landscape appearance. Such plants for the VRSS structure include buttonbush (*Cephalanthus occidentalis.*), dogwood (*Cornus spp.*), willow (*Salix spp.*), hybiscus, and *Viburnum spp*. If a compound channel cross section is desirable near or just below the baseflow elevation, a step-back terrace may be incorporated to offer an enhanced riparian zone, where emergent aquatic plants, such as bulrush (*Scirpus spp*.) and sedges (*Carex spp.*) may invade over time.

These will assimilate contaminants within the water column, though the total mass uptake may be small. Aquatic wetland plants that may be installed in the VRSS adjacent to the stream include blueflag (*Iris versicolor*, a wetland wild iris with a blue flower), pickerelweed (*Pontederia cordata*), and monkey flower (*Mimulus ringens*). The VRSS systems can be constructed on slopes ranging from 1V on 2H (1:2) to 1:0.5. When constructed in step or terrace fashion, they can also improve non-point pollution control by intercepting sediment and attached pollutants during overbank flows.

PLANNING CONSIDERATIONS

The first step in the planning process is to determine whether a VRSS structure is an appropriate alternative to address the observed and projected mechanisms of bank loss. Evaluate these to determine the extent to which they meet project objectives and constraints related to channel size, stability, and habitat. Questions to be considered using an interdisciplinary approach include the following interrelated items (not exhaustive):

1. Is a VRSS system an appropriate alternative given the magnitude of the erosion problem, e.g. its geomorphic and morphological characteristics?
2. Will the hydrology of the stream accommodate a VRSS structure?
3. Are stream velocities and shear stresses permissible?
4. Will sediment accumulation affect plant establishment and survival?
5. Will there be enough sunlight and water to support the desired system?
6. Are there riparian woody and/or wetland plants in a reference reach or nearby similar system that can be used as a template (and perhaps material source) for building the VRSS system?
7. Will site conditions during construction permit installation?
8. Have risks and specifically the consequences of failure been considered and what are they (e.g., what happens if the vegetation dies)?
9. What other erosion control devices or materials will be needed, such as grade control in the bed, internal seepage, or overbank drainage?
10. Is the required construction season available?
11. Are the costs acceptable?

VRSS structures are very flexible, and may be designed for special needs. They can be constructed in a wide range of heights, depths, and face slope angles and are very adaptable for meanders and compound channel construction. From a construction viewpoint, they easily accommodate structures such as pipes, culverts, other slope face facilities, and irregularities.

Construction Costs

Costs for VRSS structure projects are high compared to those for other vegetative bank stabilization techniques. Typically they are competitive with conventional wall structures that offer little to no environmental benefits. Following are Year 2001 cost ranges for VRSS structure projects based on the authors' experience. These include profit margins and contingency factors on contractor bid projects on sites 10 to 60 ft in height.

VRSS structure costs typically range from $15 to $35/ft per square face foot. These prices do not include design, which can be extensive due to the required geotechnical data collection and analysis. Harvesting, transportation, handling, and storage of the live-cut branch materials or rooted plants can significantly influence cost, and are included in the above range.
Construction costs also vary with the structure's design (materials, depth into the streambed, height and width, etc.), site access, time of year, degree and type of associated channel redefinition, and equipment and labor rates. Installation is relatively complex, as it can require large earth-moving machinery. Installation, excavation, and soil replacement costs are usually high.

Site Considerations

A site suited to VRSS requires a hydrologic regime that 1) keeps the invert of the structure wet during most of the growing season if the establishment of vegetation at this elevation is desirable; 2) allows the roots to reach the water table during most of the growing season; and 3) provides for flows and bank moisture sufficient to keep plants growing well, but lacks long-duration flood flows that could exceed the plant's flood tolerance. Given these requirements, the VRSS structures are suitable for a wide range of perennial and ephemeral streams. Some variation in water surface elevation associated with baseflow is allowed.

Depending upon the site-specific conditions, plant species that have the required tolerances, such as flooding, drought, and shade, are selected. The VRSS structures have a fairly wide variation to these tolerances due to a broad range of species choices. This is especially true when rooted plants are used.

Other important site considerations include shade conditions, type of substrate, and proximity to the channel thalweg. Most plants that are desired for establishment within the VRSS structure require some sunlight. Therefore, as a general rule, where vegetation establishment is desired, sunlight should exist for these structures. There are exceptions where shade-tolerant plants, such as *Viburnum spp.* can be used. The local Natural Resources Conservation Service office should be consulted for information on suitable local plants.

Substrate conditions are also important in site selection because this is the material that is typically used to build the VRSS structure and that the plants will be expected to grow in. Both the geotechnical and the agronomic characteristics of the soils should be assessed. If the in situ soils do not meet the design needs, soil amendments can sometimes be employed to provide the proper characteristics. In some cases, it will be necessary to use offsite fill materials.

When installing a VRSS structure immediately adjacent to the thalweg, ensure it is protected with a stone toe buttress to prevent scour and undercutting.

DESIGN

The design of VRSS stabilization and reinforcement measures usually involves geotechnical experts to determine slope conditions as well as the factors of safety and depth and type of failure. Site analyses, analytical computations, and modeling may be needed to identify bank loss mechanisms acting at the site, and to assess erosion potential at the toe that could lead to flanking or collapse. Experts in hydraulics and geomorphology typically conduct these assessments.

VRSS designs can be adapted to address a wide range of needs. Modifications to the toe structure, the VRSS dimensions, and material types (including vegetation) can address many site constraints. Most of the design effort is focused upon the refinement of these characteristics given the anticipated conditions at the site.

An important design step is to define the limits of protection, which frequently extend beyond the limits of any existing failures. At a minimum, the VRSS should extend several feet beyond any existing failure plane, and should incorporate banks that are susceptible to failure.

Rocks or other materials are often used to provide a stable toe and to construct refusals (keys into the bank to prevent flanking), and drains may be required to reduce the potential for certain types of failures. These measures are addressed in more detail in companion technical notes.

The elevation of vegetation within the VRSS must be evaluated with respect to the hydrology and hydraulic condition of the stream. Sustained velocity and shear stress thresholds for the materials used in the VRSS can be compared with computed values for the stream and used to assess elevations for various structural elements. The elevation of vegetation in adjacent or reference reaches can serve as a guide as well. Generally speaking, stone should extend to the elevation, above which shear stresses are not expected to exceed 2 lb/ft^2.

Limits of Vegetation

VRSS structures may be installed at any time during the year, but typically they are easiest to install in the dormant season when the water elevation is at low to normal baseflow levels. Aquatic, wetland, and woody bare root or tubling plants are most successful when installed in the spring, although fall installation is possible. The best and most cost-effective season for VRSS construction using live-cut woody branches is in the fall. With the use of cold storage, the planting season may be extended into the spring past dormancy.

The spatial extent of VRSS treatments is a function of the project objectives and the site conditions. Depth of failure may be 5 to 20 ft, or more, which governs the length and type of reinforcement. The vegetation only influences the outer 3 to 10 ft. Excavation and the use of drains, geotextiles, and other materials are needed to address the stability of the remainder of the bank.

The VRSS structure must be at an elevation that permits absorption of water to prevent desiccation of the vegetation. However, the vegetation must not be placed so low as to inundate it beyond its flood tolerance. If high VRSS structures are built, the vegetation must be able to absorb groundwater seepage from the bank. When live cut branches are used to form the brush layers between the reinforcement/ grid wraps, their basal ends are inserted well into a moist zone within the bank (Figure 8). Bare root, tublings, and container plants are typically placed in the near frontal area (Figure 9).

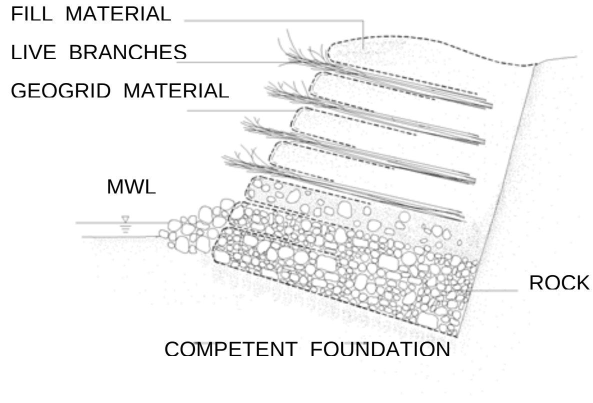

Figure 8. Live-cut branch installation

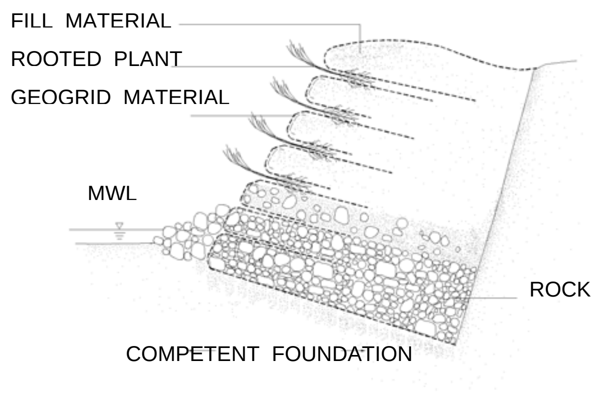

Figure 9. Rooted plant installation

On moist seeping banks, the VRSS structure typically incorporates "chimneys or curtain drain" systems along the back excavation. These systems are intended to intercept some of the seepage and direct it to the rock toe. When such internal drainage is required it is important that some groundwater seepage is allowed to occur to prevent desiccation of the vegetation.

The VRSS structural wraps (reinforcement) and vegetation are installed parallel to each other and spaced apart according to the geotechnical design parameters of the slope, such as steepness, height, depth, type of backfill and type of failure (such as wedge and rapid drawdown), type of reinforcement selected, and moisture condition requirements.

The VRSS is primarily intended to stabilize and reinforce a newly constructed fill soil slope - providing immediate and permanent structural stability and erosion control. The primary reinforcement is designed to provide global, internal and compound stability to the slope. The establishment of woody vegetation will enhance the system by producing a reinforced soil face and surface protection via the top growth. Plant selection and location must be made with respect to a moist or dry bank, elevation and aspect. Installed VRSS measures must withstand anticipated sustained velocity and shear conditions on the bank.

Only limited data have been collected for shear or velocity tolerances of VRSS structures (largely from empirical information collected from constructed projects), and these are summarized in Tables 1 and 2. Designers should exercise caution in considering limiting velocity or shear stress criteria. Failure of VRSS structures can be attributed to several mechanisms, notably flanking, undercutting, inadequate internal drainage and compound failure where failure passes through the reinforced mass.

Table 1. Stress and Velocity Levels for VRSS Structures

Time	***Velocity ft/sec***	***Shear lb/ft²***
Initial (immediately after installation)	3-5	5-9
Established (after 1 to 2 years of growth)	8	14

Success requires protection to guard against undercutting, flanking and failure due to inadequate internal drainage of the structure. For toe and flank protection, rock should be designed for velocities and shear stresses exceeding allowable limits for the soils behind and within the VRSS structure. Table 2 presents these limits. Angular rock is recommended and should be sized in accordance with the U.S. Army Corps of Engineers (1994) specifications depending on anticipated velocities and shear stress.

Flank protection can also be aided by keying the ends of the VRSS structure into the banks at both ends and protecting the flanks with a rock protection. Key ends well into the bank by inserting at least 5 linear feet of system into the bank with rock on the upstream side, which is also keyed into the bank. For banks susceptible to significant erosion, keys or refusals extend farther into the bank.

Table 2. Threshold Conditions for Substrate

Class Name	z	ϕ (DEG)	τ_c	τ_c (LB/SF)	V_c (FT/S)
Boulder					
Very Large	>80	42	0.054	37.4	25
Large	>40	42	0.054	18.7	19
Medium	>20	42	0.054	9.3	14
Small	>10	42	0.054	4.7	10
Cobble					
Large	>5	42	0.054	2.3	7
Small	>2.5	41	0.052	1.1	5
Gravel					
Very coarse	>1.25	40	0.050	0.54	3
Coarse	>0.63		0.047	0.25	2.5

Other Design Considerations

Design considerations include the height, depth, length, and type and spacing of the reinforcements to address the specific failure mechanisms (including seepage conditions). Configuration of a VRSS system is determined by the location, such as in an outside meander. The VRSS structures have a wide range of heights, depths into the bed, widths and lengths, finished slopes and angles, and can be custom-built to fit most situations.

Eroded banks are typically not conducive to immediate VRSS installation and require extensive excavation work prior to the construction of the VRSS structure. Where a previous failure has occurred, additional fill is almost always required. In most cases the existing bank substrate will be suitable for plant growth after being tested and, if necessary, ameliorated with fertilizer and/or lime. Geotechnical requirements for drainage and soil strength also need to be considered. Rock alone is often used to prevent undercutting. Fill will need to be calculated based on cross-sectional area of the bank times the length of reach. Size of rock and appropriate gradation should be determined from U.S. Army Corps of Engineers (1994).

MATERIALS

In addition to rock, geotextile, geogrid and drainage materials, VRSS structures are built using adventitiously rooting, fresh, live cut branch material, or rooted plants either in tublings, containers, or bare root.

Vegetation

The live cut branches are typically harvested from natural stands, within 40 miles of the project site. Native plants such as willow, viburnum or shrub dogwood species work well and are usually available locally. Live cut branches from 0.5 to 3 in. in diameter, with a minimum length of 6 ft are used. The live cut branches are bundled together at the harvesting site with the growing tips oriented in the same direction to assist with on-site installation.

Three layers of branches with soil in between form the complete vegetative lift. The side branches are retained in the VRSS structure vegetative layers. Container or bare root plants obtained from a nursery grower may also be used. The numbers of live cut branches, bare root, tubling or container plants vary by elevation, soil type, aspect and size, and age of vegetation and other plant characteristics. Tables 3, 4, and 5 present vegetation spacing and quantities for lifts that are 12 to 18 in. high.

As a general rule, vegetation is denser at the bottom to provide additional roughness and denser at the top to compensate for dryer conditions. It is usually advantageous to mix age, size, and species throughout the vegetative layers, with some allowance for considerations such as elevation and moisture needs for each species.

Table 3. Live Cut Branches (3–12 ft long)[1]

Orientation/Aspect	*Quantity /Lin. Ft.*	*Depth in Feet*
Northeast-wet	***8-15***	3-5
Northeast-dry	***12-15***	5-8
Southwest-wet	***8-12***	4-5
Southwest-dry	***15-20***	6-10

[1] Taken from Sotir (2002).

Table 4. Plant Spacing – Tubling or Bare Root

Orientation/Aspect	*Quantity/Lin. Ft.*
Northeast - Wet	**1-3**
Northeast - Dry	**3-4**
Southwest - Wet	**2-3**
Southwest - Dry	**4-5**

[1] Taken from Sotir (2002).

Table 5. Plant Spacing – Container (½ to 1 gal)

Orientation/Aspect	*Quantity /Lin. Ft.*
Northeast-wet	***1***
Northeast-dry	***2***
Southwest-wet	***1-2***
Southwest-dry	***2-3***

CONSTRUCTION

The first considerations concerning construction of a VRSS structure are length of repair, excavation, (width into the bank) depth, (below bed) length, overall height and refusals up and down stream, back fill material compaction, rock toe, drainage and reinforcement type, and placement. Several types of construction are possible depending upon objectives and available space.

A simple structure, 4 to 10 ft high, may require only one grid type for reinforcement and frontal wrap soil confinement with rock toe protection. More complex systems (requiring extensive geotechnical analysis and design) may require two or more reinforcement grids and/or geocomposite materials, in addition to backslope drainage.

Excavation

The typical excavation in preparation for the VRSS structure construction is determined through various geotechnical and scour analyses. Normally the toe of the structure extends below the bed. This toe area is constructed either partially (at the front) or completely of stone. The stone is usually confined by grid, geotextile, or wire where gabion basket structures are used. When deep installations are not required, a layer of wrapped rock or a reno mattress is frequently used on the bed. The reno mattress may also extend into the channel. High or steep excavation may need backslope confinement via “shoring” for temporary protection against bank failure during construction. This is especially important in seep areas and non-cohesive material such as sands or gravels.

Installation Procedures

Once the rock foundation has been completed the soil/rock and soil layers are installed above. One method using live cut branches is as follows (See Construction Sequence, Figures 2 - 7):

1. Install temporary batter board near the front of rock foundation. Place the geogrid from the back excavation up to and over the batter board leaving 2 to 3 ft of grid extending beyond the top of the batter board. Seams of the geogrid should overlap 15–18 in.
2. Line this front area by placing natural burlap or a geosynthetic on the batter board face inside the grid. The purpose of this is to contain the fines.
3. Fill area between the batter board and the back excavation with soil fill or a fifty-fifty mix of soil fill and (1-4 in.) stone. The soil fill should have been tested and ameliorated with the required fertilizers and lime as needed to promote healthy growth. Place this material in 4- to 6-in. lifts. Compact 80 – 90 percent Standard Proctor Density. A skid type compactor, roller compactor, or vibratory compactor may be used for this purpose. When this layer is installed it should be the height of the batter board in the front (12-18 in. in elevation) and sloping towards the back excavation to the previously installed foundation elevation (a wedge-shaped layer). This establishes the angled terraces (that will be maintained for each wrapped fill layer) upon which the live cut branches will be placed.
4. Machine pull the grid that extended beyond the batter board up over on top of the compacted soil stone/soil mix and secure. This can be facilitated using a board or pipe to which hooks are attached that can be used to “grasp” the geogrid.
5. Stake the geogrid with dead stout stakes, deadmen, or rebar hooks if placed into riprap, and remove the temporary batter board.
6. Place a 1- to 2-in. layer of soil evenly over the terrace from the front to the back excavation.
7. Place the live cut branches in three layers–one oriented in an upstream direction; one oriented in a downstream direction, and a final layer at right angles to the stream. Each layer of live branches has 1-2 in. of soil placed in between to ensure rooting medium.
8. A new soil/wrap layer is then started by repeating steps 1 - 7.
9. For the final lift, the geogrid should be replaced with a 400-gram coir fabric that is seeded with native grass species.

Typically the rock riprap is used in the lower one or two wrapped soil layers only. The batter boards may be set close to the front to establish a smoother front finish, or they may be stepped back to create a terrace.

When using rooted container plants or bare root stock, the installation sequence is as follows:

1. Install temporary batter board near the front of the rock foundation. Place the geogrid from the back excavation (6-8 in. wide) up to and over the batter board leaving 2-3 ft of grid extending beyond the top of the batter board.
2. Line this front area by placing natural burlap or a geosynthetic on the batter board face inside the grid. The purpose of this is to contain the fines.
3. Fill front area in a short soil wedge the height of the batter board at the front and a steep slope behind 1-2 ft wide.
4. Pull the grid down over the soil wedge and secure.
5. Place 1 in. of soil on the sloped terrace.
6. Place the bare root plants on the terrace at right angles to the stream. When container plants are used, the root ball is flattened and the roots need to be spread out along with the container soil. Leave approximately 4-12 in. protruding depending upon the size and species of the installed plants.
7. Fill and compact the remaining soil of the lift to the finish elevation, from front to back.
8. Repeat process to continue, starting with installing the temporary batter board.

When the live cut branch, bare root, or container plant installations are complete, the vegetation has a distinct upward angle.

OPERATION AND MAINTENANCE

Operation and maintenance requirements of any soil bioengineering treatment will vary depending on the stream system and its associated parameters, such as velocity, flood frequency, flood stage, timing, and future planned use. In any case, be prepared, at least early in the project life, to repair the system until the vegetation becomes well established. Minimally, inspection should occur after each of the first few floods and/or at least twice a year for the first year and once a year (preferably after the predominant flood season) thereafter.

Immediately repair observed undercutting and flanking of the treatment and any other substantial scour evidence. Examine the cut branches and rooted plants for survival and growth and absence of disease, insect, or other animal/human damage (e.g., grazing, trampling, digging, eating, and cutting). Successful plants will grow vigorously and spread their roots into the surrounding fill substrate, binding the grids and soil bank into a unitary mass.

If animal or human damage is evident or if the plants are being removed or eaten by waterfowl or beavers, preventative measures, such as exclosures, may be required. Such exclosures, especially for woody plants, may only need to be used until the vegetation is well-established for 1 to 2 years.

Assuming the VRSS structure remains in place and vegetation becomes established through the development of growth of the installed vegetation and/natural invasion, maintenance decreases over time.

Fish and aquatic invertebrate sampling is always recommended both before (to gather baseline information) and after installation (to determine habitat improvement). Sampling can be supplemented with data on channel geometry, substrate conditions, and water temperature.

APPLICABILITY AND LIMITATIONS

Techniques described in this technical note are generally applicable where primary objectives for streams include bank stabilization, habitat diversity, erosion control, water quality improvement, and aesthetics, including a diversity of riparian plants along the streambank. VRSS structures may be used in a wide variety of stream types and flow conditions. If aquatic herbaceous plants are desirable in the lower elevations, streams should not have excessive sediment loads that may completely cover and smother plants. Some caution is also needed when selecting the species for VRSS.

Exercise caution in using VRSS rock protection or other hard material when stream velocities at the bank exceed critical thresholds for underlying soils.

Trampling and grazing of the VRSS structure can be detrimental from a vegetative perspective but not from the mechanical perspectives. However, due to its typically steep face, this is rare.

Consider the time of year when installing the VRSS system. Consider consequences of failure: if the VRSS is flanked or under cut and if the failure is likely to create hazards that otherwise would not occur (e.g., trapping debris and causing undesired local scour, current deflection, and damming).

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> http://www.wes.army.mil/el/emrrpT

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