To:		New York State Department of Transportation ENGINEERING INSTRUCTION	EI 02-019
Superseded By EB 13-002 Effective 9/05/13			

Title: **SOIL BIOENGINEERING/BIOTECHNICAL ENGINEERING - DESIGN GUIDANCE**

Distribution:		Approved:
☐ Manufacturers (18)	☐ Surveyors (33)	
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ADMINISTRATIVE INFORMATION:

- **Effective Date:** This Engineering Instruction (EI) is effective immediately.
- **Superseded Issuances:** This EI does not supersede any previous issuances. It does complement EI 02-020 Soil Bioengineering/Biotechnical Engineering - Special Specification and EB 02-037 Soil Bioengineering/Biotechnical Engineering - Details
- **Disposition of Materials:** The contents of this EI ultimately will reside in the NYS Department of Transportation Highway Design Manual.

PURPOSE: To provide interim guidance to designers for incorporation into applicable projects.

TECHNICAL INFORMATION:

Definition: Soil bioengineering is the reliance on plant material for slope protection, rebuilding and stabilization, erosion control, etc.

Soil biotechnical engineering combines the use of plant materials and structural elements to achieve the same goal. The attached transmitted materials; vegetated cribwall, vegetated gabions and vegetated mats are examples of soil biotechnical engineering.

Application: Soil bioengineering/biotechnical erosion control measures are utilized in situations where soil erosion and stabilization are concerns. These situations include cut/fill slope stabilization, earth embankment protection, shallow mass movement, small gully repair and streambank stabilization. Soil bioengineering/biotechnical erosion control systems offer immediate resistance to erosion due to the placement or configuration of elements in the system. This resistance to erosion, sliding or shear displacement increases over time as root systems develop and bind the soil.

Soil bioengineering/biotechnical erosion control should only be undertaken following a thorough site assessment. This site assessment should include a multi-disciplinary consideration of slope geometry, aspect, climate, water regime, soil properties, and surrounding vegetation. Consult the Regional Geotechnical Engineer and the Regional Hydraulics Engineer about characteristics of specific sites which may warrant hard armor or a combination of hard armor and soil bioengineering erosion control.

Like other methods soil bioengineering/biotechnical has limitations. The vegetative cuttings used in these systems are living materials and must be handled properly to avoid excessive stress, such as drying or excessive heat. The plants must be installed in soil that remains moist and to the proper depth. Success is also dependent upon the available soil. Rocky soils or gravelly slopes that lack sufficient fines and/or moisture will not provide an adequate growing environment for most species, and soil-restrictive layers, such as hardpans and overly compacted soils, may prevent root growth.

Time constraints need to be considered, as installation of these techniques are best accomplished in the late fall or early spring while the plant materials are dormant. Installation should not be attempted when the ground is frozen. Summer installation is not recommended.

TRANSMITTED MATERIALS:

BACKGROUND:

This E.I. introduces additional erosion control methods for use by designers who are under increasing pressure to satisfy various regulatory agencies issuing permits to the department.

Soil bioengineering/biotechnical erosion control methods are re-vegetation and stabilization technologies applied on disturbed sites, including slopes and streambanks. Environmental benefits, which include habitat enhancement, water quality preservation and improvement, are realized through the rapid reestablishment of a natural vegetative cover. Soil bioengineering/biotechnical engineering erosion control methods are typically cost effective, non-intrusive and utilize living plant material as an integral component of the erosion control system. The plant material anchors and stabilizes soil in areas where traditional structural stabilization methods are impractical or unwarranted or where rapid re-vegetation of woody plantings is desired. Soil bioengineering/biotechnical erosion control limits site disturbance and does not have severe access requirements. Therefore, these erosion control methods are ideal for sites that are steep, inaccessible or sensitive to the use of machinery. Soil bioengineering/biotechnical erosion control techniques use native, sometimes indigenous plant materials and are visually compatible in the landscape. These characteristics can make the bioengineering/biotechnical erosion control approach especially attractive for scenic corridors and selected environmentally sensitive areas.

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Soil Bioengineering/Biotechnical Erosion Control Guidance

I. Introduction

Soil bioengineering/biotechnical erosion control methods are revegetation and stabilization technologies applied on disturbed sites, including slopes and streambanks. Soil bioengineering is the reliance on plant material for slope protection, rebuilding and stabilization, erosion control, etc. Biotechnical engineering combines the use of plant materials and structural elements to achieve the same goal.

Environmental benefits include habitat enhancement, water quality preservation and improvement, that are realized through the rapid reestablishment of a natural vegetative cover. Soil bioengineering/biotechnical erosion control methods are typically cost-effective and nonintrusive methods, that utilize living plant material as an integral component of the erosion control system. The plant material anchors and stabilizes soil in areas where traditional structural stabilization methods are impractical or unwarranted or where rapid revegetation of woody plantings is desired. Soil bioengineering/biotechnical erosion control limits site disturbance and does not have severe access requirements. Therefore, soil bioengineering/biotechnical erosion control methods are ideal for sites that are steep, inaccessible, or sensitive to the proper use of machinery. Soil bioengineering/biotechnical erosion control techniques use native, sometimes indigenous materials and are visually compatible in the landscape. These characteristics can make the soil bioengineering/biotechnical engineering erosion control approach especially attractive for scenic corridors and select environmentally sensitive areas.

Soil bioengineering/biotechnical engineering erosion control should only be undertaken following a thorough site assessment. This site assessment should include a multidisciplinary consideration of slope geometry, aspect, climate, water regime, soil properties, and surrounding vegetation. Consult the Regional Geotechnical Engineer and the Regional Hydraulics Engineer about characteristics of specific sites which may warrant hard armor or a combination of hard armor and soil bioengineering erosion control.

II. Application

A. Opportunities and Limits

1. Situations for effective soil bioengineering/biotechnical engineering erosion control

Properly designed soil bioengineering/biotechnical engineering erosion control measures are ideal in many situations where soil erosion and stabilization are concerns. These situations can include cut/fill slope stabilization, earth embankment protection, shallow mass movement, small gully repair, and streambank stabilization. Biotechnical erosion control systems offer immediate resistance to erosion due to the placement or configuration of elements in the system. This resistance to erosion, sliding, or shear displacement increases over time as root systems develop and bind the soil.

Benefits of soil bioengineering/biotechnical engineering erosion systems are their natural appearance and low cost. In areas that have aesthetic and environmental concerns, soil bioengineering/biotechnical engineering erosion control methods offer designers a means that may help to address these concerns. Stream bank stabilization offers one of the greatest opportunities for utilizing soil bioengineering/biotechnical engineering erosion control techniques. The benefits of these techniques for streams include more natural, productive riparian habitats, shade, addition of organic matter, cover for aquatic species, and improved aesthetic value and water quality.

Live staking, live fascines, brush layering, branch packing, and brush mattressing are techniques that utilize live plant material (cut stems or branches) as the primary means of soil stabilization. The cut surface of the plant material is brought into contact with soil and as root systems develop, the plants increase reinforcement over time.

Live crib walls, vegetated rock gabions, tree revetments, and joint plantings are techniques that utilize structural elements in conjunction with live stem or branch cuttings. They may be suitable for more challenging sites where the methods that utilize solely live material are not sufficient. The structural elements create open structures into which the live cuttings are placed, and provide immediate protection from erosion and sliding. This importance declines over time however, as the vegetative component becomes established. Coir/straw logs and vegetated mats are additional tools that can be used by the designer.

2. Constraints

Soil bioengineering/biotechnical engineering erosion control combines biological elements with engineering principles. Like other methods they have their limitations. For example, the engineering requirements of a project, such as compacted soil may make the successful application of these techniques untenable.

The vegetative cuttings used in these systems are living materials and must be handled properly to avoid excessive stress, such as drying or excessive heat. The plants must be installed to the proper depth in soil that remains moist. The adjacent soil should be tamped to eliminate or minimize excessive air pockets around the buried stems. The success of a system is also dependent upon the available soil. Rocky soils or gravelly slopes that lack sufficient fines and/or moisture will not provide an adequate growing environment for most species, and soil-restrictive layers, such as hardpans, may prevent root growth.

Installation of soil bioengineering/biotechnical engineering erosion control is best accomplished in the early spring or late fall while the plant materials are dormant. However, installation during the fall can leave the site vulnerable through the winter and early spring snowmelt cycles, before the dormant plants can establish themselves. When the designer anticipates work to be completed in the fall the soil bioengineering/biotechnical engineering erosion control features should be used in conjunction with other temporary erosion control measures.

Installation should not be attempted when the ground is frozen and summer installation is not recommended. Installation after some initial spring growth has started can be successful if extreme care is exercised. It is critical to use suitable plant species that are adapted to the specific climate and soil conditions of the installation site. The Regional Landscape Architect should be consulted choosing appropriate sites, plant species, and for proper placement of the plant species being used. Since timing of plant material installation is critical the Regional Landscape Architect should be consulted for the project scheduling.

Many sites will require significant earthwork for successful installation. A steep undercut or slumping bank, for example, may require regrading the slope to 1:3 or flatter to enable establishment of the plant material. Extensive grading and earthwork should be avoided as much as possible, especially in critical areas.

Backfill for soil bioengineering/biotechnical engineering systems requires a medium which must be conducive to plant growth yet more cost-effective than topsoil as specified in Section 713-01. A recommended mixture is specified in the Method and Materials section below.

Soil bioengineering/biotechnical engineering erosion control systems should receive regular inspection after installation, and provision should be made for prompt maintenance and repair as necessary. Repairs to an installation can be easily performed when problems are caught early and are not too extensive. Neglect of any small repairs can cause problems to expand and result in failure of the entire installation.

Some of the specific limitations to the use of vegetation for streambank erosion control include:

1. Lack of design criteria and knowledge about properties of vegetative materials.
2. Possible failure to grow and susceptibility to drought conditions.
3. Depredation by wildlife or livestock.

Soil bioengineering/biotechnical engineering erosion control systems are usually more cost-effective than many of the alternatives. However, where labor is scarce or very expensive, soil bioengineering/biotechnical engineering erosion control systems can be more expensive than comparable structural methods. Also, some of the cost-effectiveness of these methods derives from the harvesting of locally available plant material. If the plant material must be purchased, some of the cost benefit may be lost.

In summary, bioengineering/biotechnical engineering systems can be useful and cost-effective in controlling bank erosion or providing bank stability while increasing the aesthetic and habitat diversity of the site. Where failure of the countermeasure could lead to failure of a bridge or highway structure, the only acceptable solution may be traditional "hard" engineering approaches. Biotechnical engineering needs to be applied in a prudent manner, in conjunction with channel planform and bed-stability analysis, and rigorous engineering design.(FHWA HEC-23)

B. Characteristics

Biotechnical engineering erosion control systems utilize specific attributes of the vegetative and structural components to prevent erosion. The components of the system have differing characteristics that apply to different situations. These characteristics need to be considered prior to selecting a system for use. One attribute of vegetation is the root system's ability to bind the soil. In most cases when using soil bioengineering, topsoil will not be used due to economic constraints. On site excavation may be suitable if it meets the criterion of Soil Bioengineering backfill material as specified in the Methods and Materials section of this guidance.

1. Vegetative

a. Herbaceous vegetation

Well established herbaceous vegetation, especially grasses and forbs will provide long term protection from surface erosion by binding the soil with their roots. Herbaceous vegetation should always be considered as a component of soil bioengineering systems to aid in protection from surface erosion. This vegetative mat helps to prevent surface erosion by:

- Binding and restraining soil particles in place.
- Reducing sediment transport.
- Dissipating raindrops.
- Reducing velocity of runoff.
- Improving infiltration capacity.
- Minimizing freeze-thaw cycles of soils susceptible to frost.

One shortcoming of the exclusive use of herbaceous vegetation is that it offers less protection from shallow mass movement. However, the Department has successfully used grasses on slopes as steep as 1:2 for many years.

Herbaceous species useful as a component of soil bioengineering/biotechnical engineering erosion control systems can be found in Appendix II. Seeding is the most common, and least expensive, method of successfully establishing herbaceous vegetation. However, seedlings or established plants can also be used. Herbaceous plantings can become established in a short period of time, thus providing soil erosion protection until the soil bioengineering erosion control system develops.

b. Woody vegetation

Woody vegetation is normally more densely and deeply rooted and offers extensive protection from shallow mass movement. It does this by:

- Mechanically reinforcing the soil with extensive root systems.
- Reducing the amount of soil water through interception and transpiration.
- Buttressing and soil-arching action from imbedded stems.

This woody vegetation is installed in specified arrangements that are designed to impede erosion and offer immediate soil protection and reinforcement.

2. Structural

The role of structural elements in biotechnical engineering erosion control systems is to stabilize and support or enable the growth of the vegetative component of the system. The characteristics of a site may be such that vegetation cannot become established prior to the potential effects of erosion. Structural elements play a critical role in stabilizing soil while vegetation becomes established. Without stabilization, plantings may fail at their most vulnerable time. In many instances, a structure is designed only to be a temporary feature of the system until vegetation becomes established.

Structures are constructed from either natural or manufactured elements. Natural material such as earth, rock, stone, and timber are often less expensive, more environmentally compatible and integrates well with vegetation. Natural materials may also be available on a site at little or no cost.

Structures are generally capable of resisting higher lateral earth pressures and shear stresses than vegetation alone. In situations where such stresses are expected, biotechnical engineering erosion control measures that incorporate structures should be used.

a. Retaining structures

A retaining structure will often be necessary to protect and stabilize steep slopes. Low retaining structures at the toe of the slope make it possible to grade the slope back to a more stable angle that can be successfully revegetated, without loss of soil at the crest. (Example: Vegetated Crib Wall)

b. Grade stabilization structures

Grade stabilization structures are used to control and prevent gully erosion. This type of structure reduces the grade above it and dissipates the excess energy of flowing water within the structure itself. Debris and sediment are deposited and trapped upstream of the structure. This allows the establishment of vegetation behind the structure, which further stabilizes the ground. These structures may range from a series of simple timber check dams to complex concrete overflow structures and earth embankments with spillways. (Example: Live Fascines)

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

C. Design Considerations

The decision to use soil bioengineering/biotechnical engineering erosion control methods should be based upon a thorough investigation of the site. This investigation should take into account the soil types, slope gradient, moisture availability, climate, and the project objectives.

When soil bioengineering/biotechnical engineering controls are placed in or immediately adjacent to a stream channel, a temporary water diversion may be necessary. The designer should consider use of cofferdams, turbidity curtains, or other similar techniques to protect the stream from sediment. These items will be paid for separately and should be specified in the plans or contract documents.

If the conditions mentioned are too severe, soil bioengineering/biotechnical engineering erosion control methods alone may not be the best choice for the site. When soil bioengineering/biotechnical engineering erosion control methods are to be used, it is important to choose the proper methods. The methods chosen will be based upon what was learned from the site investigation. It is recommended to consult the Regional Geotechnical Engineer for the determination of the soil profile, analysis of slope stability, and retaining wall designs. The Regional Hydraulics Engineer should be consulted when work is contemplated adjacent to any bridge or highway structure, or where the work would be subject to stream or flood flows.

Sometimes it will be necessary to adapt a method or combine methods to fit the conditions inherent to the site. For example, on slopes that could be prone to a washout prior to root establishment, live cuttings could be supplemented with another technique, such as live fascines. Soil bioengineering/biotechnical engineering erosion control methods can also be used with other engineering methods on more difficult sites. Such combinations of methods can take advantage of their strengths to create a functioning slope-stabilization system.

The use of standard planting items, seeding, sodding, and mulching can also be incorporated into the soil bioengineering/biotechnical engineering erosion control design, as necessary, to integrate the structure with its surroundings, and improve the vegetative diversity. Collected or salvaged plant materials may also be considered with similar objectives.

D. Other Considerations

1. Monitoring and maintenance

Soil bioengineering/biotechnical engineering erosion control methods should only be used in areas where there is reasonable probability that the systems will propagate and otherwise be successful, and require minimal maintenance. The systems should be designed for areas that have sufficient moisture throughout the growing season to continuously support vegetative growth. Consult the Regional Geotechnical Engineer and the Regional Landscape Architect about specific areas of installation.

Monitoring of bioengineered structures during the life of the Contract should be done on a regular basis to assure that the natural processes are working to establish self-sustaining and stable functions of the systems. Early problem indicators such as gullying or erosion, loss of structure or plant materials, unforseen groundwater appearance, mechanical injury, and need for repair or replacement of components, etc., should be brought to the attention of the Regional Landscape Architect. Intensive maintenance may be required during monitoring period of the bioengineered structure to repair or restore problem areas, replace damaged components, or augment the original design.

Monitoring prior to the acceptance of the soil bioengineering/biotechnical engineering erosion control methods should be conducted on a bi-weekly basis and after storm events of 12 mm or more in a 12-hour period. Maintenance on the structures/plantings should be undertaken, when failures occur, to reestablish the structures and vegetated material.

General post construction maintenance of the bioengineered structure following proper establishment should be minimal, in accordance with the restorative concept of using a living material as a solution. Maintenance, other than that which will be performed for any other area of the highway right-of-way, such as pruning, vegetation removal, maintenance of sight distance, etc., should not be necessary on the bioengineered structure.

2. Hydraulic Analysis

In any situation where the use of soil bioengineering/biotechnical methods will result in an increase in vegetation over existing conditions within an area subject to a 1% annual probability of flooding, consult the Regional Hydraulics Engineer to ascertain the effect on hydraulic roughness. A hydraulic analysis may be required to assure that increased resistance to flow will not raise floodwater levels upstream in violation of Federal Emergency Management Agency (FEMA) Flood Insurance requirements.

III. Methods and Materials

A. Live cuttings/live stakes-in soil (see details)

Live cuttings/live stakes create a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by contributing to the reduction of excess soil moisture. Live cuttings/live stakes are an appropriate technique for repair of small earth slips and slumps that are frequently wet. Live cuttings are applied for vegetative growth only. The size of cuttings limit their usefulness as support members. Live stakes are used for vegetative growth as well as support of other soil bioengineering techniques.

This technique is for relatively uncomplicated site conditions when construction time is limited and an inexpensive vegetative method for stabilization is desired. It is not intended to be used where the integrity of a road or structure is dependent upon the cuttings or stakes. It is not designed for or intended to resist large, lateral earth stresses.

Live cuttings range from 12 to 25 mm in diameter and 0.3 to 1.2 m long. Live stakes range from 26 to 50 mm or 51 to 100 mm in diameter and 1.5 to 1.8 m long. The live cuttings and live stakes must have side branches cleanly removed and the bark must be intact. The basal ends should be cut at an angle for easy insertion into the soil and the top cut square. Materials harvested on site shall be installed the same day they are prepared. Nursery material must be soaked for 24 hours prior to installation. Live cuttings or live stakes could be used for any application as specified in the contract documents.

Drive the live cuttings/live stakes into the ground pointing up from the slope. Live stakes should be installed 600 to 900 mm apart using triangular spacing. The density will range from two to four live cuttings/live stakes per square meter. The buds on the live cuttings/live stakes should be oriented up. Two-thirds of the length of the live cuttings/live stakes shall be installed in the ground and soil firmly packed around them after installation. Care should be taken not to damage live cuttings/live stakes during installation. Live cuttings/live stakes that are damaged should be left in place and supplemented with an intact live cutting/live stake. A dibble or similar tool may be used to make a pilot hole for installing the plant material. Drive the live stakes into the ground with a dead blow hammer (hammer head filled with shot or sand). (Refer to details.)

B. Live cuttings/live stakes-joint planting (see details)

Joint planting involves driving live cuttings/live stakes into soil between the joints and open spaces, in rocks that are being placed on a slope face ("Stone Filling - Section 620",) or stone that has previously been placed on a slope. The roots will improve soil drainage and create a living root mat. There is no value in utilizing this technique where geotextile has been placed under the stone filling, as there is little expectancy of plant survival. Joint planting should not be used in stone fill or riprap slope protection placed adjacent to bridge or highway structures.

One-half of the live cutting/live stake should be driven into the soil below the stone filling. Approximately 50 to 100 mm should be exposed above the stone filling. A pilot hole is required to insure that the cutting/stake will not be damaged from being driven into place through the stone filling. For sizing, refer to live cuttings/live stakes in soil. (Refer to details.)

C. Live Fascines (see details)

Live fascines are long bundles of live branch cuttings bound together into sausage-like structures. Fascines are constructed only from freshly cut dormant branches of materials and from sources approved by the Engineer. Live fascines must be prepared and installed within 48 hours of the time the plant material is harvested.

The use of live fascines is an effective stabilization technique for slopes. This procedure is suited to steep, rocky slopes, where digging is difficult. The fascines enhance vegetation establishment by creating a microclimate.

When cut from appropriate species and properly installed with both live stakes and wooden posts to secure them, the live stakes will root and immediately begin to stabilize slopes. The fascines should be placed in shallow contour trenches on dry slopes. On wet slopes, to reduce erosion and shallow face sliding, the fascines should be placed on an angle to the contour to direct surface runoff toward a suitable drainage area.

Use the chart below for spacing requirements of fascine rows along a variety of slopes.

Slope	Slope Distance Between Trenches (mm)	Maximum Slope Length (m)
1:1.0 to 1:1.5	900 to 1200	4.5
1:1.5 to 1:2.0	1200 to 1500	6.0
1:2.0 to 1:2.5	1500 to 1800	9.0
1:2.5 to 1:3.0	1800 to 2400	12.0
1:3.5 to 1:4.0	2400 to 2700	15.0
1:4.5 to 1:5.0	2700 to 3000	18.0

Cuttings must come from species, such as young willows or shrub dogwoods that root easily and have long, straight branches. They should be tied together to form live fascine bundles which can vary in length (minimum length of 1.2 meters). The length of the fascines depends on site conditions and limitations in handling. Fascines are to be constructed in bundles ranging from 150 to 200 mm in diameter, with all of the growing tips oriented in the same direction. The cuttings in the bundles are staggered so that tops are evenly distributed throughout the length of the uniformly sized live fascine. Wooden support posts shall be 750mm long in cut slopes and 900 mm long in fill slopes. They must be untreated 38 by 89 mm lumber. Each length should be cut again diagonally across the 89 mm face to make two posts from each length. Only new, sound, unused lumber should be used. Any post that shatters upon installation should be left in place and supplemented with an intact post. String used for bundling should be untreated twine. If specified, live stakes may be used in place of posts.

Live stakes can also be installed on the downslope side of the bundles. The live stakes are driven below and against the bundles, between previously installed posts. The live stakes should protrude 50 to 75 mm above the top of the live fascine. Moist soil is placed along the sides of the live fascine. The top of the fascine should be slightly visible when the installation is completed.

Live fascine bundles should be prepared immediately before installation. Dig trenches, starting at the base of the slope, on the contour, just large enough to contain the live fascine. The trench will vary in width from 300 to 450 mm, depending on the individual bundle's final size.

Live fascines are placed into the trench. Posts are driven directly through the live fascine every 600 to 900 mm along its length. Extra posts should be used at connections or bundle overlaps. The tops of the posts are left flush with the installed bundle. Repeat the preceding steps at contour intervals to top of the slope. Place two rows at the top of the slope. (Intervals are specified on the details.)

Seed or other erosion control material should be placed between rows and paid for under separate items. (Refer to details.)

D. Branchpacking (see details)

Branchpacking consists of alternate layers of live branch cuttings and tamped backfill to repair small, localized slumps and holes in slopes. It is effective in earth reinforcement and mass stability of small, earthen fill sites.

Branchpacking produces a filter barrier, reduces erosion and scouring conditions, and can be used to repair holes in earthen embankments.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. Branchpacking is not effective in slump areas greater than 1.2 m deep or 1.5 m wide.

Live branch cuttings may range from 12 to 50 mm in diameter. They should be long enough to touch the undisturbed soil at the back of the trench and extend slightly from the backfill area.

Wooden posts should be used to secure the material in place. These posts should be 1.5 to 2.4 m long and made from 75 to 100 mm diameter poles or 38 by 89 mm lumber, depending upon the depth of the particular slump or hole. Where specified, live stakes may be used in place of posts.

Installation should begin at the lowest point. Wooden posts are driven vertically 0.9 to 1.2 m into the ground, approximately 300 to 450 mm apart. A layer of living branches, 100 to 150 mm thick, is placed in the bottom of the hole between the vertical posts and perpendicular to the slope face. They should be placed in a crisscross configuration with the growing tips generally oriented toward the slope face. Space branch cutting layers 900 mm apart on slopes up to 1:3. For steeper grades, spacing should be 450 to 750 mm apart. 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 tamped soil to ensure soil contact with the branch cuttings. Moist soil is necessary to insure that the live branches do not dry out. The final installation should match the existing slope. Branches should protrude slightly from the filled face. Seed or other erosion control material should be placed between rows and paid for under separate items. (Refer to details.)

E. Brushlayering (see details)

Brushlayering is somewhat similar to live fascine systems. Both involve the cutting and placement of live branch cuttings on slopes in rows. 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 perpendicular to the slope contour.

Brushlayering is not recommended for fill slopes greater than 1.0 m in depth.

Brushlayering consists of placing live branch cuttings in small benches excavated into the slope. The benches can range from 600 to 900 mm wide. This system is recommended on slopes up to 1:2 in steepness and not to exceed 4.5 m in vertical height. The portions of the brush which protrude from the slope face assist in retarding runoff and reducing surface erosion.

Brushlayering preforms several immediate functions in erosion control, earth reinforcement, and mass stability. It reinforces the soil with unrooted branch stems, traps debris on the slope, drys excessively wet sites, and redirects adverse slope seepage by acting as horizontal drains. Use the chart below for spacing requirements of brushlayer rows along a variety of slopes.

Slope Distance Between Trenches (mm)			
Slope	Wet Slopes	Dry Slopes	Max. Slope Length (m)
1:2.0 to 1:2.5	900	900	4.5
1:2.5 to 1:3.0	900	1200	4.5
1:3.5 to 1:4.0	1200	1500	6.0

Brushlayering cuttings should be 12 to 50 mm in diameter and long enough to reach the back of the bench. Side branches should remain intact for installation.

Starting at the toe of the slope, benches are excavated on the contour, or angle slightly down the slope if needed to aid drainage. The bench should be constructed 600 to 900 mm wide. The surface of the bench should be angled so that the outside edge is higher than the back of the bench. Live cuttings should be placed on the bench in a crisscross or overlapping configuration. Live branch cuttings shall be placed in layers between 75 to 100 mm thick. Branch growing tips should be aligned out of the slope face. Place backfill on top of the branches and tamp to minimize air spaces. The brush tips should extend slightly beyond the fill in order to filter the sediment. Each lower bench is filled with soil excavated from the bench above. The brushlayer rows should vary from 0.9 to 1.5 m apart, depending upon the slope angle and stability (see above table). Seed or other erosion control material should be placed between rows and paid for under separate items. (Refer to details.)

F. Brushmattressing (see details)

Brushmattressing is a combination of posts, wire, and branch cuttings installed to cover and stabilize streambanks. It may be used in conjunction with live stakes and live fascines. A brushmattress consists of live branches that are placed on stream banks, secured in place with posts and wire, and covered with soil. The application typically starts above stream-forming flow conditions and moves up the slope. It forms an immediate, protective cover over the streambanks. This technique is useful on steep, fast-flowing streams and captures sediment during flood conditions. Brushmattresses are used to rapidly restore riparian vegetation and streamside habitats.

Live materials consist of branches 1.8 to 2.7 m long and approximately 25 mm in diameter or less. They must be flexible to enable installations that conform to variations in the slope face. Brushmattresses should be constructed of 90 branches minimum, evenly distributed per linear meter for the full width of the mattress. Live stakes may be used in the installation but should be alternated with wooden posts. Live stakes, if used, should be 0.8 to 1.2 m long, driven a minimum of 0.5 m into the ground. Live fascines may also be included in the installation. If included, they should be installed at the base of the brushmattress at the mean water level (Refer to details.)

The unstable area of the streambank should be uniformly graded to a maximum steepness of 1:3. If included, the live stakes and live fascine bundles should be prepared immediately before installation. Excavate a trench for the fascine, if specified, at the base of the slope near the stream forming flow stage and on the contour. It must be large enough to accommodate a live fascine and the basal ends of the branches.

Posts made of 38 by 89 mm lumber sawn diagonally from 0.9 to 1.2 m long are installed to a minimum depth of 500 mm over the face of the graded area using a 600 mm square spacing pattern. If live stakes are specified, every other one is alternated with posts. Branches are placed in a layer 3 to 5 branches thick on the prepared slope with basal end facing down slope. If fascines are included in the installation the branches will be placed in the previously excavated fascine trench with the fascine placed on top of the branch ends. The branches should be comprised of live, quick-rooting species. Number 16 gauge nongalvanized wire is stretched diagonally from one post to another by tightly wrapping wire around each post no closer than 150 mm from its top. The wire is only to be attached to the posts and not the live stakes, if they are specified. The posts are driven into the ground until branches are tightly secured to the slope.

Once the mattress is in place, soil should be applied on top of the live cuttings to a depth of approximately 100 mm and tamped.

Live fascines, if specified, are placed in the prepared trench over the basal ends of the branches. Posts are driven into the soil in front and behind the live fascine every 600 mm along its length. The fascines are secured to the posts with 16 gauge nongalvanized wire. Any voids between brushmattress and live fascine cuttings are filled with thin layers of soil to promote rooting. The top surface of the brushmattress and live fascine installation are left slightly exposed. Wire should be secured to posts only. (Refer to details.)

G. Vegetated cribwall (see details)

A vegetated cribwall consists of a hollow, box-like interlocking arrangement of untreated logs or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings which root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members which will deteriorate over time.

The technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness at locations such as boat launches or stream/river accesses. It is not intended to be used where the integrity of a road or structure is dependent upon the cribwall. It is not designed for or intended to resist large, lateral earth stresses. It should be constructed to a maximum of 1.8 m overall height, including the excavation required for a stable foundation. A vegetative crib wall is useful where space is limited and a vertical structure in needed. The crib wall also provides immediate protection from erosion, while establishing vegetation for long-term stability. The cribwall should be battered or constructed in a stair-step fashion. (Refer to details.)

Live branch cuttings should be 12 to 50 mm in diameter and long enough to reach from the front of the structure to the undisturbed soil. Logs or timbers should range from 100 to 150mm in diameter or dimension. The length of the branch cuttings will vary with the size of the crib structure. Large spikes or rebar are required to secure the logs or timbers together. Starting at the lowest point of the slope, material is excavated 600 to 900 mm below the ground elevation until a stable foundation is reached. The back of the stable foundation (closest to the slope) is excavated slightly deeper than the front. The first course of logs or timbers is placed at the front and back of the excavated foundation, approximately 1.2 to 1.5 m apart and parallel to the slope contour. The next course of logs or timbers is placed at right angles (perpendicular to the slope) on top of the previous course to overhang the front and back of the previous course by 75 to 150 mm. Each course of the cribwall is placed in the same manner and fastened to the preceding course to the desired grade. Stone filling is placed in the bottom of the structure up to the ground level and up to the base-flow in a stream channel (See "Stone Filling - Section 620"). When the cribwall structure reaches the existing ground elevation, live branch cuttings are placed on the stone filling perpendicular to the slope. The cuttings are then covered with Soil Bioengineering Backfill Material as detailed in this section and tamped. The live branch cuttings should be placed at each course followed by the Soil Bioengineering Backfill Material to the top of the cribwall structure with growing tips slightly protruding from the cribwall face. Each layer of branches is followed with a layer of Soil Bioengineering Backfill Material tamped to ensure good contact between the live branch cuttings and soil. Some of the basal ends of the live branch cuttings in each layer should reach the undisturbed soil at the back of the cribwall. It is recommended to consult the Regional Geotechnical Engineer for aid in analyzing the configuration of the cribwall. (Refer to details.)

H. Vegetated rock gabions (see details)

Vegetated Rock Gabions begin as rectangular containers fabricated from a triple twisted, hexagonal mesh of P.V.C. coated heavily galvanized steel wire (See "Gabions - Sections 620-2.07 and 712-15"). P.V.C.-coated galvanized gabions are recommended as permanent features in stream channel applications. Empty gabions are placed in position and wired to adjoining gabions. They should then be filled with a mixture of stones conforming to the provisions of Section 712-15 and Soil Bioengineering Backfill Material as detailed in this section. The ratio of stone to backfill material will depend upon the application. When the structure is in the presence of water, the suggested mix should be 70% stone and 30% backfill material, with the stone being placed first, followed by the backfill material. The backfill material should be worked in to fill the voids in the stone. When the unit is out of the water a 50/50 mix is recommended.

This technique is appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness. It is not intended to be used where the integrity of a road or structure is dependent upon the rock gabions. It should not be used in stream channels carrying significant bedload, where abrasion of the wire mesh will destroy the gabion baskets. It is not designed for or intended to resist large, lateral earth stresses. Vegetated gabion walls should be constructed to a recommended maximum overall height of 1.5 m, including the excavation required for a stable foundation. This technique is very useful where space is limited and a more vertical structure is required.

Live branches should range from 12 to 25 mm in diameter. The length of the cuttings will vary according to the size of the gabions and the depth of the cut in the embankment. The live branches should, at a minimum, be long enough to protrude slightly from the front face of the gabion and extend at least 300 mm into the backfill. Some of the live branches should be long enough to reach beyond the back of the rock basket structure into the undisturbed soil. Inert materials include wire gabion baskets and rocks to fill the baskets.

Starting at the lowest point of the slope, material is excavated 600 to 900 mm below the ground elevation until a stable foundation is reached. The back of the stable foundation is excavated slightly deeper than the front. This will provide additional stability to the structure and ensure that the living branches root well. The fabricated wire baskets are placed in the bottom of the excavation and filled with rock.

Backfill is placed behind the wire baskets and at the horizontal joints. A 25 mm layer of soil is placed at each horizontal joint, and live branch cuttings are placed on each layer of soil. The live branch cuttings are placed with the growing tips oriented away from the slope and extended slightly beyond the exposed faces of the gabions. The cuttngs must extend at least 300 mm into the backfill. Some of the live cuttings must also extend beyond the backs of the wire baskets and be in contact with the undisturbed soil. Soil is placed over the cuttings and tamped. This sequence is repeated until the structure reaches the required height. It is recommended to consult the Regional Geotechnical Engineer for aid in analyzing the configuration of the gabions. (Refer to details.)

I. Fiber roll (see details)

A fiber roll is a coir- woven roll encased with a synthetic webbing used to dissipate energy along streams, channels, bodies of water or on slope contours.

Fiber rolls, in conjunction with plant material, are used along ponds, streams, creeks, and where water levels are relatively constant. Artificially controlled streams for hydro power are not good candidates for this technique. The rolls provide a good medium for the introduction of herbaceous vegetation. The vegetation needs to be a suitable wetland species. Well rooted dormant plants are preferred, but containerized plugs of growing plants are feasible. Planting in the fiber roll is appropriate where the roll will remain continuously wet. The plant species to be used are identified on the Supplemental Landscape Development Sheets in the project proposal or specified elsewhere in the contract documents.

Fiber rolls must be installed at an elevation which will allow the rolls to be continuously wet. This technique is not suitable where water levels fluctuate as the rolls will dry out. Size and specialized material requirements should be specified in the contract documents

A shallow trench is excavated at the toe of the slope slightly below streambed depth. The rolls are placed in the trench and anchored with 50 by 50 by 900 mm long posts. Posts are placed on both sides of the fiber roll. Twine holds the fiber rolls together. The posts should be spaced laterally on 0.6 to 1.2 m centers. Trim the top of the posts even with the top edge of rolls as necessary. The posts are tied together across the rolls with 16 gauge nongalvanized wire. Soil is placed behind the rolls and planted with suitable herbaceous or woody vegetation. Vegetation is placed in contact with the fiber rolls to promote rapid root extension into the rolls. Herbaceous vegetation may also be planted into the fiber rolls, as specified. If additional stabilization is necessary a brushmattress placed over the top of the roll will quickly reinforce the installation.

Fiber rolls may also be used on contours along slope faces as a erosion control measure. When used in this fashion it should not be used with herbaceous plant as conditions will not be favorable for plant growth.

J. Vegetated mat (see details)

A vegetative mat consists of a coir-woven blanket reinforced with organic or synthetic netting used along streams, channels, or bodies of water to control erosion and provide a suitable planting medium for selected plants. Vegetated mats are biodegradable and may contain selected preinstalled vegetation. As an alternative, nonvegetated mats can be planted or live-staked after installation (refer to details). These mats can contain grasses, sedges, or shrubs as specified. The plants dissipate the water's energy due to wave action or currents through leaf and stem elasticity. The mats provide a good medium for plant material, and they resist erosion.

The vegetated mats should be installed as per the manufacturer's recommendation. Once established, vegetation is self-maintaining. Slope geometry, water regime, and other site factors should be considered in determining the products to be specified in the contract documents.

K. Tree revetment (see details)

A tree revetment consists of a whole tree, except rootwad, cabled to an earth anchor which is buried in the stream bank. This method uses inexpensive, readily available materials to form temporary streambank protection. The tree revetments will capture sediment and enhance conditions for colonization of native species. They have self-repairing ability following damage after flood events if used in combination with other soil bioengineering/biotechnical engineering erosion control techniques. Tree revetments are not appropriate near bridges or other structures where there is a potential for downstream damage if a revetment dislodges. Tree revetments have a limited life and depend on year round stream conditions and durability of tree species used. They may be damaged in streams where heavy ice flows occur. This use should be limited to non-flashy streams, where the needs for future maintenance are not important.

A tree is placed along the stream bank with the basal end oriented upstream. The trunks are attached by galvanized cable and clamps to earth anchors set in the bank. Anchors should consist of commercially manufactured earth anchors inserted into the streambank. Multiple tree revetments along the stream are overlapped by approximately 25% of their length and secured together to insure continuous protection to the bank. The revetments should also extend vertically up the streambank covering two-thirds of the streambank.

Use trees that have a trunk diameter of 300 mm or larger and a trunk length of 6.0 m or greater. The best types of trees to be used as revetments are those that have a brushy top and are naturally durable wood, such as spruce, douglas fir, or cedar. Vegetative plantings or soil bioengineering/biotechnical engineering erosion control systems should be used within and above the structures to restore stability and establish a vegetative community. When planting in the revetment below stream-forming flow stage, plant species that will withstand inundation should be staked in openings. (Refer to details.)

There are several commercial anchoring systems available which can be installed with less disturbance to the site than is caused by installing deadmen. Substitutions for the commercial anchors may be made at the designer's discretion. Pilings may be used in lieu of earth anchors in the bank if they can be driven well below the point of a maximum bed scour. Recycled materials such as concrete anchors or structurally sound wood may also be used as substitutes, but must be a minimum of 140 mm in diameter and 1.0 m in length. These substitutes should be installed no less than 1.8 m into the streambank.

The required cable size and anchorage design are dependent upon many variables and should be custom designed to fit a specific site. A minimum cable size of 6.4 mm is recommended.

L. Log, rootwad, and boulder revetment (see details)

These revetments are systems composed of logs, rootwads, and boulders selectively placed in and on streambanks. These revetments can provide excellent overhead cover, resting areas, and shelters for insects and other fish food organisms, and can be used to increase stream velocity that results in sediment flushing and deeper scour pools.

These systems are used for stream stabilization and to create instream structures for improved fish rearing and spawning habitats. They are effective on meandering streams with out-of-bank flow conditions and they will tolerate a high boundary shear stress if logs and rootwads are well anchored. These revetments should be used in combination with soil bioengineering/biotechnical engineering erosion control systems or vegetative plantings to stabilize the upper bank and ensure a regenerative source of streambank vegetation. Log, rootwad, and boulder revetments have limited life depending on climate and tree species used. Some species, such as cottonwood or willow, often sprout and accelerate natural colonization. Revetments may need eventual replacement if natural colonization does not take place or if other soil bioengineering/biotechnical engineering erosion control methods are not used in combination.

The rootwad trunks should be conifers for maximum resistance to rot. If hardwoods must be used locust, oak or hard maple are preferred.

The combination log, rootwad, and boulder revetment is made up of a log of at least 400 mm in diameter that has a crooked and irregular shape. The rootwads should have 2.4 to 3.6 m of trunk length with numerous root protrusions attached. Loose soil should be removed, thereby exposing as many roots as possible. Rootwads are trenched into the streambank so that the tree's primary brace roots are flush with the streambank and at a slight angle facing upstream.

A footer log is installed at the toe of the eroding bank by excavating trenches at the slope or stream base to a depth of one-half the footer log diameter. The length of the footer log should be 3 to 4 times the diameter of the rootwad log, at least 1200 mm long. The footer log is placed at a slight angle upstream into the direction of the stream flow. Boulders are used to anchor the footer log against flotation.

The boulders should meet the requirements of Item 620.05M, stone filling (HEAVY), and should be placed to anchor the footer log. The boulders should have irregular surfaces. The boulders should be at least 1.0 to 1.5 times the diameter of the rootwad trunk.
If boulders are not available, logs can be pinned into a gravel and rubble substrate with 19 mm rebar 1.4 m or longer. Rebars are anchored to provide maximum pull out resistance. Cable and anchors may also be used in combination with boulders and rebars.

Backfill and combinations of vegetative plantings or soil bioengineering/biotechnical engineering erosion control systems are placed behind and above the rootwad. These can include live stakes and dormant stake plantings in the openings of the revetment below stream-forming flow stage, live stakes, bare root, or other upland methods at the top of the bank. The use of log, rootwad and boulder revetments should be limited to non-flashy streams, were the needs for future maintenance is unimportant. They should not be used upstream of bridges or other structured subject to damage or debris blockage should the revetment fail. (Refer to details.)

M. Select Clean Fill.

All soil used as backfill material should be a well-graded soil suitable for vegetative growth. When utilizing several of the above mentioned techniques substantial quantities of soil may be required. It is preferable that backfill be obtained which is more economic than topsoil. A specification has been furnished by Materials Bureau which provides guidelines with which proposed backfill can be evaluated.

APPENDIX I

Woody plants with fair to good or better rooting ability from unrooted cuttings.

Scientific name	Common name
Baccharis halimifolia*	Eastern baccharis
Cephalanthus occidentalis*	Buttonbush
Cornus amomum*	Silky dogwood
Cornus drummondii	Roughleaf dogwood
Cornus foemina*	Stiff dogwood
Cornus racemosa	Gray dogwood
Cornus rugosa	Roundleaf dogwood
Cornus sericea ssp. sericea	Red-osier dogwood
Physocarpus opulifolius*	Common ninebark
Populus balsamifera	Balsam poplar
Populus deltoides*	Eastern cottonwood
Rosa palustris	Swamp rose
Rosa virginiana	Virginia rose
Rubus allegheniensis	Allegheny blackberry
Rubus idaeus ssp. strigosus*	Red raspberry
Salix amygdaloides*	Peachleaf willow
Salix discolor*	Pussy willow
Salix exigua	Coyote willow
Salix humilis	Prairie willow
Salix interior	Sandbar willow
Salix lucida	Shining willow
Salix lutea	Yellow willow
Salix nigra*	Black willow
Salix purpurea	Purpleosier willow
Sambucus canadensis*	American elder
Sambucus racemosa ssp. pubens*	Red elderberry
Spiraea alba*	Meadowsweet spirea
Symphoricarpos albus*	Snowberry
Viburnum dentatum*	Arrowwood
Viburnum lantanoides	Hobblebush viburnum
Viburnum lentago*	Nannyberry

APPENDIX II

Grasses useful in conjunction with soil bioengineering/biotechnical engineering erosion control.

Scientific name	**Common name**
Agrostis alba	Redtop
Ammophila breviligulata	American beachgrass
Andropogon gerardii*	Big bluestem
Arundo donax	Giant reed
Elymus virginicus	Wildrye
Eragrostis trichodes	Sand lovegrass
Festuca rubra	Red fescue
Hemarthria altissima	Limpograss
Lolium perenne	Perennial ryegrass
Panicum amarulum	Coastal panicgrass
Panicum clandestinum	Deertongue
Panucum virgatum*	Switchgrass
Phalaris arundinacea	Reed canarygrass
Poa pratensis	Kentucky bluegrass
Schizachyrium scoparium*	Little bluestem
Sorghastrum nutans*	Indian grass
Spartina pectinata*	Prairie cordgrass
Zizaniopsis miliacea	Giant cutgrass

Salvage or collected materials

Cattails
Alnus roots
Swamp grasses/forbs-blueflag, sagittaria, filbert
Hammaelis

(*) - Denotes native to New York.

Glossary of Terms

POSTS - Used for supports. (Posts shall be wood but do not have to be alive. They shall not be treated lumber.)
STAKES - Used for vegetative growth and support (live plant material).
CUTTINGS - Used for vegetative growth.
FLASHY STREAM - Stream characterized by rapidly rising and falling stages.
SEED MIX - Standard seed mix per Section 610 or otherwise specified by the Regional Landscape Architect.
FORB - An herb other than grass.
DIBBLE - Small tool used for planting, or to plant by means of using a small tool (i. e. a dibble.)
CAMBIUM LAYER - A thin formative layer beneath the bark of most vascular plants that is responsible for secondary growth.
BASAL END - The base of a branch, stem, or stick, not the growing tips.