Brush Mattresses for Streambank Erosion Control

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

OVERVIEW

A brush mattress is a layer (mattress) of interlaced live branches placed on a bank face, often with a live fascine and/or rock at the base. The live branches are cut from any adventitiously sprouting (sprouts roots from stems) woody plant, such as willow and some species of shrub dogwood and alder. The mattress and the live fascines are held in place with wire or twine, live stakes, and dead stout stakes. A brush mattress, with a live fascine and/or rock at its toe, is used along the face of an eroding bank and acts principally to armor the bank (**Figure 1 a-c)**. The brush mattress has the potential to immediately slow velocities along the bank and accumulate sediment. Together with the sprouting plants, the brush mattress develops a strong network of interlocking roots and plant stems.

The brush mattress helps to control bank erosion while serving as habitat for birds, small fur-bearing animals, and insects and other organisms that in turn are fed upon by fish and other higher organisms. Once the vegetation reaches a height of a few feet, it can provide shade to the stream - lowering water temperatures, offering protection from predators, and generally improving fish habitat. The brush mattress can also improve non-point pollution control by intercepting sediment and associated pollutants coming into the stream from overbank areas and in the flow.

a. Bank conditions before brush mattress installation

b. Installation of brush mattress with rock toe, November 1998

c. Completed brush mattress after two years

Figure 1. Bank on Carson River, Nevada, (a) before, (b) during, and (c) two years after installation of brush mattress

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PLANNING

The first step in the planning process is to determine whether a brush mattress is an appropriate alternative to address the observed and projected mechanisms of bank loss. They should be evaluated to determine the extent to which they meet project objectives and constraints related to channel size, stability, and habitat. Questions that must be addressed by the team include the following inter-related items (not exhaustive):

1. Is a brush mattress 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 brush mattress?

3. Are stream velocities and shear stresses permissible?

4. Are there riparian woody or other adventitiously sprouting plants in a nearby reference reach that can be used as a template (and material source) for the brush mattress?

5. Will site conditions during construction permit installation?

6. Will sediment accumulation be a positive or negative result for plant establishment and survival?

7. Will there be enough sunlight and water to support the desired system?

8. What other erosion control devices or materials will be needed, such as grade control in the bed?

9. Is the required construction season available?

10. Have consequences of failure been considered and what are they, e.g., what happens if the brush mattress is infected by a disease or undergoes an insect infestation?

11. Are the costs acceptable?

Costs for the brush mattress can be most easily interpreted if put in terms of man hours of construction; appropriate rates of labor for time and region of the country can then be applied. A 1-m^2 of brush mattress is constructed in between ½and 1½labor-hours. This includes plant harvest, collection, transport to the project site, fabrication, and installation. Costs for construction of the dead stout stakes and coir bristle twine or wire, in 2000 dollars, are about $3.00 to $5.00 per square meter. Incidental start-up, cleanup, and site preparation costs such as bank reshaping must be included. Costs for brush mattress projects with which the authors are familiar range from $12/ to $24/$m^2$, with an average cost of about $18/$m^2$. Costs for brush mattresses on projects that are contractor bid requiring live fascine installation, maintenance, profit margins, and contingency factors, range between $25.00 and $55.00/$m^2$.

SITE CONSIDERATIONS

A site suited to a brush mattress requires a hydrological regime that 1) keeps the basal ends of the live branches moist during most of the growing season, and 2) sustains flows sufficient to keep the woody plants growing well, but not such large and long duration of flows so as to exceed the plants' flood tolerance. Given these requirements, streams best suited to brush mattresses are generally perennial, although they can be intermittent if there is sufficient ground-water or soil moisture.

Besides hydrology, other factors that are important in site selection are shade conditions and type of substrate in which the brush mattresses will be installed. Willow and alder in a brush mattress require sunlight. Some dogwood and viburnum species tolerate shade better than willow and can be used in more shaded conditions. Brush mattress is most successful when installed in sunny locations.

Substrate conditions are also important in site selection for anchoring and root penetration by the woody vegetation. Noncohesive material, such as sand or silt, may limit anchoring due to lack of friction. The dead stout stakes that hold

the woody material in place need to be longer in these instances. Conversely, substrate interspersed with rock or with a rock underlayer can adversely impact anchoring unless special equipment or materials are used.

Substrate influences root penetration and growth of the adventitiously sprouting woody plants. If the substrate is mostly clay without much sand or silt included, it can become too hard for adequate root penetration. Lack of air spaces within the clay may create an anaerobic environment – thus limiting root growth.

The brush mattress can serve as a naturally-appearing armor or liner next to the thalweg. Scour potential at the toe and the requirement of a stone bolster to protect it from undercutting must be considered in these circumstances.

DESIGN

The primary design considerations for brush mattress are:

1. Elevation along the bank with respect to the hydrology of the stream.

2. Sustained velocity and shear-stress thresholds for the brush mattress.

3. Toe and flank protection (rock toe armor guards against undercutting of the treatment and flank hardening guards against currents working their way around and under the treatment and causing it to fail from flanking).

4. Drainage over the bank or bank seepage.

5. Growth factors including soil character, nutrients, and sunlight.

6. Depredation and trampling.

Primary Design Considerations

The brush mattress is placed on a contour elevation along the bank and within the soil so that the branches in the mattress absorb water for sprouting. Most woody plants used in the mattress, such as willow, cannot tolerate permanent flooding. The brush mattress should be placed where flood durations do not exceed the plants' tolerance. Figure 2 shows a typical section of a brush mattress with the baseflow noted.

As a general rule, if there are species along a reference reach of the stream on which you are working and that species is being used, the lowest naturally occurring elevation at which that species grows will serve as a model for the lower limit of installation. This rule should be ignored on streams with aggradational or degradational trends.

The upper contour elevation limit for extending a brush mattress is dictated by the availability of sufficient moisture to support plant growth. The frequency and duration of flooding and the associated sheer stresses that occur along the bank are considerations as well. The brush mattress should be extended up the bank far enough to provide the appropriate resistance to velocity and shear at a range of flooding levels along the bank.

Few data have been collected for shear or velocity tolerances of a brush mattress. Available data come largely from empirical information. Table 1 summarizes these data, as reported in Fischenich (2001) and augmented with data from the author's projects.

Table 1. Stress and Velocity Levels for the Brush Mattress

Brush Mattress Type	*Velocity*	*Shear*
Staked only w/o rock bolster at toe (Initial)	< 4.0 ft/sec	0.4 – 3.0 lb/ft^2
Staked only w/o rock bolster at toe (Grown)	< 5.0 ft/sec	4.0 – 7.0 lb/ft^2
Staked w/ rock bolster at toe (Initial)	< 5 ft/sec	0.8 – 4.1 lb/ft^2
Staked w/ rock bolster at toe (Grown)	< 12 ft/sec	4.0 – 8.0 lb/ft^2

Schiechtl and Stern (1997) cite Florineth (1982) who gave some additional tractive (shear) force tolerances: forces of 4.2 lb/ft^2 after completion; 6.3 lb/ft^2 after 15 months; and 8.4 lb/ft^2 after the third year. This was apparently a brush mattress without a rock bolster.

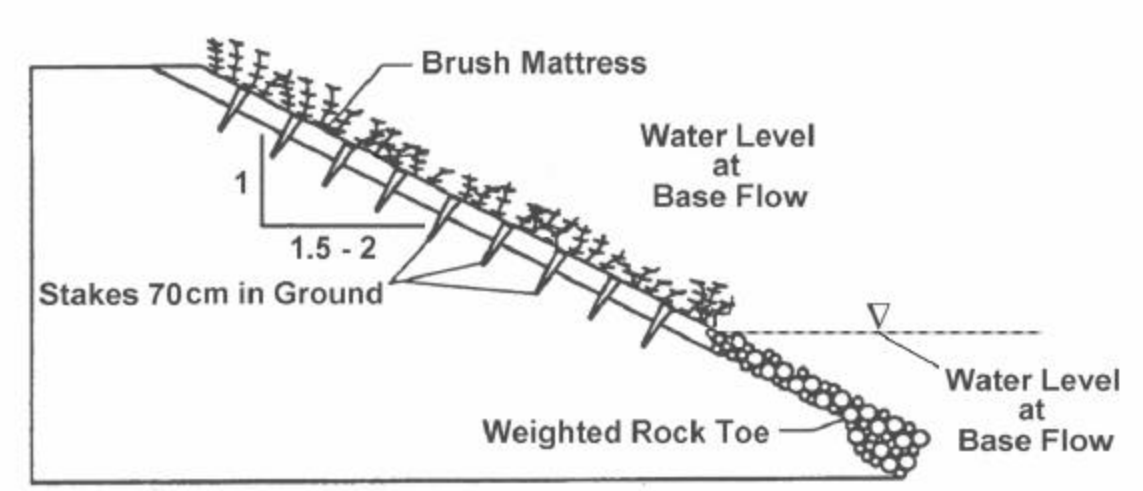

Figure 2. Profile view of brush mattress with rock toe; note relationship to water level at basal flow and that live brush is not permanently flooded

Protection to guard against undercutting and flanking is essential. Angular rock is recommended, and should be sized in accordance with U.S. Army Corps of Engineers (1994) specifications.

Flank protection can also be aided by abutting the sides of the brush mattress up against rock or some other kind of hard point at both ends. For banks susceptible to significant erosion, keys or refusals extend further into the bank.

In designing a brush mattress along an eroded bank, examine the bank for overbank drainage ways and piping features (internal erosion) that could undermine the system. Divert any drainage ways present above where the brush mattress will be installed around and away from the installation site or to a constructed drainage outlet, such as a French drain. If piping features are present, design the brush mattress with an appropriate filter, such as a granular filter or geotextile filter below it.

Other Design Considerations

Other design considerations include the length and width of the brush mattress. The brush mattress can be tailored to the slope face of the eroding bank by installing more rows, respectively (see construction below). Depending upon the amount of branching laterals, plan on using 6-15 straight flexible branches of brushy willow per linear foot for a slope length of 5 to 9 ft. If the slope face length is longer, use multiple rows of brush mattress with a minimal overlap of 1 ft (basal ends of the lower row overlapping terminal ends of the upper row). To accomplish this, construct the upper row first.

Brush mattresses can be installed on slopes >1.25H:1V, but under these conditions, sprouting of stems may occur only at the basal ends of the branches where they are buried and have good stem-to-soil contact. On steeper slopes, it may be difficult to achieve good stem-to-soil contact for sprouting to occur along the entire stem. For best results, install on slopes 2H:1V or flatter. Uniformly shape the slopes unless they occur naturally (Figure 3). Uneven slopes may lead to poor soil-to-stem contact, with air pockets occurring beneath the branches and resultant drying of the soil and branches. Consequently, branches die and sprouting does not occur.

Figure 3. Slope the bank to provide an even surface for the brush mattress

Eroded banks may not always be conducive to brush mattress installation and may require either reshaping or filling to accommodate one or more rows of brush mattress. If fill is required, rock fill is often used at the toe and at the sides to prevent undercutting and flanking. 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). If rock fill is used other than at the toe, it must be at least 18 in. of topsoil placed over the rock so that branches can root into the topsoil.

CONSTRUCTION

The primary considerations concerning construction with a brush mattress are bank preparation to include trench construction, physical handling and placement, timing, securing the branches, live fascine (if used), backfill, and possibly watering.

Banks on which brush mattresses are to be installed should foster good soil-stem contact and be even, so as to achieve slope lengths of about 5 to 18 ft (see Figure 4 using two rows). This typically requires some reworking of the bank by either grading it or filling in places. For plants to grow, do not compact soil more than 85 percent of its maximum compaction. Live fascines can be used alone or with a stone toe buttress (Figure 5).

Figure 4. Double row of brush mattress showing stake placement

Branches in the brush mattress consist of woody adventitiously sprouting willow, viburnum, shrub dogwood, or similar plant species. Use 2- to 3-year old flexible branches,

Figure 5. Branch placement beneath live fascine and against bank face

5 to 10 ft long, and flexible. Basal ends range between 0.5 and 1.5 in. in diameter. They are placed perpendicular to the bank with their basal ends inserted into a trench at the bottom of the slope in the splash zone (Allen and Leech 1997), just below any toe protection, such as a rock toe, or live fascine bundle. The branches are cut from dormant live willow or similar plants and kept moist and cold until installing. A compressed layer of branches 2 to 4 in. thick is used and is held in place by either coir bristle twine, or tie-wire (Figure 6). Wedge-shaped construction stakes, called dead stout stakes, are used to hold the twine or wire in place. These are 2 in. by 4 in. by 24 to 36 in. (depending on soil type) and are diagonally cut. A gauge and type suitable for tie-wire is No. 12 galvanized annealed. If bristle coir twine is used, it should be machine spun bristle coir, thickness 0.2 - 0.25 in., with breaking strength of 70-100 lb. Both are run perpendicular to the branches and diagonally from stake to stake and tied by use of a clove-hitch.

Figure 6. Securing a brush mattress with stakes and twine

A trench to install the live fascine is dug 8 to 10 in. deep and wide. Next, using dead stout stakes, the live fascine is loosely installed at the base of the brush mattress installation. The dead stout stakes are then driven firmly into the slope face in a square configuration approximately 12 to 18 in. apart. The branches that form the mattress are then installed with the basal ends pushed in behind the live fascine with the live branches laid in between the previously installed dead stout stakes up against the bank. Wire or coir bristle twine encircles each dead stout stake and is pulled tightly across the live branches. When this is complete, the dead stout stakes are driven into the ground a little further (1 to 3 in.) to further compress the live branches to the slope face. Lightly cover with soil and work into the branch mattress. Finally, finish installing the live fascine at the base. Live stakes may be used for deeper rooting on the mattress face and for securing if twine is used. The wedge of the stake compresses the wire or twine to hold the branches down.

Live fascine bundles may vary in length, depending on construction needs. When compressed firmly and tied, each bundle is about 6 to 8 in. in diameter. Tie bundles with either hemp binder twine, coir bristle twine, or they can be fastened and compressed by wrapping "pigtails" around the bundle. Pigtails are commonly used to fasten rebar together. If tied with binder twine, a minimum of two wraps is used in combination with a non-slipping knot, such as a square knot. Tie every foot. Live fascine bundles are staked firmly in place with dead stout stakes driven vertically directly through the bundle 36 in. on center. Also, live stakes may be installed at an angle on the downslope sides of the bundle at about the same distance, offset in between the previously installed dead stout stakes. In this way, the dead stout stakes firmly compress and secure the live fascine bundle very firmly into the trench. Where bundles overlap, additional dead stout stakes are used at the overlap.

Both brush mattress and live fascine are covered immediately with soil and worked down into the branches. Work soil into both the brush mattress and live fascine by both tamping and walking on it. If possible, lightly watering the soil after tamping is a good idea and will ensure soil-to-stem contact. Watering can often be facilitated by use of a portable, centrifugal, gasoline-powered pump, hose, and pipe-like nozzle. Water can be pumped from the stream directly onto the brush mattress. All but the outer branches of the brush mattress is covered with soil, and about 75 percent of the live fascine is covered. In both cases, leave some branches exposed to facilitate sprouting.

Figures 7 – 9 show a brush mattress immediately after construction, after one growing season, and in the second season (courtesy of Robbin B. Sotir and Assoc., Inc.). Figure 10a-b shows a schematic of a brush mattress and live fascine.

OPERATION AND MAINTENANCE

Operation and maintenance requirements vary depending on the stream system and its associated parameters, such as velocity, flood frequency, flood stage, sediment load, and timing. In any case, be prepared to repair the system until the vegetation becomes well-established. Inspection should occur after each of the first few floods or at least once a year, preferably after the predominant flood season.

Figure 7. Brush mattress after light backfill of soil

Figure 8. Brush mattress after first growing season

Figure 9. Brush mattress during second growing season

Undercutting and flanking of the treatment and any other substantial scour evidence should be addressed. Examine plants for survival, density, and absence of disease, insect, or other animal damage (e.g., grazing, trampling, digging, and cutting). Successful plants will grow vigorously and spread their roots throughout the brush mattress and surrounding substrate.

If animal damage occurs, preventative measures, such as use of exclosures, may be required. Such exclosures may only need to be temporary until plants are well-established. Unless new stems are severely eaten back to the sprouting location, they can recover fairly quickly if they are not immediately flooded for a long period.

Assuming the brush mattress remains in place and the vegetation roots and becomes established along the treatment, maintenance is greatly reduced over time.

Fish and aquatic invertebrate sampling is always recommended both before and after installation to determine habitat improvement effectiveness.

APPLICABILITY AND LIMITATIONS

Techniques described in this technical note are generally applicable where primary objectives for streams include habitat diversity, erosion control, and aesthetics. The brush mattress will provide natural armor to the bank and capture sediment during flooding. Species used within the brush mattress are generally early colonizers and will stabilize the bank as well as promote the growth of other plants that benefit by a more stable site. It is applicable particularly to streambanks that are threatened by high flows prior to vegetative cover. The brush mattress is limited to streams that can provide basal flows long enough to keep the basal ends of the branches in the brush mattress moist or wet. The brush mattress is not suited for extremely dry ephemeral streams. Exceptions occur where there is enough precipitation early in the growing season to allow the branches to sprout roots and send them down deep enough into the soil to gain moisture later in the season as precipitation events become less frequent. The brush mattress is used only at a location on the slope above basal flows.

Caution should be exercised in using a brush mattress without a rock bolster at the toe when stream velocities at the toe exceed critical thresholds for underlying soils.

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> Allen, H.H., and Fischenich, J.C. (2000). "Brush mattresses for streambank erosion control," EMRRP Technical Notes Collection (TN EMRRP-SR-23), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/emrrp*

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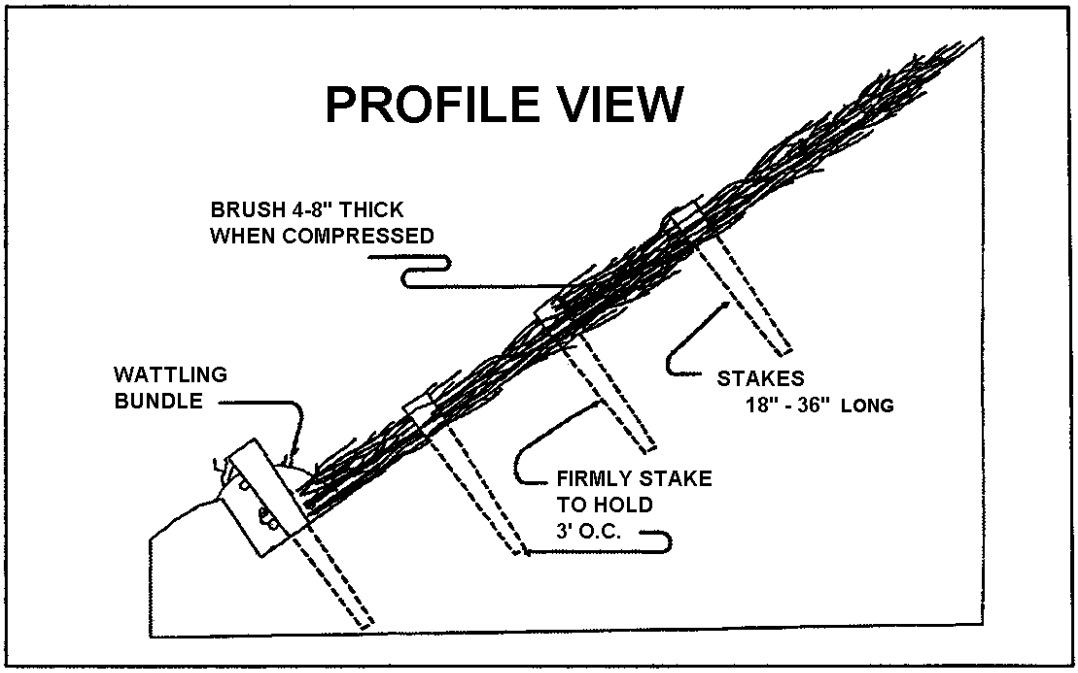
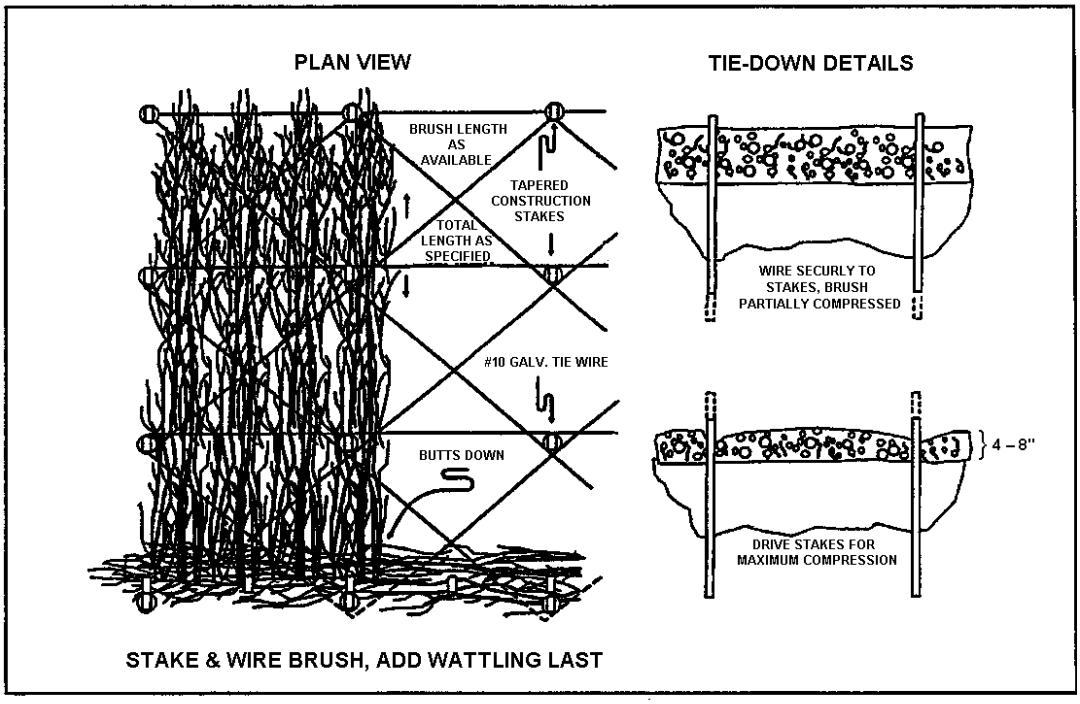


a. Profile view



b. Plan view

Figure 10. Schematic of brush mattress with live fascine at toe