Bank Stabilization Structures

Bank stabilization structures are necessary to maintain bank integrity on restored stream reaches until planted vegetation is capable of naturally stabilizing the banks. The structures are built to last until vegetation or large wood provides bank stability in perpetuity.

Bank stabilization structures also serve to diversify fish habitat by providing overhead cover, flow-path complexity, interstitial hiding spaces, and visual separation for fish. Species and age-classes typically segregate according to these microhabitat attributes to reduce inter-size class and inter-species interactions. Built with whole cottonwoods and other native riparian woody species, rootwad composites and large-woody-debris jams are designed to emulate naturally occurring habitats. The materials used for debris jams will extend varying distances from the bank to deflect scouring eddies away from the bank and to diversify fish habitat.

Certain bank stabilization techniques, variously referred to as soft bioengineering, stream-bank bioengineering, and biotechnical stream-bank stabilization, mix living plant material with nonliving materials selected for their physical properties. These techniques evolved in response to the need to stabilize soil at the land-water interface long enough for vegetation to become established. From an engineering perspective, they perform several functions: (1) geotechnical fabrics (often including organic components) increase soil surface tension, thus increasing shear resistance; (2) fine and moderately fine root systems (herbaceous vegetation and shrubs) bind together near-surface bank materials and alluvial sediments; (3) dense, woody stems add roughness to stream banks, increasing values of Manning's *n* (a roughness coefficient), thereby diffusing flow energy and trapping sediment and coarse organic debris; (4) organic three-dimensional matrices, often made from coir (the fibrous outer husk of coconuts) function as a shear resistant, surrogate rooting medium while plants become established; and (5) larger shrubs and riparian trees can have a buttressing effect, anchoring sections of stream bank to deeper soil strata or bedrock. The paragraphs that follow describe some of the bank stabilization structures appropriate for the lower mainstem.

Rootwad Revetments

The primary purpose of bank-placed rootwads is to dissipate water velocities and shear stress in the near-bank region until dense riparian vegetation becomes established. A secondary purpose is to create diverse fish habitat. Single rootwad structures consist of a footer log, anchor rocks, and a rootwad. The footer log is approximately two to three feet in diameter and 20 to 25 feet in length. The anchor rocks are placed on the footer log on either side of the rootwad. Anchor rocks are approximately 0.75 to 1 cubic yard per rock with eight to ten anchor rocks required for each revetment structure. The rootwads themselves are approximately 25 feet in length with a stem diameter of two to three feet and a six-to-eight-foot root fan. Spacing between rootwads depends on their position relative to other structures. Rootwads are often used to complement other structures to increase the amount of bank protection provided by the complementary structure. Each rootwad revetment has two to four mature willow transplants with attached root masses placed around the point of stream-bank intersection. In some cases, rootwads from cottonwoods sprout from the buried stem. Additional plantings are also made to improve long-term natural bank stability. Complementary woody debris is added to the rootwad revetments to increase fish habitat and bank protection. High flow deflector logs are placed on each structure and tied approximately to the bankfull elevation.

Large-woody-debris jams

Large woody debris stabilizes stream banks (Buffington and Montgomery 1999; Bilby 1984) and provides aquatic habitat (Bryant and Sedell 1995; Bilby and Ward 1989). Large-woody-debris jams are constructed to mimic naturally occurring woody jams that typically form in the lower half of outside meander arcs. Natural jams accumulate over time as high water events overtop the lower portion of the meander, depositing wood on the floodplain. Large wood traps smaller materials, increasing the jam volume, vertically influencing the stream from the channel bed to the floodplain and creating diverse aquatic and overhead habitat for fish (**Shields** and Knight 2003), riparian habitat for mammals and birds (Dykaar and Wigington 2000), bank protection, fine sediment deposition areas (Shields et al. 2001; Piegay and Gurnell 1997), and protected growing sites (Abbe and Montgomery 1996; Malanson and Butler 1990).

In restoration projects, woody debris jams are constructed out of several large trees, various-sized rootwads, small diameter woody material, and large anchor rocks (NRCS 2001). The large trees are trenched into the bank and anchored with large rocks. Other woody material is interlaced among the large key trees to create a diverse array of woody material. Several rootwads and logs are extended out into the channel to diversify the local aquatic environment. Over time the jams are expected to grow in size as the jam captures other woody debris transported during high water (NRCS 2001).

Log and Rock Straight Vanes Straight vanes are built of log or rock (Johnson et al. 2001). Vanes tie into the bank at approximately the bankfull elevation and intersect the channel bed at a designed distance upstream. Local channel conditions and structure objectives determine the slope and length of the vane. Straight vanes function by deflecting the high velocity thalweg away from the stream bank, thereby decreasing the near-bank shear stress. Log vanes are generally preferred over rock vanes because they are more cost-effective to build. Log structures also look more natural in the aquatic environment and decay over time. Rock vanes are generally used when large logs are not available or where it is necessary to stabilize the at the specific site.

To improve the structure, stability, and length of protected bank, single rootwad or large-woody-debris jams are typically constructed in combination with vanes. Woody debris anchored upstream and downstream of the vane increases bank roughness and fish habitat. Additionally, a tree with an attached rootwad set at the bankfull elevation at the vane tie-in point increases the structural stability of the vane and reduces the potential for floodplain scour and the resultant structure flanking.

J-Hook Log and Rock Vanes J-hook vanes are similar to straight vanes except that a log or rock “J-hook” is added to the straight vane to further concentrate the thalweg. J-hook vanes are typically preferred over straight vanes for this reason. While providing protection for the local stream bank and channel, they also maintain sediment transport. J-hook vanes provide grade control and are also used to maintain extended pool lengths in meanders. Footer rocks are placed below the predicted scour depth to prevent undermining of the structure during high flows. Where possible, logs of sufficient size are used in place of large rocks. Log vanes are typically less expensive and easier to install than rock vanes, though they are not as permanent Like straight log and rock vanes, woody debris structures are used in combination with J-hook vanes to increase habitat diversity and to extend the length of bank protection. Similarly, a tree with an attached rootwad can be used to improve vane stability and floodplain integrity.

Revegetation-Intensive Bank Stabilization Treatments

Bank stabilization treatments must be tailored to meet the needs of the specific site. So-called hard fixes, such as rip-rap at bridge abutments, can be used on banks where any level of bank migration is unacceptable. A structure built in the vicinity of a grade-control or other structure in the channel would be designed to hold it in place until the river reach has sufficient vegetation and root stability to allow for natural channel migration. In significant, nonstructured zones of the river, such as banks adjacent to a riffle or run, planted vegetation is sufficient to stabilize the channel. Often, the plans are combined with a matrix, such as coir, to provide short-term stability until the roots can establish themselves.

Bankfull Benches

Benches of varying dimensions are constructed at the bankfull level of the stream channel where appropriate. They are then aggressively planted with sod, containerized plants, and/or cuttings. This speeds the reestablishment of the herbaceous and woody plant community in the near-bank zone and reduces bank erosion as the root mass establishes. Bankfull benches are particularly effective at restoring woody plant communities in reaches where channel incisement has occurred, but the new channel design will not reactivate and rewet the historical floodplain.

Sodding

The placement of sod on eroding and/or reconstructed banks can rapidly establish vegetation and reduce bank erosion. Sods can be salvaged from the site before construction or harvested from a "donor site" (the donor site must be seeded with appropriate species after removing the sod). In both instances, the depth of the root mass, species composition, and the presence of weedy or undesirable species, such as Kentucky bluegrass (*Poa pratensis*) and Dalmatian toadflax (*Linaria dalmatica*) must be considered. Upland sods can be used, but will generally need to be planted with riparian and wetland species like sedge (*Carex* spp.) and rush (*Juncus* spp.) seedlings. This allows the upland sod to control erosion over the short term. In time it will be replaced by the planted riparian-adapted species. In all cases, sods will be planted with a combination of woody plant species, either containerized or cuttings. In some high-shearstress applications, the sod may need to be covered with an erosion-control blanket, such as a heavy woven coir (coconut fiber) blanket.

Brush Mattresses
Installing high-density, erosion-control blankets may be costly for some sites, but where there is a ready source of large shrubs, logging slash, or other smalldiameter (less than two inches) woody material, brush mattresses can be installed on banks or in floodplain areas. Brush mattresses consist of a six-inch to twelveinch layer of six-foot-or-longer brush pieces placed on the soil, and anchored with stakes and/or ropes. This treatment can be applied to stream-bank and floodplain areas, and staked with live willow cuttings or wooden stakes. Some applications require cabling or roping across the top of the mattress. Brush mattress treatments determine the treatment area, the materials, and the application methods used.

Geotextile Soil Lifts
Geotextile soil lifts, also called fabric-encapsulated lifts or vegetated geogrids, can be installed to hold banks as vegetation reestablishes in areas where the banks of the river are dominated by finer materials such as soil and gravel. One or more soil levels, six to eighteen inches deep, are constructed in sequence, each stepped slightly back and faced with one or more layer of erosion control fabric. Seed is applied under the fabric, and the fabric is commonly made of woven coir. The fabric is keyed between each layer, and cuttings, stakes, and plants are installed to further anchor the structure.

Geotextile soil lift treatments will prescribe treatment area, materials, and installation methods.

Fascines
Fascines, also called wattles or fiber rolls, can stabilize the toe of a reconstructed bank. Fascines used for applications like those on the Jocko are typically constructed out of willow branches or coir. Coir fascines will need to be used on the Jocko River because they provide much greater shear resistance, decompose slowly, and revegetate better than willow wattles. One or more (stepped) fascines are anchored to the toe with stakes (live or dead) or, in high-shear-stress applications, with “earth anchors.” Rooted plants and/or cuttings are installed in and around the fascine to replace its mass with living root mass and deposited soil.

Coir rolls can also be pre-vegetated in the nursery with a custom suite of plant species, either seeded or planted. This product, when installed on the restoration site, provides virtually complete and immediate plant cover and it anchors to the substrate much more quickly than “raw” coir products because of the roots of the plants contained within it. This method is relatively expensive so is generally used for landscapes and other applications that require “instant gratification.”

Another variation in coir technology is coir pallets, or pillows, which are similar to coir fiber rolls except that they are flattened and thus cover more surface area. They do not handle the higher shear stresses that rolls can, but they work well on wetland and pond margins or on very low-flow streams. Coir pallets are most commonly prevegetated at the nursery and unrolled and staked down after the restoration site is regraded. They provide instant revegetation.

While it is unlikely that either of these two prevegetated coir methods will be used on the Jocko River, we mention them here as one more possible solution in the toolbox. If these strategies are used, specifications will include information on coir dimensions, density, netting type (material) and quality, plant species composition, and minimum coverage on the coir product surface, as well as site application, delivery and installation details.

Grade-control Structures

The location and type of grade-control structure depends on site-specific goals and reach characteristics. Specified structures need to effectively address bed stability, bank integrity, and fish habitat concerns.

In addition to satisfying fish passage and habitat needs, grade-control structures maintain the designed channelprofile elevations. Structures typically concentrate flows to the thalweg, or deepest portion of the channel. Focusing flows in this manner sustains a deeper low-flow water column, providing better aquatic habitat connectivity during late season base flows. Flow concentration is also beneficial during flood events when the structures facilitate flow convergence and sediment transport. Convergence and hydraulic head are influenced by vane arm gradient, angle of departure from the bank, and structure elevations. A steeper vane arm gradient results in greater hydraulic acceleration over the structure and through its scour pool. This acceleration is necessary to maintain sediment transport through the pool and subsequently the depth of the pool. The vane arm gradient and arm length also affect the degree of bank protection created by the grade-control structure. A longer, flatter vane arm protects over a greater distance of bank than a short, steep vane arm.

Rootwads and other large woody debris are typically incorporated into the grade-control structure to diversify pool habitat. Woody materials are anchored between or below vane arms. How the material is positioned influences vane hydraulics and pool scour, creating a range of aquatic habitats within the vicinity of the structure.

The structures maintain fish passage through the project reach. Fish passage is typically a concern during base flows when portions of the wetted channel may become disconnected if the stream bed is too wide and the water too shallow. Each grade-control structure is designed to have no more than one-half foot to one foot of distance from the structure throat to the water surface during base flows to ensure fish passage over the structure. Gaps between structure rocks also allow fish passage from the downstream pool through the structure. For the majority of the hydrograph, water depths over the vanes will be sufficient for all species and most age-classes to pass. Fish have been observed inhabiting feeding positions on the downstream sides of vane throats where the focused flow concentrates food items and cold water. During high flows, fish likely seek refuge in the deep, complex pools. Although vanes create hydraulic acceleration, water velocities are unlikely to exceed the burst swim speeds of most fish species given the short distance of vane influence.

The hydraulic drop created by the structures also appears to attract spawning salmonids. The hydraulic formed by the vertical distance between the upstream and downstream water surfaces increases the inter-gravel flow on the upstream side of the vane. Pool tailouts downstream of the structures are also attractive spawning areas for trout. The combination of optimal gravel sizes, the short distance to deep water, and enhanced inter-gravel flow make pool tailouts downstream from the structures optimal salmonids spawning areas.

Cross Vanes
Cross vanes provide long-term grade control in reconstructed stream channels. Natural channels maintain grade control through undulations in the bed profile (riffle-pool sequences). It is necessary to include a form of grade control in reconstructed channels because following construction, the channel materials (gravel, cobble, sand) are heterogeneous and disturbed. Cross vanes are built as log or rock structures in a fashion similar to the straight log and rock vanes. Constructed scour pools below cross vanes enhance fish habitat and maintain deepwater habitat for migratory and resident fish populations.

W-Weirs
The design of the W-weir is similar to the cross vane in that both sides are vanes directed from the approximate bankfull elevation upstream to a point where the vane intersects the channel bed. The W-weir divides the river into fourths, with the vane arms intersecting the bed at one-fourth and three-fourths of the channel width (Rosgen 2001). The center portion of the structure rises in the downstream direction to form a "W" looking from upstream to downstream. The multiple vane arms and center structure increase the number of flows paths, diversifying aquatic habitat around the structure. W-weirs maintain deep pools in a manner similar to the aforementioned vanes and cross vanes.

Cobble Tailout Structures
Natural stream channels sort and transport material in a way that provides for natural grade control. Where grade control is necessary and log or large rock structures will not work, channel materials are sorted during construction to generate material ranging from the D84 – D100 of the channel bed material (the largest material that is generally not transported during bankfull flows). The size material of the structure varies, but for the Jocko River it is generally cobble-sized rock ranging from about 4 to 8 inches in diameter. Additional materials may be imported depending on the availability of materials on-site. Materials will be placed in the designed bed profile, usually at the pool tailout locations to provide grade control at pool tailouts downstream of the grade-control structures. Cobble tailouts may also be used in lieu of cross-vanes where additional grade control is necessary.

The bankfull channel will convey approximately the 1.5-year to 1.8-year-flood flow events, while larger flows will access the adjacent floodplain. Bank stabilization, grade-control, and river-boating structures would benefit the resident and migratory fisheries by providing local habitat and enhancing spawning migration routes currently impaired by poor aquatic habitat conditions. The prescribed structures do not impede upstream or downstream fish migration for native and coldwater sport fish species.