Soil Bioengineering—An Erosion Prevention Technique Applicable to Low-Volume Roads

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Soil bioengineering is one of several new and innovative engineering practices being used on the FHWA Cumberland Gap tunnel project to prevent erosion and provide permanent stream bank protection. Four installations of soil bioengineering, using primarily sandbar and black willow cuttings, were constructed to provide stable and aesthetic creek bank protection and stream redirection for Little Yellow Creek in the Cumberland Gap National Historical Park. These four installations included a live boom (stream redirection), a brush mattress, live stakes, and joint planting. During the first 6 months, the dormant, primarily willow stems and trunks in all four installations sprouted new branches, leaves, and extensive roots that retained the soil and protected the banks in an effective and aesthetic manner. Over the next 2 years, the plant material weathered an officially recorded drought, insect attack, extreme heat and cold, and moderate flooding. Throughout these attacks, the plants showed remarkable resiliency and continued to expand vertically and horizontally both above and below the ground surface. After 3 years of growth, healthy plants up to 6 ft tall are maintaining aesthetic stream bank protection and their root system has stabilized the soil that makes up the stream bank slopes.

The Cumberland Gap tunnel project consists of twin, 4,600-ft-long, two-lane highway tunnels and portal buildings, eight roadway and two pedestrian bridges, 5 mi of four-lane divided highway, 3 mi of local two-lane and park roads, along with several miles of low-volume access roads and pedestrian walkways, including parking areas. The design and construction management is being done by the Eastern Federal Lands Highway Division (EFLHD) of FHWA headquartered in Sterling, Virginia, through their Cumberland Gap project office located in Middlesboro, Kentucky. The total project price tag is approaching $250 million and the work is broken down into about 25 separate contracts. The most current design and construction techniques and innovative engineering practices are being incorporated into the project by the EFLHD where the FHWA Demonstration Projects Division originated back in 1968. The project work is entirely in the Cumberland Gap National Historical Park, dictating maximum erosion control and pollution prevention compliance. The project includes a combination of complex high-volume road installations and basic low-volume road installations. All of the work has some, if not significant, application to low-volume roads, especially in the erosion prevention and stream bank protection area.

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Low-volume roads will be considered to be those that generally have the following cost-effective design and construction characteristics

- Maximum use of readily available and easily obtainable material,
- Can be built using conventional construction equipment, and
- Maximum constructibility with simple designs.

Soil bioengineering is a new and innovative erosion prevention technique successfully used in the construction of the Cumberland Gap tunnel project that meets the cost-effective low-volume road design and construction criteria. Its specific use was stream bank protection and stabilization to prevent bank erosion. Conventional stream bank protection and stabilization has generally been to heavily reinforce the stream banks with moderate to heavy, 100- to 300-lb maximum size, compact riprap. This usually tedious operation requires many pieces of equipment to haul and place large quantities of quarry rock in unstable marshy areas adjacent to creeks. It is often an expensive operation because of the length that suitable riprap rock may have to be hauled and the cost of developing and maintaining a stable access road. Once completed, the riprap protection is usually as strong as it ever will be because the soil beneath the riprap only generates scrub brush with little to no reinforcing root system.

A decision to proceed with four soil bioengineering installations was made by EFLHD in concurrence with the National Park Service after a series of studies, meetings, and assurances by the soil bioengineering consultants.

The innovative technology and environmental aspects of soil bioengineering seemed best suited to fulfill the requirements for aesthetic, permanent stream bank protection along Yellow Creek in the Cumberland Gap National Historical Park near Middlesboro, Kentucky.

The four soil bioengineering units were installed on a newly constructed stream bank along Yellow Creek by prime contractor Melco-Greer, Inc., under CGNHP Project 25E7 during the winter of 1987. Two of these depended entirely on soil bioengineering for stream bank protection and stabilization. The third involved a combination of soil bioengineering and riprap to produce a combination system. The fourth was a special structure that redirected the stream and protected the redirected structure. It also used a combination riprap and soil bioengineering system. All four units were less than 100 ft long and used various lengths of willow branches and trunks or a minimum Class 2 (100-lb-size) riprap. The 50-year design flow along Little Yellow Creek is 2,100 ft^3/sec.

Placed in layers in a mattress-like fashion along newly graded banks adjacent to Yellow Creek, a soil bioengineering unit comprised primarily of lengthy dormant willow branches and trunks termed a "brush mattress" was constructed as shown in Figure 1. Its purpose was to quickly provide vegetation capable of retaining critical soil along the bank on the west side of the creek. Once growth is established, the extensive network of willow roots should provide a soil retention cohesiveness that is both natural and living, growing stronger with each year's growth, potentially retaining more and more soil.

Advocates maintain that the brush mattress' continued growth ensures future soil retention qualities, in contrast to riprap, the other consistently used creek bank protection technique, which may be undermined as years pass.

The second unit incorporating soil bioengineering was a mound structure, termed a "live boom," and designated and constructed to redirect water flow away from vulnerable creek bank areas, as shown in Figure 2. The live boom is constructed from below the stream bed rising through the water and protruding several feet above the water, to a height capable of ensuring maximum water deflection to protect adjacent critical creek banks. This soil bioengineering unit was a time-intensive endeavor. Like most soil bioengineering units, it must be performed while the plants are dormant, usually after the first frost in the fall and before the sap rises in the spring.

A third unit of soil bioengineering constructed was termed a "live stake." A live stake is a dormant willow stake driven randomly on about 18- to 24-in. centers throughout the area designated to be live-staked. The live stake is about 2 ft long and ½ to 1½ in. in diameter. The cut or basal end of the

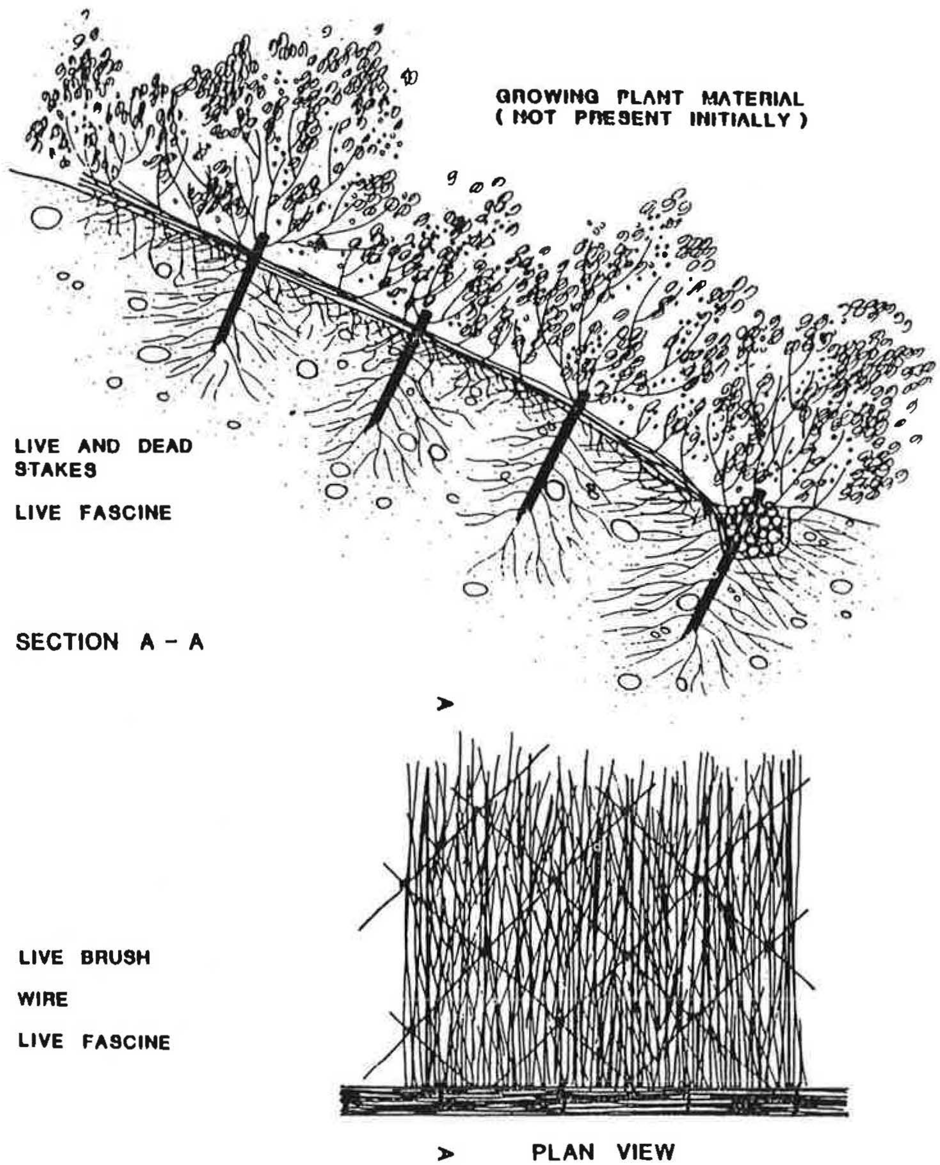

FIGURE 1 Brush mattress.

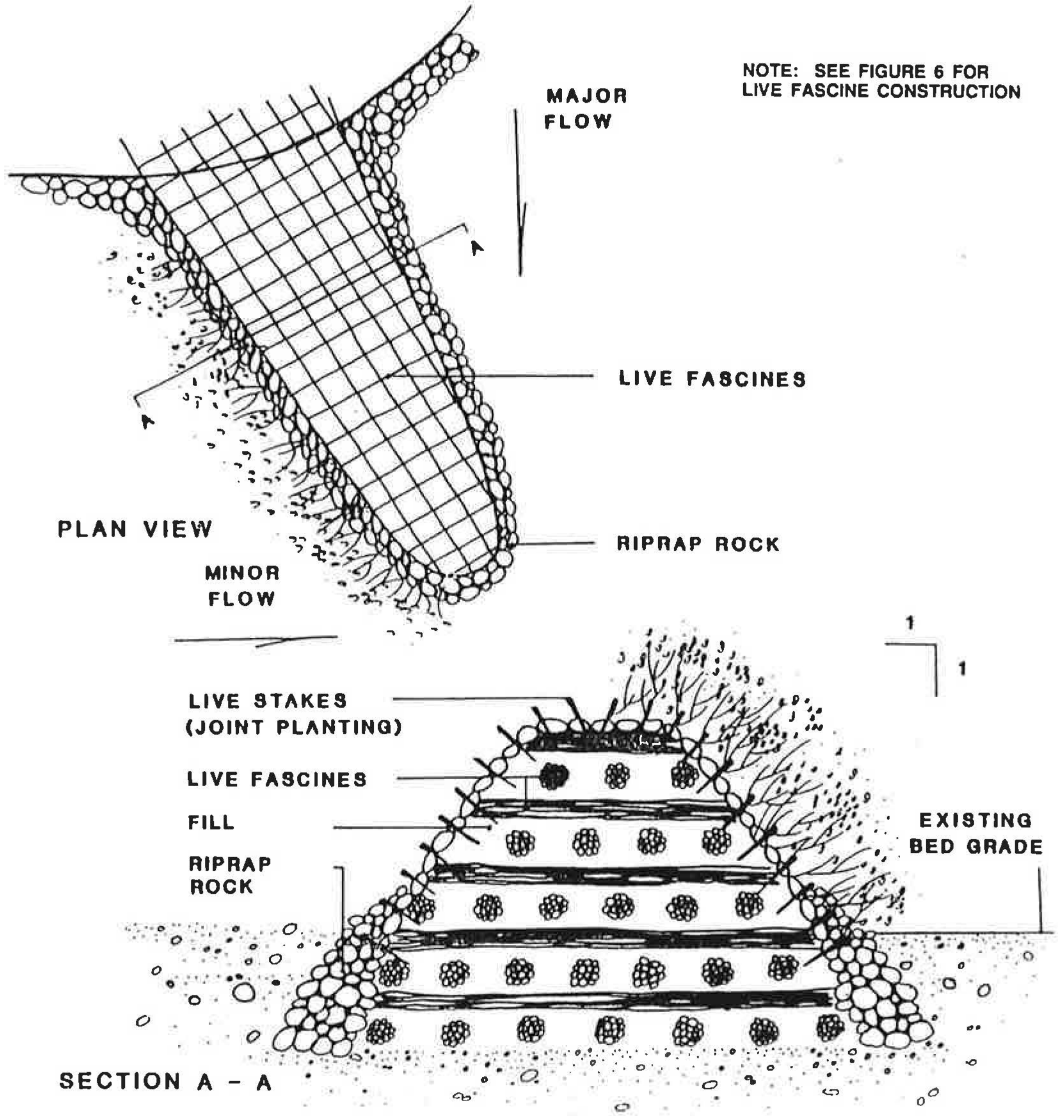

FIGURE 2 Live-boom construction.

stake, normally the rooted end, is driven into the ground, and if properly installed, will tie the bank soil together through an extensive network of below-ground-level roots and a prolific growth of above-ground-level leaves and branches as shown in Figure 3.

The fourth unit of soil bioengineering constructed is termed "joint planting." Joint planting is basically the placement of live stakes that are driven through a riprap layer to tie the underlying earth bank, surface riprap layer, and plants together in a living protective network as shown in Figure 4.

MATERIALS, EQUIPMENT, HANDLING, AND STORAGE

Materials used consisted of several rolls of hay baler twine; wire, similar to rebar tie wire used in concrete; hundreds of 2-ft × 2-in. × 4-in. diagonal wooden stout stakes (see Figure 5); hundreds of 2-ft live stakes consisting of 2-ft lengths of dormant willows ½ to 1½ in.; and 6- to 9-ft lengths of live, but dormant, primarily willow trunks and branches ½ to 1½ in. in diameter for making live fascine bundles and constructing brush mattresses. Ninety percent of the plants were sandbar or black willows. The remaining 10 percent were swamp poplar, common alder, and swamp dogwoods.

Equipment used consisted of the following: 2-ton, medium-duty, C60 Chevrolet flatbed truck; Caterpillar 235 track-mounted hydraulic excavator; three chain saws; five loping shears; three 3-lb impact-absorbing hammers; several sledgehammers; and 1 Homelite 3-in. water pump.

Two handling techniques, cutting and transportation, were used. Live but dormant plant material is cut and handled with care to avoid bark stripping and trunk wood splitting. Cuts are made 8 to 10 in. from the ground when cutting from the approved, natural growing, source sites. Cuts shall be made flat or at a blunt angle to ensure that the source sites will

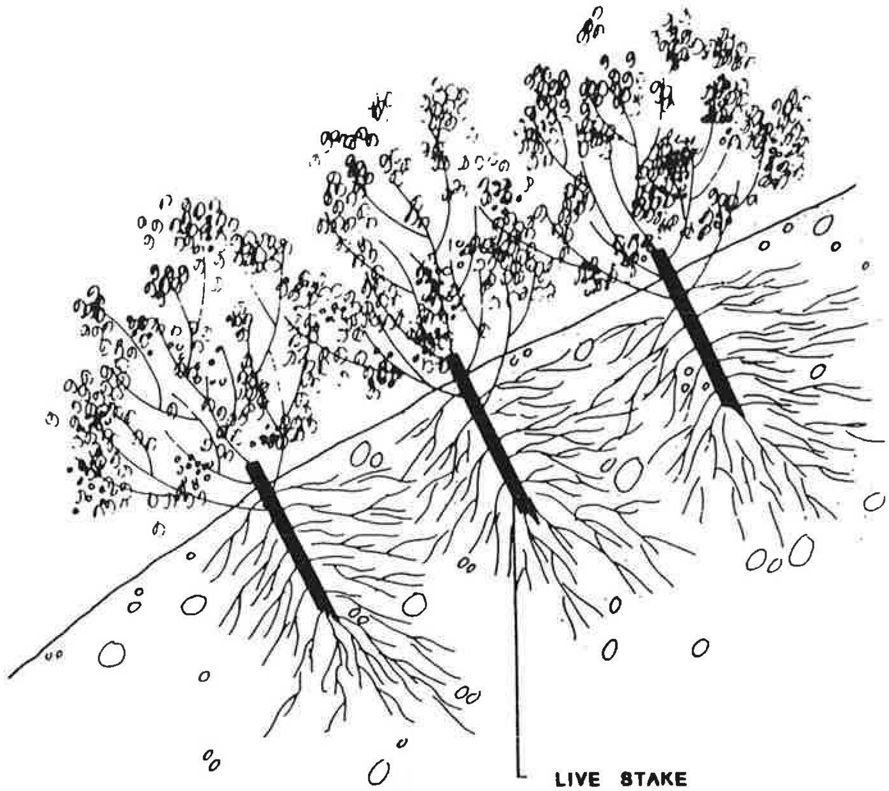

FIGURE 3 Live-stake construction.

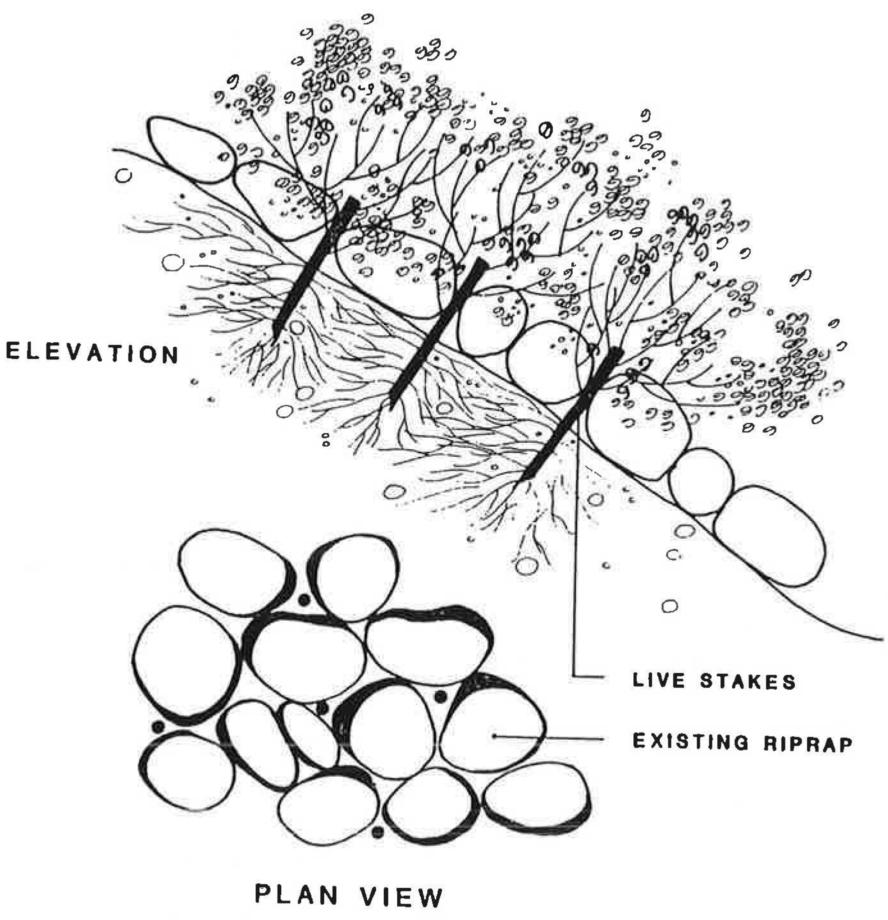

FIGURE 4 Joint planting.

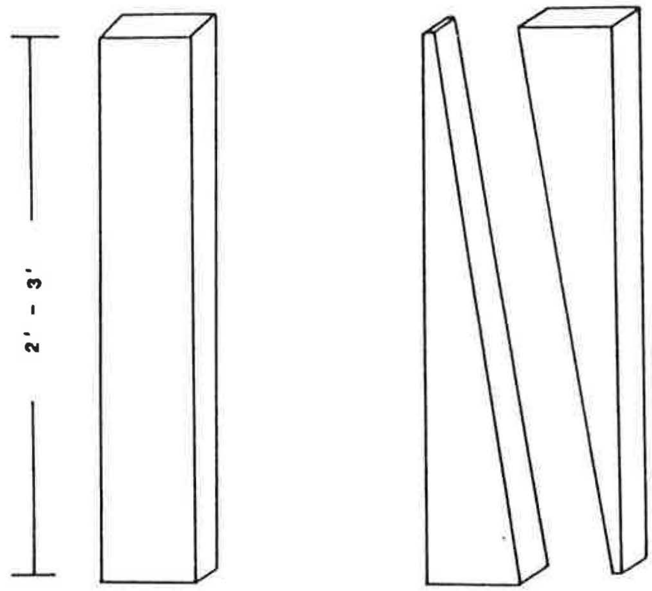

FIGURE 5 Stout stakes.

regenerate rapidly. During transportation, the live but dormant cut branch groups are placed on the transport vehicles in an orderly fashion to prevent damage and facilitate handling. The live but dormant cut plant materials shall be covered with a tarp or burlap material during transportation.

Plants not installed on the day of arrival at the job site shall be stored and protected. Outside storage locations shall be continually shaded and protected from the wind. Live but dormant cut-plant material shall be heeled-in in moist soils, or kept in water. Live but dormant cut materials shall be protected from drying at all times. When the temperature is 50°F or above, the live-cut branches shall not be stored but shall be planted on day of arrival. However, when the live-cut branches have been prepared in fabricated building lengths, such as for live-stake planting or similar uses, they shall be used that day. This prepared material may not be stored.

BRUSH MATTRESS CONSTRUCTION

During the stream channel construction, banks on the west side of Yellow Creek were realigned using 6-in. minus silty sand borrow material meeting AASHTO soil classification A–4 requirements, and were finished at a 2:1 slope. Except for areas reserved for brush mattress and live stakes, the slopes received a covering of polypropylene support (filter) fabric over which was applied a 2-ft layer of Class 2 (100-lb nominal size) limestone riprap near the outlet of a triple 10- × 10-ft reinforced concrete box culvert.

Before installation of the brush mattress, the slope receiving the brush mattress was raked and fertilized. Also, two trenches, approximately 8 ft apart and parallel to the stream, were dug to a depth of about 1 ft. Willow branch and trunk material called "live brush" were laid flat against the ground with the large cut (basal) end of the willow brush material pointing toward the creek with the smaller end pointing up the slope. The live brush material, spread evenly along the slope, was then wired to wood stakes driven on 2-ft centers to form a brush mattress. Wire was then interwoven in a zig-zag fashion and capable of holding the brush mattress closer to the ground. Sledge hammers were used for tamping the stout (nonliving) stakes deeper into the ground to ensure greater soil contact with the brush mattress and increasing the potential for quick willow growth.

Two long-life fascines, 6-in. diameter × 100-ft-long bundles, were dropped into the two previously dug trenches as shown in Figure 6. These bundles cover the cut ends of the willows along the bottom of the slope and along the middle of the slope, if two lengths of willows are used.

Afterward, this material was completely covered with topsoil, permitting a thin layer of exposure to facilitate the sun's ability to bring forth the willow growth. Small branch nodules from the cut willows lying against the soil become roots while branches facing the sun become stems. Good soil contact must exist to initiate and maintain growth. In fact, good soil contact must be maintained before completion of the brush mattress in accordance with the contract requirements. This is accomplished by uniformly tamping the topsoil, without damaging willows, to fill all voids and air pockets.

LIVE-BOOM CONSTRUCTION

The second phase of the soil bioengineering work encompassed the use of another living structure known as a "live

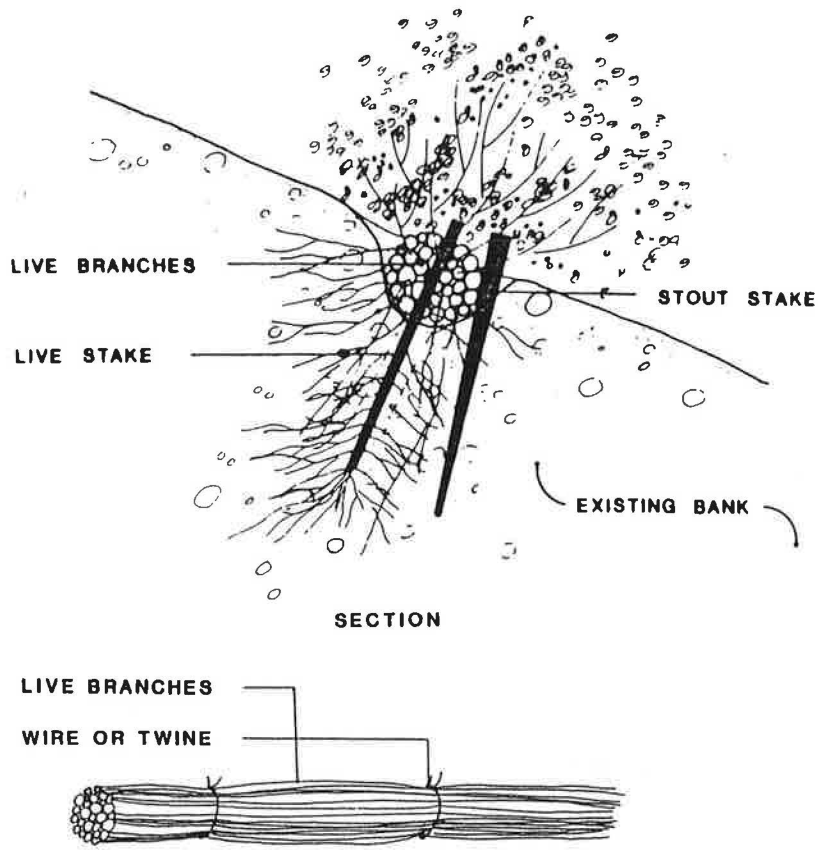

FIGURE 6 Live fascine bundle.

boom," shown in Figure 2, to effect stream redirection. The live boom begins as an area excavated within the stream bed and ends as a mound-like, triangular-shaped structure constructed of multiple layers of live but dormant willow material, termed "live fascines," similar to the ones used in the brush mattress. Each successive layer was covered with 6 in. of topsoil. However, that area below the creek was constructed using alternating layers of 6-in. maximum crusher run stone instead of soil, because the living material below the creek is not expected to grow, but merely deteriorate, providing additional plant food for living rooted material above.

The bullet-shaped live boom was constructed as an integral part of the surrounding creek bank in order to provide support to the live boom. The bullet-shaped structure was completed by driving live stakes in close proximity, on 1- to 2-ft centers, throughout the length of the live boom. Hand-placed riprap was used to armor the live boom to protect it from erosion until the willow population became established. Live stake and live fascine root growth will combine to create the live boom's soil erosion qualities. When heavy rains cause the creek to rise, the currents are deflected by the live boom while preventing erosion of critical creek bank areas. When it is not working to control the adverse effects of heavy stream flow and redirecting the stream, the live boom performs as an aesthetically pleasing ecological biome that becomes an integral part of its environment.

LIVE-STAKE CONSTRUCTION

An integral part of soil bioengineering is the use of cut primarily willow trunks and branches approximately ½ to 1½ in. in diameter and 2 ft long. These willow trunks are termed "live stakes." While still live but dormant, they are driven perpendicularly into the ground being live-staked. Live stakes are trimmed with an angled cut at the bottom or normally rooted end of the stake. The top of the stake is flat as a result of harvesting. Hence, the flat portion of the stake is tamped with an impact-absorbing hammer driving the stake deeply into the soil, exposing about 5 in. of the top portion of the stake. This unit was only used sparingly along the top portion of the creek bank to tie the brush mattress and joint planting units into the existing terrain.

If properly installed, when spring budding occurs and the sap is on the rise, the live stakes will grow into an extensive network of roots and branches. Because the live stakes are installed on about 18- to 24-in. centers throughout, growth should provide an aesthetically pleasing ground cover, as well as an interlocking network of roots.

JOINT PLANTING CONSTRUCTION

Joint planting is basically live staking, which is used in riprapped areas. This application is almost identical to live staking because it uses willows of the same diameter as live staking (½ to 1½ in.) with the length being increased by approximately the thickness of riprap. Also an iron rod with a diameter slightly smaller than the willow stake can be used to drive a pilot hole to be filled with a joint plant.

COST

The single live boom contract lump sum bid price was $2,000. However, the contractor maintains that being unfamiliar with labor-intensive soil bioengineering techniques and installation procedures, he used an unexpectedly large number of man-hours, which resulted in a huge (factor of 10+) cost and time overrun in the construction of the single live boom. It took several weeks to construct rather than the several days the contractor had estimated.

Approximately 400 yd^2 of brush mattress was constructed in a single day's time after the harvest of the willows requiring less time and manpower than expected. The contractor reported that the brush mattress cost less than the $20.00/$yd^2$ unit bid price that was based on an estimated quantity of 600 yd^2. However, on subsequently bid CGNHP Project 25E9, the average of seven contractor unit bid prices was $25.19/$yd^2$.

The joint planting was constructed at 2-ft centers throughout the riprap area. The contractor received his unit bid price of $15.00 for each of the approximately 3,500 joint stakes planted. The contractor readily admitted that this endeavor cost much less than the $15.00 each, unit bid price, that was based on an estimated quantity of 2,500. Approximately 100 joint plants were installed each single shift day. Subsequent CUGA Project 25E9 bid prices from seven contractors averaged $7.85 each, based on an estimated quantity of 1,700.

Live (dormant) stakes driven into designated areas along the top of the creek bank (not between riprap) were paid for at the unit bid price of $10.00 each, whereas their furnishing and placement cost much less. Live stakes and joint stakes are nearly identical, the only difference being that the live stakes are directly installed into the ground, whereas the joint plantings are installed into the ground through riprap layers. Approximately 100 live stakes were installed each single-shift day. Subsequent CUGA Project 25E9 unit bid prices from seven contractors averaged $6.88 each for the estimated quantity of 6,500.

CONCLUSION

In the Cumberland Gap National Historical Park, four installations of soil bioengineering using primarily willow cuttings were utilized to provide stable and aesthetic creek bank protection and stream redirection. These four included a live boom (stream redirection), a brush mattress, live stakes, and joint planting. During the first 6 months, the dormant (primarily) willows in all four installations vigorously grew from a dormant state to a flourishing vegetative system beginning to retain the soil and to protect the banks in an effective and aesthetic manner. Root systems were found to exceed the surface trunk and branch system. Over the next 2 years, the plants weathered an officially recorded drought, insect attack, extreme heat and cold, and recent high water. Throughout these attacks, the plant materials showed remarkable resiliency and continued to expand vertically and horizontally both above and below the ground surface. After 3 years of growth, healthy plant materials up to 6 ft tall are maintaining aesthetic stream bank protection while the root system has stabilized the soil that makes up the stream bank slopes.