Biotechnical engineering as an alternative to traditional engineering methods

A biotechnical streambank stabilization design approach

Ming-Han Li*, Karen E. Eddleman

Texas Transportation Institute, 3135 TAMUS, College Station, TX 77843-3135, USA

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Abstract

Focus on ecologically fragile streams in the US has resulted in heightened recognition and popularity of biotechnical streambank stabilization methods. This ancient technique re-emerges in the US in response to the link between traditional protection measures and numerous occurrences of streambank failures. The purpose of this study was to investigate biotechnical engineering as a viable alternative to traditional channelization and hard-armoring methods. Primarily by literature review, this study analyzed and organized various streambank stabilization approaches in traditional engineering, fluvial geomorphological, ecological and biotechnical engineering perspectives. Strengths and weaknesses in these four perspectives are discussed, suitable biotechnical alternatives are presented, and a cost-strength matrix of biotechnical techniques is introduced.

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1. Introduction

In the US, traditional streambank stabilization applications such as channelization and hard-armoring techniques have been preferred as best standardized practice. Channelization reduces the meander of a stream channel to minimize the natural erosion process. Hard-armoring methods, such as stone riprap, concrete pavement, rock gabions, bulkheads made of steel, concrete or aluminum, sack revetments, asphalt mixes, and jetties, reinforce streambank shear strength (Keown, 1983). Many governmental agencies favored stone or concrete riprap because over time, a high degree of precision and confidence in construction has developed from research and analysis. In engineering viewpoints, these methods have been successful for their immediate protection of properties or infrastructure adjacent to the stream after projects were completed.

What was thought successful in the past is being re-evaluated in context of impacts resulting from excessive and rapid urbanization, and public awareness of these new environmental issues. Increasing failures of traditional channelization and armoring methods are generating questions as to whether traditional practices are appropriate in every setting. One specific situation that almost always guarantees a failure is the use of hard armoring only around bridge abutments and streambanks, upstream and downstream of a bridge. Fig. 1 demonstrates an occurrence of failure...
resulting from this type of situation. Concern about traditional methods increased in the 1970s. The interest in natural techniques called biotechnical engineering was raised, and the benefits and advantages of biotechnical engineering were gradually re-examined (Riley, 1998).

An assessment of failures reveals that many natural stream components critical to ecological benefits are removed when channelization and hard armoring take place. Pools, riffles, point bars and flood plains critical to riparian and aquatic habitats are diminished or eliminated when streams are straightened (see Fig. 2). Straightening channels increases velocity, and hard armoring removes vegetation that can cool water temperature, all of which makes it difficult for fish to survive. Detailed consequences and impacts on stream biota were summarized by Simpson et al. (1982). Those impacts include loss of riparian habitat, reduced diversity, loss of fish habitat, influence on fish reproduction process, etc.

In addition to the loss of ecological benefits, traditional methods may transfer scouring and erosion problems to another area of the stream, rather than heal the entire stream. Traditional methods are typically “point-focused” solutions that concentrate on exact areas that exhibit problem symptoms. These methods attempt to isolate a stream’s form from its process with the use of channelization or hard
armoring. This method can conversely lead to violent interactions between form and process, such as excessive erosion and deposition. A stream’s dynamic equilibrium function is disrupted when traditional methods are used to force unnatural conditions on a stream and separate the stream’s physical form and the fluvial process. Channelization minimizes stream sinuosity and hard armoring reduces bank roughness, both of which eliminate a natural stream’s ability to dissipate flow energy, resulting in more serious erosion downstream.

The purpose of this study was to investigate biotechnical streambank stabilization as an alternative to traditional engineering practice. The objective was to identify biotechnical techniques that can complement traditional engineering method’s weaknesses, and evaluate such techniques in their applicable conditions, cost, strength and limitations.
2. Methods

2.1. Identification of strengths and weaknesses of various streambank stabilization approaches

A stream is a complex system. A holistic approach to stream problems that incorporates knowledge from multiple disciplines and identifies strengths and weaknesses from different perspectives can create better solutions (FISRWG, 1998). The authors reviewed disciplines such as hydraulic and geotechnical engineering, fluvial geomorphology, hydrology, biology, ecology, botany, and landscape architecture for their contributions to streambank stabilization practices. From this review, the authors organized the various methods and approaches into traditional engineering, fluvial geomorphology, ecology and biotechnical engineering perspectives.

2.2. Identification of suitable biotechnical streambank stabilization alternatives

Biotechnical techniques were evaluated for their applicability as alternatives to channelization and hard-armoring methods. Data of each technique’s applicable bank zones, strength, cost, construction timing, and property was collected. Techniques were selected which evidenced strengths with the potential to compensate for weaknesses of traditional methods.

2.3. Cost-strength analysis of biotechnical streambank stabilization techniques

Cost and strength data of biotechnical streambank stabilization techniques were transformed to a cost-strength matrix (Landphair and Li, 2001). This matrix is the first attempt to mitigate the disorderly and confusing cost information in the literature. Three levels of cost and strength categorized as low, medium and high, distinguish selected techniques. Details of the matrix are described in Section 3.4.4.

2.4. Documentation

Information and data collected were consolidated in a format that includes illustrations, figures and texts. This document can provide convenient knowledge of biotechnical techniques for professionals in research, training, education, or practice.

3. Results and discussion

3.1. Traditional engineering in streambank stabilization

Traditional methods employ conventional knowledge to secure a streambank. While this practice is workable and has, over time, become easy to reproduce, it has not proven to be the best solution. One primary goal of traditional channel design is to produce a stable channel, which means the channel never changes its plan form and cross-sections (Lane, 1954). The purpose of this goal is often to protect existing properties or infrastructure near streams. However, problems resulting from increased runoff due to urbanization cannot be solved.

Traditional engineering theories of stable channel design are: (1) maximum permissible velocity; (2) regime; and (3) tractive force, all of which are based on the same assumption of steady and uniform flow in straight channels (Chow, 1959). The problem with this assumption is that a natural stream usually meanders and is often characterized by unsteady, non-uniform flow. Due to the lack of a steady-state flow condition, the use of these assumptions for channel design is questionable.

In practice, a channelization project seeks to minimize the natural erosion process and reduce the meander of a stream channel. These projects require the installation of rock or concrete blocks in order to protect the channel bottom and its banks, and the construction of grade-control structures and energy dissipaters to diffuse the flow energy. This approach destroys the basic physical equilibrium of streams and has demonstrated numerous adverse physical and ecological impacts. Riley (1998) claimed that channelization projects reduce the changing rates in equilibrium cycles, and create uniform channel conditions, depths and velocities. No consideration is given to what secondary effect or impact this practice will have on the upstream and/or downstream areas. In the past, engineers have generally assumed that once the traditional methods were in place, the project was complete. Therefore, important follow-up evaluations are necessary.
were not emphasized. For the past several decades, many channelization projects failed and unfortunately there were few lessons learned because post-project evaluations were rarely performed.

Another popular method is to install concrete or stone riprap. Concrete riprap can be installed anywhere with little consideration of regional and site conditions. Stone riprap designs focus on specific stone and channel factors, including: stone shape, size, weight, durability, etc. (Biedenharn et al., 1997). Although favored and applied with comprehensive design recommendations, riprap stabilization is not necessarily guaranteed to succeed. Fig. 1 shows common riprap failures around bridge abutments. Installing riprap requires clearance of natural vegetation for construction and results in the loss of existing vegetative cover, a natural means of stream erosion control. Concrete riprap with a smooth surface is prone to accelerate stream flow, which causes erosion downstream. Although failure is always possible, Racin et al. (1996) observed that most (rippedraped) sites are not normally field evaluated after they are built. Consequently, there has been little investigation and even less documentation of a benefit to cost relationship. Despite this lack of documentation, its use was continued and promoted as economical given the lack of adequate alternatives (Simons and Associates, 1982).

While traditional methods are blamed for destroying the environment, many engineers consider the amount of information available on biotechnical stabilization techniques inadequate to promote its use. With low engineer confidence in using woody vegetation on streambanks, current engineering practices are monotonic with little consideration of environmental sensitivity. Fischenich (1997, p. 2) properly described this situation:

The inability of engineers to calculate the effect of most types of vegetation upon channel conveyance prevents the development of projects that include appropriate vegetation within the riparian zone for environmental benefits, while providing the adequate conveyance. Thus, current practice calls for designs that use monotypic grasses that offer little habitat or aesthetic value and require strict maintenance requirements to keep the project within the narrow confines of known conveyance parameters.

So while it may be accepted knowledge that traditional methods are ecologically damaging, engineers must make the decision to use what they can rely on as standardized practice in the interests of cost, benefit, safety and liability. Now more and more studies have contributed to the knowledge of vegetative erosion control. This knowledge helps develop guidance in biotechnical streambank stabilization.

3.2. Fluvial geomorphology in streambank stabilization

An unstable stream tends to migrate or meander laterally. Meandering is the result of erosion–deposition processes tending toward the most stable form (Langbein and Leopold, 1966). As such, the form of a stream is a function of on-going fluvial processes, namely, the flow and sediment erosion/transport/deposition (Leopold et al., 1964). Due to dramatic changes in runoff processes, increases in sediment yield, and intrusion of human settlement in floodplains, the magnitude and frequency of an urban channel’s peak flow can increase over time. As a result, in order for the form of a stream to accommodate the increased runoff process, the stream channel must enlarge, downcut (Schumm et al., 1984), and/or migrate laterally (Langbein and Leopold, 1966).

Fortunately, increased understanding of streams and rivers, obtained over the past 20 years, has advanced fluvial geomorphology as a tool for developing streambank stabilization recommendations. Many streambank stabilization projects have applied fluvial geomorphology (Turini-Smith, 1994; Kondolf and Micheli, 1995; Lagasse et al., 1995, 1997; USDA/NRCS, 1996; Biedenharn et al., 1997; Larson and McGill, 1997; Dutnell, 1998, 1999; FISRWG, 1998), but these projects are relatively recent. In order to gain recognition, these applications must be documented systematically to provide the evidence needed to ensure this practice achieves design goals.

A recent popular geomorphic approach in the US is the classification of streams. The stream classification system evolved from William Davis’s "The Geographical Cycle" (Davis, 1899) and is contemporarily promoted by David Rosgen, a professional hydrologist. The objectives of the system are to predict a river’s behavior from its appearance and extrapolate site-specific data to other streams with similar
characteristics. This is a first step in developing technical information for stream restoration design, but the use of the stream classification system needs additional development and guidance. The stream classification system is recommended by the National Research Council (1992) but its use is questioned by Kondolf (1995). According to Kondolf (2000), agency managers and non-geomorphological professionals adopted its use quickly because it seems fairly simple to apply. Yet, many projects that applied the stream classification system have experienced failures (Kondolf, 2000). This is a matter of great concern since it appears to be the misinterpretation of geomorphology and natural processes by inexperienced users. Careful planning and training for the use of the stream classification system must be imposed so that this system will not be negated by careless mistakes.

3.3. Ecological perspective in streambank stabilization

When the natural process conflicts with human interests, human solutions, be they functional and practical, usually modify nature’s process and can over time prove to be detrimental to the environment. According to Riley (1998), the most geographically widespread practices impacting the stream environments are channelization projects. Such practices rarely consider the impact on the ecological system but instead focus on:

- drainage for the reclamation of wetlands;
- flood control by enhancing channel capacity;
- navigation by enlarging channels;
- erosion control by hard-armoring channels.

Also according to Petts and Calow (1996), rivers in developed countries are intensively regulated and therefore, are hydraulically optimal but ecologically poor.

The principle of channelization, to reliably control the built stream environment, underscores the inverse relationship between traditional engineering approaches and thriving ecosystems. Destructive natural disturbances have the potential to damage designed structures at unpredictable magnitudes. In contrast, native biota adapts to periodic flood disturbances and even channel changes, thereby increasing the likelihood that streambanks will maintain their natural course (Petts and Calow, 1996; Kondolf, 2000). The ecosystems benefit from non-disastrous natural disturbances, which tend to produce the greatest species diversity (Connel, 1978; Pickett and White, 1985).

The use of riparian vegetation in streambank stabilization can be the catalyst for flourishing ecosystems as well as high public opinion because it advantageously impacts water quality, wildlife habitat, and aesthetic impression. As surface runoff reaches the streambank, the vegetation acts as a partial filter, removing the sediment and nutrients that would otherwise enter the stream without any form of treatment. Tree foliages create shade that helps maintain stream temperatures in ranges necessary for in-stream aquatic habitat. Aesthetically, the public will almost always favor vegetative cover over visually intrusive concrete or stone riprap (Binford and Buchenau, 1993; Thompson and Green, 1994).

3.4. Biotechnical engineering approach in streambank stabilization

3.4.1. Foundation literature and authors

The re-emergence of biotechnical streambank stabilization methods in the US has been fairly consistent without significant departure from what is generally accepted as effective technique. More than 100 English biotechnical engineering publications recognize four authors/publishers as the foundation of biotechnical stabilization research and practice: (1) Hugo Schiechtl (e.g. Schiechtl, 1980; Schiechtl and Stern, 1997); (2) Robbin Sotir (e.g. Gray and Sotir, 1996; Sotir and McCaffrey, 1997); (3) the US Army Corps of Engineers (USACE) (e.g. Fischenich, 2000; Allen and Leech, 1997); and (4) the US Department of Agriculture, Natural Resource Conservation Service (USDA/NRCS) (e.g. USDA/SCS, 1992; USDA/NRCS, 1996). The US biotechnical practice has a strong tie to the Europe tradition. In fact, the book entitled Bioengineering for Land Reclamation and Conservation and authored by Hugo Schiechtl (1980), a European practitioner, has become one of the most influential references in the US contemporary biotechnical practice. Almost all the American literature after 1980 has been directly or partially based on the foundation built by Schiechtl, most of which had cited Schiechtl’s works, including Brosius (1985), Greenway (1987), Stiles (1991), Turnin-Smith (1994), Gray and Sotir (1996), Riley (1998), Lewis (2000) and so on.
3.4.2. Fundamentals of biotechnical streambank stabilization

Biotechnical streambank stabilization methods accomplish stabilization goals that have been overlooked in traditional engineering practice. Ecologically, biotechnical methods offer a natural healing process (e.g., Gray and Sotir, 1996; Schiechtl and Stern, 1997) and maintain or even enhance the aesthetic value of a stream (Ree, 1949; Parsons, 1963; Schiechtl, 1980). In this respect, biotechnical applications are suitable alternatives to traditional practices. An application that offers environmental advantages certainly interests researchers. This benefit coupled with the physical vegetative coverage, achieves a level of sustainability and protection comparable to the engineering properties of several traditional applications. This form of stabilization is proving to be a suitable alternative to traditional methods.

The physical vegetative coverage on streambanks provides underground soil reinforcement and surface protection from scour. The level of vegetation for protecting the soil depends on the combined effects of roots, stems and foliage (Coppin and Richards, 1990). Root systems and streambank stabilization through soil-root interaction. Gray and Leiser (1982), Greenway (1987), Coppin and Richards (1990), Styczen and Morgan (1995), and Wu (1995) have developed theoretical models of root-reinforced soils. The mechanics of root-reinforcement are similar to the basic mechanics of engineering reinforced-earth systems (Coppin and Richards, 1990). Woody vegetation installed on slopes and streambanks provides resistance to shallow mass-movement by counterbalancing local instabilities. The primary stabilization mechanisms include (Gray and Sotir, 1996):

- reinforcing the soil with tensile fibers of the root mass;
- increasing shear strength by reducing pore-pressures through transpiration;
- anchoring the slope through deep root penetration into more stable strata.

Foliage and stems of shrubs and trees on streambanks can decrease flow velocities, and dissipate flow energy by redistributing the flow pattern and direction. Vegetation’s engineering properties reduce surface erosion, which can (Greenway, 1987; Coppin and Richards, 1990):

- intercept raindrops, prevent soil compaction and maintain infiltration;
- slow surface runoff;
- restrain soil particle detachment via shallow, dense root systems, consequently reducing sediment transport;
- delay soil saturation through transpiration.

In order to attain optimum stabilization, vegetation must establish quickly and solidly on streambanks. For biotechnical stabilization techniques that only use vegetative materials, the stabilization is vulnerable at the early stage but becomes stronger as the vegetation is established. For techniques that combine plant and inert materials, inert materials support major loads at the early stage. As the vegetation matures, root systems will bind soils, inert materials and vegetation altogether on the streambank, and increase the safety factor of structural protection (Biedenham et al., 1997).

From the engineering perspective, vegetation’s use on streambanks is not always ideal. Excessive foliage can lead to the reduction in channel capacity and a greater flood potential upstream. Trees planted on certain parts of levees may have roots undermining the levee stability (USACE, 1999). Greenway (1987), and Coppin and Richards (1990) have analyzed vegetation’s engineering functions and determined that its effects are both adverse and beneficial, depending on the circumstances. Therefore, it is important not to solve a streambank problem by employing a single perspective. Strengths and weaknesses of different design perspectives should complement each other in order to create the best solutions.

3.4.3. Classification

Biotechnical techniques can be classified according to their strength levels from low to intermediate and to high. They include: (1) low-strength surface protection such as hydroseeding; (2) intermediate surface treatments; (3) high strength bank and slope reinforcement. Schiechtl and Stern (1997) used “bank protection” and “bank stabilization” to differentiate biotechnical techniques, in which bank protection is mainly seeding, and bank stabilization techniques contain woody planting as well as combined applications of planting and artificial structures.
Another classification system is based on streambank zones with different relative elevations, inundation frequencies, and durations (Johnson and Stypula, 1993; Allen and Leech, 1997). Allen and Leech (1997) defined four different zones, as (see Fig. 3):

- **Toe zone**: The bank portion between the bed and average normal stage.
- **Splash zone**: The bank portion between normal high-water and normal low-water levels.
- **Bank zone**: The bank portion above the normal high-water level.
- **Terrace zone**: The bank inland from the bank zone.

Although these techniques are classified based on the strength level or streambank zones, they can be applied simultaneously. Combining different biotechnical techniques even with structural components (Henderson, 1986) is actually more effective than using any specific one alone. This is because a stream environment is often complex and has a wide range of needs in different zones. The example in Fig. 4 illustrates erosion control blankets with seeding and a biotechnical technique: live fascines installed together to enhance both riparian vegetation and surface erosion control.

### 3.4.4. Cost-strength matrix

An ideal tool for biotechnical streambank stabilization planning, is one that as concisely as possible presents summarized cost data, and concurrently indicates the reported strength achieved by a particular method in a particular cost range. This tool, developed by Landphair and Li (2001) and modified for this study as a cost-strength matrix, offers a streamlined path through the planning, selection and application processes. Cost and strength data from Gray and Sotir (1996), Allen and Leech (1997), Schiechtl and Stern (1997), and Gerstgraser (1999) were re-organized for the matrix. The matrix mitigates a common problem in the literature, that is, cost data is not organized in a consistent format.

Fig. 5 presents the cost-strength matrix. Both the X and Y axes are divided into three levels: low (L), medium (M), high (H). The location of the concentric circle indicates the cost-strength information for specific biotechnical methods, in which the dark circle is located approximately at the mean value, and the large circle covers most of the varied values in the literature. It should be noted that the strength of biotechnical methods enhances with time. For methods that have
much weaker strength at the early stage after completion, a gray concentric circle that indicates the early strength is shown. The units for “cost” and “strength” are US dollars per meter, and pascals (newtons per meter squared), respectively, with the relative values shown in the figure.

3.4.5. Twelve common biotechnical streambank stabilization techniques

Once a stream becomes unstable, streambank erosion is often severe and requires high-strength stabilization measures. To address the need of streambank stabilization, the techniques presented in Table 1 focus on bank stabilization techniques stronger than hydroseeding. Twelve biotechnical streambank stabilization techniques are identified. They are:

1. live stakes;
2. live fascines;
3. brush layering;
4. branchpacking;
5. vegetated geogrids;
6. live cribwall;
7. joint planting;
8. brushmattress;
9. tree revetment;
10. root wad;
11. dormant post-plantings;
12. coconut fiber rolls.


3.4.6. A vegetated geogrids technique example

A four-layer vegetated geogrids under construction is shown in Fig. 6(a). The vegetated geogrids were installed to build a roadway embankment, and simultaneously protect the embankment (i.e. a streambank) from erosion. The construction of the vegetated geogrids was completed in February 2001. Five months later, cuttings on the streambank showed significant growth (see Fig. 6(b)).

3.5. Post-project evaluation

3.5.1. Monitoring criteria

As mentioned in Section 3.1, the lack of post-project evaluation has been a common problem in channelization projects. The same negligence of post-project evaluations evidenced in channelization projects also holds true for stream restoration and streambank stabilization projects (Kondolf, 1995; Kondolf and Micheli, 1995; Kondolf, 1998). This may be due to the difficulties in measuring variables of the complex stream environment, and unwillingness to fund monitoring activities by most agencies (Kondolf, 1995). If researchers seek to avoid repeating the same mistakes and understand how streams respond to stabilization actions, projects must be monitored after they are completed. Kondolf and Micheli (1995) presented a thorough discussion on the evaluation criteria for different project objectives. For the objective of streambank stabilization, they suggested collecting the following data for at least 10 years to monitor a project:

- channel cross-sections;
- water surface elevations;
- channel width-to-depth ratio;
- streambank and bed erosion rates
- longitudinal profile;
- aerial photos.

In addition to the above data, a biotechnical project that uses live cuttings or posts should be monitored for plant growth because the survival of planted cuttings or posts is correlated to the success of a biotechnical project. In fact, data on plant survival and growth has been the most commonly used parameters to measure project success (Manci, 1989). Rainfall and temperature data should also be collected because weather affects plant growth.
Table 1
Overview of bank stabilization techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
<th>Cost/Strength Matrix</th>
<th>Applied Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live Stakes</td>
<td>Live, re-usable woody cuttings inserted and tamped directly into soil. Root system bonds soil together; foliage helps reduce flow energy.</td>
<td><img src="image1" alt="Cost/Strength Matrix" /></td>
<td><img src="image2" alt="Applied Zones" /></td>
</tr>
<tr>
<td><strong>Application and Properties:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Most effective when used on small, simple problem sites.</td>
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<td>- Suitable for streambanks with gentle slopes.</td>
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<tr>
<td>- Enhance performance of surface erosion control materials such as rolled erosion control products (RECPs).</td>
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<tr>
<td>- Stabilize transitional areas between different biotechnical techniques.</td>
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<tr>
<td>- Inexpensive.</td>
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<tr>
<td>Live Fascines</td>
<td>Live cuttings tied together in linear cylindrical bundles. Installed in shallow trenches that normally match contours.</td>
<td><img src="image3" alt="Cost/Strength Matrix" /></td>
<td><img src="image4" alt="Applied Zones" /></td>
</tr>
<tr>
<td><strong>Application and Properties:</strong></td>
<td></td>
<td></td>
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<tr>
<td>- Terrace and check dam-like structures break up slope length and reduce sheet flow velocity.</td>
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<tr>
<td>- Protect slopes from shallow slide failures (1 to 2 feet in depth).</td>
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<tr>
<td>- Effective on gentle slopes (less than 33%).</td>
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<tr>
<td>- Cause little site disturbance if installed properly.</td>
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<tr>
<td>- Other techniques such as live staking, post plants and RECPs can be easily applied together.</td>
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<tr>
<td>Brushlaying</td>
<td>Live cuttings installed into streambanks between layers of soil in crisscross or overlapping pattern.</td>
<td><img src="image5" alt="Cost/Strength Matrix" /></td>
<td><img src="image6" alt="Applied Zones" /></td>
</tr>
<tr>
<td><strong>Application and Properties:</strong></td>
<td></td>
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<tr>
<td>- Live cuttings protruding beyond the face of the streambank increase the hydraulic roughness which reduces runoff velocity.</td>
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<tr>
<td>- Layers of live cuttings filter sediment out of the slope runoff.</td>
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<tr>
<td>- Stabilize slopes against shallow sliding.</td>
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<tr>
<td>- Cuttings installed inside the streambanks reinforce slopes by the root-stem-soil structure.</td>
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<tr>
<td>- Preferred on fill rather than cut slopes.</td>
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</tbody>
</table>
Table 1 (Continued)

**Branching**

Brushlayering with wood staking and compacted backfill, used to repair small slumps and holes in streambanks.

Cost/Strength Matrix:

<table>
<thead>
<tr>
<th>Strength</th>
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<tbody>
<tr>
<td>High</td>
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<tr>
<td>Medium</td>
</tr>
<tr>
<td>Low</td>
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</tbody>
</table>

Application and Properties:
- Effective and inexpensive method to repair holes in streambanks that range from 0.75 to 1.5 meters in height and depth.
- Provides immediate soil reinforcement.
- Not effective in slump areas greater than 1.5 meters deep or 1.5 meters wide.

**Vegetated Geogrids**

Brushlayering incorporated with natural or synthetic geotextiles wrapped around each soil lift between the layers of live cuttings.

Cost/Strength Matrix:

<table>
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<tr>
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<tbody>
<tr>
<td>High</td>
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<tr>
<td>Medium</td>
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<tr>
<td>Low</td>
</tr>
</tbody>
</table>

Applied Zones:

- High
- Medium
- Low

Application and Properties:
- High strength technique that stabilizes steep slopes up to 1:1.
- The system must be built during low flow conditions.
- Labor intensive; can be complex and expensive.
- Useful in restoring outside bends where erosion is a problem.
- Capture sediments, which rapidly rebuilds to further stabilize the toe of the streambank.
- Provide immediate stabilization without vegetation growth.

**Live Cribwall**

Box-like interlocking arrangement of untreated log or timber members. Structure is filled with suitable backfill material and layers of live cuttings that root inside the crib structure and extend into the slope.

Cost/Strength Matrix:

<table>
<thead>
<tr>
<th>Strength</th>
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<tbody>
<tr>
<td>High</td>
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<tr>
<td>Medium</td>
</tr>
<tr>
<td>Low</td>
</tr>
</tbody>
</table>

Applied Zones:

- High
- Medium
- Low

Application and Properties:
- Effective on outside bends of streams where high strength is needed.
- Appropriate at the base of a slope as a toe protection.
- Effective where a steep slope face is needed and a more vertical structure is required.
- Maintains a natural appearance and provides excellent habitats.
- Provides immediate protection from erosion, while established vegetation provides long-term stability.
- Has to be battered if the system is built on a smooth, evenly sloped surface.
- Can be complex and expensive.
Table 1 (Continued)

**Joint Planting**

Rock ripraps with live stakes tamped into joints or openings between rocks.

Application and Properties:
- Enhance aesthetics of existing rock ripraps.
- Provide better habitats than riprap alone.
- Improve the strength of ripraps alone.
- Provides immediate protection and is effective in reducing erosion on actively eroding banks.
- Many available design guidelines because the riprap is widely used.

**Brushmatress**

Live cuttings installed with branches parallel to the slope direction to form a mattress. Cut ends of live cuttings keyed into the toe protection at the slope bottom.

Application and Properties:
- Provide immediate but low-strength protection on streambanks.
- Effective on streambanks with steepness less than 50 percent.
- Captures sediment during floods.
- Rapidly restores riparian vegetation and streamside habitat.

**Tree Revetment**

A series of whole, dead trees cabled together and anchored by earth anchors in the streambank.

Application and Properties:
- Semi-permanent; has a limited life.
- Uses inexpensive, readily available materials.
- May require periodic maintenance to replace damaged or deteriorating trees.
- Has self-repairing abilities following damage after flood events if used in combination with biotechnical techniques.
- Should be used in combination with other biotechnical techniques.
- Not appropriate near bridges or other structures where downstream damage is possible if the revetment dislodges during flood events.
Table 1 (Continued)

<table>
<thead>
<tr>
<th>Log and Rootwad Revetment</th>
<th>(Rootwad is shown below.)</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logs and rootwad systems anchored on streambanks that provide wildlife and fish habitats.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Application and Properties:**
- Have limited life depending on climate and tree species used.
- Create instream structures for improved fish habitat.
- Effective on meandering streams with out-of-bank flow conditions.
- Sustain high shear stress if logs and rootwads are well anchored.
- Should be used in combination with other biotechnical techniques.
- Enhance diversity of riparian corridor.

**Applied Zones:**

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**Dormant Post Plantings**

Woody live posts planted along streambanks in a square or triangular pattern.

**Application and Properties:**
- Enhance conditions for colonization of native species.
- Self-repairing, damaged posts can develop multiple stems.
- Can be used in combination with other biotechnical techniques.
- Posts protruding out of streambanks can deflect higher streamflows and trapping sediment.
- Well-suited to smaller, non-gravelly streams where ice damage is not a problem.

**Cost/Strength Matrix:**

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**Coconut Fiber Rolls**

Coconut bark fibers bound together with twine woven from coconut to form a cylindrical structure. Installed at the toe of the slope, generally at the stream-forming flow stage.

**Application and Properties:**
- Trap sediment that encourages plant growth within the fiber roll and provides toe protection.
- Flexible; can mold to existing curvature of streambank.
- Produce a well-reinforced streambank with little site disturbance.
- Prefabricated materials can be expensive.
- Should be used in combination with other biotechnical techniques.

**Cost/Strength Matrix:**

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Fig. 6. A vegetated geogrids example.

(a) construction of four layers of vegetated geogrids

(b) five months after construction

Fig. 6. A vegetated geogrids example.
3.5.2. Indicators of possible failures and common failure modes

Biotechnical methods risk failure as do all engineering applications. An exact cause of failure is difficult to assign in a biotechnical streambank stabilization project because current knowledge of vegetative properties are still limited. The fluvial process interacting with vegetation further complicates the stabilization mechanism of a biotechnical project. Sources that documented failure cited the following causes:

- selection of unsuitable species (Schiechtl, 1980);
- flood–large enough to wash out project before root system established and stabilized bank (Allen and Leech, 1997);
- drought–inadequate rainfall during plant establishment (Schaefer and Naeth, 2000);
- soil conditions unsuitable for plantings to root and grow (Gray and Sotir, 1996);
- soil moisture extraction and other hydrologic effects of woody vegetation not taken into account when bank stabilized (Gray and Sotir, 1996);
- failure of structural materials (Gray and Sotir, 1996);
- inadequate site preparation, grading and drainage control (Gray and Sotir, 1996);
- livestock grazing (Allen and Leech, 1997);
- insect infestation (USDA/SCS, 1992);
- plant disease (USDA/NRCS, 1996).

Despite the difficulty of identifying the actual failure cause, the following phenomena, when observed during monitoring, can be indicators of possible failures:

- erosion at the toe of the underwater slope, leading to failure of the overlying bank;
- erosion of the soil along the banks, caused by currents;
- sloughing of saturated cohesive banks incapable of free drainage;
- flow slides (liquefaction) in saturated silty and sandy soil;
- erosion of soil by groundwater seepage out of the bank;
- erosion of the upper bank or the river bottom due to wave action;
- freeze-thaw action;
- abrasion by ice and debris;
- shrinking and swelling of clays.

Unlike a stream stabilized with traditional methods, streambanks that show the above symptoms can be economically repaired and further erosion prevented. Coincidently, an applicable and cost-effective measure used to repair those problems is a biotechnical method such as live stakes and joint planting.

3.6. Limitations of biotechnical streambank stabilization

While it is vegetation that makes biotechnical methods a viable streambank stabilization option, it is ironically, working with vegetation that seems to pose the most difficulty on a biotechnical project. Ultimately the stabilization mechanism of biotechnical methods relies upon the establishment of live materials. Schiechtl and Stern (1997) grouped biotechnical project limitations resulting from the use of vegetation into three general categories: (1) biological; (2) technical; (3) time limits. Similarly, the authors found that vegetation has hindered or potentially can hinder a stabilization project in the following ways:

- Limited habitats of certain aquatic plants raise doubts as to their ability to reproduce.
- Biotechnical methods require time to reach full strength, in contrast to traditional methods that reach designed intensity soon after completion.
- The dormancy requirement of live cutting techniques makes the biotechnical methods in warm regions with short, rainy winters very difficult.
- Short growing seasons in certain regions can negatively affect establishment and strength.
- Construction for biotechnical methods is restricted to dormant periods or growing seasons depending on the selection of vegetation. Seeding is mostly performed in growing seasons, and woody live cuttings planted during dormant periods. For catastrophic failures that need instant repair, biotechnical methods may not be applicable. For streams that are frequently inundated during plants’ dormant periods, it is difficult to implement biotechnical methods.
- Streambanks with excessive flow velocity and turbulence require very high shear strength that biotechnical methods may not provide.
- With limited technical design guidelines, even well executed vegetative protection may not achieve the
same degree of confidence or offer as high a safety factor as structural protection.

- Warmer regions utilize biotechnical methods less than the climatic counterpart, so fewer qualified contractors will be available in these areas.

It is obvious that the problem of streambank stabilization has no universal solution. Fortunately, weaknesses in biotechnical engineering can be supplemented by traditional methods, and vice versa. Limitations of biotechnical engineering should not preclude the consideration or use of these methods for a streambank stabilization project. On the contrary, the constraints presented here stress the importance of the appropriate application of biotechnical engineering as an alternative to traditional methods.

4. Conclusion

Measuring the success of a streambank stabilization project is an obscure task at best. In the context of traditional streambank stabilization methods, success is achieved through a singular emphasis on controlling the stream. Where we’ve tried to exert control without understanding the mechanisms at work, detrimental effects have manifested themselves in costly repairs, retrofitting projects, and erosion occurring elsewhere on the stream. Fluvial geomorphology shows promise and improvement over traditional stabilization practices by incorporating stream behavior into stabilization design. It also fits well with biotechnical engineering’s holistic and cross-discipline approach. With the help of past mistakes and current learning, biotechnical methods can offer ecologically focused alternatives to traditional practice.

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References


Johnson, A.W., Stepp, J.M. (Eds.). 1993. Guidelines for Bank Stabilization Projects in the Riverine Environments of King County (Draft). Surface Water Management Division, King County Department of Public Works, Seattle, WA.


Ming-Han Li is an Associate Transportation Researcher for the Environmental Management Program of the Texas Transportation Institute (TTI). He has a multi-disciplinary education background, including a BS in agricultural engineering from National Taiwan University, an MS in civil engineering from the University of Texas, Austin and an MLA from Texas A&M University. Mr. Li’s research interests are in biotechnical engineering, hydraulics, hydrology and landscape ecology. Mr. Li is also a Lecturer in the Department of Landscape Architecture and Urban Planning at Texas A&M University.

Karen E. Eddleman is a Research Associate for the Environmental Management Program of TTI. She holds a BA in English from Texas A&M University. Ms. Eddleman’s training in research techniques, technical writing, and technical editing enables her to contribute a broad range of skills to the research efforts undertaken by the Environmental Management Program of TTI. In addition to streambank stabilization, Ms. Eddleman has research experience in stormwater quality, erosion control, the public participation process for highway projects, and other areas related to the environment.