STRUCTURAL BIOENGINEERING TECHNIQUES FOR RIVERBANK EROSION CONTROL

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Abstract. Streambank protections are precautions taken against the erosion of both water flow and moving ice. The use of various structures and the subsequent development of vegetation emphasize the strong suits of both parts – the strength of the structure (limited in time) and the flexibility of the vegetation (long lasting). In order for this system to work, it is necessary that the artificial structure holds long enough for the vegetation to take up the main role. This material describes the minimum conditions that need to be attained for the development of crib walls associated with vegetation for the protection of mountain streambanks.

Keywords: *streambank soil bioengineering, crib wall, forming discharge, bankfull discharge*

1. Introduction

The term **"***Streambank Soil Bioengineering***"** has been used to refer to a large number of techniques. There are many definitions of Streambank Soil Bioengineering in the specialized literature but all of them basically define the category by the material that is used in the techniques. The definition of Streambank Soil Bioengineering that is used in the recently released NEH 654 (USDA, 2007) is as follows: *Streambank soil bioengineering is defined as the use of living and nonliving plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, and vegetative establishment.*

One of the benefits of biological engineering compared to structural engineering (Evette et all, 2009) is its capacity to increase its resistance over time, because plants that form part of these structures (as stakes, layering, plantings, etc.) grow and spread over the soil that they are holding in place. This process provides long-term protection, which is capable of self-regeneration. If the vegetation dies, the protection does not last long, and costly repairs are then necessary. By combining these biological and structural elements, the streambank is immediately protected (due to the strength of the structure) while the protection itself is long-lasting due to the limitless growth potential of the vegetation.

Vegetation, per se, is not a panacea for controlling erosion and must be considered in light of site-specific characteristics (Allen, Leech 1997). When vegetation is combined with low-cost building materials or engineered structures, numerous techniques can be created for streambank erosion control.

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Advantages of using planted vegetation (Allen, Leech 1997)
There are five mechanisms through which vegetation can aid erosion control:

- reinforce soil;
- dissipate wave energy;
- intercept water;
- enhance water infiltration;
- deplete soil water by uptake and transpiration.

Vegetation can protect streambanks in four specific ways. First the root system helps hold the soil together and increases the overall bank stability by its binding network structure, i.e., the ability of roots to hold soil particles together. Second, the exposed vegetation (stalks, stems, branches, and foliage) can increase the resistance to flow and reduce the local flow velocities, causing the flow to dissipate energy against the deforming plant rather than the soil. Third, the vegetation acts as a buffer against the abrasive effect of transported materials. Fourth, close-growing vegetation can induce sediment deposition by causing zones of slow velocity and low shear stress near the bank, allowing coarse sediments to deposit. Vegetation is also often less expensive than most structural methods; it improves the conditions for fisheries and wildlife, improves water quality, and can protect cultural/archeological resources.

Using planted vegetation for streambank erosion control also has limitations. (Allen, Leech 1997) These may include its occasional failure to grow; it is subject to undermining; it may be uprooted by wind, water, and the freezing and thawing of ice; wildlife or livestock may feed upon and depredate it; and it may require some maintenance. Most of these limitations, such as undermining, uprooting by freezing and thawing, etc., can often be lessened or prevented by use of bioengineering measures.

Live cribwall—A live cribwall consists of a boxlike interlocking arrangement of untreated log or timber members(USDA 1996). (fig. 1).

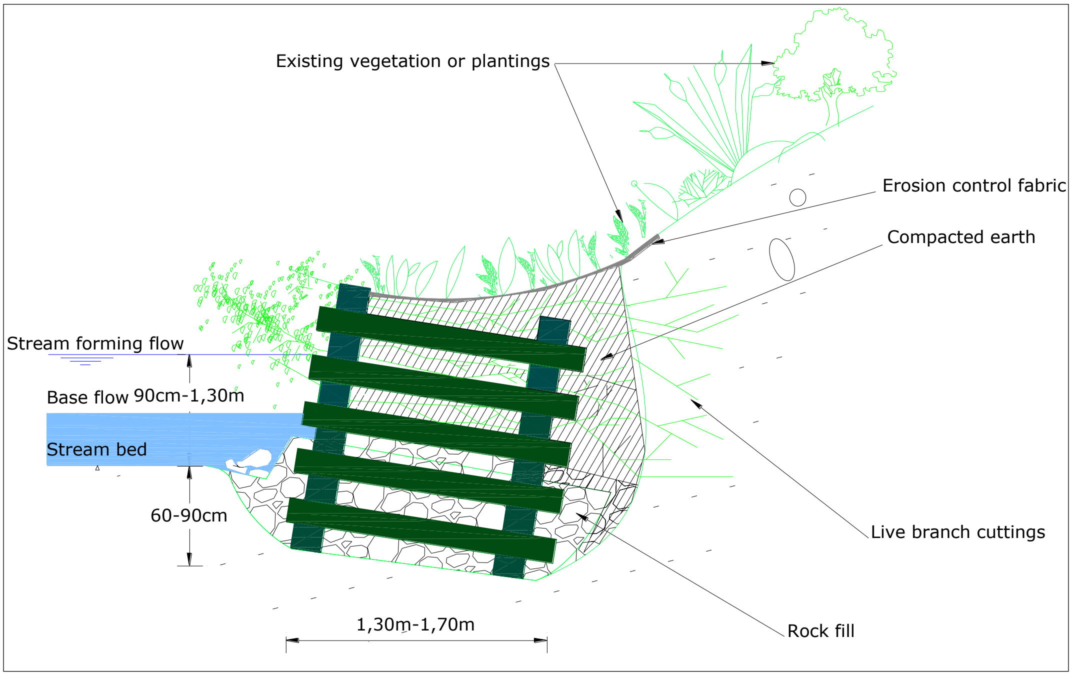

Figure 1: Live crib wall cross section

The structure is filled with suitable backfill material and layers of live branch cuttings that root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members

2. Crib wall using in Romania

In Romanian specialized literature (Manoliu 1973, Baloiu 1980, Hancu 2008), crib walls are box shaped structures made out of logs. After the initial structure is built, it is filled with river rock, crushed stone, ballast or sometimes even soil. The cribs walls can be either solid or have small gaps if the wood beams are place one on top of each other without prior processing (fig. 2).

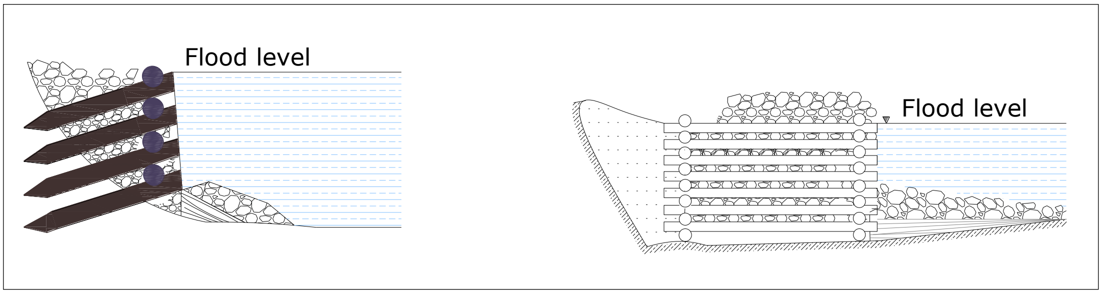

Figure 2: Crib wall cross section

Design normative (GE-027-97; NP 067-02) have adopted these concepts and contain guidance provisions regarding the execution of these structures (crib wall). However, they contain no specifications regarding foundation depths, crib fillings, life span or the use of vegetation. These types of works have only recently restarted to be used in Romania (2000). In the past decade, especially after 2005, this system has been used particularly in mountain regions (due to easy access to wood). A series of these cribs have been built on Moldovita river (fig. 3; 4; 5)

Figure 3: Crib wall bank protection on Moldovita river in straight zone

Figure 4: Crib wall bank protection on Moldovita river in bend zone

Figure 5: Crib wall bank filling with river ballast

As the previous pictures show, the concern to entwine the crib walls with vegetation is absent. Because of this, once the logs decay (roughly 8-10 years), the system becomes vulnerable.

3. Live crib wall dimensioning

It is necessary that crib walls done along river banks have a greater life span that the wood logs that make them up. In order to achieve this, three conditions must be met:

a) the width of the resulting riverbed must be big enough to ensure the safe passage of flood flows

b) the size of the structure itself, as well as its installation parameters (foundation depth, bank stability, etc) must consider potential flood parameters

c) vegetation planted in the structure must be done so that is may achieve maturity before the logs decay

Determining riverbed width

The riverbed shape is determined by the maximum water flow levels, since these have enough energy to reshape the banks and thalweg. However, these levels occur with reduced frequency. In order for significant changes to take place, the frequency needs to reach certain levels as well. The channel-forming discharge concept takes into account both intensity and frequency.

In the minor riverbed, instability is not present during low water levels, only when water levels are high enough to reshape it. Often times, the minor riverbed is left changed once flood waters regress. The channel-forming discharge concept is the lowest water discharge level at which these changes can occur.

In essence, the channel-forming discharge is a synthetic value, since it factors the effects of flood waters as a whole. Changing high water discharge conditions has effects on the channel-forming discharge values, in the way that various flood attenuation installations may indirectly increase a stream's stability, whereas damming may destabilize otherwise stabile streams. (Aurel C Ilie 2007)

The channel-forming discharge concept (USDA 2007, cap 5) is based on the idea that, for a given alluvial channel, a single steady discharge exists and that, given enough time, it would produce channel dimensions equivalent to those produced by the natural hydrograph. This discharge is thought to dominate channel form and process. Estimates of channel-forming discharges are used to classify stream types, estimate channel dimensions, assess stability, and express hydraulic geometry relationships. While many techniques and methodologies are used to estimate a channel-forming discharge in stable alluvial channels, all can be characterized as one of four main types. These are:
• discharge based on bankfull indices
• discharge based on drainage area
• discharge based on specified statistical recurrence intervals
• discharge based on an effective discharge calculation

- *the bankfull discharge* is the discharge that fills a stable alluvial channel, up to the active floodplain level. This is determined by on-site observations of the riverbed's configuration.
- *discharge based on drainage area*. Many equations are available that correlate dominant discharge to drainage area. These offer a quick technique for assessing a dominant discharge. For example Emmett (1975) developed for the Salmon River in Idaho, following relation

$Q=28,3F_B$, where (1)

Q= discharge [ft^3/s]

F_B= drainage area [mi^2]

- *discharge based on recurrence interval*. The oldest estimate of this discharge was given by Leopold and Maddock (1953-USDA 1996) and it is the annual average flow. Specialized literature estimates the characteristic recurrence interval is somewhere between 1 and 3 years, with an average value of 1.58 years.
- *the effective discharge* is a theoretical discharge that determines an order of magnitude for the geometric parameters of the alluvial channel if it remains constant indefinitely for a section of the alluvial channel; if is the discharge that carries the most river deposits.

Determining it requires knowledge of the discharge time curve as well as the flow of sediments.

Once the channel-forming discharge is set, morpohometric equations are used to approximately determine the riverbed cross section (width W). The following example use Nixon's relations(Manoliu 1973, USDA 2007):

$$W = a \cdot Q^b \text{ in which} \tag{2}$$

W = the channel width
Q = the channel-forming discharge
a=2,99 (USDA 2007)
a=2,8 (Manoliu, 1973)
b=0,5 as seen in both Romanian works (Manoliu, 1973; Baloiu 1980; Hancu, 1998) as well as foreign (USDA 2007), including in the Altunin, Buzunov equation used for works done in Romania on the Jiu river.

$$W = A \cdot Q^{0,5}/S^{0,2} \tag{3}$$

A = the channel stability coefficient with values between 0,7 (mountainside) and 1,3 (hillside)
S is the riverbed slope

In the Altunin equation, the channel forming discharge is the one with a 5-10% probability.

Dimensioning of the protective structure

The size of the crib walls is determined by the need to ensure a balance between the size of the crib and the bank it reinforces. The main forces at work are: earth pressure, buoyant force due to log imersion, and tractive force due to stream flow

$$\tau = 0,75 \gamma h S \text{, in which} \tag{4}$$

τ = tractive force
γ = volumetric weight of the water
h = water depth (h is an approximation of the hydraulic radius: $h \approx R = A/P$)
S = riverbed slope

The balance of these forces is certain in traditional structures as long as the thalweg doesn't erode and drive the ground from under the cribs. This is why the foundation depth for the crib needs to be below the potential erosion depth.

Observation: the channel width and section is determined by the channel-forming discharge, but the crib wall size is determined by the maximum discharge levels in accordance with the importance class of the structure.

In order to calculate the potential erosion depth, the following equation has been used (USBR 1984)

$$d_f = d_i \left(\frac{q_f}{q_i} \right)^m \tag{5}$$

where
d_f = scoured depth below design floodwater level
d_i = average depth at bankfull discharge
q_f = design flood discharge per unit width
q_i = bankfull discharge per unit width
m = exponent varying from 0,67 for sand to 0,85 for coarse gravel

Introducing vegetal elements to the structure

Woody plants placed in live cribwalls may extend the longevity of a log cribwall; as their root systems become more extensive, they can provide the stability that would otherwise be lost as log crib members rot over time.

One of the greatest challenges for designing live cribwalls is providing a suitable growing environment. Cribwall backfill must be fine enough to retain moisture so that plants can grow. However, fine backfill is more likely to be washed through the gaps between cribwall members. A granular filter or biodegradable erosion-control fabrics may be used to reduce soil loss. Cribwall backfill must also have enough organic content to provide nutrients to plants placed within live cribwalls. Live cribwalls may require irrigation, and plant selection should be based upon the frequency and duration of inundation

4. Examples for Moldovița River

After the flooding of 2008, during which historic levels were recored, a series of log cribwalls have been done along the banks of the Moldovita river (ABA Bacau). The dimensioning as well as the execution itself was done by rule of thumb, in accordance with local knowledge. Currently, data from the references listed is being used for the works near Moldovita.

Dimensioning of the alluvial channel

Determining of the alluvial channel width has been done considering that the channel forming discharge is the bankfull discharge. Two relatively stable sections have been identified, one upstream and one downstream from the consolidations(fig. 6 upstream; fig. 7 downstream).

Figure 6: Upstream section for bankfull discharge determination

$Q_{f,am}$ = 236 m^3/s
$Q_{f,av}$ = 198 m^3/s
The average of these values is Q_{fm}= 217 m^3/s
The width of the channel is
$W_1=2,99\cdot217^{0,5}$= 44 m, or
$W_2=2,8\cdot217^{0,5}$ = 41 m, or

Figure 7: Downstream section for bankfull discharge determination

W_3= $1\cdot236^{0,5}/0,007^{0,2}$= 41 m, or
W_4=$1\cdot198^{0,5}/0,005^{0,2}$= 40 m
Since the results show a variance between 40-44m, an average value is determined.
W=42m

Dimensioning of the structure
Scoured depth is according equation:

$$d_f = d_i\left(\frac{q_f}{q_i}\right)^m = 1,9\left(\frac{539}{236\cdot1,5}\right)^{0,8} = 2,65m$$

A 50% increase of the alluvial channel has been considered during floods (the current configuration also has greater widths).

It result a scour depth of 75 cm (scour depth is difference beetwen d_f and d_i) for the historical floods of Moldovita in 2008 (539 m^3/s at the Dragosa hydrometric station downstream from Moldovita vilage)

Conclusions

The following **conclusions** can be drawn:
Log cribwalls can be done traditionally under these conditions:
- the foundation depth needs to be lower than the potential erosion depth
- introducing plant life to the structure
- the cribwall filling has to contain enough ground to ensure the growth of vegetation

If all these conditions are met, the life expectancy of these installations greatly exceeds that of the logs themselves. Most of this kind of works done recently (in the Siret basin) don't have an integrated concept as a starting point and rely solely on the endurance of the log structures. Because of this, these cribs have the lifespan of the wood that is in them.

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