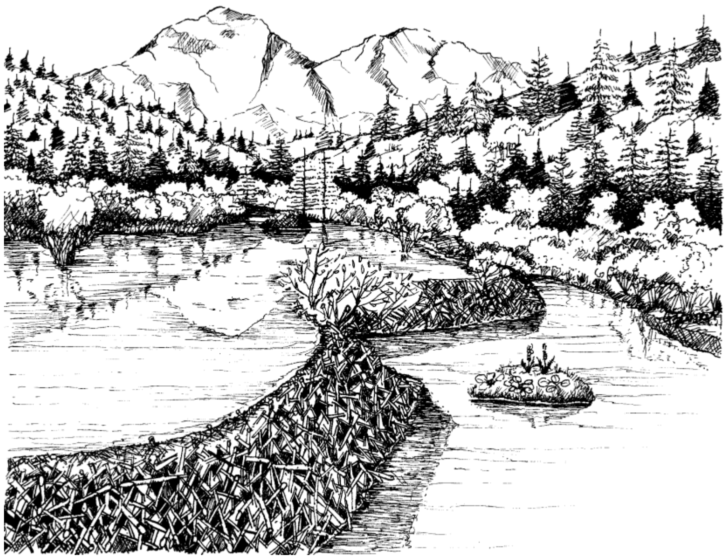
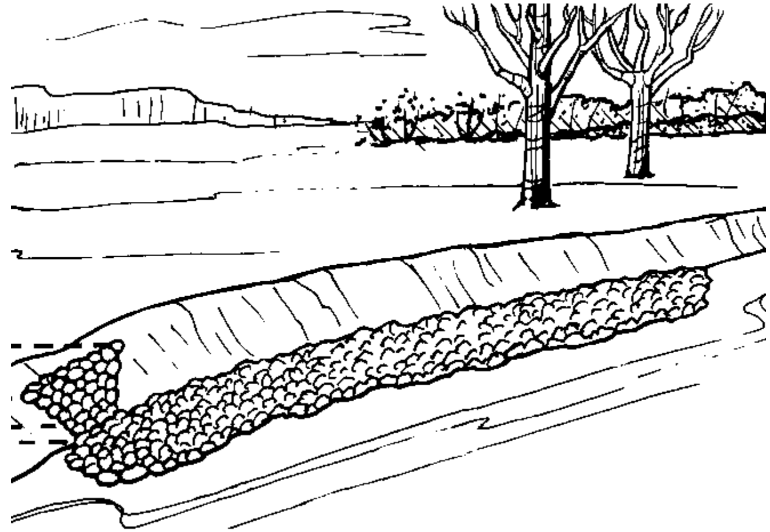
River Bank Protection





Amrapalli Garanaik

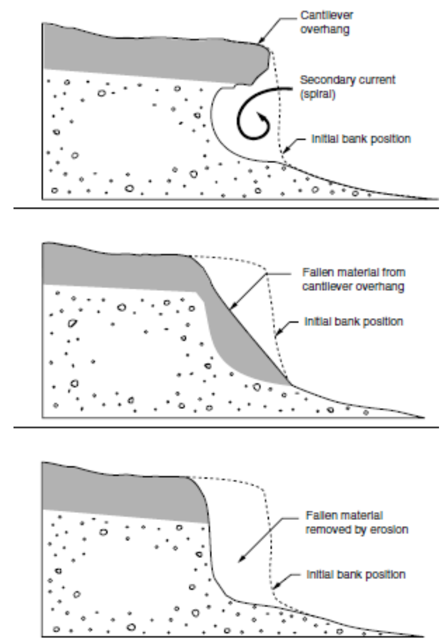
Joel Sholtes

CIVE 717 – April 11, 2013

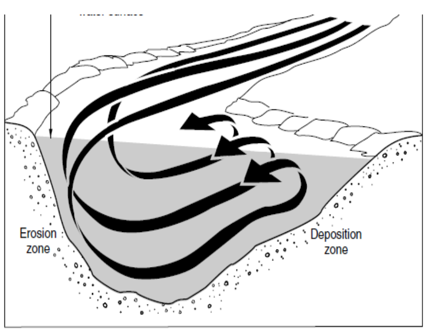
Bank Degradation: Cause and Effect

Bank erosion is a natural process in stable rivers; however, it can become accelerated and exacerbated by direct and indirect human impacts.

- **Bank destabilization causes:**
  - *Direct*: Livestock trampling, removal of riparian vegetation
  - *Indirect*: Channel incision, then widening from hydrologic alteration in watershed
- **Bank destabilization processes:**
  - *Hydraulic*: Toe scour -> cantilever failure or rotational slide
  - *Geotechnical*: Channel incision -> supercritical bank height and bank failure from mass wasting, or due to positive pore pressure in stream bank (Fischenich, 1989)



Bank Failure by Toe Scour
(Johnson & Stypula 1993)



Secondary flow hydraulics enhance bank erosion on outer banks in meander bends.
(Kunzig 1989)

Impacts of Bank Degradation

Societal Impacts

- Property loss from undermining structures
- Sedimentation of in-stream structures

Environmental Impacts

- Fine Sediment Loading
  - Water quality impacts from fine sediment and attached nutrients (e.g., Sekely et al. 2002)
  - Aquatic habitat fouling and eutrophication
- Channel Widening:
  - As banks widen, sediment transport capacity decreases and aggradation may occur potentially smothering aquatic habitat
  - Riparian habitat can also be damaged-

Bank Stability Governing Equations

Stability of non-cohesive sediment on an angled bank (Julien 2010)

$$\theta = tan^{-1}\left(\frac{sin\theta_o}{sin\theta_1}\right) \qquad a_\theta = \sqrt{cos^2\theta_1 - sin^2\theta_o}$$

$$\eta_o = \frac{\tau_0}{\tau_c} \cong \frac{21\tau_o}{(\gamma_s - \gamma_m)d_s} \qquad \eta_1 \cong \eta_o \sin(\lambda + \beta + \theta)$$

$$\beta = tan^{-1}\left[\frac{\cos(\lambda+\theta)}{\frac{\sqrt{1-a_\theta^2}}{\eta_o tan\phi} + \sin(\lambda+\theta)}\right]$$

$$SF = 1 = \frac{a_\theta tan\phi}{\eta_1 tan\phi + \sqrt{1-a_\theta^2}\, cos\beta}$$

θ = ratio of projected components of shear force on the embankment (°)
θ_o =downstream bedslope(°)
θ_1 = bank angle (°)
λ = streamline deviation angle (°)
a_θ = fraction of submerged weight normal to the embankment
β = direction of motion of sediment particle on the bank (°)
φ = bank material friction angle (°)
τ_o, τ_c = flow shear stress, critical shear stress (Pa)
SF = Safety Factor: Ratio of resisting to driving forces,
= unity for incipient motion of bank particle

Planar (Wedge) Failure Analysis for Steep Banks (Terzaghi 1943)

$$H_c = \frac{4c' \sin\alpha \cos\phi'}{\gamma[1 - \cos(\alpha - \phi')]}$$

Effective bank cohesion and material friction angle can be measured in situ or estimated based on bank material properties.

H_c = critical bank height for slab failure (m)
c' = effective bank cohesion (kPa)
α = bank angle (°)
φ' = effective bank material friction angle (°)
γ = unit weight of soil (kN/m^3)

Bank Stabilization Objectives and Approaches

- Protect river banks from degradation
- Prevent lateral migration of alluvial channel when property at risk

Two main approaches for river bank stabilization

- **Strengthening the bank**
  - Hard Approaches : Riverbank riprap & retaining walls
  - Softer Approaches: Bioengineering and vegetation

- **Reducing Hydrodynamic force**
  - Flow control structures

Hard Approaches: Riprap

- Constructed against a bank/escarpment to protect it from erosion while absorbing wave and flow energy.
- Permanent ground cover structure made up of large loose angular stones.

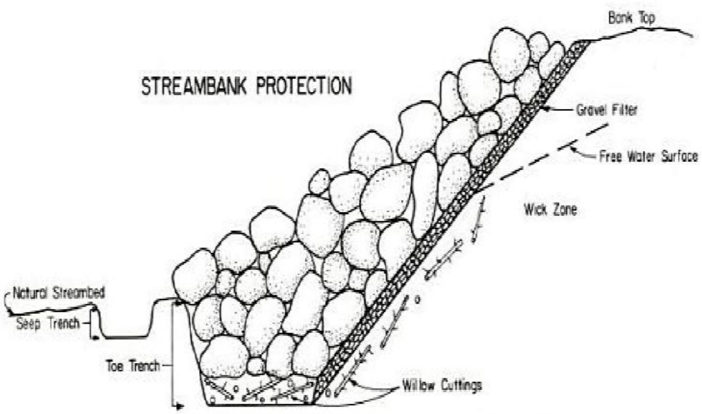
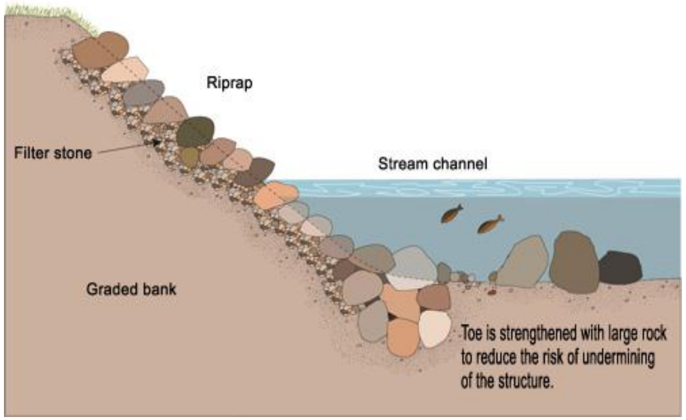


Image from Poudre river showing Riprap



Cross section of Riprap stream bank
(http://www.nfl.dfo-mpo.gc.ca/e0005488)

Design methods for Riprap

- ## Shear-stress method

Effective rock size required for riverbank stabilization under applied shear stress is estimated from Lanes relationship:

$$d_m = \frac{\tau_0}{\tau_{*c}\gamma(G-1)\left[\sqrt{1-\frac{\sin^2\phi_1}{\sin^2\phi}}\right]}$$

d_m = effective rock size
τ_0 = applied shear stress
τ_{*c} = critical Shield parameter
ϕ_1 = side slope of bank
ϕ = angle of repose of riprap rock
γ = unit weight of water
G= Specific weight of rock

- ## Velocity method

Effective rock size required for riverbank stabilization under applied critical shear velocity:

$$V_c = K_c\sqrt{2(G-1)gd_s}$$

$$K_c = \log\left(\frac{4h}{d_s}\right)\sqrt{\tan\phi}$$

V_c = critical mean flow velocity
d_s = stone diameter
ϕ = angle of repose of riprap rock
h= flow depth
h/ d_s=relative submergence

Design methods for Riprap(Cont'd)

- Riprap gradation

Size of representative of stability of riprap is determined by the larger size of rock as these are not transported under given flow condition.

Riprap with angular stone is more stable.

For poor gradation of riprap a filter is placed between riprap and bank material

Table 8.2. *Suggested riprap size gradation*

Percent finer by weight	Sieve diameter ($\times d_{50}$)	Stone diameter ($\times d_{50}$)
0	0.25	—
10	0.35	0.28
20	0.50	0.43
30	0.65	0.57
40	0.80	0.72
50	1.00	0.90
60	1.20	1.10
70	1.60	1.50
90	1.80	1.70
100	2.00	1.90

From: Julien, 2002

Design methods for Riprap (Cont'd)

Riprap Filter

- Used under riprap revetment to allow water to drain easily from bank without carrying out soil particles
- Filter thickness should not be less than 6-9 in
- Opening of 25% to 30% is desirable to minimize clogging and reduce head loss
- Two types: Gravel filter and synthetic fabric filters

Suggested specification for gradation of filter material size

Julien, 2002

$$\frac{d_{50}(filter)}{d_{50}(base)} < 40$$

$$5 < \frac{d_{15}(filter)}{d_{15}(base)} < 40$$

$$\frac{d_{15}(filter)}{d_{85}(base)} < 5$$

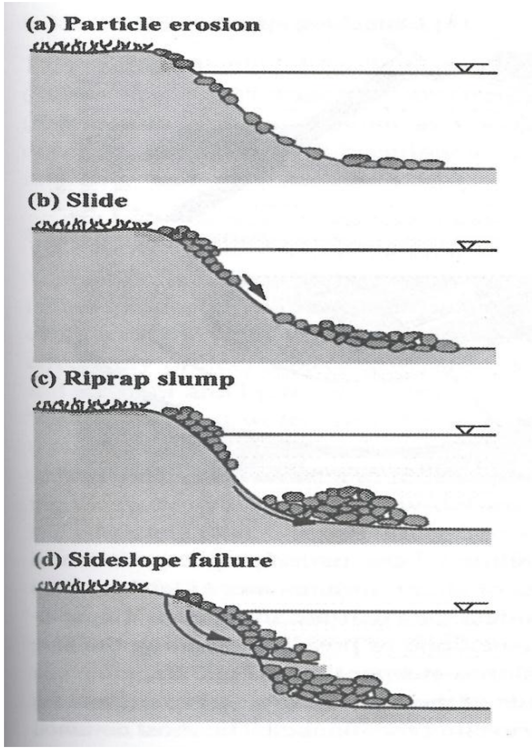
Riprap Failure and its Prevention

Riprap can fail due to particle erosion, translational slides, slumps and side slope failure

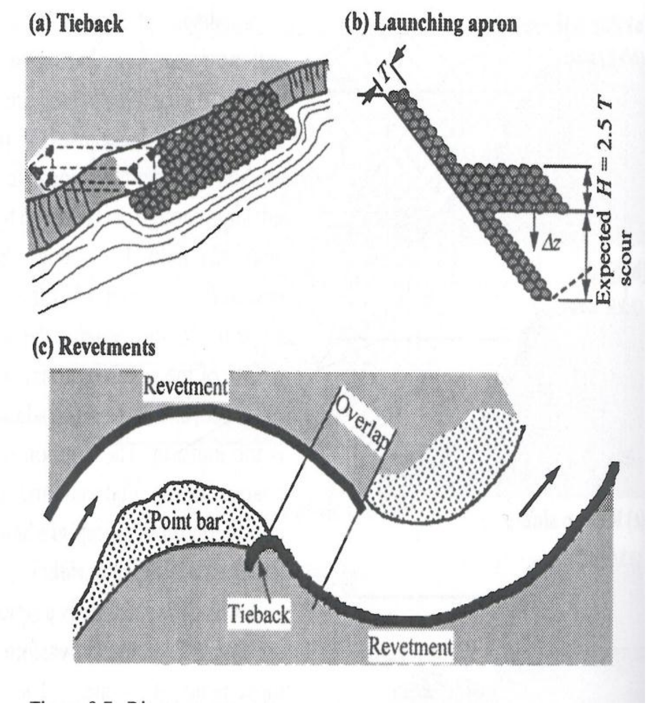
Riprap should not be used on slopes steeper than 1V:1.5H

Upstream and downstream ends of structure should be tied into stream banks

A launching apron is an effective revetment for riprap protection



Types of Riparian failure



Types of Riparian protection

Diagrams From: Julien, 2002

Engineered Revetments

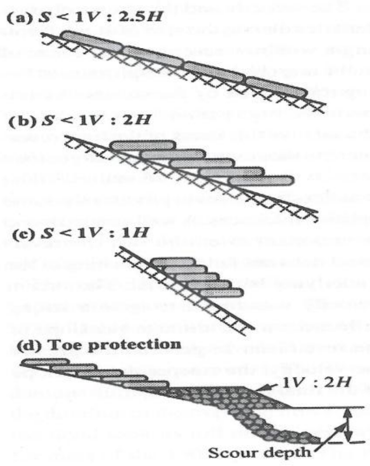
- **Gabions and mattresses** are rectangular wire box filled with small stones, stacked on steep slopes and provide higher resistance for the velocity range of 2-5 m/s in which small riparian stone are unstable.

- **Sacks and blocks** are filled with soil or sand-cement and are used for emergency stream bank protections

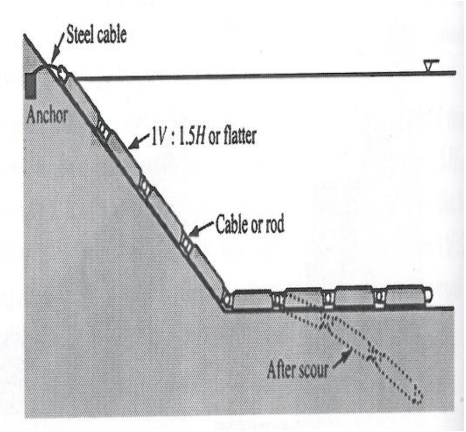
- **Concrete mattresses** are precast concrete blocks held together by steel rods or cables and used in large river for complete coverage of river bank with facilities for fines to pass through.

- **Soil cement** are concrete used in place of riparian stone in the bank to stabilize the embankment. These are economical but have lower strength, are impermeable and sensitive to temperature freeze thaw cycles.

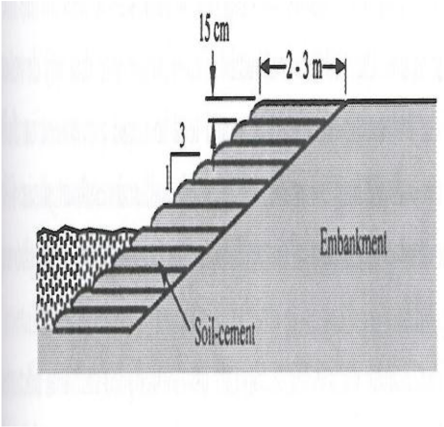
Gabions



Sacks and blocks



Concrete mattresses



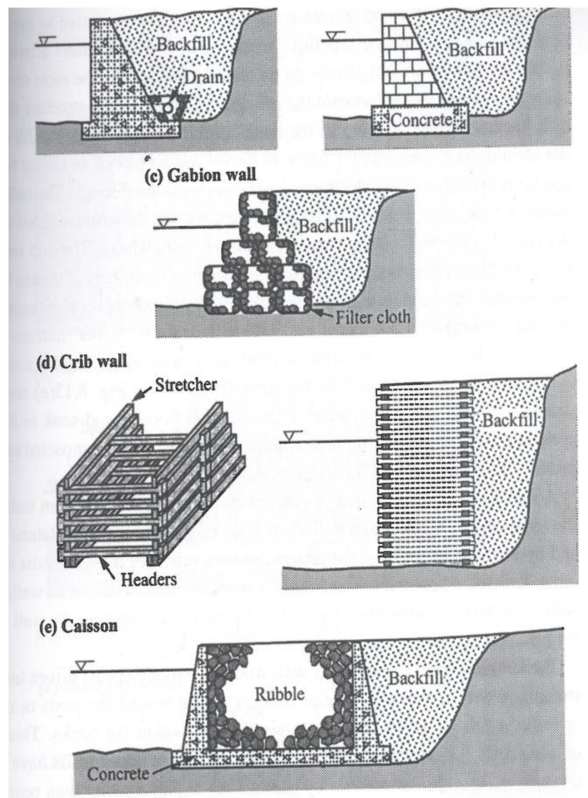
Soil cement

Diagrams From: Julien, 2002

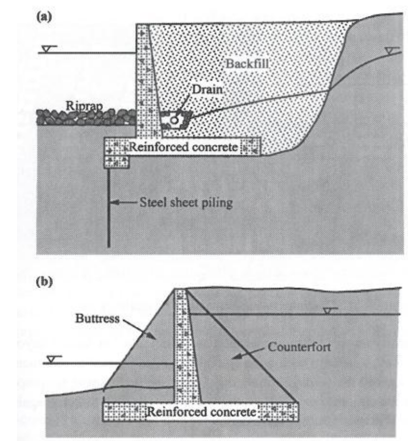
Retaining Walls

Retaining walls are vertical structures use to prevent streambank erosion or failure. Gravity walls, cantilever walls, sheet piling walls are example of retaining walls

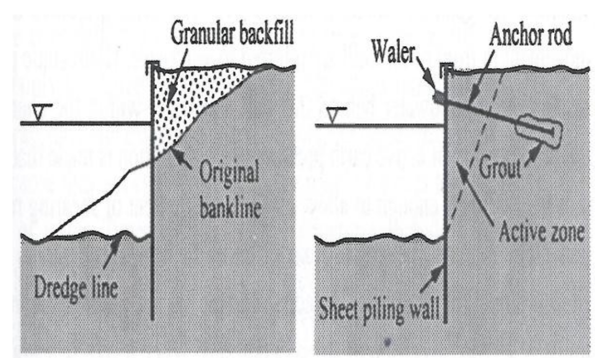
- Gravity walls are massive and failure of wall is resisted by weight of wall.
- Cantilever walls are with reinforced concrete base and designed to resist lateral and hydrostatic pressure.
- Sheet pilling walls are flexible bulkheads and used in soft soil and tight spaces.



Gravity walls



Cantilever wall

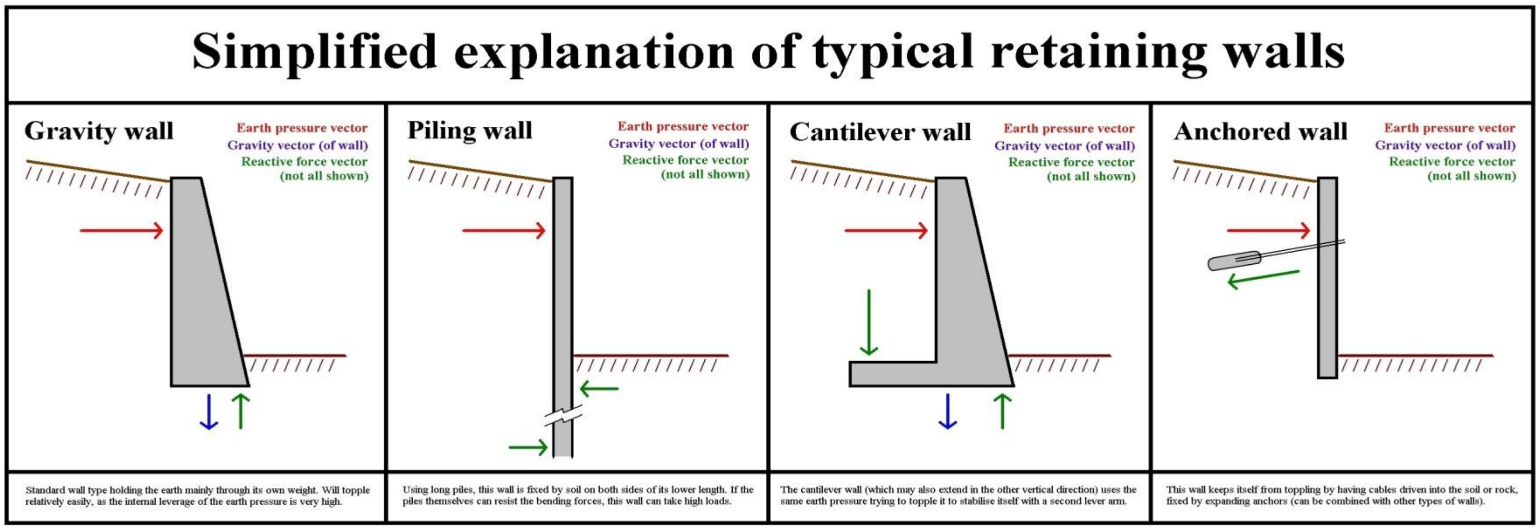


Sheet piling walls

Diagrams From: Julien, 2002

Retaining Wall stability

Active and passive earth pressures, hydrostatic pressure and soil resistance to erosion are computed for stability analysis of retaining walls.

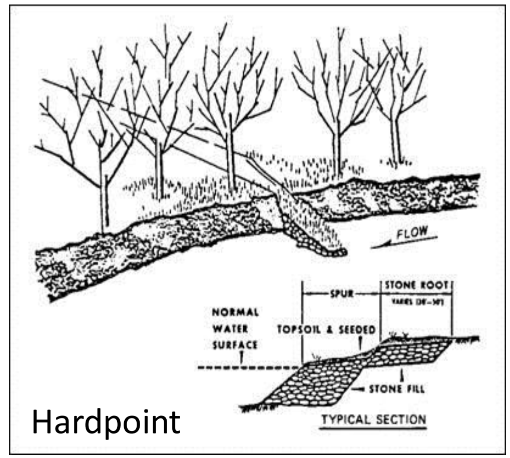


Stability is checked against overturning, bearing capacity, sliding, collapse

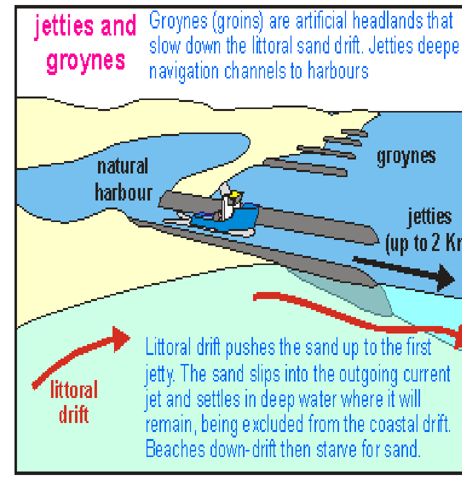
Flow Control Structures

In some cases flow hydraulics can be manipulated to reduce bank erosion or induce sedimentation avoiding direct engineering or bio engineering bank stabilization methods. These *flow control* or *hydrodynamic structures* have the following attributes:

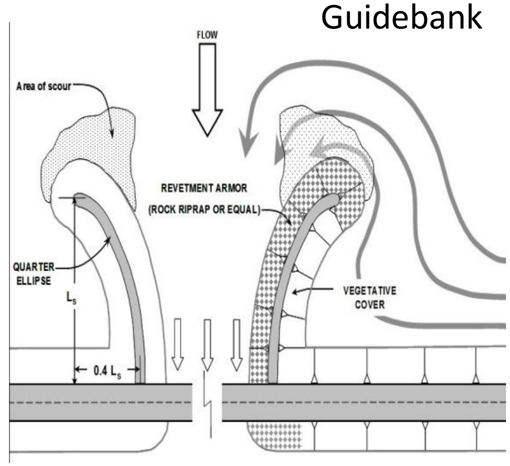
- Reduce hydrodynamic forces against stream banks
- Control the direction, velocity, or depth of flowing water
- Reduce the possibility of bank degradation by diverting the flow
- These structures generally have certain degree of permeability

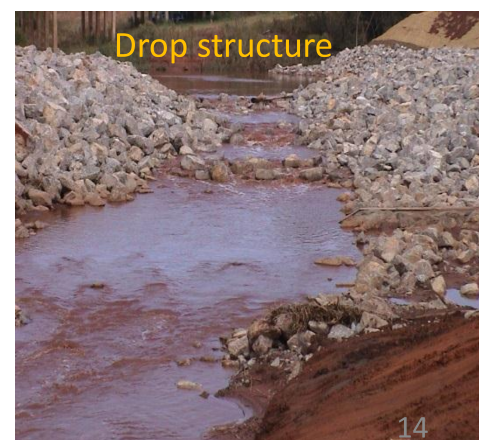


Hardpoint



Guidebank





Soft(er) Approaches: Bioengineering

Use of live vegetation and woody material for bank stabilization.

Often less costly in terms of materials (locally sourced), labor (often hand labor), and, once established, maintenance.

Requires time (several seasons) to establish, but self maintaining and re-generating once establish.

Table 3.2 *Maximum tractive forces for bioengineering*

Technique	Shear (Pa) immediately after completion	Shear (Pa) after 3-4 seasons
Reed plantings (herbaceous)	10	70
Deciduous trees plantings	50	290
Willow Wattle	145	190
Brush Layer	50	340
Brush Mattress	120	725
Rip-rap with live cuttings	480	725

Adapted from Schiechtl and Stern (1994).

Pole Plantings

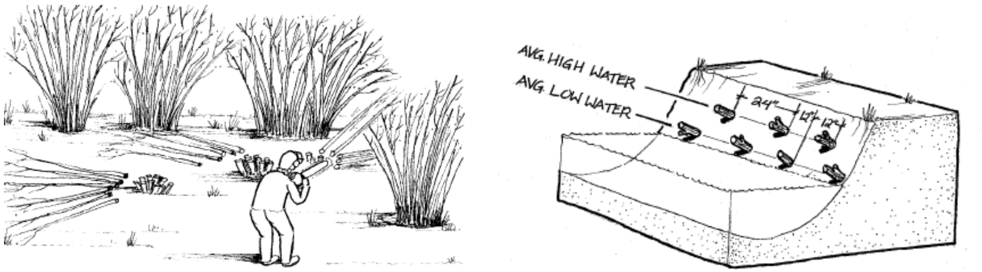
Pole plantings, or live stakes, provide an inexpensive approach to bank stabilization. Stakes can often be cut from on-site or nearby vegetation and are installed by hand.

Live stakes (e.g. willow) generally require a shallow water table, often a feature of riparian areas.

They require 1-2 years to establish roots and resist erosion.

http://www.goldenvalleymn.gov/

Willow Harvesting & Design Sketch



Bentroup and Hoag 1998

http://www.nrcs.usda.gov

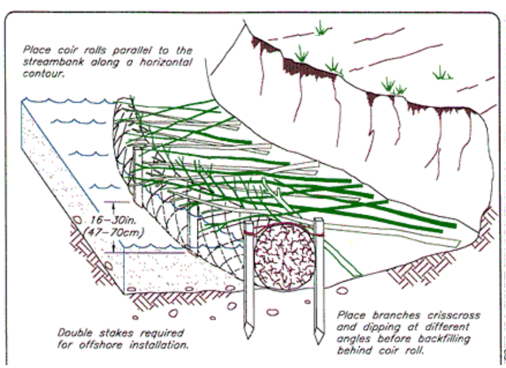
Coir Rolls

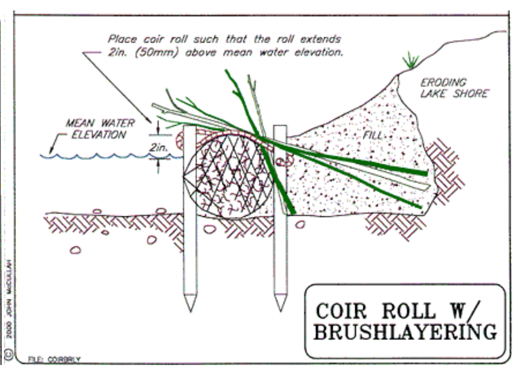
In lieu of rock or cement, coir logs, made of soil and geotextile fabric, can be used as structural members, as protection from scour, and as a substrate for vegetation to grow on and eventually stabilize.

Below are design sketches showing pole plantings tucked into the bank in between the coir rolls. This vegetation will eventually sprout, providing increased resistance to erosion and stabilizing the bank over the long term.

An example of coir rolls is shown on the right. Grass has been planted in the rolls. Rock has been placed on the bank toe for added protection from scour. Often the best design solution couples hard design elements such as this with bioengineering techniques.

Wash Creek Bank Stabilization Project
Hendersonville, NC.





http://www.erosioncontrol.com/

Tree and Brush Revetment

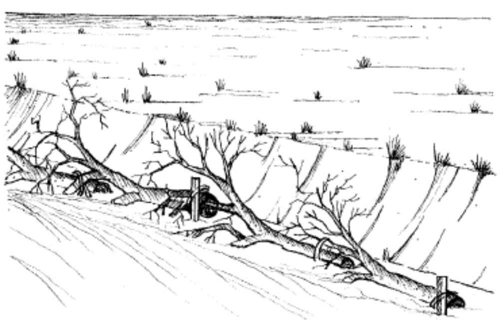
Often more resistant material is necessary to protect the bank toe from scour. In place of field stone, an economical approach (in terms of materials and labor) involves revetment with anchored trees and brush.

Woody material can be anchored into the stream bed (as shown below) or tied into the bank using an excavator if such resources are available.

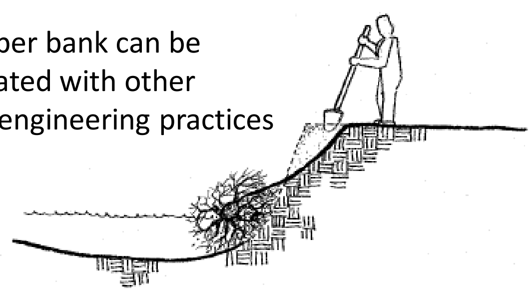
Other bioengineering treatments must be used to stabilize the upper bank slope.

A community funded and constructed project, installed with hand labor, is shown on the right. Clearly this approach is most appropriate in smaller streams and rivers.

Design Sketches



Upper bank can be treated with other bioengineering practices



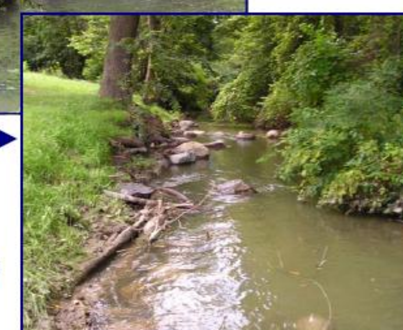
Bentroup and Hoag 1998

East Garden Park Eastlake, OH

◄ *Before Construction*
Nearly vertical bank with exposed roots, little riparian vegetation, and severe erosion.

▲ ◄ *During Installation*
Kicker logs and brush packing collected on site.

After Construction ►
Bank stabilized with vegetation. Tree revetment catches sediment, limiting erosion and improving water quality.



http://www.crwp.org/

Comparing Hard and Soft Approaches

Hard, Engineering Approaches

- Advantages:
  - Durable, highly stable, can give rise to vegetation
  - Local damages can be repaired easily
- Disadvantages:
  - Need construction practice and restricted to some design parameter
  - Need manpower, materials, equipment
  - Comparatively costly

Soft, Bioengineering Approaches

- Advantages:
  - Long-term, re-generating protection
  - Often less costly
  - Potential for better environmental outcomes
- Disadvantages:
  - May require time to establish
  - Not always practical (requires, soil, water and mild slopes)
  - Can cause damage later on via wind-throw of mature vegetation

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