3.3.2.1 Bank Protection

Source: TDEC

Definition and Purpose

Bank protection is the stabilization of the side slopes of a waterbody. This can be vegetative, structural, or a combined method, such as bioengineered soil stabilization (See Section 3.3.2.2). Bank protection is necessary to repair and/or prevent erosion in areas where increased runoff rates and volumes are anticipated from development, construction, or stream alteration.

Appropriate Applications

Bank protection is appropriate where there is existing erosion or erosion is anticipated. This could be along straightened channels, in locations of (upstream) development, exposed streambanks, or where highly erosive flows have been observed.

Limitations and Maintenance

Few limitations exist for this practice as long as the protection is applied appropriately so as to withstand erosive forces and is firmly secured so the practice cannot become dislodged and migrate downstream. Otherwise, bank protection may require continual replacement or maintenance. Timing limitations exist for vegetative measures as they will not immediately stabilize the banks. Bank protection measures must not reduce the hydraulic capacity of the stream.

Installing bank protection in jurisdictional waters requires additional permits, such as an ARAP, and therefore, both the conditions of the CGP and ARAP must be followed. A Section 404 permit from USACE may also be required, and if the proposed bank protection is to be completed in a TVA reservoir, a TVA 26a permit may also be necessary. Local permitting may be required in addition to state and federal permitting requirements. Consider the criteria and conditions of the necessary permits during the planning stages of the project and EPSC plans.

Planning and Design Considerations
Several options exist for bank protection, including grass, trees, conventional, soil, and void-filled riprap, concrete, fabric-formed revetments, grouted riprap, erosion control blankets, turf reinforced matting, coir matting, benching, geotextile containment, etc. Some of these bank protection measures can be used in conjunction with bioengineered soil techniques as presented in Section 3.3.2.2 (GSWCC, 2016). It is ideal to install bank protection when a stream diversion (Sections 3.3.2.3 and 3.3.2.4) is in place (i.e., dry conditions). This prevents the transport of disturbed sediment downstream. Consider the following site specific conditions when selecting bank protection materials (ALSWCC, 2018):

- The overall condition of the stream within and adjacent to the reach is to be stabilized;
- Current and future watershed conditions;
- Velocity at full channel flow;
- Shear stress at full channel flow;
- Sediment load in the stream;
- Channel slope;
- Controls for bottom scour;
- Soil conditions;
- Present and anticipated channel roughness;
- Compatibility of selected protection with other improvements at the site;
- Changes in channel alignment; and
- Fish and wildlife habitats.

A well-conceived bank protection design consists of an interdisciplinary team, including (but not limited to) engineers, hydrologists, and wildlife biologists. Key considerations include stream geomorphology, stabilization of the channel bottom, and appropriate selection of bank protection measures based on velocity and shear stress. The channel bottom must be stabilized before installing bank protection to enhance long-term success. Grade control may be necessary to prevent stream downcutting (ALSWCC, 2018). Vegetated protection is typically preferred as it is inexpensive and resembles natural stream characteristics. However, vegetated banks do not provide immediate stabilization and do not provide as much stability under high flow conditions as other, typically structural materials (Tables

3.3.2.1-A and 3.3.2.1-B). Design velocities are to be determined by the designers under the appropriate design storm, which may be a local regulation. If no design storm is specified due to the project location and local government ordinances, utilizing the upstream channel capacity, estimated bankfull velocity, or the 2-year, 24-hour design storm are appropriate alternatives.

Table 3.3.2.1-A: Velocity thresholds for bank protection materials. Sources: FHWA (1998) and TDOT.

Material	Maximum Velocity (ft/s)
Bare Soil	-
Silt of fine sand	1.5
Sandy loam	1.75
Silt loam	2
Stiff clay	3.75
Ordinary firm loam	2.5
Fine gravel	2.5
Graded, loam to cobbles (noncolloidal)	3.7
Graded, silt to cobbles (colloidal)	4
Alluvial silts (noncolloidal)	2
Alluvial silts (colloidal)	3.7
Coarse gravel (noncolloidal)	4
Cobbles and shingles	5
Shales and hard pans	6
Sod	4
Lapped sod	5.5
Vegetation	Table 3.3.2.1-B
Conventional Riprap (Class A1, I)	5
Conventional Riprap (Class B, II)	10
Conventional Riprap (Class C, III)	12
Conventional Riprap (Class C, IV)	15
Conventional Riprap (Class D, V)	20

Table 3.3.2.1-B: Maximum velocity threshold for vegetated bank protection on slopes. Source: Adapted from TDOT

Vegetation Type	Exit Channel Slope Range (%)	Maximum Velocity[a] (ft/s)
Bermudagrass	0 - 5	6
	5 - 10	5
	> 10	4
Kentucky Bluegrass, Buffalo Grass, Smooth Brome	0 - 5	5
	5 - 10	4
	> 10	3
Grass Mixture	0 - 5	4
	5 - 10	3
Alfalfa, Crabgrass	0 - 5	2.5
Common Lespedeza, Sudangrass	0 - 5	2.5

[a]Based on erosive soils

Even if velocity permits a certain protective material, shear stress, the force per unit area exerted parallel to the streambank, must be checked to ensure compatibility. Streambanks are considered stable when the velocity criteria are met, and permissible shear stress (Table 3.3.2.1-C) is less than the tractive force (TDOT). Tractive forces are the hydrodynamic forces of flowing water in a channel. In a uniform flow, the tractive force is equal to the effective component of the gravitational force acting on the body of water, parallel to the bottom of the channel. Thus, the maximum shear stress for a straight channel occurs at the channel bottom and is less than or equal to the shear stress at maximum depth, which can be expressed as:

$$\tau_{max} = \gamma \times d \times S \qquad \text{(Eqn 12)}$$

where τ_{max} is the maximum shear stress in pounds per square foot, γ is the unit weight of water (62.4 pounds per cubic foot), d is the maximum depth of flow in feet, and S is the average bed slope or energy slope in feet per foot.

Concentrated flow traversing a bend imposes a higher shear stress on the inner bank within the curve and the outer bank downstream of the curve compared to a straightened reach. Maximum shear stresses in bends are a function of the ratio of the radius of curvature, R_C, to the channel bottom width, b. As this ratio decreases, the bend becomes sharper and shear stresses increase. Maximum shear stress in a bend can be calculated by the following equation:

$$\tau_{bend} = \tau_{max} \times K_b \qquad \text{(Eqn 13)}$$

where τ_{max} is calculated from Eqn 12 and K_b is a dimensionless factor accounting for the increased stress. This dimensionless factor is calculated by Eqn 14.

$$K_b = 2.36 \times e^{-0.082 \times R_C / b} \qquad \text{(Eqn 14)}$$

Table 3.3.2.1-C: Shear stress thresholds for bank protection materials. Sources: FHWA (1998) and TDOT.

Lining Category	Lining Type	Permissible Unit Shear Stress	
		(lb/ft^2)	(Pa)
Erosion Control Blanket[a]	Type 1	1.5	72
	Type 2	1.75	84
	Type 3	2	96
	Type 4	2.25	108
Turf Reinforced Mat[a]	Type 5 - unvegetated	3	144
	Type 5a	6	288
	Type 5b	8	384
	Class 5c	10	480
Grass	Class A	3.7	177
	Class B	2.1	101
	Class C	1	48
	Class D	0.6	29
	Class E	0.35	17
Conventional Riprap	Class A1, I	3	144
	Class B, II	4	192
	Class C, III	5	239
	Class C, IV	6	287
	Class D, V	7+	335
Bare Soil	Non-cohesive	See Hydraulic Engineering Circular No. 15	
	Cohesive		

[a]General values based on vendor information, refer to Section 4.2.6.10 for detailed information.

When working around a water resource, such as a stream, consider the different zones within the riparian area and their susceptibility to erosion (NCDEQ, 2013). Typically, riparian areas consist of five zones, including toe zone, bank zone, overbank zone, transitional zone, and upland zone (Figure 3.3.2.1-A), though each zone may not be prevalent in streams impacted by development.

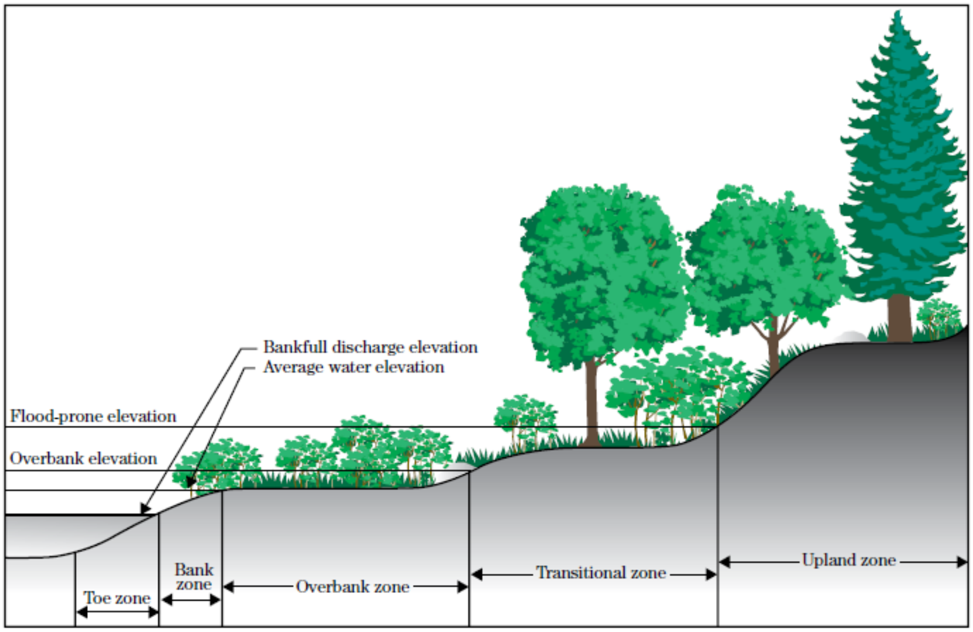

Figure 3.3.2.1-A: Riparian zones. Source: NRCS (2007).

The toe zone is located below baseflow water levels. This zone is perhaps the most critical to be stabilized, as it is continuously subjected to flow (NRCS, 2007). Because this zone is inundated (with the exception of drought periods), it is likely that no woody vegetation exists, nor would it be feasible to introduce woody vegetation as a protective measure. In the toe zone, nonliving protection (most commonly, structural) is most ideal.

The bank zone is the area situated between the typical water level and the bankfull discharge height. In this zone, the potential for erosion is high, but only during stormflow. Furthermore, this zone experiences wet and dry cycles, debris deposition, and in winter months, it can be subjected to freeze-thaw cycles. These exposures may exacerbate erosion potential. This zone is often covered by early-growing herbaceous and small woody plants with flexible stems. Such species may include willows, dogwoods, elderberries, and small shrubs (NRCS, 2007). Because this zone is subjected to erosive forces and there is a low potential of protection from natural vegetation, bank protection is likely necessary. Planting vegetation may provide adequate protection in small water bodies, especially if the upstream has little development. However, nonliving protection will likely be more effective.

The overbank zone is located above the bankfull discharge elevation, which floods approximately every two to five years. It is typically a flat area because it has been formed by sediment deposition when flooded. Vegetation found in this zone is generally flood tolerant, provides shade for the stream, and offers a riparian habitat for wildlife. Protection usually does not need to extend into this zone as long as existing vegetation is present and healthy (NRCS, 2007). However, support this zone with vegetative protection if needed. Typically, this zone is where the preservation of riparian buffer zones (Section 3.3.3.2) would begin.

The transitional zone and upland zone are seldomly subjected to erosion from the stream. The transitional zone may be flooded approximately every 50 years while the upland zone would be subjected to erosion from sheet flow and land disturbance (NRCS, 2007). Bank protection measures are not applicable in these zones.

When the velocity and shear stress align with vegetative design, incorporating diverse plant species is ideal. Consider natives first. However, there are difficulties when it comes to establishing natives, such as acquiring 70% vegetative cover and time to germination. Native vegetation can be supplemented with nurse crops in order to provide erosion control while the natives germinate and grow. See Section 4.2.6.11 Vegetation and Landscaping: Permanent for further details on native establishment. If native plants are not feasible, then consider non-invasive species for stabilization. Where high velocities, channel bends, steep slopes, or highly erodible soils exist, structural protection will be more desirable than vegetation. Common structural bank protection materials include conventional riprap, gabions, fabric-formed revetments, and reinforced concrete walls.

Conventional riprap is one of the most commonly used materials for bank protection, providing stability and erosion resistance in high-flow environments. To ensure its effectiveness, size riprap to withstand the expected flow conditions. The first step in this process is to determine the design velocity and maximum shear stress, based on either bankfull flow or a more conservative design storm. Machined riprap is categorized into different classes based on median stone size (D_{50}). Class A-1 has a D_{50} of nine inches and is placed at a minimum depth of 18 inches. Class A-2, though similar in material, is hand-placed at a depth of 12 inches and is generally not recommended due to its reduced stability. Class B and C


Source: NCDEQ (2013)

riprap have a D_{50} of 15 and 20 inches, respectively. For slopes steeper than 3H:1V, refer to Chapter 4 of the FHWA publication HEC-15 to ensure stability. Permissible velocities for riprap classes are presented in Table 3.3.2.1-A. However, using shear stress calculations provides a more accurate assessment of stability, and these thresholds must also be checked (Table 3.3.2.1-C). Additional considerations to prevent failure include ensuring that bank slopes do not exceed a maximum of 2H:1V, incorporating geotextile filter fabric between the soil and conventional riprap to prevent piping, and extending the riprap toe at least one foot below the streambed. Ideally and when possible, extend riprap up to the 2-year water surface elevation or bankfull flow unless a combination of vegetative measures is determined to provide sufficient protection. Where possible, consider the use of soil riprap or void-filled riprap in place of conventional riprap as a bioengineered soil technique (Section 3.3.2.2).

Gabions are stone-filled wire baskets that are semi-flexible and permeable. Because of their flexibility, gabion structures remain structurally sound and function during earth movement. Void spaces in gabions absorb energy from flowing water, thereby reducing velocity. Because this material is permeable, place a geotextile fabric between the gabions and soil subgrade to prevent any piping. Stone size is less critical for gabions on steep slopes (as opposed to riprap alone) because the wire mesh allows the material to act as a single unit. However, the stability and allowable shear stress of wire-enclosed riprap depends on the integrity of the wire mesh. In channels with high sediment yields, the wire mesh may be abraded and could potentially fail. In such conditions, the use of these structures are not advised. Check manufacturer specifications for permissible shear stresses of wire.


Source: TDEC

Fabric-formed revetments are manufactured, large, quilted envelopes that are pumped with fine-aggregate grout onsite. These systems are inexpensive and take only a few minutes to set in place. Essentially, they are cast-in-place rigid linings that are durable, flexible, and semi-permeable. Due to their flexibility, fabric-formed revetments are ideal with stream banks having irregular surfaces. Furthermore, the permeability of geotextile fabrics allows water filtration, which can be beneficial to the local ecosystem. There are various options for revetments on the market. Be sure to check manufacturer specifications to ensure the proper selection for each site and permissible shear stresses. Additionally, follow all manufacturer specifications during installation.


Source: GSWCC (2016)

Reinforced concrete retaining walls may be necessary in urban settings or constrained sites to replace cut or fill slopes, in areas with poor soils, or where a wall is necessary to achieve stable slopes. Designing retaining walls is a complicated process and site specific; thus, an engineered design is required. Many factors need to be considered, such as allowable stresses and forces outside and within the wall, allowable height, wall thickness, foundation design, footers, bearing values of soils, a factor of safety, etc. The foundation must include a method of draining excess water from behind the wall. Begin and end all structural protection methods along stable reaches of the stream.

The velocity and shear stress discharging from the protected to a natural stream reach must be considered, particularly if the reach was straightened. Ensure protected banks do not increase the velocity of water such that downstream erosion occurs. If the velocity or shear stress is too high, consider designing a transition in the bank protection to slow the erosive forces, thereby protecting the downstream channel bed and banks.

Example Application

Always ensure that the maximum velocity and shear stress are less than the permissible velocities and shear stresses of bank protection. Maximum velocities and shear stresses in streams are to be calculated by design engineers registered in Tennessee.

References

ALSWCC. (2018). *Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas*.
FHWA. (1998). *HEC 11: Design of Riprap Revetment*.
FHWA. (2005). *HEC 15: Design of Roadside Channels with Flexible Linings.*
GSWCC. (2016). *Manual for Erosion and Sediment Control in Georgia*.
NCDEQ. (2013). *Erosion and Sediment Control Planning and Design Manual*.
NRCS. (2007). *National Engineering Handbook: Part 654 Stream Restoration Design*.
TDOT. *Drainage Manual Ch5.*