ARIZONA DEPARTMENT OF WATER RESOURCES
FLOOD MITIGATION SECTION

State Standard

for

Watercourse Bank Stabilization

Under authority of ARS 48-3605(a), the Director of the Arizona Department of Water Resources establishes the following standard for watercourse bank stabilization in Arizona:

The guidelines outlined in State Standard Attachment 7-98 entitled "Watercourse Bank Stabilization" or by an alternative procedure reviewed and accepted by the Director will be used in the development of designs for watercourse bank stabilization for fulfilling the requirements of Flood Insurance Studies, and local community and county flood damage prevention ordinances.

For the purpose of application of these guidelines, bank stabilization standards will apply to all watercourses identified by the Federal Emergency Management Agency as part of the National Flood Insurance Program, all watercourses which have been identified by a local floodplain administrator as having significant potential flood hazards, and all watercourses with drainage areas more than 1/4 square mile or a 100-year discharge estimate of more than 500 cubic feet per second. Application of these guidelines will not be necessary if the local community or county has in effect a drainage, grading or stormwater ordinance which, in the opinion of the Department, results in the same or greater level of flood protection as application of these guidelines would ensure.

This requirement is effective June 1, 1998. Copies of this State Standard and State Standard Attachment 7-98 can be obtained by contacting the Department's Flood Mitigation Section at (602) 417-2445.

NOTICE

This document is available in alternative formats. Contact the Department of Water Resources, Dam Safety Section at (602) 417-2445 or (602) 417-2455 (TDD).

ARIZONA DEPARTMENT OF WATER RESOURCES
FLOOD MITIGATION SECTION

Watercourse Bank Stabilization

500 North Third Street
Phoenix, Arizona 85004

(602) 417-2445

STATE STANDARD ATTACHMENT **MAY 1998**
SSA 7-98

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INTRODUCTION

Project Background

The guidelines which follow were developed based on research of available resources and references on the current state of the practice of streambank stabilization within Arizona and the surrounding region as a part of Phase I of this project. Based on the results of the Phase I effort, an evaluation of the following selected methods was performed as a part of Phase II of this project:

- Rock Riprap
- Gabions/Wire-Tied Rock
- Concrete/Shotcrete
- Grouted Rock
- Vegetation/Bio-Mechanical

The guidelines contained herein are a result of the above described evaluation process. Details of the Phase I research and Phase II evaluation are documented in the final reports for each of the respective phases which are available through the Arizona Department of Water Resources.

General

Streambank stabilization is a complex subject. There are no simple approaches which are guaranteed to work under all the possible combinations of stream conditions which exist within Arizona. However, past experience has shown that there is a need to identify procedures which can be utilized for the design of streambank stabilization projects which range from the very simple to the very complex. Simple procedures are needed to provide economical designs for relatively inexpensive streambank stabilization by individual property owners, while identification of acceptable detailed design procedures is needed to provide direction to community government agencies regarding acceptable procedures for larger scale, more complex private-sector and public-sector projects. Utilizing the three-level approach common to most state standards, a series of procedures has been developed herein to provide guidance in the design of streambank stabilization which spans the spectrum from simple to complex designs. Every attempt has been made to develop simple and conservative design procedures for the most basic stabilization methods while, at the same time, providing direction on design procedures for larger and more complex projects.

Prior to developing a design for bank stabilization, the party interested in pursuing the streambank stabilization option should thoroughly review the document titled "Streambank Protection Guidelines for Landowners and Local Governments," Malcolm P. Keown, U.S. Army Corps of Engineers, 1983. That document is an excellent overview of the nature of natural stream systems, the causes of streambank erosion and failure, and possible approaches to stabilization of streambanks. It should be noted that the spectrum of possible streambank stabilization methods is extremely wide, ranging from the most common rock-riprap protection to intricate networks of training devices designed to slow stream flow and induce sediment deposition to reclaim lost streamside lands. After reviewing the referenced document, the party interested in pursuing a streambank stabilization project may well conclude that none of the methods or procedures outlined herein are appropriate for their situation, or that streambank stabilization is not a reasonable or viable option at all for their situation. Upon investigating the time and expense involved in pursuing bank stabilization, many parties may find that avoiding, or simply setting improvements back from, the streambank or erosion-prone area is a more economical solution to their problem.

Limitations of Procedures

In general, the lower the procedure level (e.g., Level 1 is lower than Level 3), the simpler the level of evaluation--but the more conservative the resulting design parameters--will be for a given protection method. This approach reduces the level of evaluation (normally reducing design costs), but usually overestimates the values of the design parameters (typically resulting in increased construction costs). Thus, generally speaking, the lower-level procedures result in lower design costs, while the higher-level procedures result in lower construction costs. It should also be recognized by the owner/builder of the bank-stabilization project that the design of projects utilizing Level 3 procedures will be based upon data more specific to the project site, and which are therefore more likely to yield designs with the highest probability of success in providing long-term protection.

It should also be noted by the user that these procedures are intended primarily for use in areas not mapped by the Federal Emergency Management Agency (FEMA) as Special Flood Hazard Areas (SFHA) on the community's Flood Insurance Rate Maps (FIRMs). *None* of the procedures described herein will necessarily result in designs which satisfy FEMA requirements, such as freeboard and levee-certification criteria. For guidance on designs intended to satisfy FEMA requirements, the reader is referred to the appropriate FEMA regulations regarding revision and/or amendment of FIRMs.

Use-Based Application of Bank Stabilization Procedures

Because of the uncertainties in developing simplified standards for bank-stabilization procedures, a decision was made to limit the applicability of the procedures based on the type of use or protection to be provided by the bank-stabilization project. By limiting the applicability in this manner, the level of confidence in the procedures can be matched to the risk associated with the particular application. The following matrix provides an index to the applicability of the various procedure levels to the types of uses for which they can be confidently applied.

<table>
<tr><th rowspan="2">Intended Purpose of Bank Stabilization Project</th><th colspan="3">Level of Analysis/Design</th></tr>
<tr><th>Level 1</th><th>Level 2</th><th>Level 3</th></tr>
<tr><td>Prevent additional loss of streambank or reclaim land lost to erosion.</td><td colspan="2">Acceptable</td><td rowspan="2">Preferred</td></tr>
<tr><td>Protect existing improvements threatened by erosion.</td><td colspan="2">Not recommended where stabilization is required by local authorities as a condition of approval for repair, expansion or other modification of the existing bank improvements. Otherwise acceptable.</td></tr>
<tr><td>Protect new improvements threatened by erosion.</td><td colspan="2">Not Recommended</td><td>Recommended</td></tr>
<tr><td>Other</td><td colspan="3">Site-specific evaluation by engineer needed to determine appropriate procedure level.</td></tr>
</table>

BANK-STABILIZATION PROCEDURES

Level 1 and Level 2: Rock-Riprap and Wire-Tied Rock Mattress Procedures

These procedures should be pursued only after the interested party has thoroughly reviewed the options and considerations for streambank stabilization as outlined in "Streambank Protection Guidelines for Landowners and Local Governments," Malcolm P. Keown, U.S. Army Corp of Engineers, 1983, and has concluded that these methods of bank stabilization are appropriate for their situation. These procedures should only be utilized where the proposed bank-stabilization project will be confined to a single property or group of properties under one ownership, or the project will be represented by all owners in the plan and application for bank stabilization. The proposed bank-stabilization should be evaluated to insure that it will not adversely impact upstream or downstream areas. The design of the project should also be evaluated to insure that the provisions of all applicable local regulations are respected. Level 1 procedures should only be used where the design discharge is less than or equal to 3,000 cubic feet per second (CFS).

Having affirmatively made the above determinations, determine whether rock riprap or wire-tied rock mattress design is to be used. Then determine which level of analysis (Level 1 vs. Level 2) is to be performed. Then utilize the combination of design procedures and typical sections provided within the following matrix, based upon the level of analysis and type of stabilization to be used:

Level of Analysis	Bank-Stabilization Type	
	Rock Riprap	**Wire-Tied Rock Mattress**
Level 1 (for design discharge ≤ 3,000 CFS only)	Determine the design parameters using Table 1, and then complete the "Typical Level 1/Level 2 Design Section for Rock Riprap Bank Stabilization"	Determine the design parameters using Table 2, and then complete the "Typical Level 1/Level 2 Design Section for Wire Mattress Stabilization"
Level 2	Determine the design parameters using Table 3, and then complete the "Typical Level 1/Level 2 Design Section for Rock Riprap Bank Stabilization"	Determine the design parameters using Table 4, and then complete the "Typical Level 1/Level 2 Design Section for Wire Mattress Stabilization"

The typical sections referred to in the table above are located in Appendix A of this document. Tables 1 through 4 are on the pages which follow this section.

The difference between the Level 1 and Level 2 procedures is a function of the level of analysis done to determine key design parameters. The Level 1 procedures rely upon analyses performed to Level 1 standards, utilizing other State Standards, while the Level 2 procedures rely upon the corresponding Level 2 analyses from these other State Standards. The other standards utilized by reference include SSA2-96: "Requirements for Floodplain and Floodway Delineation in Riverine Environments," and SSA5-96, "State Standard for Watercourse System Sediment Balance." Performance of the more detailed hydrologic and floodplain analyses associated with the Level 2 procedure should, in most cases, result in a more refined determination of the various design parameters (i.e., mean stone size, scour depth, bank-height requirement, etc.) which, in turn, should result in reduced construction costs from that which would be determined utilizing the Level 1 procedures. Mixed use of different level procedures (e.g., using level 2 hydrology with level 1 median riprap stone size determination) may be employed but should be evaluated on a case by case basis at the discretion of the user and with approval of the local jurisdiction.

The resulting typical section can be applied over the reach to be protected. Great care should be taken in insuring that the filter layer and toe are constructed per the specifications on the typical section, as the success or failure of these stabilization methods is highly dependent upon the performance of these two parts of the design. As a part of the design process, the location and alignment of the project must be field staked so as to allow field inspection as a part of the engineering review called out above.

TABLE 1: LEVEL 1 ROCK RIPRAP DESIGN PARAMETERS		
Step No.	**Level 1 Riprap Bank-Stabilization Design Parameter Description (See Appendix A for Typical Section)**	**Variable Determined**
1	Compute the 100-year discharge, Q_{100}, per Level 1 procedures in SSA2-96 ("Requirements for Floodplain and Floodway Delineation in Riverine Environments")	Q_{100}
2	Compute the flood depth, Y, per Level 1 procedures in SSA2-96	Y
3	Compute the Median Riprap Stone Size, D_{50}, using Figure 1.	D_{50}
4	Compute the total scour depth, d_s, per Level 1 procedures in SSA5-96 (State Standard for Watercourse System Sediment Balance)	d_s
5	Compute the required Height of the Bank Protection, H, as follows: H (feet) = Y, if Y $\leq$ the existing bank height;[1] H (feet) = The existing bank height, if Y > existing bank height	H
6	Compute the Riprap Layer Thickness, T, as follows: T (feet) = 2 x D_{50} for hand-placed material; T (feet) = 3 x D_{50} for dumped material	T
7	Compute the Length of Top-of-Bank Key-In, L_k, as the greater of the two values determined as follows: L_k (feet) = 5 x (Y-H) L_k (feet) = 2 x T	L_k
8	Compute the Width of the Bank Stabilization Cut-off, W, as follows: W (feet) = 5 x H This is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the bank stabilization in order to prevent outflanking by the streamflow.	W

[1] NOTE: Due to the very conservative nature of the level 1 flood depth estimate a freeboard component is not included in this level 1 height of bank protection estimate.

TABLE 2: LEVEL 1 WIRE-TIED ROCK MATTRESS DESIGN PARAMETERS		
Step No.	**Level 1 Wire-Tied Rock Mattress Bank-Stabilization Design Parameter Description (See Appendix A for Typical Section)**	**Variable Determined**
1	Compute the 100-year discharge, Q_{100}, per Level 1 procedures in SSA2-96 ("Requirements for Floodplain and Floodway Delineation in Riverine Environments")	Q_{100}
2	Compute the flood depth, Y, per Level 1 procedures in SSA2-96	Y
3	Compute the total scour depth, d_s, per Level 1 procedures in SSA5-96 (State Standard for Watercourse System Sediment Balance)	d_s
4	Compute the required Height of Bank Protection, H, as follows: H (feet) = Y, if Y $\leq$ the existing bank height;[2] H (feet) = The existing bank height, if Y > existing bank height	H
5	Determine the Wire-Tied Rock Mattress Thickness, T, using Table 5.	T
6	Compute the Length of the Toe Apron, L_{ta}, as follows: L_{ta} (feet) = 2.24 x d_s	L_{ta}
7	Compute the Length of the Top-of-Bank Key-In, L_k, as the greater of the two values determined as follows: L_k (feet) = 5 x (Y-H) L_k (feet) = 2 x T	L_k
8	Compute the Width of Bank Stabilization Cut-off, W, as follows: W (feet) = 5 x H This is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the bank stabilization in order to prevent outflanking by the streamflow.	W

[2] NOTE: Due to the very conservative nature of the level 1 flood depth estimate a freeboard component is not included in this level 1 height of bank protection estimate.

TABLE 3: LEVEL 2 ROCK RIPRAP DESIGN PARAMETERS		
Step No.	**Level 2 Riprap Bank-Stabilization Design Parameter Description (See Appendix A for Typical Section)**	**Variable Determined**
1	Compute the 100-year discharge, Q_{100}, per Level 2 procedures in SSA2-96 ("Requirements for Floodplain and Floodway Delineation in Riverine Environments")	Q_{100}
2	Compute the flood depth, Y, per Level 2 procedures in SSA2-96	Y
3	Compute freeboard, FB, per "Design Manual for Engineering Analysis of Fluvial Systems," ADWR, 1985, Section 4.6.5. Eqn. 4.28a	FB
4	Compute the Median Riprap Stone Size, D_{50}, using Figure 2.	D_{50}
5	Compute the total scour depth, d_s, per Level 2 procedures in SSA5-96 (State Standard for Watercourse System Sediment Balance)	d_s
6	Compute the required Height of Bank Protection, H, as follows: H (feet) = the existing bank height, if Y+FB > existing bank height; H (feet) = Y+FB, if Y+FB $\leq$ existing bank height	H
7	Compute the Riprap Layer Thickness, T, as follows: T (feet) = 2 x D_{50} , for hand placed or keyed in place material; T (feet) = 3 x D_{50} , for dumped material	T
8	Compute the Length of the Top-of-Bank Key-In, L_k, as the greater of the two values determined as follows: L_k (feet) = 5 x (Y-H) L_k (feet) = 2 x T	L_k
9	Compute the Width of Bank Stabilization Cut-off, W, as follows: W (feet) = 5 x H This is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the bank stabilization in order to prevent outflanking by the streamflow.	W

TABLE 4: LEVEL 2 WIRE-TIED ROCK MATTRESS DESIGN PARAMETERS		
Step No.	**Level 2 Wire-Tied Rock Mattress Bank Stabilization Design Parameter Description (See Appendix A for Typical Section)**	**Variable Determined**
1	Compute the 100-year discharge, Q_{100}, per Level 2 procedures in SSA2-96 ("Requirements for Floodplain and Floodway Delineation in Riverine Environments")	Q_{100}
2	Compute the flood depth, Y, per Level 2 procedures in SSA2-96	Y
3	Compute freeboard, FB, per "Design Manual for Engineering Analysis of Fluvial Systems," ADWR, 1985, Section 4.6.5. Eqn. 4.28a	FB
4	Compute the total scour depth, d_s, per Level 2 procedures in SSA5-96 (State Standard for Watercourse System Sediment Balance)	d_s
5	Compute the required Height of Bank Protection, H, as follows: H (feet) = the existing bank height, if Y+FB > existing bank height; H (feet) = Y+FB, if Y+FB $\leq$ existing bank height	H
6	Determine the Wire-Tied Rock Mattress Thickness, T, using Table 6.	T
7	Compute the Length of the Toe Apron, L_{ta}, as follows: L_{ta} (feet) = 2.24 x d_s	L_{ta}
8	Compute the Length of the Top-of-Bank Key-In, L_k, as the greater of the two values determined as follows: L_k (feet) = 5 x (Y-H) L_k (feet) = 2 x T	L_k
9	Compute the Width of Bank Stabilization Cut-off, W, as follows: W (feet) = 5 x H This is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the bank stabilization in order to prevent outflanking by the streamflow	W

TABLE 5: LEVEL 1 WIRE-TIED ROCK MATTRESS THICKNESS		
MINIMUM RECOMMENDED STANDARD WIRE-TIED ROCK MATTRESS THICKNESS (FT)	APPLICABLE DISCHARGE RANGE (CFS)	
	FOR STRAIGHT REACHES	FOR CURVED REACHES
0.75	0 TO 1,250	0 TO 300
1.00	1,250 TO 2,500	300 TO 600
1.50	2,500 TO 7,000	600 TO 1,800
3.00	7,000 TO 40,000	1,800 TO 10,000

NOTE: The thickness of mattresses used as bank toe aprons should be a minimum of 12 inches.

REFERENCES: Standard Wire-Tied Rock Mattress Thicknesses from FHWA, HEC-11, 1989; Discharge Ranges based on thickness criteria from "Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona," 1989, combined with Level 1 Median Riprap Stone Size procedure (see Figure 1).

TABLE 6: LEVEL 2 WIRE-TIED ROCK MATTRESS THICKNESS					
MINIMUM RECOMMENDED STANDARD WIRE-TIED ROCK MATTRESS THICKNESS (FT)	APPLICABLE VELOCITY RANGE (FT/S)				
	FOR BEND ANGLE ≤ 18°	FOR BEND ANGLE = 25°	FOR BEND ANGLE = 35°	FOR BEND ANGLE = 45°	FOR BEND ANGLE 60°
0.75	UP TO 9	UP TO 7	UP TO 6	UP TO 5	UP TO 4
1.00	9 TO 10	7 TO 9	6 TO 7	5 TO 6	4 TO 5
1.50	10 TO 13	9 TO 11	7 TO 9	6 TO 7	5 TO 6
3.00	13 TO 18	11 TO 15	9 TO 13	7 TO 11	6 TO 9

NOTE: The thickness of mattresses used as toe aprons should be a minimum of 12 inches.

REFERENCES: Standard Wire-Tied Rock Mattress Thicknesses from FHWA, HEC-11, 1989; Velocity Ranges based on thickness criteria from "Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona," 1989, combined with Level 2 Median Riprap Stone Size procedure (see Figure 2).

FIGURE 1

Level 1 Median Riprap Stone Size (D50)

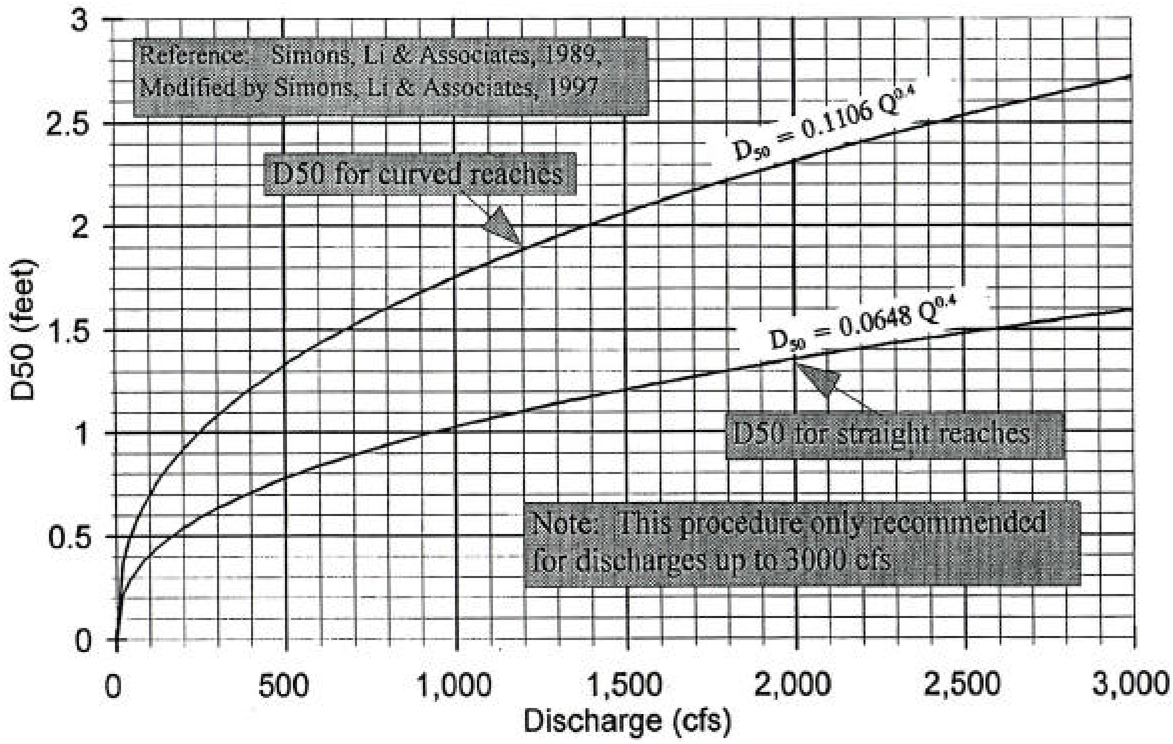
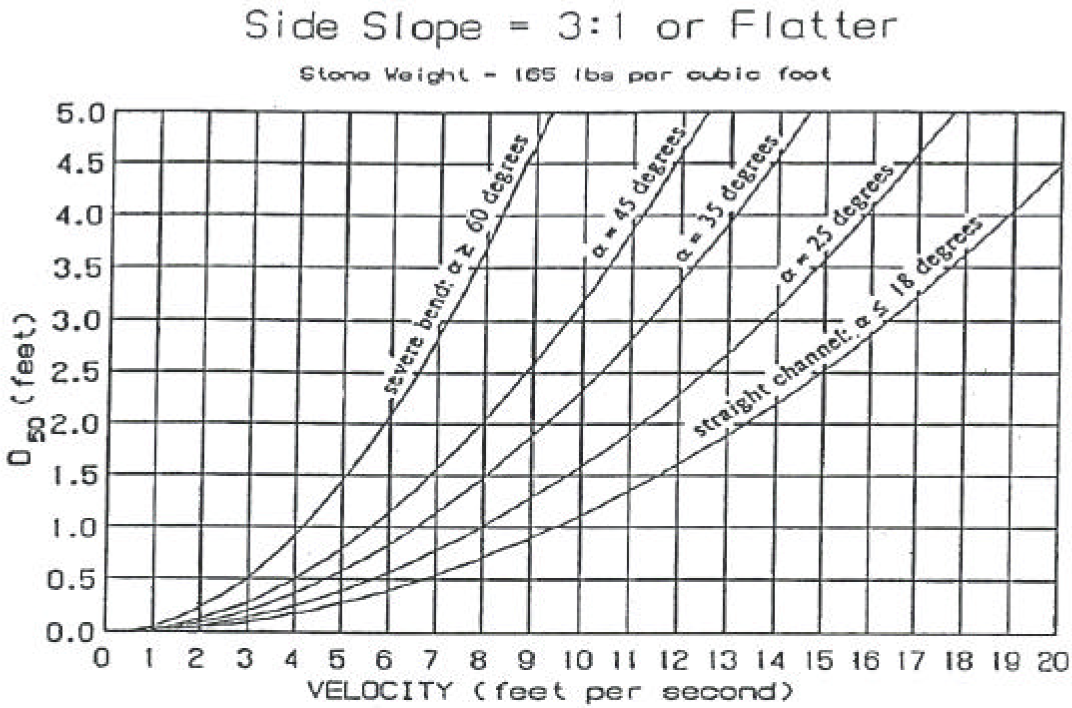
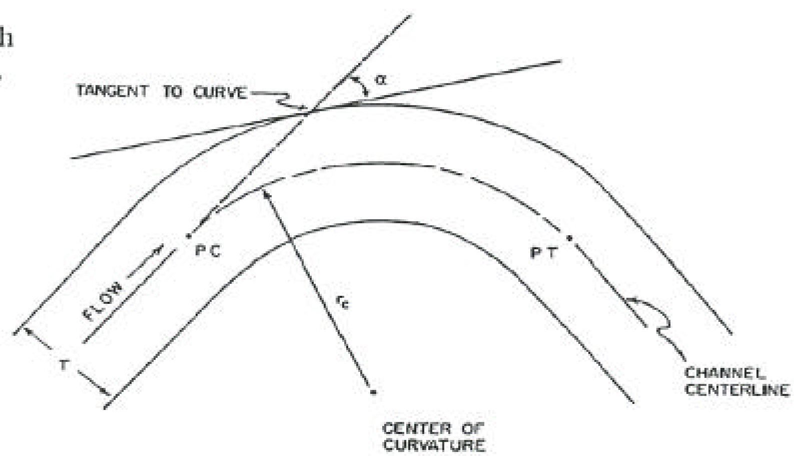


FIGURE 2
Level 2 Median Riprap Stone Size (D_{50})



NOTE: For side slope = 2:1 multiply D_{50} determined from chart by 1.14. Side slopes steeper than 2:1 should not be used.

Definition Sketch for bend angle α



PT = Downstream point of tangency to the centerline radius of curvature.
PC = Upstream point of curvature at the centerline radius of curvature.

SOURCE: SIMONS, LI & ASSOCIATES, INC. (1988)

Level 3: Applicable to All Five Selected Stabilization Methods

This level of evaluation should be utilized for all but the simplest bank-stabilization projects (i.e., all but those which can be addressed within the constraints outlined for Level 1 and Level 2 conditions). This level of evaluation involves modeling of both the hydraulic and sediment-transport characteristics of the local watercourse in order to simulate the erosion/sedimentation and channel deformation processes which are expected to occur in the area proposed for bank stabilization. For this level of analysis, Level 3 hydrologic and floodplain analysis should be performed (per SSA2-96), and Level 3 sediment-transport modeling should be performed (per SSA5-96). Analysis and design should be performed by or under the direction of a Registered Engineer with experience in the fields of surface-water hydrology, hydraulics, sediment-transport, fluvial geomorphology, and the practical applications thereto. The following references are recommended for consultation in the design of the selected bank-stabilization methods:

For general information and guidance:

- "Streambank Protection Guidelines for Landowners and Local Governments," Malcolm P. Keown, U.S. Army Corp of Engineers, 1983.

- For purposes of hydrologic and floodplain analysis, the procedures referenced in SSA2-96 and SSA5-96 should be utilized.

- For design purposes, the references listed in Table 7 (following page) should be utilized.

- Table 8 provides a list of computer programs which are based on well-established procedures referenced for use in other parts of this standard.

Example Applications

Example applications of the Level 1 and Level 2 procedures for Rock-Riprap and Wire-Tied Rock Mattress designs are contained in Appendix B of this report. Example applications of Level 3 procedures can be found in the references listed in Table 7.

TABLE 7: REFERENCES RECOMMENDED FOR LEVEL 3 BANK-STABILIZATION DESIGN					
Reference	**Bank-Stabilization Method**				
	Rock Riprap	**Gabions/ Wire-Tied Rock**	**Concrete/ Shotcrete**	**Grouted Rock**	**Vegetation/ Bio-Mechanical**
"Drainage Design Manual for Maricopa County, Vol. II, Hydraulics," Flood Control District of Maricopa County, 1996	●	●	●		
"Standards Manual for Drainage Design and Floodplain Management in Tucson, Arizona," City of Tucson, 1989	●	●	●		
"Hydraulic Design of Flood Control Channels," U.S. Army Corp of Engineers (USACOE), Engineering Manual EM 1110-2-1601, 1995	●				
"Design of Riprap Revetment," Federal Highway Administration (FHWA), HEC-11, 1989	●	●	●	●	
"Urban Highways, Channel Lining Design Guidelines," Arizona Department of Transportation, 1989			●		
"Streambank and Shoreline Protection," Chapter 16, Engineering Field Handbook, Natural Resources Conservation Service, 1996					●

TABLE 8: RECOMMENDED COMPUTER PROGRAMS FOR LEVEL 3 BANK-STABILIZATION DESIGN					
Computer Program Reference	**Bank-Stabilization Method**				
	Rock Riprap	**Gabions/ Wire-Tied Rock**	**Concrete/ Shotcrete**	**Grouted Rock**	**Vegetation/ Bio-Mechanical**
HYCHL (SUBROUTINE OF HYDRAIN), FHWA, 1996[3]	●				
RIPRAP DESIGN 2.0, WEST Consultants, 1996	●				
RIPWIN, River & Stream Management Software Company, 1996	●				

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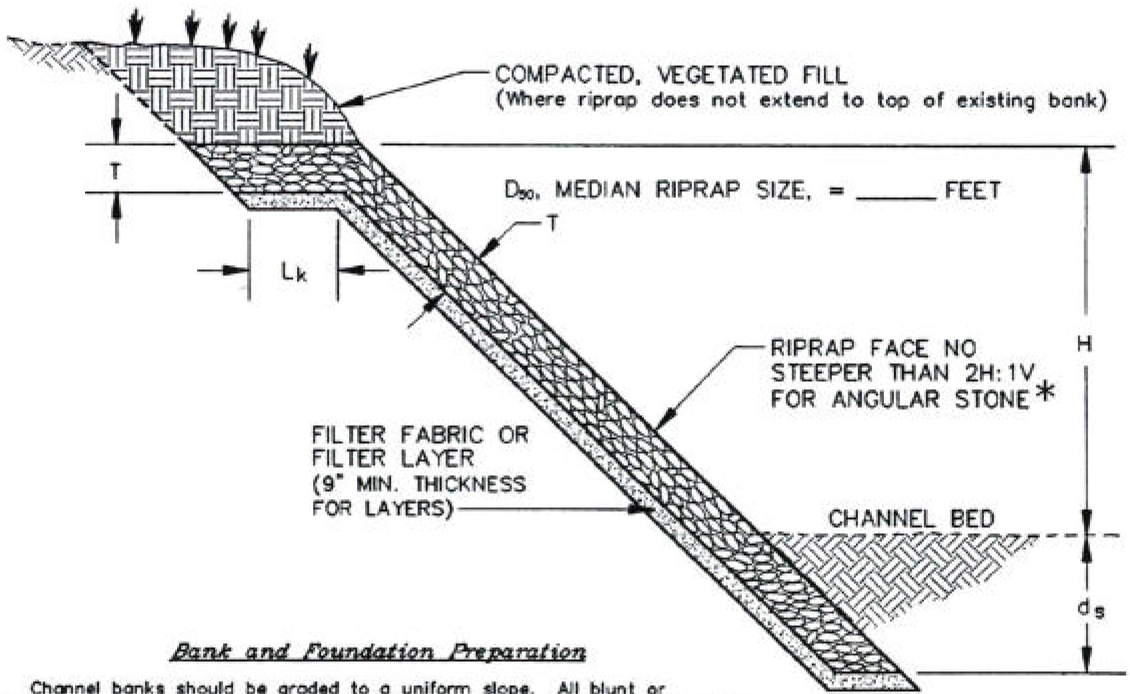
[3] It is noted that HYCHL includes methods for the evaluation of other bank-stabilization methods; however, they are based on procedures from HEC-15, which are intended for application where Q ≤ 50 cfs.

APPENDIX A

TYPICAL SECTIONS FOR LEVEL 1 / LEVEL 2 BANK STABILIZATION

TYPICAL DESIGN SECTION FOR ROCK RIPRAP BANK STABILIZATION



Design Dimensions as determined from Level 1 or Level 2 procedures.

Dimension	Value
H (feet)	
T (feet)	
d_s(feet)	
L_k(feet)	
W (feet)	

W is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the stabilization.

Bank and Foundation Preparation

Channel banks should be graded to a uniform slope. All blunt or sharp objects (such as rocks or tree roots) protruding from the graded surface should be removed. Large boulders near the outer edge of the toe and apron should be removed.

Riprap Gradation and Stone Shape

The gradation of rock riprap should follow a smooth curve. The ratio of the largest size rock to D_{50} should be about two, and the ratio of D_{20} to D_{50} should be about one-half. The stone should be hard, dense and durable and should be resisant to weathering and fracturing.

The shape of the riprap stone should be "blocky," rather than elongated. More nearly cubicle stones "nest" together, and are more resistant to movement. Also, stones with sharp, clean edges and relatively flat faces will form a riprap mass having an angle of internal friction greater than rounded stones, and therefore will be less susceptible to slope failures. The following shape specifications are suggested for riprap obtained from quarry operations:

* 1. The stone shall be predominantly angular in shape. Where angular stone is not available, side slopes should be no steeper than 3H:1V.
2. Not more than 25 percent of the stones reasonably distributed throughout the gradation shall have a length more than 2.5 times the breadth or thickness.
3. No stone shall have a length exceeding 3.0 times its breadth or thickness.

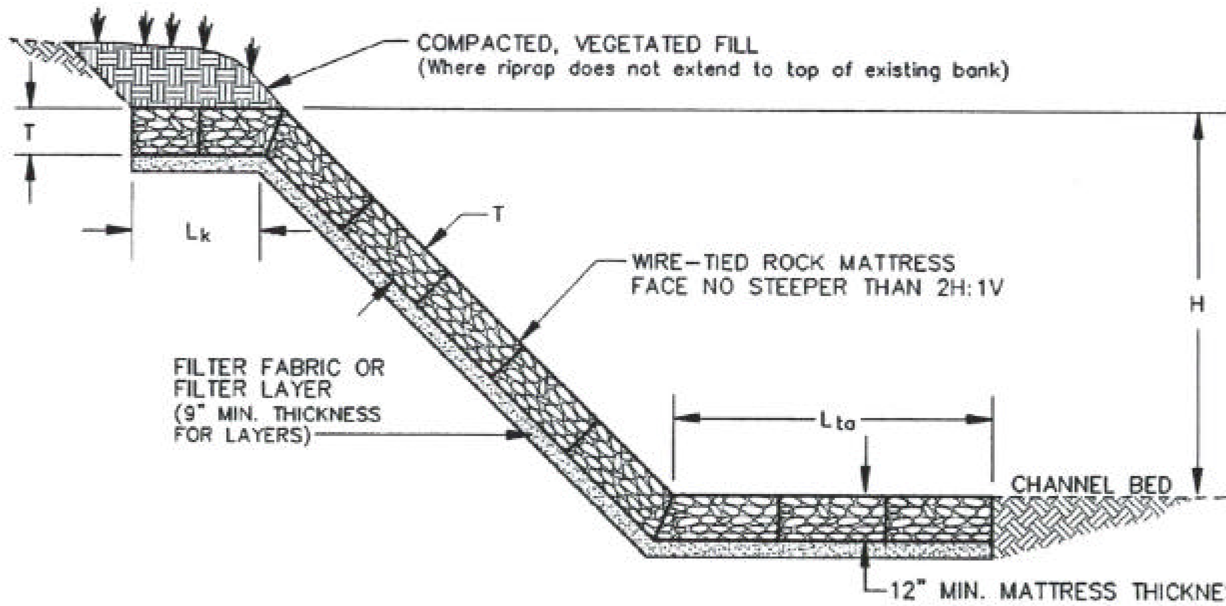
Riprap Filters

Filters are generally required underneath rock riprap to prevent fine material from being leached out through the riprap. Two types of filter materials are commonly used: gravel filters and fabric filters. Gravel filters consist of a layer of well-graded sands and gravels. Generally, the thickness of a gravel filter should not be less than nine inches, and may vary depending upon the riprap thickness. A suggested specification for a gravel-filter gradation is as follows:

$$\frac{D_{50}\,(\text{filter})}{D_{50}\,(\text{base})} < 40 \quad \textit{and} \quad \frac{D_{15}\,(\text{filter})}{D_{85}\,(\text{base})} < 5 < \frac{D_{15}\,(\text{filter})}{D_{15}\,(\text{base})} < 40$$

Fabric filter cloths have been used beneath riprap and other revetments with good success. Although some care must be exercised in placing large rocks on the fabrics, it is generally much easier and more economical to install a fabric filter than a gravel filter. Unfortunately, a fabric filter will also preclude the growth of vegetation through the riprap. Consult fabric manufacturer for design guidance if filter fabric is used.

TYPICAL DESIGN SECTION FOR WIRE-TIED ROCK MATTRESS BANK STABILIZATION



Design Dimensions as determined from Level 1 or Level 2 procedures.

Dimension	Value
H (feet)	
T (feet)	
L_{ta} (feet)	
L_k (feet)	
W (feet)	

W is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the stabilization.

Bank and Foundation Preparation

Channel banks should be graded to a uniform slope. All blunt or sharp objects (such as rocks or tree roots) protruding from the graded surface should be removed. Large boulders near the outer edge of the toe and apron area should be removed.

Mattress Unit Size and Configuration

Indivual mattress units should be a size that is easily handled on site. Commercially available gabion units come in standard sizes. Manufacturers literature indicates that alternative sizes can be manufactured when required, provided that the quantities involved are of a reasonable magnitude. The mattress should be divided into compartments so that failure of one section of the mattress will not cause loss of the entire mattress. Compartmentalization also adds to the structural integrity of individual gabion units. For this reason, it is recommended that diaphragms be installed at a nominal 2 foot spacing within each of the gabion units to provide the recommended compartmentalization.

Stone Size and Quality

The maximum size of stone should not exceed the thickness of individual mattress units. The stone should be well graded within the sizes available with no stone smaller than the wire–mesh opening. Common median stone size used in mattress design range from three to six inches for mattresses less than one foot thick. For mattresses of larger thickness, rock having median size up to one foot is used. The stone should be hard, dense, and durable and should be resistant to weathering and fracturing. No stone should have a length exceeding three times its breadth or length.

Basket Fabrication

Refer to FHWA HEC–11, "Design of Riprap Revetment", and to manufacturers literature and specifications.

Riprap Filters

Filters are generally required underneath rock riprap to prevent fine material from being leached out through the riprap. Two types of filter materials are commonly used: gravel filters and fabric filters. Gravel filters consist of a layer of well–graded sands and gravels. Generally, the thickness of a gravel filter should not be less than nine inches, and may vary depending upon the riprap thickness. A suggested specification for a gravel–filter gradation is as follows:

$$\frac{D_{50}\,(\text{filter})}{D_{50}\,(\text{base})} < 40 \quad \textit{and} \quad \frac{D_{15}\,(\text{filter})}{D_{85}\,(\text{base})} < 5 < \frac{D_{15}\,(\text{filter})}{D_{15}\,(\text{base})} < 40$$

Fabric filter cloths have been used beneath riprap and other revetments with good success. Although some care must be exercised in placing large rocks on the fabrics it is generally much easier and more economical to install a fabric filter than a gravel filter. Fabrics must be keyed in and overlapped and should preferably be of a non–woven type. Unfortunately, a fabric filter will also preclude the growth of vegetation through the riprap or, alternatively, the fabric can be damaged by vegetation. Consult fabric manufacturer for design guidance if filter fabric is used.

APPENDIX B

EXAMPLE APPLICATIONS

EXAMPLE APPLICATIONS

Problem Description: A 100 foot straight reach of a small wash near Holbrook, Arizona in Navajo County, Arizona has a contributing drainage area of 300 acres (0.47 square miles) and has been experiencing erosion along a bank which crosses a privately owned parcel. The owner of the parcel would like to protect the bank of the wash to prevent additional loss of land, loss of riparian vegetation and prevent eventual possible damage to a storage building near the bank. The height of the bank along the 100 foot reach is approximately 5 feet from the sand bed channel to the obvious point of inflection with the adjacent overbank area.

Objective: Develop a simple design for relatively inexpensive bank protection which either the owner can build or which can be built by a small contractor.

Level 1 Rock Riprap Design

The following steps follow the steps in Table 1 of this standard:

Step 1: A Level 1 100-year peak discharge (Q_{100}) of 1,800 cfs is determined using Figure D-1 from SSA 2-96 (Page D-2)

Step 2: A Level 1 flood depth (Y) of 4.7 feet is determined using the Region I-D equation on page E-1 of SSA 2-96.

Step 3: A Level 1 median riprap stone size (D_{50}) of 1.3 feet is determined from Figure 1 of this standard using the curve for straight reaches.

Step 4: A Level 1 total scour depth (d_s) of 4.9 feet is determined as the sum of 3.1 feet of general degradation plus 1.8 feet of long-term degradation using the Level 1 equations for scour from pages CDE-2 and CDE-3, respectively, of SSA 5-96.

Step 5: The required height of bank protection (H) is set equal to the computed flood depth of 4.7 feet.

Step 6: The riprap layer thickness (T) is determined as 2 x D_{50} = 2.6 feet using the first equation (for hand placed material) for this step shown in this standard.

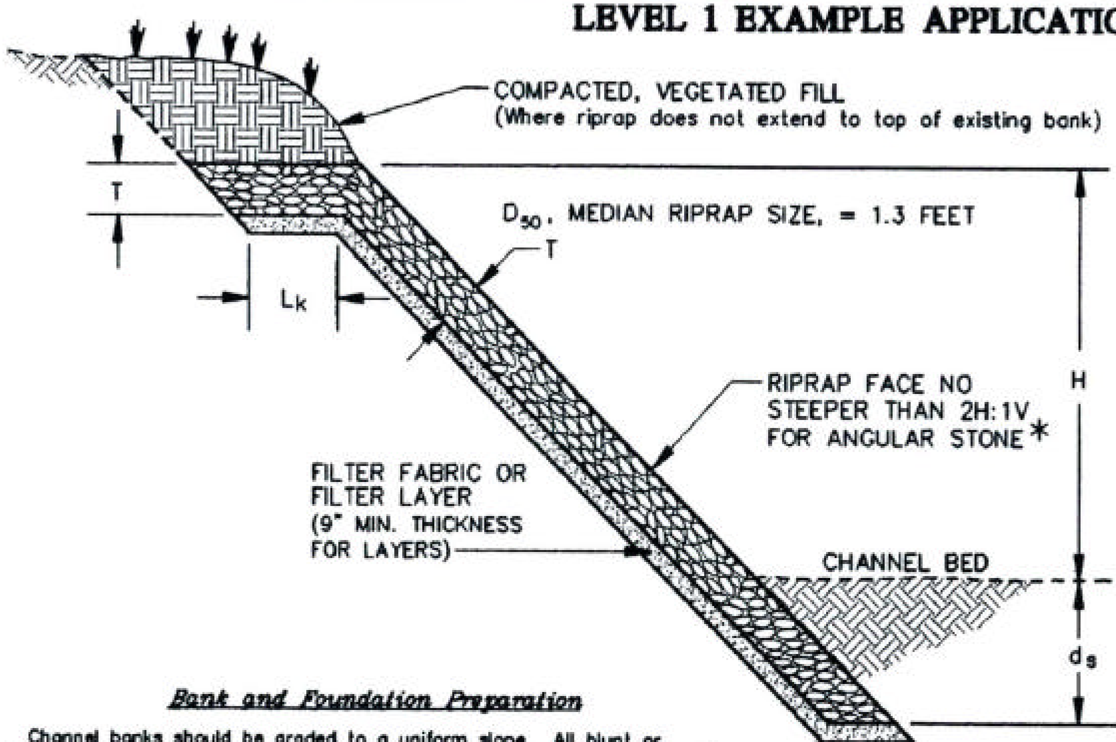
Step 7: The length of the top-of-bank key-in (L_k) is determined to be 2 x T = 5.2 feet.

Step 8: The width of the bank stabilization cut-off is determined to be 5 x H = 23.5 feet.

The typical section for rock riprap stabilization contained in Appendix A of this standard is completed by filling in the table of design parameters using the values determined in Steps 1 through 8. The resulting typical design section is attached. The typical section and supporting calculations are then submitted to the agency having jurisdiction for such activity for review and approval as required by this standard and the owner or his contractor can construct the stabilization along the threatened bank segment.

TYPICAL DESIGN SECTION FOR ROCK RIPRAP BANK STABILIZATION

LEVEL 1 EXAMPLE APPLICATION



Design Dimensions as determined from Level 1 or Level 2 procedures.

Dimension	Value
H (feet)	4.7
T (feet)	2.6
d_s(feet)	4.9
L_k(feet)	5.2
W (feet)	23.5

W is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the stabilization.

Bank and Foundation Preparation

Channel banks should be graded to a uniform slope. All blunt or sharp objects (such as rocks or tree roots) protruding from the graded surface should be removed. Large boulders near the outer edge of the toe and apron should be removed.

Riprap Gradation and Stone Shape

The gradation of rock riprap should follow a smooth curve. The ratio of the largest size rock to D_{50} should be about two, and the ratio of D_{20} to D_{50} should be about one-half. The stone should be hard, dense and durable and should be resisant to weathering and fracturing.

The shape of the riprap stone should be "blocky," rather than elongated. More nearly cubicle stones "nest" together, and are more resistant to movement. Also, stones with sharp, clean edges and relatively flat faces will form a riprap mass having an angle of internal friction greater than rounded stones, and therefore will be less susceptible to slope failures. The following shape specifications are suggested for riprap obtained from quarry operations:

* 1. The stone shall be predominantly angular in shape. Where angular stone is not available, side slopes should be no steeper than 3H:1V.

2. Not more than 25 percent of the stones reasonably distributed throughout the gradation shall have a length more than 2.5 times the breadth or thickness.

3. No stone shall have a length exceeding 3.0 times its breadth or thickness.

Riprap Filters

Filters are generally required underneath rock riprap to prevent fine material from being leached out through the riprap. Two types of filter materials are commonly used: gravel filters and fabric filters. Gravel filters consist of a layer of well-graded sands and gravels. Generally, the thickness of a gravel filter should not be less than nine inches, and may vary depending upon the riprap thickness. A suggested specification for a gravel-filter gradation is as follows:

$$\frac{D_{50}(\text{filter})}{D_{50}(\text{base})} < 40 \quad \textit{and} \quad \frac{D_{15}(\text{filter})}{D_{85}(\text{base})} < 5 < \frac{D_{15}(\text{filter})}{D_{15}(\text{base})} < 40$$

Fabric filter cloths have been used beneath riprap and other revetments with good success. Although some care must be exercised in placing large rocks on the fabrics, it is generally much easier and more economical to install a fabric filter than a gravel filter. Unfortunately, a fabric filter will also preclude the growth of vegetation through the riprap. Consult fabric manufacturer for design guidance if filter fabric is used.

Level 1 Wire-Tied Rock Mattress Design

The following steps follow the steps in Table 2 of this standard:

Step 1: A Level 1 100-year peak discharge (Q_{100}) of 1,800 cfs is determined using Figure D-1 from SSA 2-96 (Page D-2)

Step 2: A Level 1 flood depth (Y) of 4.7 feet is determined using the Region I-D equation on page E-1 of SSA 2-96.

Step 3: A Level 1 total scour depth (d_s) of 4.9 feet is determined as the sum of 3.1 feet of general degradation plus 1.8 feet of long-term degradation using the Level 1 equations for scour from pages CDE-2 and CDE-3, respectively, of SSA 5-96.

Step 4: The required height of bank protection (H) is set equal to the computed flood depth of 4.7 feet.

Step 5: The wire-tied rock mattress thickness (T) is determined to be 1.0 feet from Table 5 of this standard.

Step 6: The length of toe apron (L_{ta}) is determined to be 2.24 x d_s = 11.0 feet.

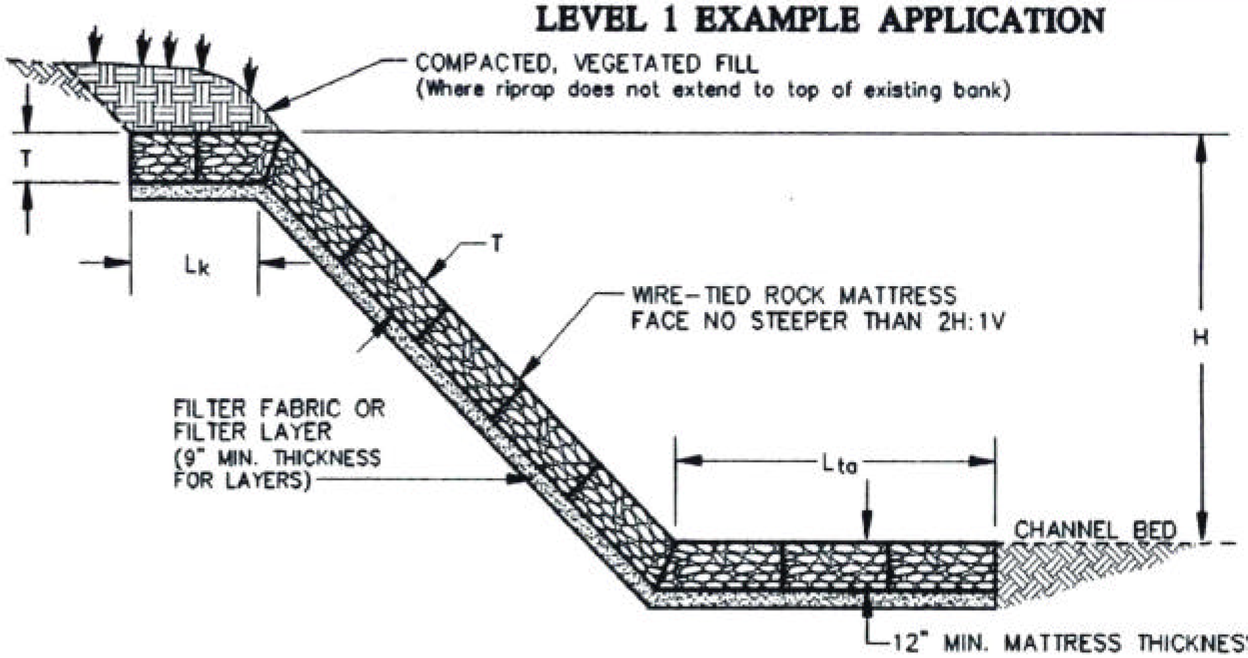
Step 7: The length of the top-of-bank key-in (L_k) is determined to be 2 x T = 2.0 feet.

Step 8: The width of the bank stabilization cut-off is determined to be 5 x H = 23.5 feet.

The typical section for rock riprap stabilization contained in Appendix A of this standard is completed by filling in the table of design parameters using the values determined in Steps 1 through 8. The resulting typical design section is attached. The typical section and supporting calculations are then submitted to the agency having jurisdiction for such activity for review and approval as required by this standard and the owner or his contractor can construct the stabilization along the threatened bank segment.

TYPICAL DESIGN SECTION FOR WIRE-TIED ROCK MATTRESS BANK STABILIZATION

LEVEL 1 EXAMPLE APPLICATION



Design Dimensions as determined from Level 1 or Level 2 procedures.

Dimension	Value
H (feet)	4.7
T (feet)	1.0
L_{ta} (feet)	11.0
L_k (feet)	2.0
W (feet)	23.5

W is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the stabilization.

Bank and Foundation Preparation

Channel banks should be graded to a uniform slope. All blunt or sharp objects (such as rocks or tree roots) protruding from the graded surface should be removed. Large boulders near the outer edge of the toe and apron area should be removed.

Mattress Unit Size and Configuration

Indivual mattress units should be a size that is easily handled on site. Commercially available gabion units come in standard sizes. Manufacturers literature indicates that alternative sizes can be manufactured when required, provided that the quantities involved are of a reasonable magnitude. The mattress should be divided into compartments so that failure of one section of the mattress will not cause loss of the entire mattress. Compartmentalization also adds to the structural integrity of individual gabion units. For this reason, it is recommended that diaphragms be installed at a nominal 2 foot spacing within each of the gabion units to provide the recommended compartmentalization.

Stone Size and Quality

The maximum size of stone should not exceed the thickness of individual mattress units. The stone should be well graded within the sizes available with no stone smaller than the wire-mesh opening. Common median stone size used in mattress design range from three to six inches for mattresses less than one foot thick. For mattresses of larger thickness, rock having median size up to one foot is used. The stone should be hard, dense, and durable and should be resistant to weathering and fracturing. No stone should have a length exceeding three times its breadth or length

Basket Fabrication

Refer to FHWA HEC-11, "Design of Riprap Revetment", and to manufacturers literature and specifications.

Riprap Filters

Filters are generally required underneath rock riprap to prevent fine material from being leached out through the riprap. Two types of filter materials are commonly used: gravel filters and fabric filters. Gravel filters consist of a layer of well-graded sands and gravels. Generally, the thickness of a gravel filter should not be less than nine inches, and may vary depending upon the riprap thickness. A suggested specification for a gravel-filter gradation is as follows:

$$\frac{D_{50}(\text{filter})}{D_{50}(\text{base})} < 40 \quad \textit{and} \quad \frac{D_{15}(\text{filter})}{D_{85}(\text{base})} < 5 < \frac{D_{15}(\text{filter})}{D_{15}(\text{base})} < 40$$

Fabric filter cloths have been used beneath riprap and other revetments with good success. Although some care must be exercised in placing large rocks on the fabrics, it is generally much easier and more economical to install a fabric filter than a gravel filter. Fabrics must be keyed in and overlapped and should preferably be of a non-woven type. Unfortunately, a fabric filter will also preclude the growth of vegetation through the riprap or, alternatively, the fabric can be damaged by vegetation. Consult fabric manufacturer for design guidance if filter fabric is used.

Level 2 Rock Riprap Design

The following steps follow the steps in Table 3 of this standard:

Step 1: A Level 2 100-year peak discharge (Q_{100}) of 526 cfs is determined using Table G-4 from SSA 2-96 (Page G-3) (an annual evaporation (EV) of 55 inches from Figure G-3).

Step 2: A Level 2 flood depth (Y) of 3.0 feet by applying the normal depth procedures as outlined in SSA 2-96 (Page 7) to field surveyed cross-sections. A flow velocity (V) of 7 feet per second is also determined from the normal depth procedure.

Step 3: A Level 2 freeboard (FB) of 0.7 feet is determined from Eqn. 4.28a of the manual referenced for this step ("Engineering Analysis of Fluvial Systems", ADWR, 1985). The 0.7 foot value is based on the value of $2h_a = 2(.027xV^2) = 0.7$ and values of 0 for y_{se} and y_s due to the straight nature of the subject channel reach.

Step 4: A Level 2 median riprap stone size (D_{50}) of 0.6 feet is determined from Figure 2 of this standard using the curve for straight reaches.

Step 5: A Level 1 total scour depth (d_s) of 2.8 feet is determined as the sum of 1.9 feet of general degradation plus 0.9 feet of long-term degradation by applying the Level 2 100-year peak discharge of 526 cfs to the Level 1 equations for scour from pages CDE-2 and CDE-3, respectively, of SSA 5-96. Per SSA 5-96, a minimum total scour depth of 3.0 feet should be used. Application of the Level 2 procedures for scour from SSA 5-96 pages CDE 3 - CDE 6 indicates that the channel is erosive and that armoring will not control degradation so that the Level 1 total scour depth (d_s) of 3.0 feet, determined above, should be used.

Step 6: The required height of bank protection is determined as the sum of the computed flood depth (Y) of 3.0 feet plus the 0.7 foot freeboard (FB) for a total height (H) of 3.7 feet.

Step 7: The riprap layer thickness (T) is determined as 2 x D_{50} = 1.2 feet using the first equation (for hand placed material) for this step shown in this standard.

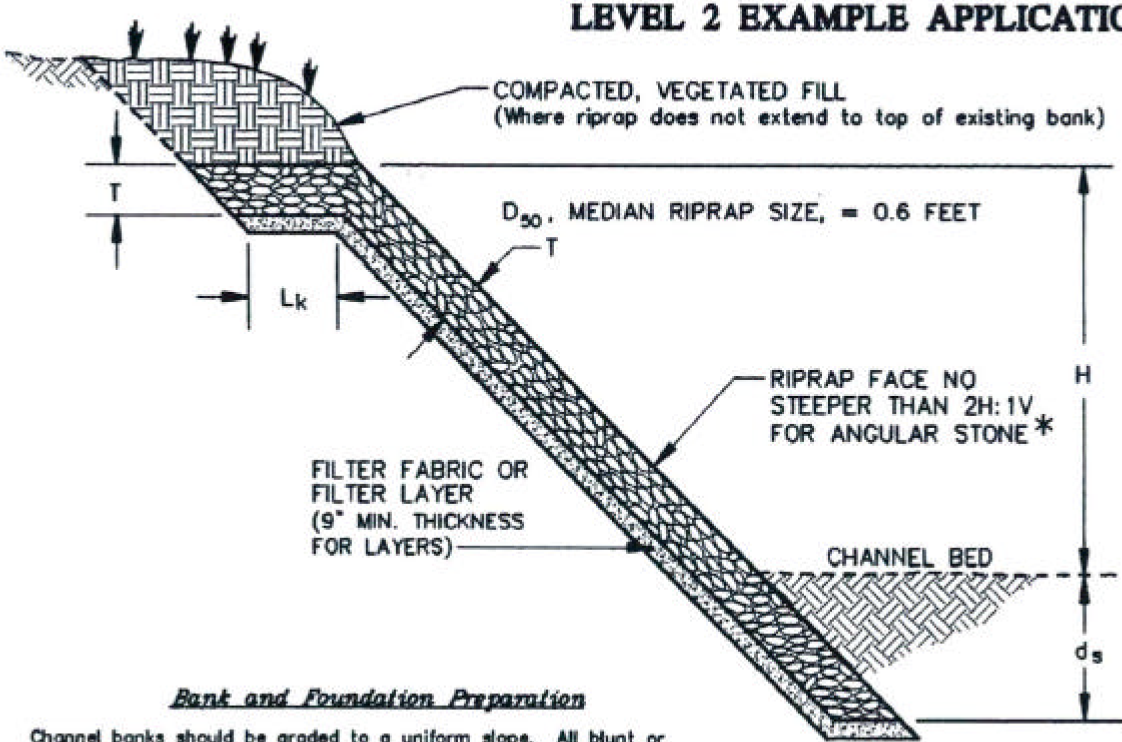
Step 8: The length of the top-of-bank key-in (L_k) is determined to be 2 x T = 2.4 feet.

Step 9: The width of the bank stabilization cut-off is determined to be 5 x H = 18.5 feet.

The typical section for rock riprap stabilization contained in Appendix A of this standard is completed by filling in the table of design parameters using the values determined in Steps 1 through 8. The resulting typical design section is attached. The typical section and supporting calculations are then submitted to the agency having jurisdiction for such activity for review and approval as required by this standard and the owner or his contractor can construct the stabilization along the threatened bank segment.

TYPICAL DESIGN SECTION FOR ROCK RIPRAP BANK STABILIZATION

LEVEL 2 EXAMPLE APPLICATION



Design Dimensions as determined from Level 1 or Level 2 procedures.

Dimension	Value
H (feet)	3.7
T (feet)	1.2
d_s(feet)	3.0
L_k(feet)	2.4
W (feet)	18.5

W is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the stabilization.

Bank and Foundation Preparation

Channel banks should be graded to a uniform slope. All blunt or sharp objects (such as rocks or tree roots) protruding from the graded surface should be removed. Large boulders near the outer edge of the toe and apron should be removed.

Riprap Gradation and Stone Shape

The gradation of rock riprap should follow a smooth curve. The ratio of the largest size rock to D_{50} should be about two, and the ratio of D_{20} to D_{50} should be about one-half. The stone should be hard, dense and durable and should be resisant to weathering and fracturing.

The shape of the riprap stone should be "blocky," rather than elongated. More nearly cubicle stones "nest" together, and are more resistant to movement. Also, stones with sharp, clean edges and relatively flat faces will form a riprap mass having an angle of internal friction greater than rounded stones, and therefore will be less susceptible to slope failures. The following shape specifications are suggested for riprap obtained from quarry operations:

* 1. The stone shall be predominantly angular in shape. Where angular stone is not available, side slopes should be no steeper than 3H:1V.

2. Not more than 25 percent of the stones reasonably distributed throughout the gradation shall have a length more than 2.5 times the breadth or thickness.

3. No stone shall have a length exceeding 3.0 times its breadth or thickness.

Riprap Filters

Filters are generallly required underneath rock riprap to prevent fine material from being leached out through the riprap. Two types of filter materials are commonly used: gravel filters and fabric filters. Gravel filters consist of a layer of well-graded sands and gravels. Generally, the thickness of a gravel filter should not be less than nine inches, and may vary depending upon the riprap thickness. A suggested specification for a gravel-filter gradation is as follows:

$$\frac{D_{50}(\text{filter})}{D_{50}(\text{base})} < 40 \quad \textit{and} \quad \frac{D_{15}(\text{filter})}{D_{85}(\text{base})} < 5 < \frac{D_{15}(\text{filter})}{D_{15}(\text{base})} < 40$$

Fabric filter cloths have been used beneath riprap and other revetments with good success. Although some care must be exercised in placing large rocks on the fabrics, it is generally much easier and more economical to install a fabric filter than a gravel filter. Unfortunately, a fabric filter will also preclude the growth of vegetation through the riprap. Consult fabric manufacturer for design guidance if filter fabric is used.

Level 2 Wire-Tied Rock Mattress Design

The following steps follow the steps in Table 4 of this standard:

Step 1: A Level 2 100-year peak discharge (Q_{100}) of 526 cfs is determined using Table G-4 from SSA 2-96 (Page G-3) (an annual evaporation (EV) of 55 inches from Figure G-3).

Step 2: A Level 2 flood depth (Y) of 3.0 feet by applying the normal depth procedures as outlined in SSA 2-96 (Page 7) to field surveyed cross-sections. A flow velocity (V) of 7 feet per second is also determined from the normal depth procedure.

Step 3: A Level 2 freeboard (FB) of 0.7 feet is determined from Eqn. 4.28a of the manual referenced for this step ("Engineering Analysis of Fluvial Systems", ADWR, 1985). The 0.7 foot value is based on the value of $2h_a = 2(.027xV^2) = 0.7$ and values of 0 for y_{se} and y_s due to the straight nature of the subject channel reach.

Step 4: A Level 1 total scour depth (d_s) of 2.8 feet is determined as the sum of 1.9 feet of general degradation plus 0.9 feet of long-term degradation by applying the Level 2 100-year peak discharge of 526 cfs to the Level 1 equations for scour from pages CDE-2 and CDE-3, respectively, of SSA 5-96. Per SSA 5-96, a minimum total scour depth of 3.0 feet should be used. Application of the Level 2 procedures for scour from SSA 5-96 pages CDE 3 - CDE 6 indicates that the channel is erosive and that armoring will not control degradation so that the Level 1 total scour depth (d_s) of 3.0 feet, determined above, should be used.

Step 5: The required height of bank protection is determined as the sum of the computed flood depth (Y) of 3.0 feet plus the 0.7 foot freeboard (FB) for a total height (H) of 3.7 feet.

Step 6: The wire-tied rock mattress thickness (T) is determined to be 0.75 feet from Table 6 of this standard.

Step 7: The length of toe apron (L_{ta}) is determined to be 2.24 x d_s = 6.7 feet.

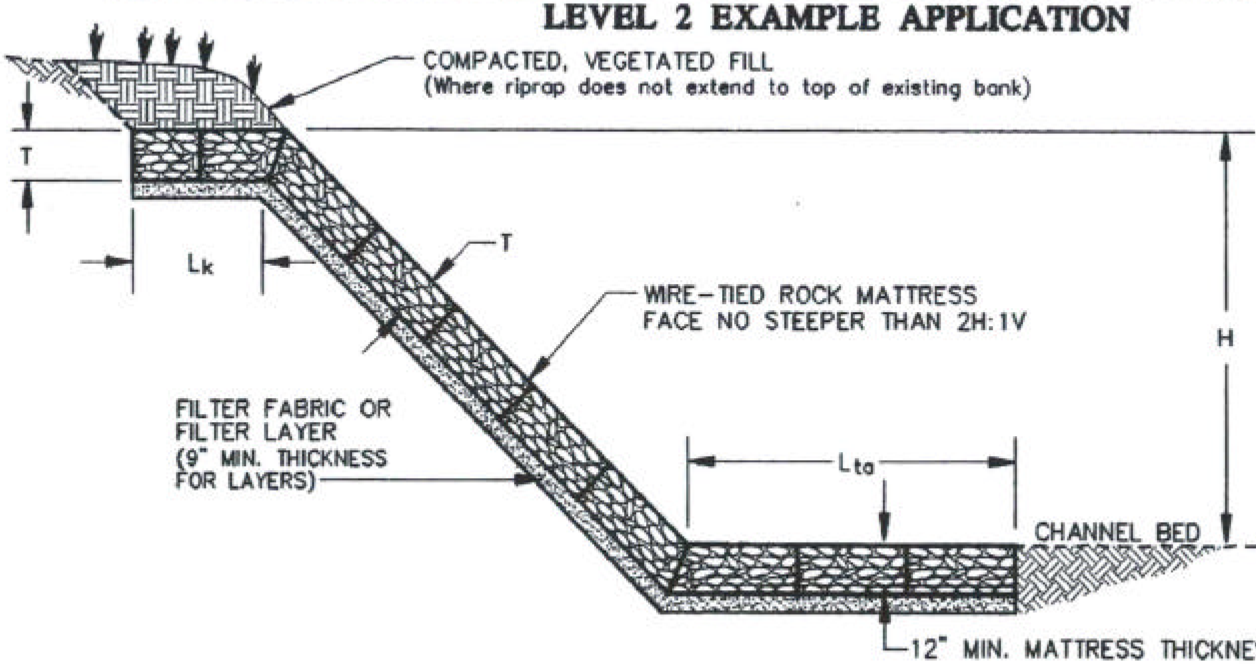
Step 8: The length of the top-of-bank key-in (L_k) is determined to be 2 x T = 1.5 feet.

Step 9: The width of the bank stabilization cut-off is determined to be 5 x H = 18.5 feet.

The typical section for rock riprap stabilization contained in Appendix A of this standard is completed by filling in the table of design parameters using the values determined in Steps 1 through 8. The resulting typical design section is attached. The typical section and supporting calculations are then submitted to the agency having jurisdiction for such activity for review and approval as required by this standard and the owner or his contractor can construct the stabilization along the threatened bank segment.

TYPICAL DESIGN SECTION FOR WIRE-TIED ROCK MATTRESS BANK STABILIZATION

LEVEL 2 EXAMPLE APPLICATION



Design Dimensions as determined from Level 1 or Level 2 procedures.

Dimension	Value
H (feet)	3.7
T (feet)	0.75
L_{ta} (feet)	6.7
L_k (feet)	1.5
W (feet)	18.5

W is the distance which the bank stabilization should be keyed back into the existing bank at the upstream and downstream ends of the stabilization.

Bank and Foundation Preparation

Channel banks should be graded to a uniform slope. All blunt or sharp objects (such as rocks or tree roots) protruding from the graded surface should be removed. Large boulders near the outer edge of the toe and apron area should be removed.

Mattress Unit Size and Configuration

Indivual mattress units should be a size that is easily handled on site. Commercially available gabion units come in standard sizes. Manufacturers literature indicates that alternative sizes can be manufactured when required, provided that the quantities involved are of a reasonable magnitude. The mattress should be divided into compartments so that failure of one section of the mattress will not cause loss of the entire mattress. Compartmentalization also adds to the structural integrity of individual gabion units. For this reason, it is recommended that diaphragms be installed at a nominal 2 foot spacing within each of the gabion units to provide the recommended compartmentalization.

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Basket Fabrication

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Riprap Filters

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$$\frac{D_{50}(\text{filter})}{D_{50}(\text{base})} < 40 \quad \textit{and} \quad \frac{D_{15}(\text{filter})}{D_{85}(\text{base})} < 5 < \frac{D_{15}(\text{filter})}{D_{15}(\text{base})} < 40$$

Fabric filter cloths have been used beneath riprap and other revetments with good success. Although some care must be exercised in placing large rocks on the fabrics, it is generally much easier and more economical to install a fabric filter than a gravel filter. Fabrics must be keyed in and overlapped and should preferably be of a non-woven type. Unfortunately, a fabric filter will also preclude the growth of vegetation through the riprap or, alternatively, the fabric can be damaged by vegetation. Consult fabric manufacturer for design guidance if filter fabric is used.