1
APPENDICES

Appendix 1

Riprap Quality: Riprap quality determination refers to the physical characteristics on the rock particles that make up the bank protection. Qualities determined to be most important include density, durability and shape. Requirements for each of these properties are outlined in the specifications:

Specific Gravity (Density): The design stone size for a channel depends on the particle weight, which is a function of the density or specific gravity of the rock material. The minimum value for specific gravity is 2.5. All stones composing the riprap should have a specific gravity equal to or exceeding 2.5, as determined by standard test procedures in ASTM C127.

Durability: Durability addresses the in-place performance of the individual rock particles. The rock particles must have sufficient strength to withstand abrasive action without reducing the gradation below specified limits. Qualitatively, a stone that is hard, dense, and resistant to weathering and water action should be used.

Laboratory tests should be conducted to document the quality of the rock. Specified tests that should be used to determine durability include: the durability index and absorption test (ASTM C127). Based on these tests the durability absorption ratio (DAR) is computed, using Equation 7.8, as follows:

$$D.A.R. = \frac{Durability\ Index}{\%\ Absorption\ +\ 1} \qquad \textbf{(A.1)}$$

The following specifications are used to accept or reject material:

1. DAR greater than 23, material is accepted;

2. DAR less than 10, material is rejected;

3. DAR 10 through 23:

    a. Durability Index 52 or greater, material is accepted; and

    b. Durability Index 51 or less, material is rejected.

Shape: There are two basic shape criteria. First, the stones should be angular and, second, no more than 25 percent of the stones should have a length more than 2.5 times the breadth. Angularity is a qualitative parameter that is assessed by visual inspection. There are no standard tests used to evaluate this criteria.

Riprap Layer Characteristics: The major characteristics of the riprap layer include: characteristic size; gradation; thickness; and filter-blanket requirements.

Characteristic Size: The characteristic size in a riprap gradation is the D_{50}. This size represents the average diameter of a rock particle for which 50 percent of the gradation is finer, by weight.

Gradation: To form an interlocking mass of stones, a range of stone sizes must be specified. The object is to obtain a dense, uniform mass of durable, angular stones with no apparent voids. The recommended maximum stone size is 2 times the D_{50}, and the recommended minimum size is one-third of the D_{50}. A gradation coefficient of 1.5 is required and can be determined by the following equation:

$$G = (D_{84}/D_{50} + D_{50}/D_{16}) \qquad \textbf{(A.2)}$$

Table 7.4 provides design gradations for specified classes of riprap.

Thickness: The riprap-layer is to be at least 1.5 times the D_{100} value, but need not exceed twice the same value. The thickness is measured perpendicular to the slope upon which the riprap is placed.

Riprap linings shall have a minimum thickness of 1.5 times D_{100}.

Filter Blanket Requirements: The need for a filter blanket is a function of particle size ratios between the riprap and the underlying soil which comprise the channel bank. The inequities, Equations 7.10 and 7.11 that must be satisfied are as follows:

$$\frac{(D_{15})Filter}{(D_{85})Base} < 5 < \frac{(D_{15})Filter}{(D_{15})Base} \qquad \textbf{(A.3)}$$

$$\frac{(D_{50})Filter}{(D_{50})Base} < 40 \qquad \textbf{(A.4)}$$

The relationship must hold between the filter blanket and base material and between the riprap and filter blanket. If the inequities are satisfied by the riprap itself, then no filter blanket is required. If the difference between the base material and the riprap gradation is very large, then multiple filter layers may be necessary.

Table 7.4
Design Gradation for Specified Classes of Rip-Rap

Percent Passing	Size	D^{50} Class , In[(1)]						
		6	8	12	18	24	30	36
100 to 90	2.0 D_{50}	12	16	24	36	48	60	72
85 to 70	1.5 D_{50}	9	12	18	27	36	45	54
50 to 30	1.0 D_{50}	6	8	12	18	24	30	36
15 to 5	0.67 D_{50}	4	5	8	12	16	20	24
5 to 0	0.33 D_5	2	3	4	6	8	10	12

(1) Stone size in inches can be converted to an equivalent spherical stone by applying the equation:

$$D_s = (\frac{6W}{\Pi\gamma_s})\frac{1}{3} \qquad \textbf{(A.5)}$$

Where:

D_s = Equivalent volume spherical stone diameter, in feet.

W = Weight, in lbs.

γ = Saturated surface dry specific gravity of stone in lbs/ft^2

γ can range from 145 lbs/ft^3 to 160 lbs/ft^3.

To simplify the use of a gravel filter layer, Table 7.5 outlines recommended standard gradations. The Type I bedding in Table 7.5 is designed to be the lower layer in a two-layer filter for protecting fine grained soils. When the channel is excavated in coarse sand and gravel (i.e., 50 percent or more, by weight retained on a No. 40 sieve), only the Type II filter is required. Otherwise, two bedding layers, (Type I topped by Type II) are required. For the required bedding thickness, see Table 7.6.

Table 7.5
Gradation of Gravel Bedding

Standard Sieve Size	Type I	Type II
	(Percent Passing by Weight)	
3 inches	--	90-100
1-1/2 inches	--	--
3/4-inch	--	20-90
#4	95-100	0-20
#16	45-80	--
#50	10-30	--
#100	2-10	--
#200	0-2	0-3

Table 7.6
Thickness Requirements for Gravel Bedding

Rip-Rap Classification	Minimum Bedding Thickness, Inches		
	Fine Grain Native Soils		Coarse Grain Native Soil
	Type I	Type II	Type III
6 - 8	6	6	9
12	9	9	12
18	9	12	12
24	9	12	12
30	12	14	12
36	12	14	15

Filter Fabric Requirements: The design criteria for filter fabric are a function of the permeability of the fabric and the effective opening size. The permeability of the fabric must exceed the permeability of the underlying soil, and the apparent opening size (AOS) must be small enough to retain the soil.

The criteria for apparent opening size are as follows:

1. For soil less than 50 percent of the particles, by weight, passing a No. 200 sieve, the AOS should be less than 0.6 mm (a No. 50 sieve).

2. For soil with more than 50 percent of the particles, by weight, passing a No. 200 sieve, the AOS should be less than 0.3 mm (a No. 50 sieve).

The site conditions and specific applications and installation procedures must be carefully considered in evaluating filter fabric as a replacement for granular bedding material.

Hydraulic Design Requirements: Channel linings constructed of placed, graded riprap to control channel erosion have been found to be cost effective where channel reaches are relatively short, 0.25 miles or less. Situations where riprap linings may be appropriate are:

1. Major flows are found to produce channel velocities in excess of allowable non-eroding values;

2. Channel side slopes of 3:1; and

3. Rapid changes in channel geometry occur, such as channel bends and transitions.

Riprap Sizing: The procedures described in *Hydraulic Design of Flood Control Channels* (Corps of Engineers, EM-1110-2-1601, 1991) shall be used for the design of graded riprap channel linings or bank protection.

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