SLOPE PROTECTION
Revised Oct 98

1. Replacement or overlayment of the existing slope protection.

1.1. Replacement of the existing slope protection. Slope protection on the riverside slope of the flood control projects and on the channel slopes should be restored to the original thickness, gradation and quality as the existing protection. The original gradation can be obtained from the Local Protection Section. The rock quality and placement should conform to the requirements as described below.

1.2. Overlayment of the existing slope protection. If the slope protection will be overlain by a new layer, the existing protection may be considered a bedding material. The new layer should have the same thickness and gradation as the original, except that the new layer should be a minimum 15 inches thick. Thickness will be based on the placement, durability of rock, and on what can be obtained economically from the quarry.

1.3. Rock quality. The following requirements should be considered.

1.3.1. The rock should be sound durable stone, free from cracks, seams, shale parting, and overburden spoil. The minimum specific gravity of the rock should be 2.4.

1.3.2. Stone should be approximately rectangular in cross sections and be relatively free from thin slabby pieces having elongation ratio greater than 3. In no case should the quantity of stone having an elongation ratio greater than 3 exceed 5 percent by weight.

1.3.3. Deleterious substances in rock which include soft, friable particles, rock fines (3 inches and smaller), objectionable materials and other foreign matter, shall not exceed 5 percent.

1.3.4. The rock should be obtained from a COE approved source. A list of the approved sources is attached at the end of this appendix.

1.4. Placement. The stone protection should be placed to full layer thickness measured normal to the slope, in a manner that will minimize segregation and avoid displacing the underlying material. Stone should be placed by any method that will avoid segregation. Crawler type equipment or the operation of similar equipment that tends to crack or break the stone, will not be permitted on stone protection materials. The larger stone should be well distributed and the finished stone protection should be free from pockets of small stones and clusters of large stones.

1.5. Gradation. The original gradation should be used in the overlaid protection with a stone size recommended for 50 percent by weight. If quarry run rock is used, the quarry run rock should have 50% by weight rock specified at a minimum weight and no more than 15% rock less than 5 lbs. The 50 percent by weight, W_{50} specified should be approximately 1/4 of the maximum size stone w_{100}. The maximum size stone w_{100} should fit within the layer thickness used as determined from the spherical shape equation shown in paragraph 2.1 below. Shale particles are not allowed.

2. New slope protection. If modifications of the river channel or levee slope requires new slope protection the design analysis should be made with respect to the following criteria. The criteria applies to riprap design and evaluation for both open channel flow and for design for flow immediately downstream of stilling basins, miscellaneous structures, bridges and or other turbulent areas.

2.1 General. The ability of riprap slope protection to resist the erosive forces of channel flow depends on the interrelation of the following factors;

a. Stone-shape
b. Size
c. Weight
d. Durability of the stone used
e. Riprap gradation
f. Layer thickness
g. Channel alignment
h. Channel cross-section
g. Hydraulic gradient
i. Velocity distribution

Construction quality control of both stone protection and riprap placement is essential for successful bank protection. Riprap protection for flood-control channels and appurtenant structures should be designed so that any flood that could reasonably be expected to occur during the service life of the channel or structure would not cause damage exceeding nominal maintenance or replacement. Riprap should be blocky in shape rather than elongated, as more nearly cubical stones “nest” together best and are more resistance to movement. The stone should have sharp, angular, clean edges at the intersections of relatively flat faces. The stone should be predominantly angular in shape. The ability of riprap to resist erosion is related to size and weight of the stones. Design guidance is often expressed in terms of the stone size D%, where % denotes the percentage of the total weight of the graded material (total weight including quarry wastes and spalls) that contains stones of less weight. The relation between size and weight of stone is described herein using a spherical shape by the equation:

$$D\% = \left(\frac{6 * W\%}{p * g_s}\right)^{1/3}$$

where: *D%* = equivalent-volume spherical stone diameter, in feet.
W% = weight of individual stone having diameter of D%.

g_s = saturated surface dry specific or unit weight of stone, in pcf. The unit weight of stone g_s generally varies from 150 to 175 pcf.

2.2 Riprap guidance to be used in design are as follows.

2.2.1 EM-1110-2-1601, dated 1 July 1991 and Change 1, dated 30 June 1994: Used for guidance in computing the shear forces on riprap layers for both channel bottom and the side slopes of open channel flow conditions. Also this EM should be used for guidance in preparing riprap gradation and thickness to be required in plans and specifications for construction. If quarry run rock is used, adhere to paragraph 1.5 of this appendix for guidance, as used for replacement and overlay of the existing slope protection.

2.2.2 ETL 1110-2-120, is used for determining riprap gradation and thicknesses in design only within EM-1110-2-1601. This method for determining stone size uses depth-averaged velocity. The method is based on the idea that a designer will be able to estimate local velocity better than local boundary shear. This method is based on a large body of laboratory data that has been compared to available prototype data (Maynord 1988). This method is applicable to side slopes of 1(V) on 1.5(H) or flatter. Computer programs are available from the WES library. The latest programs to be used for open channel flow are “RIPRAP 15" and “CHANLPRO”, version 1.0, dated February 1997. “CHANLPRO” options are as follows:

a. Riprap Design
b. Gabion Design
c. Scour depth estimation

2.2.3 Memorandum Report : INVESTIGATION OF SCOUR AND PROTECTION AROUND BRIDGE PIERS, dated November 1974. The investigation Report was done by U S Army Engineer Waterways Experiment Station, Vicksburg Mississippi to determine the minimum stone size that would remain stable at the location of the most severe attack on willow mattresses around caissons of bridge piers. This method is to be used in turbulent areas around and downstream of Bridge Piers, Stilling Basins, and other turbulent areas of channels or streams upstream or downstream of structures. This method using equations with a Froude Number for flow, as follows:

$$F = \frac{\overline{V}}{\sqrt{g * D}}$$

where:

$\bar{V}$ = average velocity in the channel cross section
D = depth of flow at the pier or caisson
g = acceleration of gravity, ft /sec²

This report gives some empirical method equations for determining minimum stone size, predicting scour depth around piers or caissons and for estimating the minimum extent of protection upstream and downstream required from piers or caissons. General equations for determining an average stone, would be:

$$d_{50}/D = 2.5 * F^3$$

$$D_s / W_p = C * (D/ d_{50})^P * F^3$$

$$D_s / W_p = 75 * F^3 \quad \textit{(Blunt Piers / Caissons)}$$

$$D_s / W_p = 26 * F^3 \quad \textit{(Streamlined Piers / Caissons)}$$

where:

D = Depth of flow at pier or caisson
D_{max} = Maximum depth of flow in channel cross section

d_{50}	=	Average stone diameter in feet
D_s	=	Depth of scour
p	=	Exponent Assume p = 1.0
W_p	=	Width of pier
W_c	=	Width of caisson
W_m	=	Width of mattress or riprap protection around pier or caisson.
C	=	Coefficient: C= 1.4 for rectangular C= 1.0 for cylindrical (piers)

The length of the mattress or riprap protection should be as follows:

$$L_m(U.S.)/W_c = 290*(D/D_{max})^{1.7}*F^{2.8}$$

$$L_m(D.S.)/W_c = 3500*(D/D_{max})^{1.6}*F^{4.2}$$

where: L_m (D.S.) = Length of mattress or riprap protection downstream of caisson measured from the tail of the caisson

L_m (U.S.) = Length of mattress or riprap protection upstream of caisson measured from the front of the caisson

2.2.4 ISBASH'S Equation:

$$V_c = C*(2*g*\frac{g_s - g_w}{g_w})^{1/2}*(d_{50})^{1/2}$$

where: V_c = velocity, ft/sec

C = coefficient (0.86, high turbulence and 1.20, low turbulence)
g = acceleration of gravity, ft/sec^2
g_s = specific weight of rock, lb/ft^3
g_w = specific weight of water, lb/ft^3
d_{50} = average diameter of stone (ft)

The "ISBASH" method can be used in lieu of Memorandum Report described in par.6.2.3; INVESTIGATION OF SCOUR AND PROTECTION AROUND BRIDGE PIERS, for non-complex small projects for design around bridge piers, stilling basins, and other turbulent areas in the vicinity of hydraulic structures.

2.3 Self launching of riprap. The self launching approach for riprap offers economy and ease of construction by letting the stream do the excavation, since the stream works for free. However, it does require a larger volume of material in the toe section than if the toe is placed in an excavation since the launching process may be irregular. The launching of riprap is required where erodible soils in the channel bottom can be predicted, such as erodible sands or even highly weathered rock. The launch slope for a non-cohesive soil material is to be assumed at 1V on 2H. Thickness after launching is equal to 1.5 times the thickness T(inches) of the bank revetment or slope protection. Using these assumptions the volume needed is equal to 1.5T times the launch slope length times the computed scour depth ($D_{(scour)}$-ft). This equates to be the following:

$$Vol(\ ft^3/ft) = 1.5 * T/12\sqrt{5} * (\ D_{scour} - ft)$$

and the thickness of the new toe is = 3.35 T.

3. Kansas City District suggested riprap and bedding gradations. Gradations used in and around the Kansas City area for construction specifications are as follows.

SUGGESTED RIPRAP GRADATION

Weight per stone in lbs	Percent lighter than by weight
15-inch (minimum layer thickness)	
160	100

Weight per stone in lbs	Percent lighter than by weight
120	85-95
40	30-50
10	0-15
18-inch (minimum layer thickness)	
300	100
200	85-95
75	30-50
10	0-15
21-inch (minimum layer thickness)	
400	100
300	85-95
100	30-50
20	0-15
24-inch (minimum layer thickness)	
700	100
525	85-95
175	30-50
30	0-15
27-inch (minimum layer thickness)	
1000	100
750	85-95
250	30-50
35	0-15
30-inch (minimum layer thickness)	
1300	100
1000	85-95

Weight per stone in lbs	Percent lighter than by weight
325	30-50
45	0-15
33-inch (minimum layer thickness)	
1700	100
1300	85-95
425	30-50
60	015
36-inch (minimum layer thickness)	
2300	100
1725	85-95
575	30-50
80	0-15

SUGGESTED BEDDING GRADATION

Weight per stone in lbs	Percent lighter than by weight
6-inch (minimum layer thickness) Sieve size	
6	100
3	75-95
1	40-60
1/4	5-25

4. References. The following references are recommended.

4.1 EM-1110-2-1601, HYDRAULIC DESIGN OF FLOOD CONTROL CHANNELS, is used for guidance in computing the shear forces on riprap layers for both channel bottom and the side slopes of open channel flow conditions and guidance for preparing riprap gradations and thicknesses in construction specifications..

4.2 ETL 1110-2-120, includes additional guidance for riprap channel protection and is used for determining riprap gradation and thicknesses in design only within EM-1110-2-1601.

4.3 INVESTIGATION OF SCOUR AND PROTECTION AROUND BRIDGE PIERS, Memorandum Report dated November, 1974 done by U S Army Engineer Waterways Experiment Station, Vicksburg Mississippi. Method to be used in turbulent areas around and downstream of bridge piers, stilling basins, and other turbulent areas of channels or streams upstream or downstream of structures.

4.4 ETL 1110-2-318, DYNAMIC STABILITY OF DUMPED RIPRAP: The basic strategy of this method is to build an extensive stone berm which can adjust and deform in response to severe wave action.

4.5 ETL 1110-2-194, GABION CHANNEL CONTROL STRUCTURES. Present design criteria for channel control structures in trapezoidal channels constructed of gabions developed from model tests at Waterways Experiment Station.

4.6 ETL 1110-2-334, DESIGN AND CONSTRUCTION OF GROUTED RIPRAP, provides the design and construction guidance of grouted riprap.

4.7 ETL 1110-2-286, USE OF GEOTEXTILES UNDER RIPRAP, provides guidance for placement of plastic filter fabric beneath bedding and riprap as a filter for fine soil materials.

4.8 EM 1110-2-2302, CONSTRUCTION WITH LARGE STONE, provides guidance on effective and economical selection, evaluation, and use of large-stone materials in construction. Large stone refers to the size of granular construction materials generally coarser than aggregate, that is averaging 3 inches or greater.