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Use of Riprap for Bank Protection

Hydraulic Engineering Circular No. 11

June 1967

U.S. Department of Transportation
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FEDERAL HIGHWAY ADMINISTRATION

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16. Abstract

This manual provides detailed design guidance for sizing and placing riprap. Sketches illustrate design and placement for dumped stone, hand-placed, wire-enclosed, grouted and concrete bag riprap. Sample specifications for the various riprap materials are provided.

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U.S. DEPARTMENT OF TRANSPORTATION

Bureau of Public Roads

USE OF RIPRAP FOR BANK PROTECTION

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I - INTRODUCTION

1.1 - General

The erosive power of moving water is impressive when its effect is viewed in the Grand Canyon. The same erosive force, to a lesser extent, can damage or destroy an unprotected highway embankment. If erosion of the highway embankment by a stream is to be prevented, the need for bank protection must be anticipated and the proper type and amount of protection provided in the right places. Bank protection is usually costly, but the consequential damages of not providing protection where needed far outweigh the initial cost. Delay in providing protection can also lead to increased costs.

Four general methods of protecting a highway embankment from stream erosion are:

(1) Relocating the highway away from the stream

(2) Moving the stream away from the highway by a channel change

(3) Changing the direction of the current with training works

(4) Protecting the embankment from erosion

This circular is limited to discussing protection of the highway embankment by use of riprap.

Riprap has been defined (1)[1] as "a layer, facing or protective mound of stones randomly placed to prevent erosion, scour or sloughing of a

1. Underlined numbers in parentheses refer to publications listed in the references at the end of this circular.

structure or embankment; also the stone so used." Highway bridge engineers (2) have broadened the quoted definition of riprap to include mortated and grouted riprap, concrete riprap in bags, concrete slab riprap, and stone riprap for foundation protection. Material such as broken concrete is classified as dumped riprap in this publication.

Embankments and streambanks are sometimes protected by walls or continuous revetments such as slope paving or articulated concrete blocks. Of the various bank protection materials, riprap has been most used and the most economical and successful material (3). Although riprap has been used for bank protection since the dawn of history, little research was done prior to 1946 on design. Much remains to be learned.

The meager information now available was for the most part, developed for upstream slope protection of earth dams and for protection of overflow embankments. The June 1948 Proceedings of the American Society of Civil Engineers (4) contains a summary of slope protection methods. This summary is the principal source of material for this circular, complemented by more recent research on protecting earth dams (3, 5 and 7).

The various methods of bank protection used by the California Division of Highways are discussed in their publication, "Bank and Shore Protection in California Highway Practice" (6). Slope protection of embankments and streambanks from stream attack differs from slope protection for earth dams. The dam face must be protected from wave action and seepage acting normal to the dam face (1 and 6) while protection of highway embankments must resist both parallel and oblique flow as well as scour at the base of the protection.

This circular discusses only the design and construction of riprap protection for highway embankments and streambanks. The design criteria used by several governmental agencies are compared in appendix A. Appendix B contains a sample specification for riprap.

1.2 - Types of Riprap

The types of riprap slope protection discussed in this circular are:

(1) Dumped riprap

(2) Hand-placed riprap

(3) Wire-enclosed riprap

(4) Grouted riprap

(5) Concrete riprap in bags (sacked concrete)

(6) Concrete-slab riprap

A filter layer under all riprap is essential (3) unless the bank material meets the filter requirements. (See section 2.7.)

(1) Dumped riprap is graded stone dumped on a prepared slope in such a manner that segregation will not take place. Dumped stone riprap is the most flexible of the types considered here and will adjust itself to uneven bank settlement. In most areas dumped stone is the least costly type.

(2) Hand-placed riprap is stone laid carefully by hand or by derrick following a more or less definite pattern with the voids between the larger stone filled with smaller stone and the surface kept relatively even. The resulting protection approaches good dry rubble in quality and appearance, but this type of riprap is rigid and lacks the strength necessary to bridge even minor movement of the surface which it protects.

(3) Wire-enclosed riprap is stone placed in wire baskets or in wire covered mats. Wire-enclosed riprap is generally used because rock of suitable size is not available. This riprap is effective until the wire enclosure fails.

(4) Grouted riprap is riprap with the interstices filled with portland cement mortar. The use of grouted riprap is seldom justifiable when stone of suitable size is available.

(5) Concrete riprap in bags is concrete in cement sacks or suitable burlap bags that are hand placed in contact with adjacent bags.

(6) Concrete-slab riprap is plain or reinforced concrete slabs poured or placed on the surface to be protected. The slabs poured or placed on the surface to be protected. The slabs are not connected to each other.

II - DESIGN

2.1 - Design of Dumped-Stone Riprap

The resistance of dumped stone to displacement by moving water depends upon:

(1) Weight, size, shape, and composition of the individual stones

(2) The gradation of the stone

(3) The depth of water over the stone blanket

(4) The steepness and stability of the protected slope

(5) The stability and effectiveness of the filter blanket on which the stone is placed.

(6) The velocity of the flowing water against the stone

(7) The protection of toe and terminals of the stone blanket

The design of a dumped-stone blanket for bank protection is similar to that for a stone-lined channel discussed in section 4.12 of reference 8. The principal difference between stone linings and stone bank protection is that in linings the channel bed is also lined, and the lining is generally continuous throughout the length of channel wherein erosion is imminent. Bank protection is generally limited to problem areas. The toe and terminals of the bank protection are particularly vulnerable to attack by the current. At some locations, wave action may present a more severe form of attack than water flowing parallel to the embankment; such cases may require heavier protection. Protection from wave action is discussed in references 1, 4, 6, and 7.

2.1.1 - Size of Stone

The size of stone needed to protect a streambank or highway embankment from erosion by a current moving parallel to the embankment is determined by the use of figures 1 and 2. Size (k) is the diameter, in feet, of a spherical stone that would have the same weight as the 50 percent size of stone. The size of stone is found by a trial-and-error procedure which consists of first estimating a stone size.

The mean velocity (V_m) of the stream during the design flood must then be converted to velocity against the stone by use of figure 1. The ratio ($\frac{k}{d}$) of the equivalent spherical diameter of the 50 percent stone size to the depth of flow during the design flood is computed by using 0.4 of the total depth when the depth of flow exceeds about 10 feet. The reason for this is that use of the total depth would result in a stone size which would be adequate at the total depth but which might be too light to provide protection near the water surface.

With the velocity against the stone (V_s) enter figure 2 and read the stone size for the embankment slope. The stone size from figure 2 is the 50 percent (median) size, by weight, of a well-graded mass of stone with a unit weight of 165 pounds per cubic foot. If the stone size from figure 2 agrees with the assumed stone size, this is the correct size. If not, the procedure is repeated until the assumed size is in reasonable agreement with the size from figure 2.

When the unit weight of the stone is other than 165 pounds per cubic foot, the size from figure 2 should be corrected by Creager's equation (discussion of in reference 4):

$$k_w = \frac{102.5\ k}{w - 62.5}$$

where k = stone size from figure 2

k_w = stone size for stone of w pounds per cubic feet

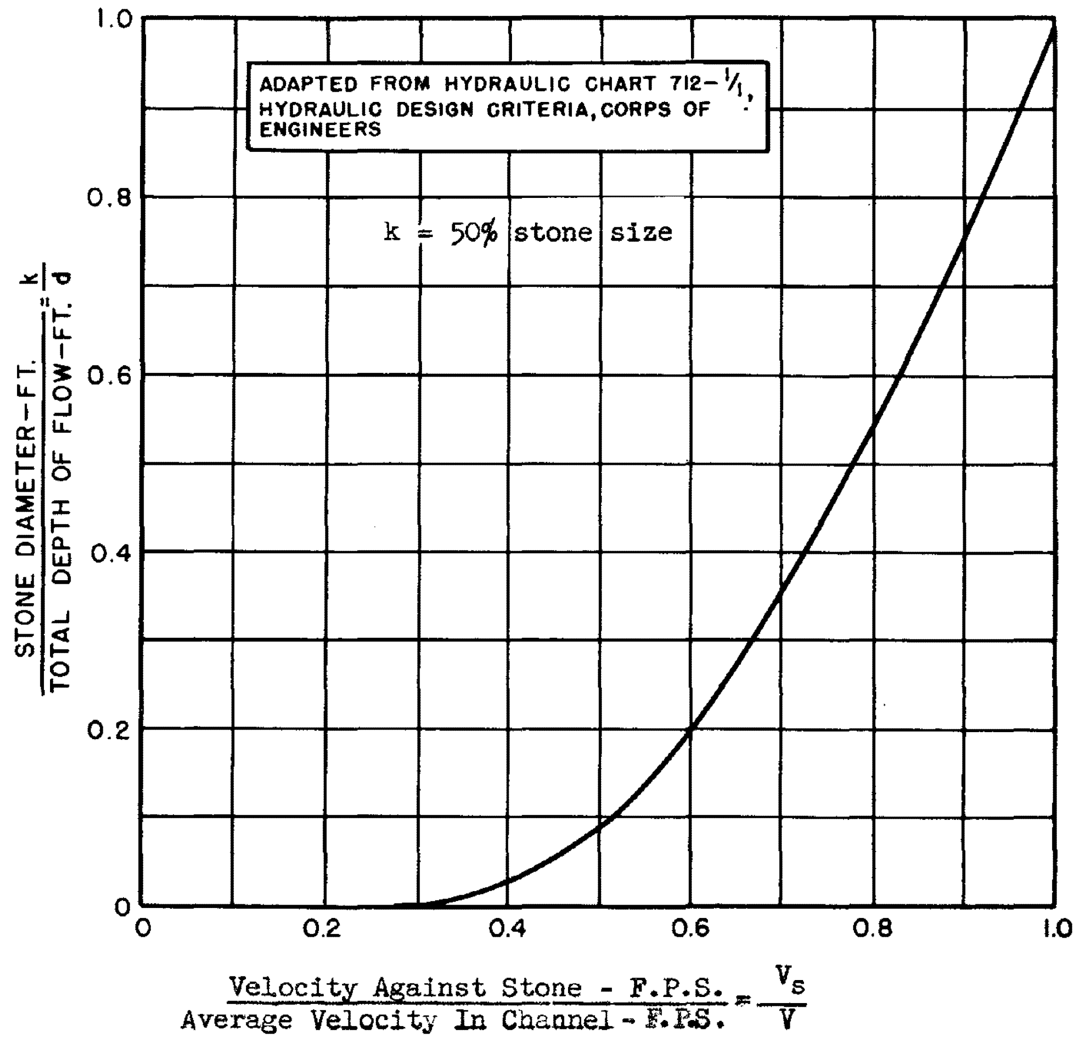


FIG. 1 - VELOCITY AGAINST STONE ON CHANNEL BOTTOM

The size of stone required to resist displacement from direct impingement of the current as might occur with a sharp change in stream alinement is greater than the value obtained from figure 2, although research data is lacking on just how much larger the stone should be. The California Division of Highways (6) recommends doubling the velocity against the stone as determined for straight alinement before entering figure 2 for stone size. Lane (9) recommends reducing the allowable velocity by 22 percent for very sinuous channels; for determining stone size by figure 2, the velocity (V_s) would be increased by 22 percent. Until data are available for determining the stone size at the point of impingement, a factor which would vary from 1 to 2 depending upon the severity of the attack by the current, should be applied to the velocity V_s before entering figure 2.

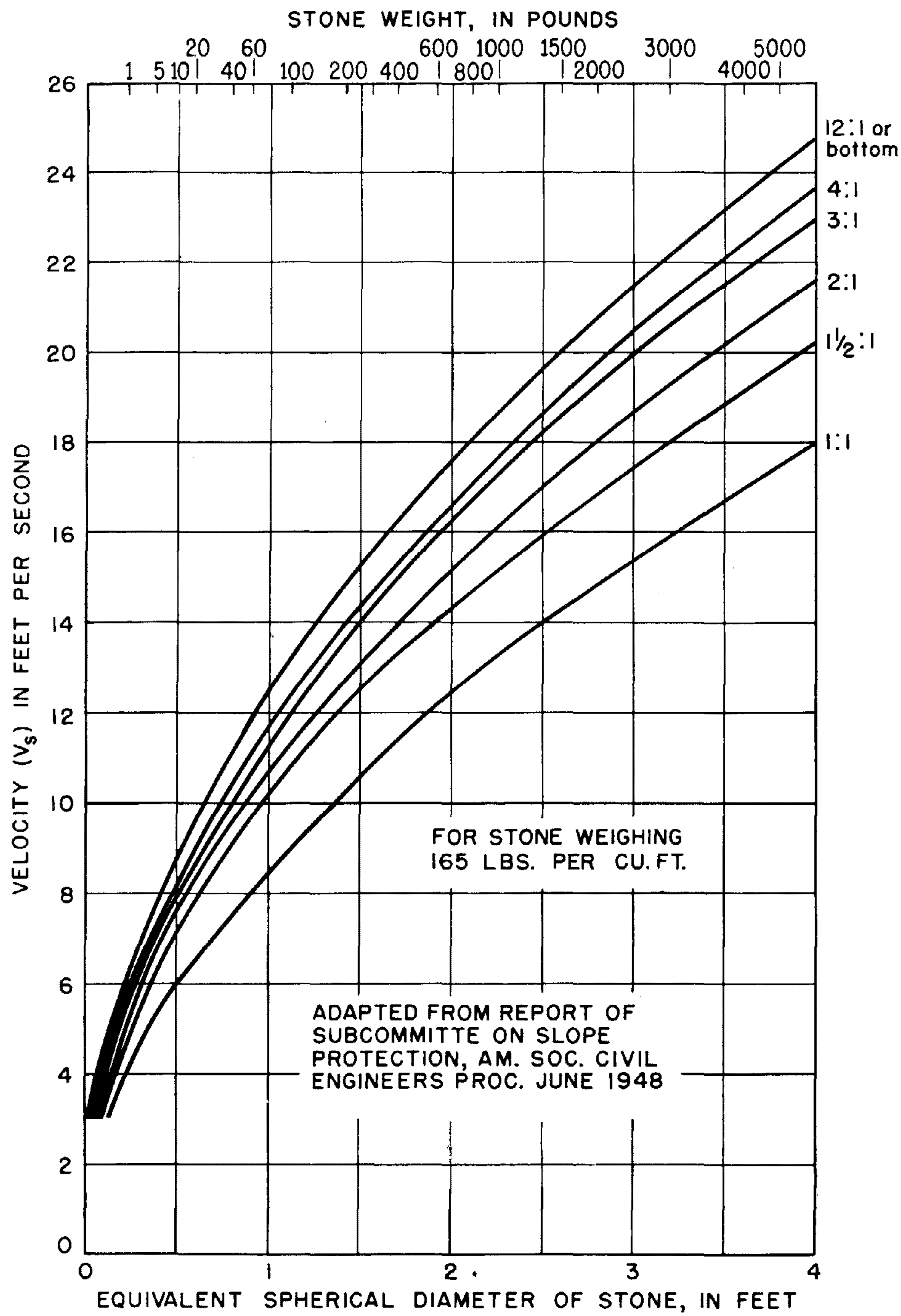


FIG. 2-SIZE OF STONE THAT WILL RESIST DISPLACEMENT FOR VARIOUS VELOCITIES AND SIDE SLOPES

2.1.2 - Extent of Stone Blanket

The upper vertical limit of the protective cover should extend above design high water. The allowance for freeboard depends upon the velocities near the riprap cover and, at some locations, upon the height of waves that might be generated on the water surface. Established sod above the stone protection will provide considerable protection from floods which overtop the riprap cover.

Where the stream channel is composed of sand or silt, bank protection should extend a minimum vertical distance of 5 feet below the streambed on a continuous slope with the embankment (figure 3A). On the outside of curves or sharp bends, scour is particularly severe, and the toe of the bank protection should be placed deeper than in straight reaches. Where a toe trench cannot be dug, the riprap blanket should terminate in a stone toe at the level of the streambed (figure 3B). The toe provides material which will fall into a scour hole and thus extend the blanket.

On large rivers or tidal estuaries having a considerable depth of flow at low water stages, the Corps of Engineers carries the stone protection 5 feet vertically below mean low water and omits the toe. The stone blanket should be keyed into a berm when a toe or toe trench is not provided. The purpose of the toe protection is to prevent undermining, not to support the blanket. Unless the protection has sufficient stability to support itself on the embankment slope, the protection cannot be considered adequate.

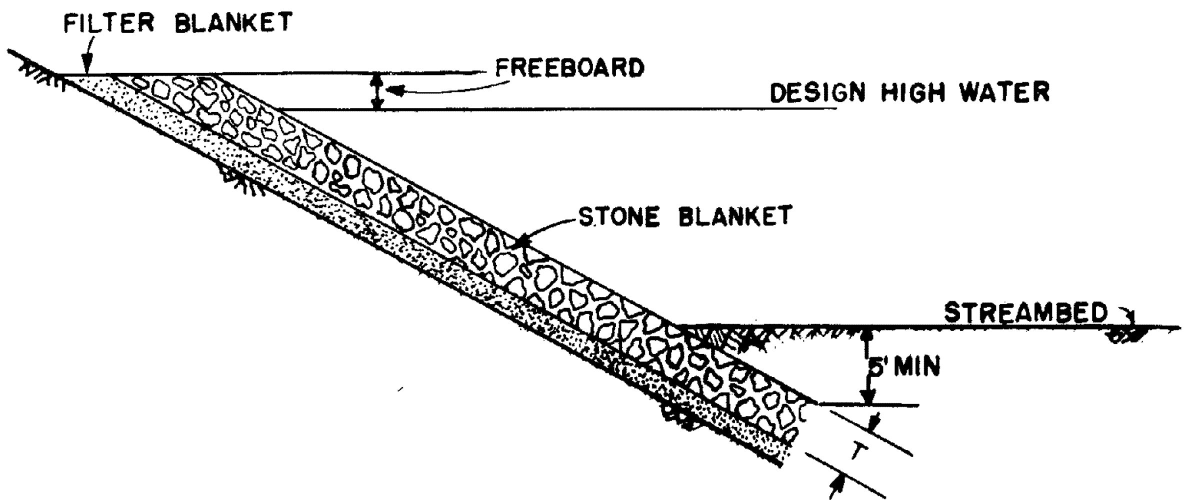
The bank protection should extend both upstream and downstream from the points of reverse curvature on the outside of a curved channel. Bank protection is usually not required on the inside of the curve unless return of overbank flow creates a scour problem. On a straight channel, bank protection should begin and end at a stable feature in the bank if practicable. Such features might be outcroppings of erosion resistant materials, trees, vegetation, or other evidence of stability. When a stable feature does not exist, cutoffs should be provided (figure 4). If the protective cover is long, intermediate cutoffs might be required to reduce the hazard of complete failure of the stone blanket.

2.1.3 - Thickness of Stone Blanket

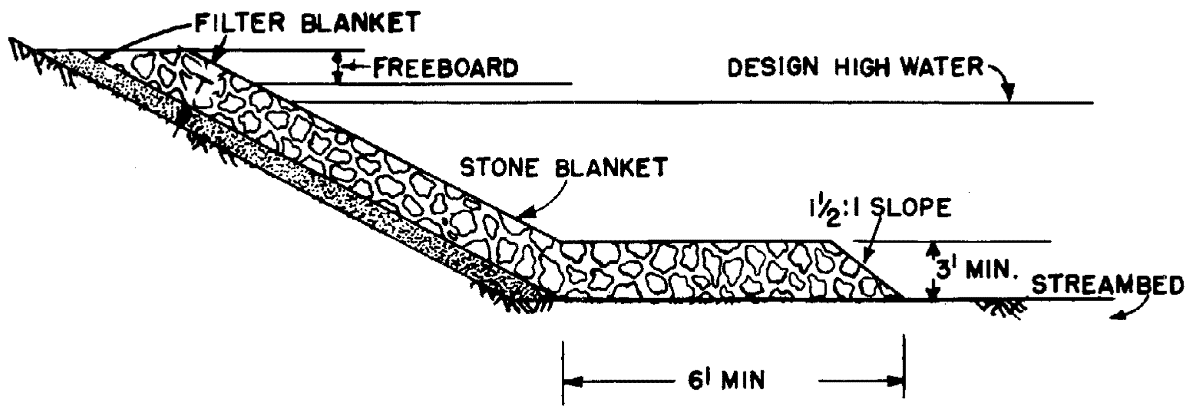
The thickness of the stone blanket should be at least equal to the maximum size stone (section 3.1.1).

2.2 - Design of Hand-Placed Riprap

Hand-placed riprap was at one time considered superior to dumped stone, and both the size of stone and the thickness of the hand-placed stone blanket

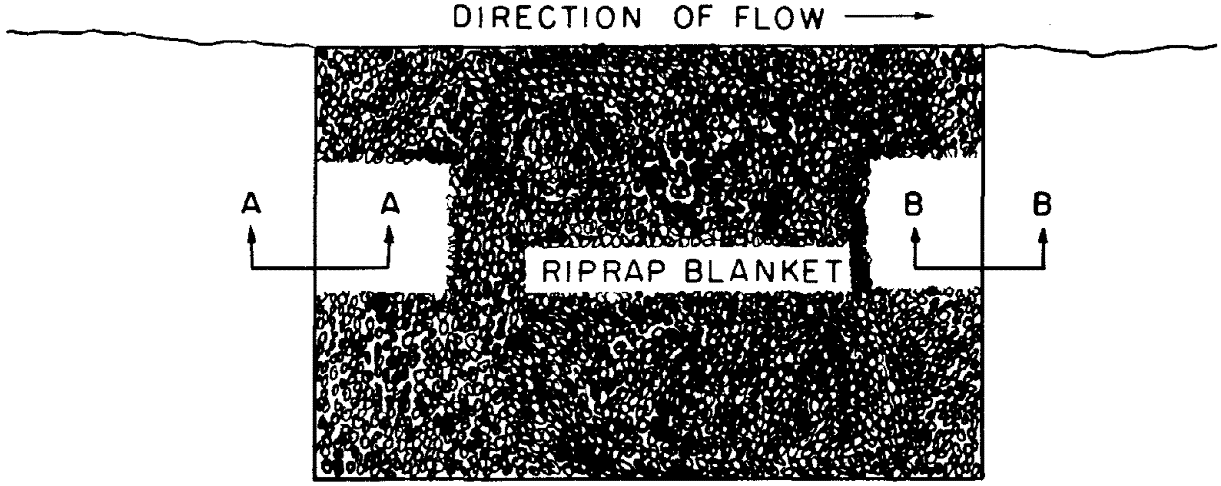


A – STONE BLANKET AND TOE TRENCH DETAIL

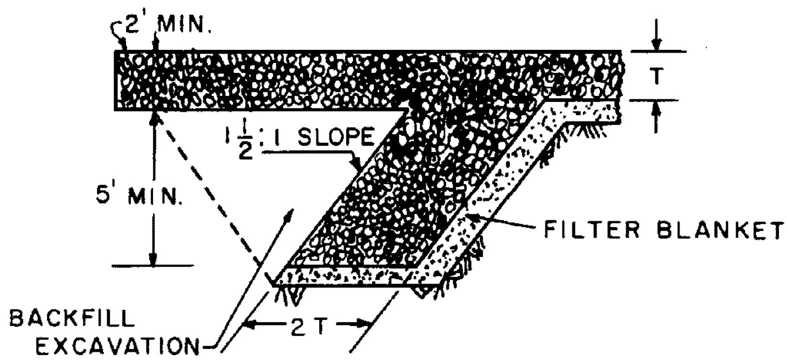


B – STONE BLANKET AND TOE DETAIL

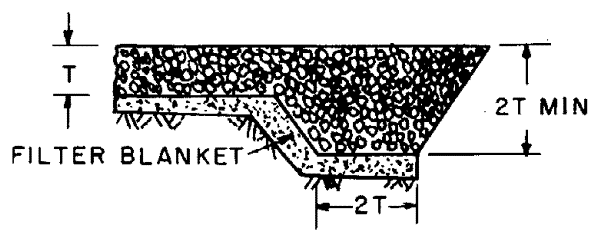
FIG. 3 – TYPICAL SECTIONS, STONE SLOPE PROTECTION FOR TANGENT REACHES WITH EROSIVE BEDS



PLAN



SECTION A-A



SECTION B-B

FIG. 4-DETAILS OF CUTOFF AT TERMINALS OF RIPRAP BLANKET

was specified as one-half that required for dumped stone (4, p. 857). The supposed superiority of hand-placed riprap was refuted by a performance survey of the majority of the large earth dams in the United States conducted by the Corps of Engineers in 1946. The survey showed that hand-placed riprap was not as satisfactory as an equivalent thickness of dumped riprap. The percentage of failures in hand-placed riprap slope protection was six times that of dumped riprap, and the percentage of failures of concrete pavement used for slope protection was slightly over seven times that of dumped riprap (7, p. 204).

The Corps of Engineers opinion, as stated by Middlebrooks (3, p. 713), is: "Hand-placed riprap is not as satisfactory as an equivalent thickness of dumped riprap, and a filter layer underneath all riprap is essential.

Hand-placed riprap requires a much firmer support from the bank being protected than does dumped riprap because it does not have the strength to resist nor the capability to adjust to movement of the supporting material. Hand-placed riprap is particularly susceptible to damage from ice floating in the stream.

Except for method of placing and greater emphasis on firm support and protection of blanket edges, the discussion under dumped riprap applies to hand-placed riprap.

2.3 - Design of Wire-Enclosed Riprap

The use of wire-enclosed riprap is generally restricted to locations where the only rock economically available is too small for dumped riprap. The design of wire-enclosed riprap is somewhat arbitrary, being dependent upon the size of rock available. The mesh size of the wire is also dependent upon the size of rock used for riprap. Wire-enclosed riprap has been used in some instances as toe protection for other types of riprap. This type of protection is flexible to an extent, but the protection is limited to the life of the wire used for enclosing the stone. California (6, p. 144) has found that wire-enclosed riprap does not work well on curves where displacement might require a lengthening or shortening of the protection.

The wire baskets are first formed and then filled with stone. The baskets are tied together to form a mattress and anchored to the slope. For light exposure, a continuous blanket of small stones retained between top and bottom spreads of wire fencing might suffice. On all designs the blanket should be divided into compartments so that one compartment can fail without losing all of the blanket.

Baskets 4 or 5 feet square are a convenient size, although larger sizes might be used. The dimensions of commercial fencing available might govern the dimensions of the baskets in order to minimize cutting of the wire in fabricating the baskets. Mattresses may be placed with the long dimension either traverse to the slope or parallel to the slope. The practice of the California Division of Highways is given on pages 143 to 151 of reference 6.

Figure 5 shows the standard drawing for wire-enclosed riprap used by the Bureau of Public Roads, Denver Regional Office. The drawing shows details for a 5-foot square basket, 1 1/2 feet deep, made of 12 1/2 gage galvanized fencing. The ends of a 5 x 8-foot length of fencing are turned up to form the bottom of the basket. A similar section inverted, forms the top and the other two sides. The sections of wire are held together with four ties of No. 9 gage annealed wire, and the corners of wire baskets are fastened at 8-inch intervals with No. 12 gage galvanized wire or with No. 9 gage galvanized hog rings. The rock filled baskets make contact with each other are are fastened together at 1-foot intervals. A steel stake 5 feet or more in length is driven into the subgrade through the center of each basket to anchor the basket to the slope. A different method of fabricating the baskets is shown in figure 5A.

Wire-bound rock sausages suggested by Posey (10) are a form of wire-enclosed riprap. Rock-filled gabions, which are similar to the sausages, have been in use for many years in foreign countries. An Italian firm supplies a patented prefabricated wire gabion. The U.S. Forest Service has a specification for wire-mesh gabions. The Forest Service gabion is a rectangular basket which is furnished by a contractor in the size or sizes specified.

The discussion of the extent of stone blanket in section 2.1.2 also applies to wire-enclosed riprap.

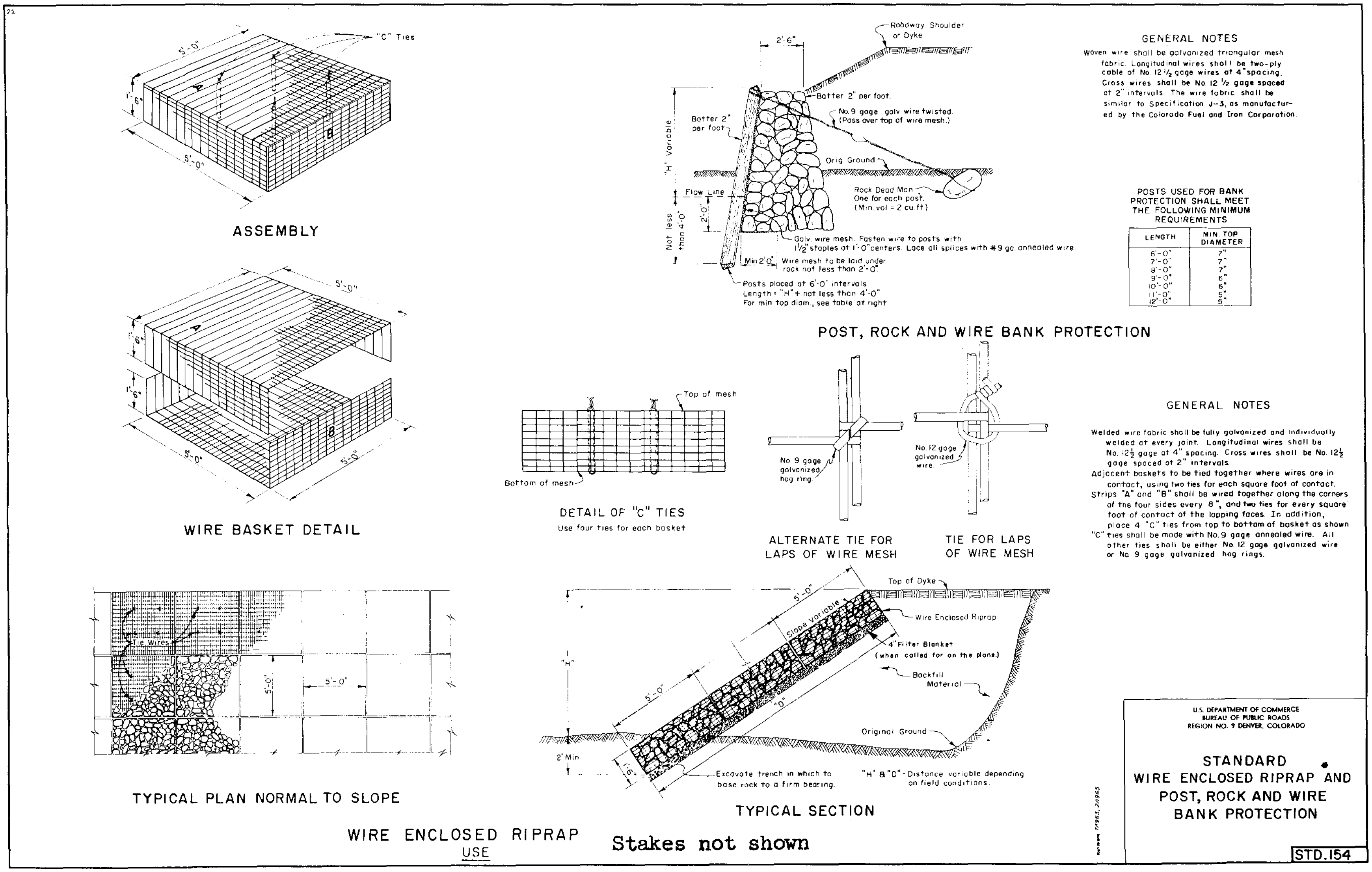
2.4 - Design of Grouted Riprap

Grouted riprap is used where stone of suitable size for other types of riprap are not available. Wire can be embedded in the riprap to increase the tensile strength of the protective cover. The finished protection is rigid and has little strength. For this reason, the embankment protected must provide adequate support and the edges of the riprap cover must be protected from undermining at the toe and at the terminals. Design data are lacking for determining the specific thickness of the cover. The grouted riprap may be left with a rough surface by brushing the grout until from one-fourth to one-half the depth of the stone is exposed.

Weep holes should be provided in the blanket to provide rapid relief of any hydrostatic pressure behind the blnaket. Filter blankets are generally necessary as in the case of other types of riprap.

2.5 - Design of Concrete Riprap in Bags (Sacked Concrete

Concrete riprap in bags generally consists of approximately 2/3-cubic foot of class C concrete (3 1/2 bags cement per yard) in a burlap bag or in a cement sack. This type of riprap provides a heavy protection regardless of the requirements of the site. The riprap has little flexibility,



LENGTH	MIN. TOP DIAMETER
6'-0"	7"
7'-0"	7"
8'-0"	7"
9'-0"	6"
10'-0"	6"
11'-0"	5"
12'-0"	5"

FIG. 5 - DETAILS OF WIRE-ENCLOSED RIPRAP

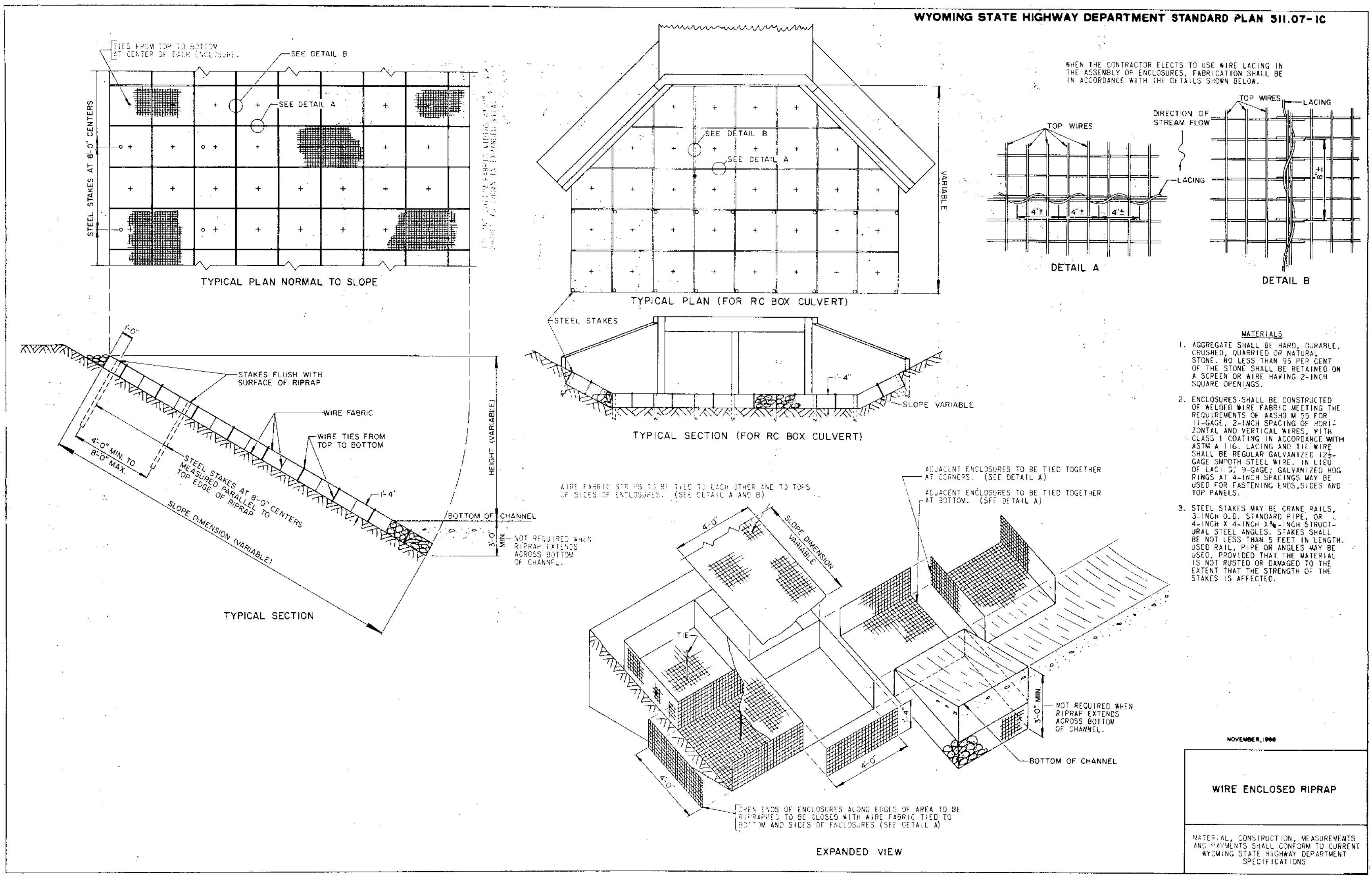


FIG. 5-A - STANDARD PLAN FOR WIRE-ENCLOSED RIPRAP

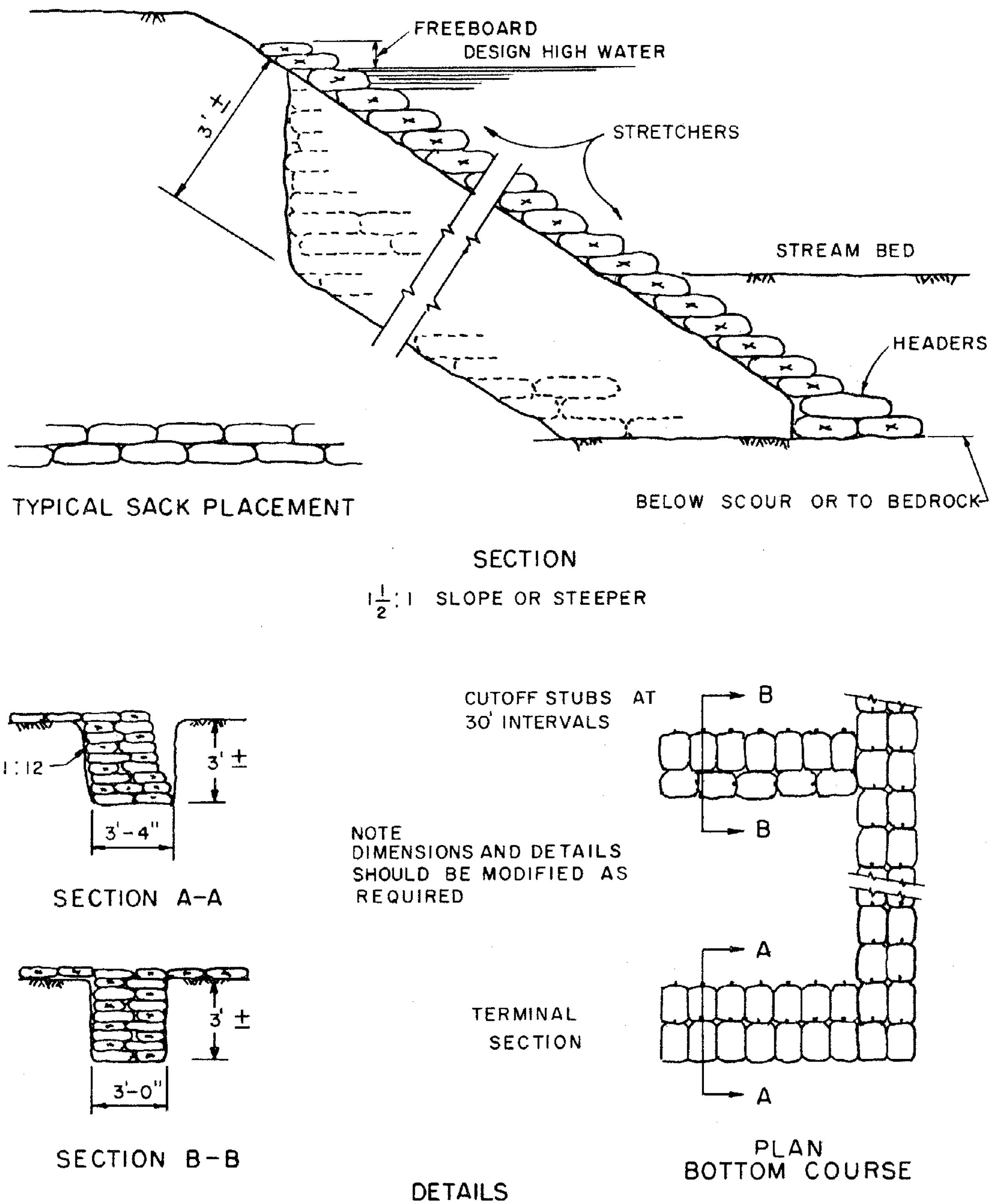


FIG. 6 – TYPICAL SECTION AND DETAILS OF SACKED CONCRETE SLOPE PROTECTION

low tensile strength and is susceptible to damage from floating ice. It requires firm support from the protected bank and usually requires a filter blanket underneath the riprap. Adequate protection of the terminals and toe is essential. The toe trench must end in firm support and extend below the depth of anticipated scour. Details of terminal protection and cutoff stubs are shown in figure 6. (See also p. 134-135, 6.)

The bags make close contact with each other and some bond is secured between the bags by the cement mortar leaking through the porous bags. Flat slopes reduce the area of contact between the sacks and thus bond is less. Slopes of the protected embankment are generally 1 1/2:1. If the slopes are as flat as 2:1, all sacks after the bottom row should be laid as headers (long way of sack in line with the slope) rather than as stretchers (long way at right angles to slope direction).

Concrete riprap in bags is sometimes placed as a dry mix. The riprap is thoroughly wetted as the work progresses. Some bond between sacks is probably lost by this method, but it allows the sacks to be filled at a convenient location and brought to the construction site. A well graded filter blanket is essential to drain the water that is added during construction.

2.6 - Design of Concrete-Slab Riprap

Concrete slabs, plain or reinforced, are cast in place on the prepared slope (2, p. 266-267). The slab is generally 4 inches thick of class B concrete (4 1/2 bags cement per yard) except when the slab is exposed to salt water in which case class A concrete is used. Joints between slabs are discussed in section 4.7. Precast concrete slabs can be used in place of cast-in-place slabs.

Concrete slabs 6 1/2 feet by 5 feet and 8 inches thick were used on the Belle Fourche Dam (Bureau of Reclamation) in South Dakota. The slabs were much deteriorated after 40 years of service in spite of considerable maintenance. Continuous reinforced concrete pavement used on earth dam faces has a much better service record than concrete-slab riprap.

A variation in concrete slab riprap is discussed by Parsons and Apmann (11). The slabs discussed in reference 11 are 4-inch thick, cellular concrete blocks, 16 inches by 24 inches. Each block contains 24 2-inch by 2-inch holes that go completely through the block. Gravel or crushed stone can be placed in the holes. The weight of each block is about 80 pounds. The experimental revetment has given 8 years of satisfactory service.

2.7 - Design of Filter Blanket

A filter blanket is usually needed beneath the riprap cover to prevent the water from removing bank material through voids in the riprap (3, p. 713). Removal of bank material leaves cavities behind the riprap cover and failure of the cover might result, particularly if the riprap cover is rigid and cannot slump to continue contact with the supporting soil. Whether a filter blanket is needed will depend upon the gradation of the bank material and the openings or voids in the riprap cover. For dumped riprap, a filter ratio of 5 or less between layers will usually result in a stable condition (12). The filter ratio (13), is defined as the ratio of the 15 percent particle size (D_{15}) of the coarser layer to the 85 percent particle size (D_{85}) of the finer layer. An additional requirement for stability is that the ratio of the 15 percent particle size of the coarser material to the 15 percent particle size of the finer material should exceed 5 but be less than 40. This requirement can be stated thus:

$$\frac{D_{15}\text{ (of riprap)}}{D_{85}\text{ (of bank)}} < 5 < \frac{D_{15}\text{ (of riprap)}}{D_{85}\text{ (of bank)}} < 40$$

If a single layer of filter material will not satisfy the filter requirements, one or more additional layers of filter material must be used. The filter requirement applies between the bank material and the filter blanket, between successive layers of filter blanket material if more than one layer is used, and between the filter blanket and the stone cover. In addition to the filter requirements, the grain size curves for the various layers should be approximately parallel to minimize the infiltration of the fine material into the coarser material. Not more than 5 percent of the filter material should pass the No. 200 sieve.

The thickness of the filter blanket ranges from 6 inches to 15 inches for a single layer or from 4 inches to 8 inches for individual layers of a multiple layer blanket. Where the gradation curves of adjacent layers are approximately parallel, thickness of the blanket layers should approach the minimum. Thickness of individual layers should be increased above the minimum proportionately as the gradation curve of the material comprising the layer departs from a parallel pattern. Requirements for filters have been investigated by Bertram (14), the Waterways Experiment Station (13, 15, and 16), and the Bureau of Reclamation (17). "Design of Small Dams" (7, p. 175) contains a typical filter design.

An example of a filter design for dumped riprap follows. It is assumed that riprap is to be used to protect a streambank with the gradation in the filter shown in figure 7. The gradation curves of the riprap and of the sand and gravel available for use are also shown on figure 7.

Example 1

Material	Particle Size D_{15}	Particle Size D_{85}
Riprap	90 mm	308 mm
Streambank	0.006 mm	0.10 mm
Sand	0.14 mm	2.4 mm
Gravel	4.0 mm	50 mm

Is filter required?

$$\frac{D_{15}\text{ (riprap)}}{D_{85}\text{ (streambank)}} = \frac{90}{0.10} = 900 > 5 \qquad \text{Yes.}$$

Can a single layer of gravel be used?

$$\frac{D_{15}\text{ (riprap)}}{D_{85}\text{ (gravel)}} = \frac{90}{50} = 1.8 < 5 \qquad \text{Ok.}$$

$$\frac{D_{15}\text{ (gravel)}}{D_{85}\text{ (streambank)}} = \frac{4.0}{0.10} = 40 > 5 \qquad \text{No.}$$

Can a layer of sand and a layer of gravel be used?

1st requirement

$$\frac{D_{15}\text{ (riprap)}}{D_{85}\text{ (gravel)}} = \frac{90}{50} = 1.8 < 5 \qquad \text{Ok.}$$

$$\frac{D_{15}\text{ (gravel)}}{D_{85}\text{ (sand)}} = \frac{4.0}{2.4} = 1.7 < 5 \qquad \text{Ok.}$$

$$\frac{D_{15}\text{ (sand)}}{D_{85}\text{ (streambank)}} = \frac{0.14}{0.10} = 1.4 < 5 \qquad \text{Ok.}$$

2nd requirement

$$\frac{D_{15}\text{ (riprap)}}{D_{15}\text{ (gravel)}} = \frac{90}{4.0} = 22 < 40 \qquad \text{Ok.}$$

$$\frac{D_{15}\text{ (gravel)}}{D_{15}\text{ (sand)}} = \frac{4.0}{0.14} = 29 < 40 \qquad \text{Ok.}$$

$$\frac{D_{15}\text{ (sand)}}{D_{15}\text{ (streambank)}} = \frac{0.14}{0.006} = 23 < 40 \qquad \text{Ok.}$$

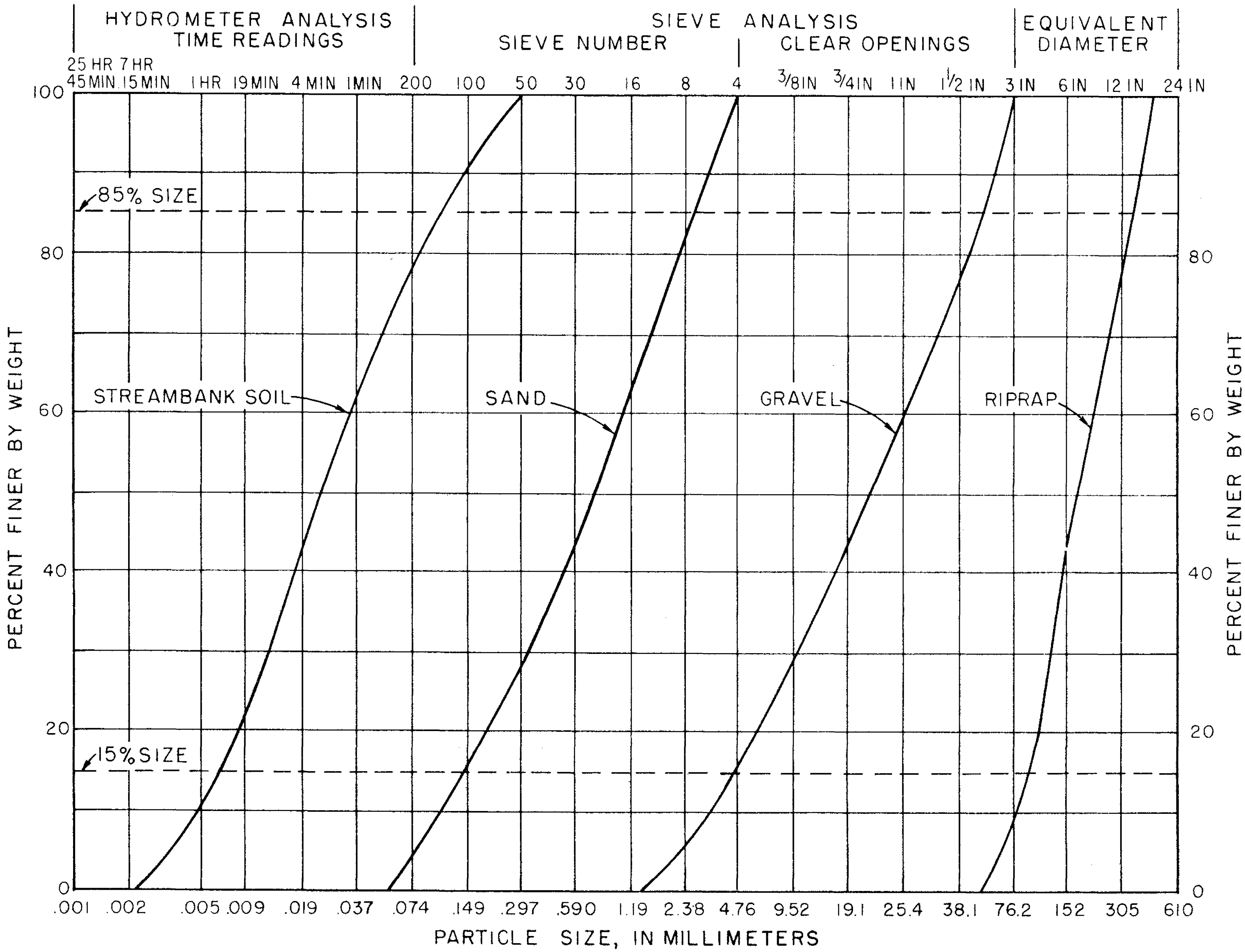


FIG. 7-GRADATION CURVES FOR FILTER DESIGN

The gradation of the sand and the gravel is satisfactory; if adequate placing methods are to be used, two minimum thickness layers (4 or 5 inches) can be used, one of sand and one of gravel.

For riprap other than dumped stone, the maximum size of openings in the cover is used as the criterion. Then:

$$\frac{D_{85} \text{ of the filter}}{\text{Maximum opening in cover}} = 2 \text{ or more } (\underline{7}, \text{ p. } 174)$$

When weep holes are used in a solid cover, an inverted filter should be used under the weep holes in addition to the filter blanket.

III - MATERIALS

Broken concrete may be substituted for stone when it meets the requirements for stone.

3.1 - Dumped-Stone Riprap

Stone used for dumped riprap should be hard, durable, angular in shape; resistant to weathering; free from overburden, spoil, shale, and organic material; and should meet the gradation requirements for the class specified. Neither breadth nor thickness of a single stone should be less than one-third its length. Rounded stone or boulders are not acceptable. Shale and stone with shale seams are not acceptable. The minimum weight of the stone should be 155 pounds per cubic foot as computed by multiplying the specific gravity (bulk-saturated-surface-dry basis, AASHO Test T 85) times 62.3 pounds per cubic foot (18).

The sources from which the stone is to be obtained should be selected well in advance of the time when the material will be required in the work. The acceptability of the stone is determined by service records and/or by suitable tests. If testing is required, suitable samples of stone should be taken in the presence of the engineer in sufficient time for testing before the placing of riprap is expected to begin.

In the absence of service records, resistance to disintegration from environmental exposure is determined by the sulfate soundness test or by the abrasion test in the Los Angeles machine. The freezing and thawing test furnishes a useful guide in judging the soundness of stone subject to weathering action, but it should not be used as an arbitrary basis for rejection. In locations not subject to freezing or where the stone is exposed to salt water, the sulfate soundness test (AASHO Test T 104 for ledge rock using sodium sulphate) should be used. Stones should have a loss not exceeding 10 percent with the sulfate test after five cycles.

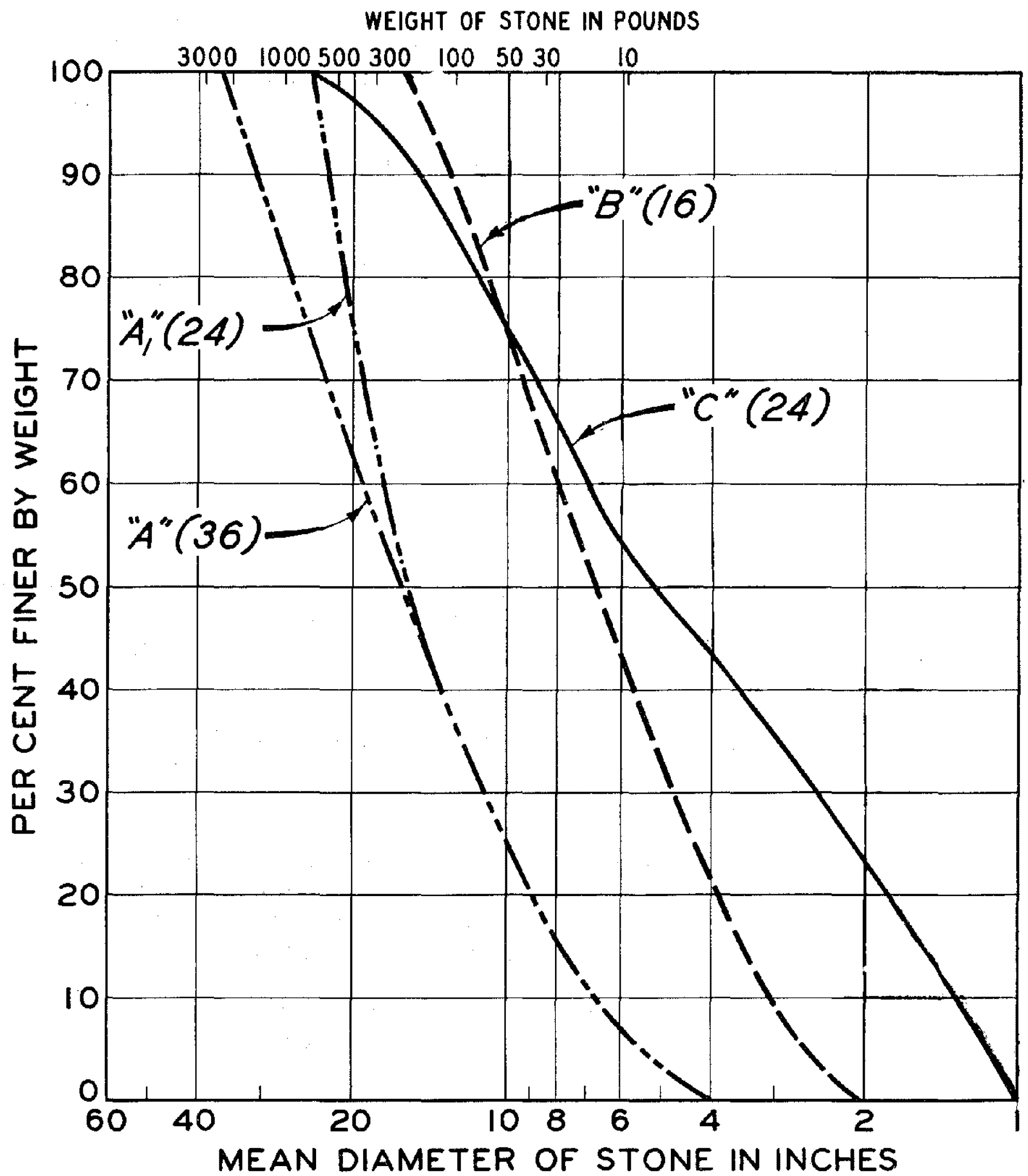
When the abrasion test in the Los Angeles machine (AASHO Test T 96) is used, the stone should have a percentage loss of not more than 40 after 500 revolutions. When the freezing and thawing test (AASHO Test T 103 for ledge rock, Procedure A) is used, the stone should have a loss not exceeding 10 percent after 12 cycles of freezing and thawing. The limits given here for the tests should be checked by testing local rock that has given good service when used as riprap under similar environmental conditions.

3.1.1 - Gradation of Stone

Many specifications for riprap contain no provisions for controlling gradation of the riprap other than a requirement that at least a given percentage of the stones should be heavier than a stated weight. Some specifications require the larger stone to be relatively uniform in size. Failure to require well-graded stone may result in a blanket with large voids that will allow the embankment or the filter material to be withdrawn through the riprap by the action of the water.

The superiority of a dense mass of well-graded angular stone over a mass of large stone with correspondingly large voids has been demonstrated by observation of completed installations and by tests at the Corps of Engineers Waterways Experiment Station (5). The tests were made to determine the size of rock needed to protect the slopes of overflow dikes on the Arkansas River. Two gradations, "A" and "A_1" (figure 8), failed under the same conditions although gradation "A" had maximum pieces 36 inches in equivalent diameter (2,300 pounds) as opposed to maximum pieces 24 inches in equivalent diameter (700 pounds) for the gradation "A_1". The 50 percent stone size of each gradation was 16 inches (200 pounds). Two other gradations, "B" and "C" (figure 8), failed under the same conditions. Gradation "C" had maximum pieces 24 inches (700 pounds) in equivalent diameter and gradation "B" had maximum pieces 16 inches (200 pounds) in equivalent diameter. However, 75 percent of each of these gradations consisted of stone 10 inches (50 pounds) in equivalent diameter or smaller. In the model tests, the large pieces were dislodged by undercutting resulting from the removal of the smaller pieces. Murphy and Grace (5) concluded that pieces of stone larger than those which represented some critical size (the 60 to 65 percent size in these tests) do not increase the effectiveness of the particular gradation.

In figure 8 both gradation curves "A_1" (24") and "B" (16") were found to be highly satisfactory by the Waterways Experiment Station. Curves approximately parallel to these curves and passing through the theoretical size (figure 2) at the 50 percent point should make an acceptable gradation. Unless the quantity of riprap used at a particular location is large, it might prove undesirable to specify separate gradations to fit conditions at each site. Several classes of riprap might be defined in the specifications and a suitable class selected for conditions at a particular site.



PROTECTIVE STONE
GRADATION CURVES

FIG. 8 - GRADATION CURVES FOR STONE

The three classes of riprap described in appendix B, section 10-2.1, are intended to provide a light, medium, and heavy class of riprap of satisfactory gradation. The three classes shown in the sample specifications might not provide a suitable range of riprap size for conditions in some States. Individual specifications might have heavier or lighter classes or they might provide the following single gradation referenced to the 50 percent size (k).

Size of stone		Percent of total weight smaller than the given size
3k		100
2k		80
1k		50
0.1k	not to exceed	10

Each load of riprap should be reasonably well graded from the smallest to the maximum size specified. Stones smaller than the specified 10 percent size and spalls should not be permitted in an amount exceeding 10 percent by weight of each load.

Gradation of the riprap being placed is controlled by visual inspection. To aid the inspector's judgment, two or more samples of riprap of the specified gradation should be prepared by sorting, weighing and remixing in proper proportions. Each sample should weigh about 5 tons. One sample should be placed at the quarry and one sample at the construction site. The sample at the construction site could be a part of the finished riprap blanket. These samples should be used as a frequent reference for judging the gradation of the riprap supplied.

Methods for determining the gradation of gravel-paved streambeds are discussed in reference 19. These methods can be adapted to checking gradation of riprap in place.

3.2 - Hand-Placed Riprap

Stone used for hand-placed riprap should be of better quality than specified for dumped riprap. Stone should be roughly square or rectangular to facilitate laying them up. The gradation curves for dumped riprap are not applicable. Only enough rock fragments to fill the openings between the larger stone should be permitted. (See reference 2, p. 264.)

3.3 - Wire-Enclosed Riprap

Stone used for wire-enclosed riprap should meet the requirements for dumped-stone riprap except for size and gradation of stone. The stone should be well graded within the sizes available and 70 percent of the stone, by weight, should exceed in least dimension the wire-mesh opening. The maximum size of stone should not exceed the thickness of the riprap.

Baskets for the riprap are generally formed of galvanized woven-wire fencing of No. 9 or No. 12 gage wire. Ties, hog rings, and lacing wire should be No. 9 galvanized wire.

3.4 - Grouted Riprap

Grout for grouted riprap consists of one part portland cement and three parts of sand, thoroughly mixed with water to produce grout having a thick creamy consistency. The minimum amount of water should be used to prevent excess shrinkage of the grout after placement. The cement, sand, and mixing shall conform to the specifications for concrete masonry in reference 2.

The stones for grouted riprap should, in general, meet the requirements for dumped riprap except for size and gradation of stone. Size and gradation should be determined for each particular project, depending upon the stone available. Stone should be clean and free of fines which prevent penetration of grout; care should be taken in placing the stone to keep earth or sand from filling the spaces between the stones.

3.5 - Concrete Riprap in Bags

Concrete should be class C (2). Sacks should be cloth cement sacks or burlap grain sacks.

Each bag should contain about 2/3-cubic foot of concrete securely tied if in cement sacks or the top folded around the bag if in burlap sacks.

3.6 - Concrete-Slab Riprap

Concrete for concrete-slab riprap should be class B (2) unless the riprap is exposed to salt water, in which case it should be class A. The slabs may be of either plain or reinforced concrete. Materials and construction shall conform to the specifications for concrete masonry in reference 2.

3.7 - Filter Blanket

All material comprising the filter blanket should be tough, durable particles reasonably free from thin, flat, and elongated pieces and should contain no organic matter nor soft, friable particles. The gradation of material in each layer of the blanket is determined as explained in section 2.7.

IV - CONSTRUCTION

Inspection by the engineer during all phases of construction is essential to ensure proper placement of the protective cover.

4.1 - Areas to be Protected

Brush, trees, stumps, and other objectionable material should be removed from slopes and other areas to be protected by riprap, and the areas should be dressed to a smooth surface. All soft or spongy material should be removed to the depth determined by the soils engineer and replaced with suitable material. Filled areas should be compacted as for embankments. Sand slopes protected by riprap should be no steeper than 2:1. The toe trench, when specified (see section 2.1.2), should be dug and maintained until the riprap is placed. The filter blanket should be placed on the prepared slope or on the area to be provided with foundation protection as discussed in section 4.8. Protection for structure foundations should be provided as early as the foundation construction permits.

4.2 - Dumped Riprap

Stone for riprap should be placed on the filter blanket or, when the filter blanket is not required, directly on the prepared slope or area in a manner which will produce a reasonably well-graded mass of stone with the minimum practicable percentage of voids. The entire mass of stone should be placed in conformance with the lines, grades, and thicknesses shown on the plans. The riprap should be placed to its full course thickness at one operation and in such a manner as to avoid displacing the underlying material. Placing riprap in layers or by dumping into chutes and similar methods likely to cause segregation should not be permitted.

The larger stones should be well distributed and the entire mass of stone should conform approximately to the gradation specified in section 3.1.1 The riprap should be so placed and distributed that there will be no large accumulations of either the larger or smaller sizes of stone.

Some roughness in surface is desirable to breakup wave action and decrease the velocity of the water, but the mass should be fairly compact with all sizes of material placed in their proper proportions. Hand placing or rearranging of individual stones by mechanical equipment may be required to the extent necessary to secure the results specified.

When the embankment is constantly exposed to attack, the riprap protection should be placed in conjunction with the construction of the embankment with only sufficient lag to allow for proper stabilization of the embankment. Care should be exercised to prevent mixture of embankment and riprap materials. When the embankment to be protected is constructed in lifts, riprap could be dumped directly in place from the surface of each lift.

When riprap and filter material are dumped under water, thickness of the layers should be increased up to double the thickness provided above water, depending upon conditions at the site. Methods should be used that will minimize segregation to insure that the minimum required thickness of well-graded material will be obtained in both riprap and filter.

4.3 - Hand-Placed Riprap

Stones are hand (machine) placed on the prepared slope in a more or less definite pattern with a minimum amount of voids and with the top surface relatively smooth. Joints should be broken as much as possible, and joint openings to the underlying soil should be avoided by careful arrangement of the various sizes of stones and closing the openings with spalls or small rock fragments.

The slope protected should provide firm support for the stone covering because this type of riprap is rigid and has little strength to resist movement in the supporting soil. A filter blanket is necessary for hand-placed riprap under the same conditions that it would be required for dumped riprap. The size of the largest openings in the riprap cover will govern the design of the filter blanket. (See section 2.7.)

Stones that are roughly square or rectangular in shape lay up better than rounded or irregular stone. The size of the stone and the thickness of the blanket should be at least as much as would be required for dumped riprap (3).

4.4 - Wire-Enclosed Riprap

Construction details for wire-enclosed riprap vary with the design and the purpose for which the protection is provided. The wire-enclosed riprap may be fabricated where it is to be placed or it may be fabricated at an off-site location. When the stone-filled baskets are fabricated and brought to the site, the method used for moving and placing them must not damage the baskets by breaking or loosening strands of wire or ties, or by removing any of the galvanizing, or by breaking the enclosed rock.

One method of constructing a mattress in place is to lay wire fencing on the slope and place the required thickness of graded stone on the fencing. Mats approximately 3 feet by 12 feet are formed by wrapping the fencing around the stone and lacing the open ends together with 1/4-inch cable. The mats are connected to each other and the seam secured with hog-ring ties at 1-foot intervals. The mats are formed into a mattress to cover the specified area and the wire mattress is securely anchored at approximately 12-foot intervals by a 1/2-inch cable extending from anchorages at the top of the protection to the bottom of the protection. At the bottom of the riprap the anchor cable can return on the underside a sufficient distance for anchoring. The anchor cable is securely fastened to each mat with cable clamps.

A second method is to place the baskets, made of wire fencing, on the slope. (See figure 5.) The required thickness of graded stone, usually about 1 1/2 feet, is placed in the 5-foot by 5-foot baskets. A method that has been successfully used to fill the baskets is to fasten one side of the top section of the wire basket to the bottom section with hog-ring ties. The top is raised and folded back. A four-sided metal form is placed inside the bottom section of the wire basket and the form is filled with stone. The side of the form which closes the open end of the wire basket is detachable and remains in place after the remainder of the form is removed. The top section of the wire basket is closed over the stone and the bottom edge of the closing side is secured to the bottom section with hog-ring ties. The detachable side of the form is then withdrawn and the edges of the closing side are fastened with hog-ring ties. Baskets should bé in contact and connected to each other and to the top portion by hog-ring ties or by lacing. (See figure 5.) The wire baskets form a continuous mattress to cover the specified area and each basket of the wire mattress is securely anchored by a steel stake 5 feet long or more, driven through the center of the basket into the material below. The baskets in figure 5A are somewhat easier to fill. The top is open and the cover is securedy by wire lacing or hog rings after filling with stone.

4.5 - Grouted Riprap

The stones are placed on the prepared slope and are thoroughly moistened. Any excess of fines should be sluiced to the underside of the stone blanket before grouting. The grout is delivered to the site by any means that will insure uniformity and prevent segregation of the grout. If penetration of grout is to be obtained by gravity flow into the interstices, the grout should be spaded or rodded into the interstices to completely fill the voids in the stone blanket. If pressure grouting is used, care should be taken to avoid unseating the stones and grout should be spaded or rodded into the voids. Penetration of the grout should be to the depth specified. When a rough surface is specified, stone should be brushed until from one-fourth to one-half of the depth of surface stone is exposed. For a smooth surface, grout should fill the interstices to within 1/2 inch of the surface. Weep holes should be provided through the blanket.

Where the depth specified for grouting is in excess of 12 inches, such as cutoff walls, the riprap should be placed in lifts of 12 inches or less; each lift should be grouted prior to placing the next lift. The succeeding lifts should be constructed and grouted before the grout in the previous lift has hardened.

Grout should be placed only when the temperature is above 35°F. and rising. It should be protected from freezing and cured as for concrete. After grouting is completed, no load should be placed on the grouted riprap until the grout has cured.

4.6 - Concrete Riprap in Bags

Cloth cement sacks about two-thirds filled and securely tied or burlap grain sacks containing about 2/3 cubic feet of concrete and folded at the top are immediately placed in position after filling. The fold on burlap bags is placed underneath the bag for headers and against the previously placed sack for stretchers. When the protected slope is 1 1/2:1 or steeper, a bed consisting of two rows of sacks placed as stretchers is followed by a row of sacks placed as headers. Succeeding rows of sacks are placed as stretchers with joints between sacks staggered. (See figure 6.) Each sack is hand placed and pushed into firm contact with adjacent sacks. On slopes flatter than 1 1/2:1 all rows after the bed row are placed as headers.

Cutoffs and weep holes shall be placed as shown on the plans or as directed by the engineer. The finished work should present a neat appearance with parallel rows of sacks and no sack shall protrude more than 3 inches from the finished surface.

The riprap should be placed only when the temperature is above 35°F. and rising. It should be protected from freezing and cured as for concrete.

Whenever placement of concrete riprap in bags is delayed sufficiently to affect the bond between succeeding courses, a small trench about half the depth of sack should be excavated back of the last row of sacks in place and the trench filled with fresh concrete before the next layer of sacks is laid. At the start of each day's work or when a delay of over 2 hours occurs during the placing of successive layers of sacks, the previously placed sacks should be moistened and dusted with cement to develop bond.

4.7 - Concrete-Slab Riprap

Slabs of the dimensions and type, plain or reinforced, shown on the plans are poured in place with class B concrete unless otherwise specified. Alternate slabs should be poured and the remaining panels should be poured later (2, p. 266).

Unless otherwise specified, the slabs should be laid in horizontal courses, and successive courses should break joints with the preceding ones. Horizontal joints should be normal to the slope and should be cold joints without filler. The joints extending up the slope should be formed with 3/4-inch lumber, which should be removed and the joint left open. The slabs should be finished with a wood float. The pouring and curing should be carried out as specified for class B concrete in reference 2.

4.8 - Filter Blanket

When required (section 2.7), a filter blanket should be placed on the prepared slope or area to the full specified thickness of each layer in one operation, using methods which will not cause segregation of particle sizes within the bedding. Compaction of filter is not required, but the surface of the finished layer should be reasonably even and free from mounds or windrows. Additional layers of filter material, when required, should be placed in the same manner, using methods which will not cause mixing of the materials in the different layers.

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Appendix A - COMPARISON OF METHODS FOR DETERMINING STONE SIZE

The procedure for determining stone size given in section 2.1.1 of this circular is referred to in this appendix as the Bureau of Public Roads method for identification purposes only. It is essentially the procedure given in reference 4 with emphasis on gradation of stone as learned from the experiments described in reference 5. Emmons and Meyer, in their discussion of the ASCE paper (4) on slope protection methods, stated that TVA had used the procedures described since 1940.

To show the variability in riprap sizes as determined from several procedures in common use, figure 9 has been plotted. Figure 9 shows the size of stone required to resist displacement for various velocities as determined by (1) the California Division of Highways method (6, p. 112); (2) the Bureau of Public Roads method (described in this circular); (3) the Bureau of Reclamation method (20, p. 207-217); (4) and (5) the Corps of Engineers method (21, p. 72). A research report (22) by the Waterways Experiment Station presents a rational approach for the hydraulic design of riprap and presents curves that range from about one grid to the left of curve 1 (in figure 9) for channels with quarrystone to about one grid to the right of curve 4 for small turbulent stilling basins.

The curves of figure 9 are not directly comparable to each other because the size of stone given refers to a different "percentage finer than" on the gradation curve. The curves for the California method and the BPR method have been computed for a 2:1 slope, but the slope is not given as a factor in the Corps of Engineers curves or in the Bureau of Reclamation curve.

The Bureau of Reclamation stone sizes are for use downstream from stilling basins. The Corps of Engineers (21) has two curves, No. 4 for direct attack and for use downstream from hydraulic structures where turbulence is high and No. 5 for protecting straight channels. In the California method, protection from direct attack is accomplished by doubling the velocity used to select stone size for straight channels. This in effect moves the curve to the right of the "turbulent flow" curve of the Corps of Engineers. The Bureau of Public Roads method recommends multiplying the velocity against the stone (V_s) by a factor between 1 and 2 before selecting stone size for protection from direct impingement. It also recommends using the mean velocity (V_m) rather than the velocity against the stone in determining stone size to be used immediately downstream from a culvert or an energy dissipator.

The thickness of the stone blanket is given as (1) sufficient for two layers of overlapping stone by California; (2) equal to the equivalent diameter of the maximum size stone by the Bureau of Public Roads; (3) 1.5 times the maximum stone size by the Bureau of Reclamation; (4) and (5) equal to the longest dimension of the maximum size stone required by the Corps of Engineers.

All methods specify a filter blanket when needed to prevent the bank material from filtering through the riprap cover, although the criteria for designing the filter blanket differ.

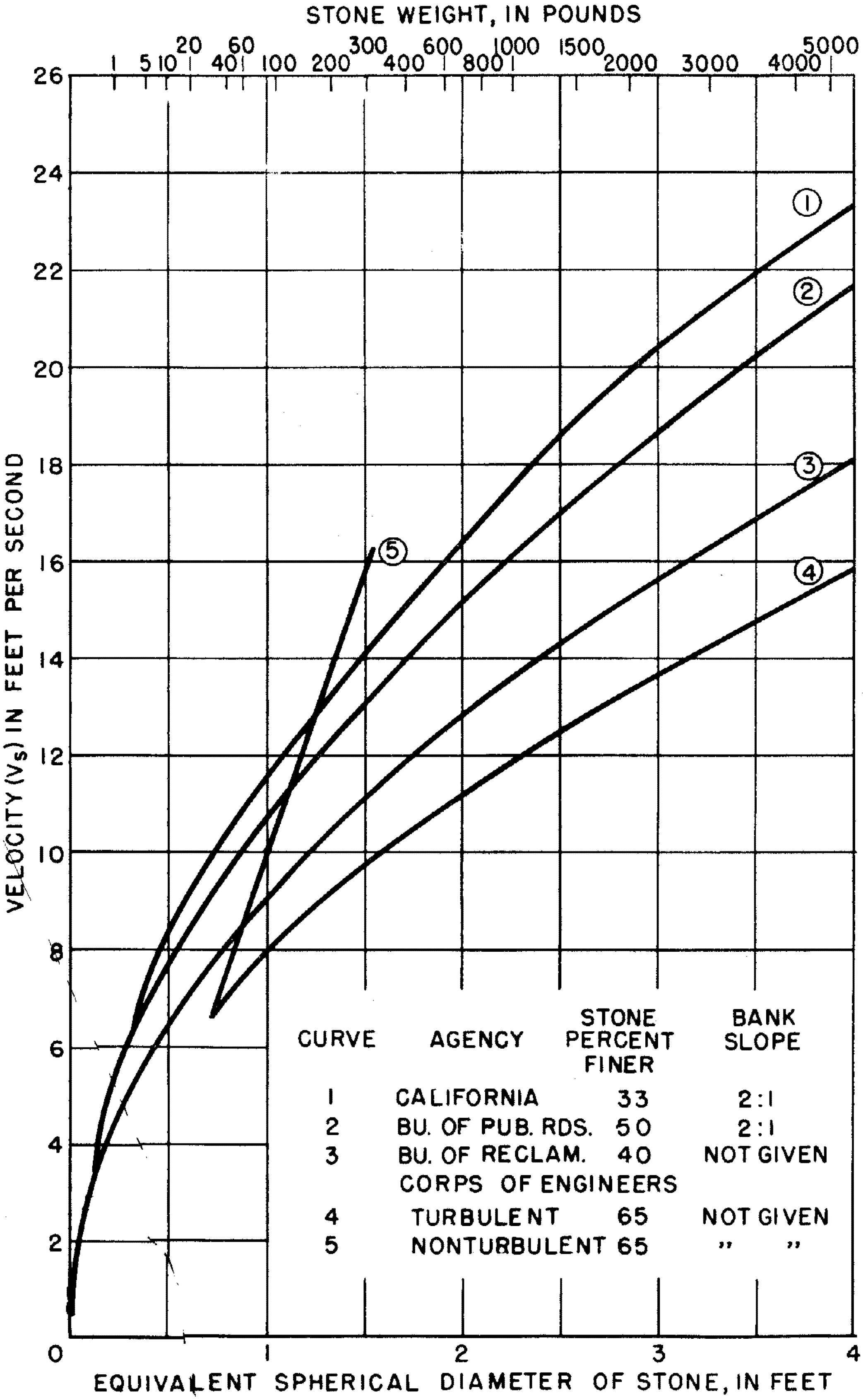
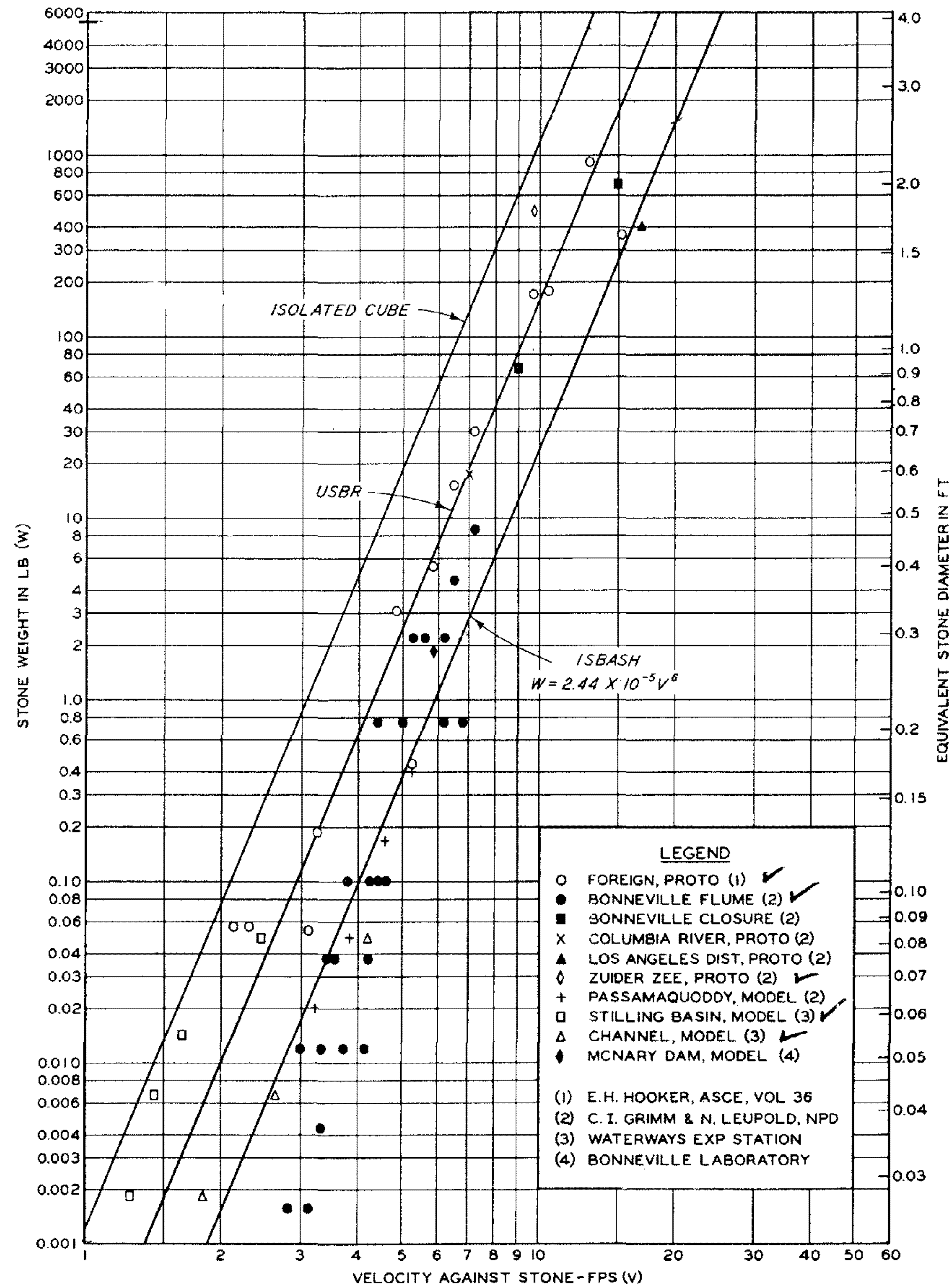


FIG. 9—COMPARISON OF SIZE BY VARIOUS METHODS

Figure 10, prepared by the Waterways Experiment Station, Corps of Engineers, compares design criteria with both model and prototype observations extending over the period from the early work of Dubuat in 1786 to the McNary Dam closure study at Bonneville Hydraulic Laboratory. The right hand curve of figure 10 corresponds very nearly to the 12:1 slope curve of figure 2 and the USBR curve corresponds very nearly to the 1:1 slope curve of figure 2. The isolated cube curve is based on air tunnel tests at the State University of Iowa. These test data have been evaluated in terms of water overturning isolated cubical stones resting on a smooth channel bottom.

The Bureau of Reclamation publication (20, p. 209) has a curve similar to figure 10 which shows the plotting of 12 observations of riprap performance, both satisfactory and failures. The slope of the embankment is not always given for evaluating the effect of slope, but all failures plot to the right of the Bureau of Reclamation curves on figures 9 and 10.

The methods compared here show considerable variability in the size of stone required to resist a particular velocity. This variability in results obtained with different design methods, and the uncertainty as to which method gives correct results, illustrates the need for research in riprap design methods.



Note:✓ V based on V_s others on V_m

NOTE: SPECIFIC WEIGHT OF ROCK = 165 LB/CU FT.

RIVER CLOSURES

VELOCITY VS STONE WEIGHT

HYDRAULIC DESIGN CHART 712-1

FIG. 10

REVISED 8-58 WES 6-57

Appendix B - SAMPLE RIPRAP SPECIFICATIONS

Purpose

The SAMPLE specifications are intended as a guide only. For use in a particular State, the test values in section 10-2.1 should be modified by the experience of the State regarding the weathering of local rock. Sections on various types of riprap which are not applicable in a particular State may be deleted or specifications for other types of riprap might be added. The omission of specifications for hand-placed stone riprap will be noted. The poor performance and high cost of hand-placed riprap as contrasted with dumped riprap make its use in highway construction undesirable except in a few instances where it is used for improving the esthetic quality of the protection.

The three classes of riprap described in section 10-2.1 are intended to provide a light, medium, and heavy class of riprap of satisfactory gradation. The three classes shown in these SAMPLE specifications might not provide a suitable range of riprap size for conditions in some States. Individual specifications might require heavier or lighter classes or they might provide the following single gradation referenced to the 50 percent size (k).

Size of stone	Percent of total weight smaller than the given size
3k	100
2k	80
1k	50
0.1k	10

Classes of concrete in these guide specifications are defined in AASHO "Standard Specifications for Highway Bridges" and in most State specifications. References to sections of specifications can be found in the AASHO bridge specifications but would more properly be covered by the State specifications of which the riprap specifications would become a part.

The principal sources of material for these SAMPLE specifications are various Corps of Engineers publications and specifications; the report of the ASCE Subcommittee on Slope Protection of the Committee on Earth Dams of the Soil Mechanics and Foundations Division, June 1948 Proceedings; the California Division of Highways publication, "Bank and Shore Protection in California Highway Practice"; and the U.S. Bureau of Reclamation's publication, "Design of Small Dams."

Division II, Part 5

Construction Details - Incidentals

SECTION 10 - RIPRAP

10-1 Description

This work consists of furnishing all plant, labor, equipment, and materials and performing all work necessary to place a protective covering of erosion-resistant material on the slopes of embankments, dikes, or streambanks, at culvert inlets and outlets, on bottoms and side slopes of channels, at abutment wings, at structure foundations, at other locations shown on the plans, or as directed by the engineer. The work shall be done in accordance with these specifications and applicable special provisions and in conformity with the lines and grades shown on the plans or established by the engineer.

The types of riprap included in this specification are:

10-1.1 - Dumped Riprap -- Dumped riprap consists of stone or broken concrete dumped in place on a filter blanket or prepared slope to form a well-graded mass with a minimum of voids.

10-1.2 - Wire-Enclosed Riprap -- Wire-enclosed riprap consists of mats or baskets fabricated from wire mesh, filled with stone, connected together and anchored to the slope. Details of construction may differ depending upon the degree of exposure and the service, whether used for revetment or used as a toe protection for other types of riprap.

10-1.3 - Grouted Riprap -- Grouted riprap consists of riprap with all or part of the interstices filled with portland cement mortar.

10-1.4 - Concrete Riprap in Bags -- Concrete riprap in bags consists of concrete in cement sacks or suitable burlap bags.

10-1.5 - Concrete-Slab Riprap -- Concrete-slab riprap consists of concrete, plain or reinforced, poured in place or precast concrete blocks.

10-1.6 - Filter Blanket -- A filter blanket consists of one or more layers of graded material placed on the bank before placing the riprap in order to prevent the bank material from passing through the riprap protection. The thickness and gradation of filter blanket will be shown on the plans.

10-2 - Materials

10-2.1 - Dumped Riprap -- Stone used for dumped riprap shall be hard, durable, angular in shape; resistant to weathering and to water action; free from overburden, spoil, shale and organic material; and shall meet the gradation requirements for the class specified. Neither breadth nor thickness of a single stone should be less than one-third its length. Rounded stone or boulders will not be accepted unless authorized by special provisions. Broken concrete may be substituted for stone when authorized by special provisions. Shale and stone with shale seams are not acceptable. The minimum weight of the stone shall be 155 pounds per cubic foot as computed by multiplying the specific gravity (bulk-saturated-surface-dry basis, AASHO Test T 85) times 62.3 pounds per cubic foot.

The sources from which the stone will be obtained shall be selected well in advance of the time when the stone will be required in the work. The acceptability of the stone will be determined by service records and/or by suitable tests. If testing is required, suitable samples of stone shall be taken in the presence of the engineer at least 25 days in advance of the time when the placing of riprap is expected to begin. The approval of some rock fragments from a particular quarry site shall not be construed as constituting the approval of all rock fragments taken from that quarry.

In the absence of service records, resistance to disintegration from the type of exposure to which the stone will be subjected will be determined by any or all of the following tests as stated in the special provisions:

(1) When the riprap must withstand abrasive action from material transported by the stream, the abrasion test in the Los Angeles machine shall also be used. When the abrasion test in the Los Angeles machine (AASHO Test T 96) is used, the stone shall have a percentage loss of not more than 40 after 500 revolutions.

(2) In locations not subject to freezing or where the stone is exposed to salt water, the sulfate soundness test (AASHO Test T 104 for ledge rock using sodium sulphate) shall be used. Stones shall have a loss not exceeding 10 percent with the sulfate test after five cycles.

(3) When the freezing and thawing test (AASHO Test 103 for ledge rock procedure A) is used as a guide to resistance to weathering, the stone should have a loss not exceeding 10 percent after 12 cycles of freezing and thawing.

Stone shall be free from overburden, spoil, shale, and organic material and shall meet the following gradation requirements for the class specified:

Size of stone		Percent of total weight smaller than the given size
	Class I	
100 lb.		100
60 lb.		80
25 lb.		50
2 lb.	not to exceed	10
	Class II	
700 lb.		100
500 lb.		80
200 lb.		50
20 lb.	not to exceed	10
	Class III	
2,000 lb.		100
1,400 lb.		80
700 lb.		50
40 lb.	not to exceed	10

Each load of riprap shall be reasonably well graded from the smallest to the maximum size specified. Stones smaller than the specified 10 percent size and spalls will not be permitted in an amount exceeding 10 percent by weight of each load.

Control of gradation will be by visual inspection. The contractor shall provide two samples of rock of at least 5 tons each, meeting the gradation for the class specified. The sample at the construction site may be a part of the finished riprap covering. The other sample shall be provided at the quarry. These samples shall be used as a frequent reference for judging the gradation of the riprap supplied. Any difference of

Any difference of opinion between the engineer and the contractor shall be resolved by dumping and checking the gradation of two random truck loads of stone. Mechanical equipment, a sorting site, and labor needed to assist in checking gradation shall be provided by the contractor at no additional cost to the State.

10-2.2 - Wire-Enclosed Riprap -- Stone used for wire-enclosed riprap shall meet the requirements of section 10-2.1 except for size and gradation of stone. Stone used shall be well graded within the sizes available and 70 percent, by weight, shall exceed in least dimension the wire mesh opening. The maximum size of stone, measured normal to the slope, shall not exceed the mat thickness.

Wire mesh shall be galvanized woven fencing conforming to the specifications for Fence Fabric, section __, and shall be of the gage and dimensions shown on the plans. Ties and lacing wire shall be No. 9 gage galvanized unless otherwise specified.

10-2.3 - Grouted Riprap -- Grout for grouted riprap shall consist of one part portland cement and three parts of sand, thoroughly mixed with water to produce grout having a thick creamy consistency. The minimum amount of water should be used to prevent excess shrinkage of the grout after placement. The cement, sand, and mixing shall conform to the specifications for Concrete Masonry, section ___.

The stones for grouted riprap shall meet the requirements of section 10-2.1 except for size and gradation. Size and gradation will be specified for each particular project. Stone shall be free of fines which prevent penetration of grout and care shall be taken in placing the stone to keep earth or sand from filling the spaces between the stones.

10-2.4 - Concrete Riprap in Bags -- Concrete riprap in bags shall consist of class C concrete in cement sacks or suitable burlap bags. Each bag shall contain about 2/3 cubic foot of concrete, securely tied if in cement sacks or folded if in burlap bags, and shall immediately be placed in the work.

10-2.5 - Concrete-Slab Riprap -- Concrete for concrete-slab riprap shall be class B unless the riprap is exposed to salt water, in which case it shall be class A. The slabs shall be of two types, plain concrete or reinforced. If reinforcement is specified, it shall be furnished as shown on the plans. Except as modified herein, materials and construction shall conform to specifications for Concrete Masonry, section ___.

10-2.6 - Filter Blanket -- The filter blanket shall consist of one or more layers of gravel, crushed rock, or sand of the thickness shown on the plans. The gradation of material in each layer of the filter blanket shall meet the requirements of the special provisions. All material comprising the filter blanket shall be composed of tough, durable particles, reasonably free from thin, flat, and elongated pieces, and shall contain no organic matter nor soft, friable particles in quantities in excess of those approved by the engineer.

10-3 - Construction Details

Slopes to be protected by riprap shall be free of brush, trees, stumps, and other objectionable material and be dressed to a smooth surface. All soft or spongy material shall be removed to the depth shown on the plans or as directed by the engineer and replaced with approved material. Filled areas will be compacted as specified for Embankments, section ___. A toe trench as shown on the plans shall be dug and maintained until the riprap is placed.

Protection for structure foundations shall be provided as early as the foundation construction permits. The area to be protected shall be cleaned of waste materials and the surfaces to be protected prepared as shown on the plans. The type of riprap specified will be placed in accordance with these specifications as modified by the special provisions.

When shown on the plans, a filter blanket shall be placed on the prepared slope or area to be provided with foundation protection as specified in section 10-3.6 before the stone is placed.

10-3.1 - Dumped Riprap -- Stone for riprap shall be placed on the prepared slope or area in a manner which will produce a reasonably well-graded mass of stone with the minimum practicable percentage of voids. The entire mass of stone shall be placed so as to be in conformance with the lines, grades, and thicknesses shown on the plans. Riprap shall be placed to its full course thickness at one operation and in such a manner as to avoid displacing the underlying material. Placing of riprap in layers, or by dumping into chutes, or by similar methods likely to cause segregation will not be permitted.

The larger stones shall be well distributed and the entire mass of stone shall conform to the gradation specified in section 10-2.1. All material going into riprap protection shall be so placed and distributed that there will be no large accumulations of either the larger or smaller sizes of stone.

It is the intent of these specifications to produce a fairly compact riprap protection in which all sizes of material are placed in their proper proportions. Hand placing or rearranging of individual stones by mechanical equipment may be required to the extent necessary to secure the results specified.

Unless otherwise authorized by the engineer, the riprap protection shall be placed in conjunction with the construction of the embankment with only sufficient lag in construction of the riprap protection as may be necessary to allow for proper construction of the portion of the embankment protected and to prevent mixture of embankment and riprap. The contractor shall maintain the riprap protection until accepted, and any material displaced by any cause shall be replaced to the lines and grades shown on the plans at no additional cost to the State.

When riprap and filter material are dumped under water, thickness of the layers shall be increased as shown on the plans; and methods shall be used that will minimize segregation.

10-3.2 - Wire-Enclosed Riprap -- The plans and supplemental specifications will show details of wire-enclosed riprap and specify the construction procedure to be used.

10-3.3 - Grouted Riprap -- The stones shall be placed on the prepared slope substantially to the dimensions shown on the plans. The stones shall be thoroughly moistened and any excess of fines shall be sluiced to the underside of the stone blanket before grouting.

The grout may be delivered to the place of final deposit by any means that will insure uniformity and prevent segregation of the grout. If penetration of grout is obtained by gravity flow into the interstices, the grout will be spaded or rodded into the interstices to completely fill the voids in the stone blanket. Pressure grouting shall not unseat the stones; and after placing by this method, the grout shall be spaded or rodded into the voids. Penetration of the grout shall be to the depth specified on the plans. When a rough surface is specified, stone shall be brushed until from one-fourth to one-half of the depth of surface stone is exposed. For a smooth surface, grout shall fill the interstices to within a 1/2 inch of the surface.

Weep holes shall be provided through the blanket as shown on the plans or as directed by the engineer. Where the depth specified for grouting is in excess of 12 inches, such as cutoff walls, the riprap shall be placed in lifts of 12 inches or less and each lift shall be grouted prior to placing the next lift. The succeeding lifts shall be constructed and grouted before the grout in the previous lift has hardened.

Grout shall be placed only when the temperature is above 35°F and rising. It shall be protected from freezing and cured as specified in section __.

10-3.4 - Concrete Riprap in Bags -- Cloth cement sacks about two-thirds filled and securely tied or burlap grain sacks containing about 2/3 cubic feet of concrete and folded at the top are immediately placed in position after filling. The fold on burlap bags shall be placed underneath the bag for headers and against the previously placed sack for stretchers. When the protected slope is 1 1/2:1 or steeper, a bed consisting of two rows of sacks placed as stretchers shall be followed by a row of sacks placed as headers. Succeeding rows of sacks shall be placed as stretchers with joints between sacks staggered. Each sack shall be hand placed and pushed into firm contact with adjacent sacks. On slopes flatter than 1 1/2:1 all rows after the bed row shall be placed as headers.

Cutoffs and weep holes shall be placed as shown on the plans or as directed by the engineer. The finished work shall present a neat appearance with parallel rows of sacks, and no sacks shall protrude more than 3 inches from the finished surface.

The riprap shall be placed only when the temperature is above 35°F. and rising. It will be protected from freezing and cured as specified in section __.

Whenever placement of concrete riprap in bags is delayed sufficiently to affect the bond between succeeding courses, a small trench about half the depth of a sack shall be excavated back of the last row of sacks in place and the trench filled with fresh concrete before the next layer of sacks is laid. At the start of each day's work or when a delay of over 2 hours occurs during the placing of successive layers of sacks, the previously placed sacks shall be moistened and dusted with cement to develop bond.

<u>10-3.5 - Concrete-Slab Riprap</u> -- Slabs of the dimensions and type, plain or reinforced, shown on the plans shall be poured in place with class B concrete unless otherwise specified. Alternate slabs shall be poured and the remaining panels shall be poured later.

Unless otherwise specified, the slabs shall be laid in horizontal courses and successive courses shall break joints with the preceding ones. Horizontal joints shall be normal to the slope and shall be cold joints without filler. The joints extending up the slope shall be formed with 3/4-inch lumber, which shall be removed and the joint left open. The slabs shall be finished with a wood float.

The pouring and curing shall be carried out as specified for class B concrete in section __.

<u>10-3.6 - Filter Blanket</u> -- When required, a filter blanket shall be placed on the prepared slope or area to the full specified thickness of each layer in one operation, using methods which will not cause segregation of particle sizes within the bedding. The surface of the finished layer should be reasonably even and free from mounds or windrows. Additional layers of filter material, when required, shall be placed in the same manner, using methods which will not cause mixture of the material in the different layers.

10-4 - Method of Measurement

The quantity of riprap to be paid for, of specified thickness and extent, in place and accepted, shall be measured by one of the following methods as specified for the type of riprap placed. Riprap placed outside the specified limits will not be measured or paid for, and the contractor may be required to remove and dispose of the excess riprap without cost to the State.

(1) Per cubic yard: The quantity for dumped riprap, grouted riprap, concrete riprap in bags, and filter blanket shall be the number of cubic yards as computed from surface measurements parallel to the riprap surface and thickness measured normal to the riprap surface.

(2) Per square yard: The quantity for wire-enclosed riprap and concrete-slab riprap shall be the number of square yards obtained by measurements parallel to the riprap surface.

10-5 - Basis of Payment

The quantities determined, as provided in section 10-4, shall be paid for at the contract unit price per unit of measurement for each particular item listed in the following schedule and shown in the bid schedule, which price shall be full compensation for furnishing all material, tools, and labor; the preparation of the subgrade; the placing of the filter blanket when required; the placing of the stone; the grouting when required; furnishing steel for reinforced concrete-slab riprap; and all other work incidental to finished construction in accordance with these specifications.

Pay Item	Unit of Measurement
( ) Dumped riprap	per cubic yard
( ) Wire-enclosed riprap	per square yard
( ) Grouted riprap	per cubic yard
( ) Concrete riprap in bags	per cubic yard
( ) Concrete-slab riprap	per square yard
( ) Filter blanket	per cubic yard
( ) Broken concrete riprap	per cubic yard

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