Standard Guide for Placement of Riprap Revetments[1]

This standard is issued under the fixed designation D6825; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This guide covers methods to place riprap with associated filters for erosion control purposes. This guide does not recommend a specific course of action because of the diverse methods and procedures that are capable of producing a functional product. This guide identifies favorable riprap qualities and recommends practices best suited to obtain those qualities. The production of rock, use of recycled materials, rock with cut dimensions, and engineering and revetment design are beyond the scope of this guide. Special forms of riprap, including hand placed riprap, grouted riprap, or keyed (plated) riprap that is tamped into place to smooth the surface, are also beyond the scope of this guide.

1.2 This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been developed and approved through the ASTM consensus process

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

1.4 *This standard may involve hazardous operations and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C33 Specification for Concrete Aggregates
C136 Test Method for Sieve Analysis of Fine and Coarse Aggregates
D75 Practice for Sampling Aggregates
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D4992 Practice for Evaluation of Rock to be Used for Erosion Control
D5519 Test Methods for Particle Size Analysis of Natural and Man-Made Riprap Materials
D6092 Practice for Specifying Standard Sizes of Stone for Erosion Control

2.2 *AASHTO Standard:*[3]

M 288 Geotextile Specification for Highway Applications

3. Terminology

3.1 *Definitions*—See Terminology D653 for general definitions.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bedding*—an aggregate mixture placed below the riprap. Bedding material is usually sand and gravel sized, but may include cobble sized material. If placed without a geotextile, the bedding material may be used as a filter. If placed in conjunction with a geotextile, the bedding may provide a cushion for protection of the geotextile during riprap placement and provide confinement of the geotextile. It is possible to have more than one bedding layer.

3.2.2 *chinking*—the practice of filling riprap surface voids with smaller sized rock or aggregate.

3.2.3 *clam shell*—a bucket tool that is operated from a dragline or crane. The bucket is hinged at the top and opens like a clam so that rock can be placed without dropping it.

3.2.4 D_x—the particle diameter at which x % by weight (dry) of the particles of a particular sample are finer.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

***A Summary of Changes section appears at the end of this standard**

3.2.5 *filter*—any substance, as geotextile or layer of sand/aggregate, placed to provide separation and retention of materials, while allowing water to pass.

3.2.6 *floater*—a individual rock within the riprap layer that is not interlocked with the surrounding rocks.

3.2.7 *maximum aspect ratio*—the ratio of the greatest to the least dimension, measured across mutually perpendicular axes, for any piece of rock; synonym, *slabbiness*.

3.2.8 *orange peel*—a bucket tool that is operated from a dragline or crane and resembles the shape of an orange peeling. The sides lift up and out so that rock can be placed without dropping it.

3.2.9 *pit run material*—rock that has been blasted but not processed to remove undersize pieces; synonym, *shot rock* or *quarry run*.

3.2.10 *revetment*—bank protection by armor, that is, by facing of a bank or embankment with erosion-resistant material.

3.2.11 *riprap*—material generally less than 2 tons (1.8 tonnes) in mass, specially selected and graded. When properly placed, riprap prevents erosion through minor wave action, or strong currents and thereby preserves the shape of a surface, slope, or underlying structure. Riprap may be specifically produced for the intended purpose, or it may be a by-product from a mining operation, structure demolition, or industrial process.

3.2.12 *rock*—any naturally formed aggregate of mineral matter occurring in large masses or fragments. Rock may be either insitu or excavated material.

4. Significance and Use

4.1 Riprap is a commonly used form of scour protection and general slope protection. Riprap provides a long term solution when properly sized and installed. Riprap has structural flexibility so it will conform to irregular surfaces and adapt to minor subgrade settlement. It is often appropriate for use in conjunction with soil bioengineering (vegetation establishment) alternatives. In some environments, riprap may provide habitat for benthic organisms and fish.

4.2 Revetments provide a facing or lining to armor a surface; and the layer thickness is typically minimized while providing the necessary resistance to scour. In this case, standardized practices to obtain consistent coverage having acceptable thickness tolerances and voids become important.

4.3 This guide may be used by owners, installation contractors, regulatory agencies, inspection organizations, and designers and specifiers who are involved in the construction of riprap revetments. Modifications may be required for specific job conditions. This guide is not intended for construction specifications on large projects, but may be referenced where preparation of job specific construction specifications are not justified. If this practice is included by reference in contract documents, the specifier must provide a list of supplemental requirements.

5. Planning for Riprap Placement

5.1 Site conditions, level of protection required, construction methods, and equipment may affect the sizing, thickness, and lateral extent of a riprap revetment. For some small projects, riprap may be dumped with minimal analysis or quality control, and still fulfill the intended purpose. For larger projects and critical structures, engineering, careful placement, and quality control become increasingly justified to minimize material costs and reduce the chance of failure. The degree of control appropriate should be appropriate for each project. The methods for placement and quality control should be compatible with the level of site investigation and other considerations included in Table 1. Table 1 includes factors which should be considered, but are beyond the scope of this guide. Some recommended publications (**1-7**)[4] from the Army Corps of Engineers and the Federal Highway Administration for additional information on these factors and engineering criteria are given in the References section.

NOTE 1—Slope stability should always be considered. If it is not investigated analytically by a qualified professional, then it should at least be considered subjectively in light of the site conditions and surrounding conditions (riverbanks, shorelines, or landforms). Many agencies have generalized maximum allowable slopes (usually in the range of 1.5H:1V to 3H:1V); however, these must be recognized as site specific. Limitations of the foundation, bank, material interfaces, seepage conditions, or toe scour may lead to instability.

6. Riprap Materials

6.1 *Stone Sources and Evaluation*—Rock must be durable material. In some cases, a source may be established based on rock classification, geologic evaluation, and observations of existing installations showing that the rock is durable. If a history of rock durability is not established, sampling and testing the rock may be required. Acceptable material properties for rock are dependent on the conditions (such as abrasion and saturation frequency due to wave run-up) and climate in the vicinity of where it will be used. Source selection must also consider the material properties available from local sources. Riprap is most commonly produced at a quarry, but it may also be screened from a gravel pit operation, processed from rock collected from some other source, or manufactured from crushed hydraulic-cement (recycled) concrete.

NOTE 2—Borrowing stone, cobbles or gravel from stream or lake beds that do not otherwise need to be disturbed may have environmental consequences and may not be allowed under state and federal permits.

6.1.1 *Sampling and Testing Rock Sources*—Practice D4992 provides guidance on sampling a source rock. Acceptance criteria, as outlined in EM 1110-2-2302 (1), should be considered. Also consider characteristics of rock found in nearby quarries. Information provided with rock samples should include the location from which the sample was taken, and the stratigraphy for samples obtained at quarries. (See Note 3).

NOTE 3—Due to the relative cost of producing and transporting riprap in relation to placing it at the site, there is a potential for disputes where sampling and testing at the source have implied acceptance of the material and the Owner later rejects the material at the placement site. Contract

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

TABLE 1 Predominant Factors for Placement and Maintenance of Riprap

Factor	Site Condition	Design Control	Construction Control	Post Construction Control
Hydraulic bed shear stress Flow velocity or wave amplitude Flow turbulence Flow depth or wave run-up Water density (salinity)	X	--	--	--
Debris impact and ice action	X	--	--	X
Bed slope, side slopes (hydraulic stability)	X	X	--	--
Slope Stability (see Note 1)	X	X	--	--
Site Conditions (under water placement, temporary access, encroaching structures, property limits, meandering rivers and scour adjacent to revetment)	X	--	--	X
Environmental considerations (water quality, recreation use, affects on vegetation and wildlife)	X	--	--	--
Rock availability and cost	X	--	--	--
Risk analysis (critical structure, return period for design storm or flood event)	X	X	--	--
Filter requirements (subgrade drainage, filter clogging, installation damage, particle retention, degradation)	X	X	X	--
Rock gradation, angularity and placement	--	X	--	--
Revetment thickness	--	X	X	X
Revetment extent (toe protection, key-in, free board)	--	X	--	X
Construction methods and equipment	--	X	X	--
Quality control / quality assurance	--	X	X	--
Disturbances (people moving stones, animals burrowing through filters)	--	X	--	X
Material durability (rock degradation, exposure of geotextile)	X	X	X	X

specifications should clearly state where the riprap will be sampled for testing and what constitutes final acceptance of the material.

6.2 *Riprap Grading*—Recommended gradation requirements for processed riprap are given in Practice D6092. The gradations are considered to be optimum size variations considering rock stability, riprap voids affecting filtration of the subgrade, and typical quarry processing capabilities. Research at the Corps of Engineers Waterways Experiment Station in the 1960s and 1970s confirmed that there is an optimum size variation for riprap stability. Riprap layers consisting of unform size rocks have a rougher surface to hydraulic flow generating greater tractive shear stress, which may lead to instability. The voids in a well graded riprap mix are partially filled with smaller rocks, resulting in a smoother surface and lower tractive shear stress. Material that is too broad in grading is susceptible to segregation and loss of the small stones.

6.2.1 *Sampling and Testing Material Gradations*—The riprap grading should be verified. When gradation tolerances are critical, the grading should be determined in accordance with Test Methods D5519. Riprap samples should be taken from stockpiles, loaded trucks or in place test plots. Bedding and filter materials should be sampled in accordance with Practice D75 and tested in accordance with Test Method C136.

NOTE 4—Due to the economical limitations of obtaining the number and size of samples to be statistically meaningful, the Owner and Contractor should have a partnering relationship. Both parties should make an effort to be present during rock source sampling and field testing.

6.2.2 Pit run material, rather than processed rock, is often used due to it's lower cost, greater availability, and broader grading. For similar rock stability and filtration characteristics, pit run material must be placed in greater thickness and stone size than processed riprap.

6.3 *Recycled Materials*—Recycled materials may be used for sustainable design and development. However, quality assurance of recycled material is generally more difficult to monitor when compared to the quality assurance of natural materials. The material must be appropriate for the intended use. Crushed hydraulic-cement concrete may be obtained from various sources with inconsistent strength and durability. Slabs in the source material and the amount of reinforcing steel can complicate control of the grading requirements and the aspect ratio of individual stones.

7. Filter Materials

7.1 *Purpose of Filters*—For revetments placed as thin facings or linings, a filter is required to prevent loss of the subgrade by turbulent flow through the voids in the riprap. Filters for riprap consist of bedding or geotextiles. Filters are selected to provide soil retention and adequate permeability for subgrade drainage. This requires balancing two opposing criteria: the opening sizes (voids) must be small enough to retain the subgrade particles and large enough to provide adequate permeability for water passage. In some cases, multiple layers may be required.

7.2 *Bedding*—Bedding material should be composed of tough, durable particles, free from thin, flat and elongated pieces, and should contain minimal quantities of organic matter and soft friable particles. Aggregates should generally meet the quality requirements of Specification C33. Some typical gradation requirements for bedding materials are given in Practice D6092. It is sometimes more economical to specify a commonly produced gradation, such as a state transportation department gradation for concrete or bituminous aggregate. It may be necessary to adjust the gradation requirements to meet filter requirements for protection of the subgrade soils.

7.3 *Geotextiles*—The geotextiles must have adequate strength to withstand installation stresses during placement. AASHTO M 288 provides recommended geotextile properties for survival during construction. The geotextile properties are related to specific placement conditions and equipment operation.

8. Handling and Transportation

8.1 Riprap should be handled and selectively loaded onto trucks in a manner to avoid segregation and provide a distribution of rock sizes. Each truckload should be representative of the gradation requirements.

8.2 Rock breakage during handling and transportation will reduce the rock sizes and alter the gradation before final placement. The rock susceptibility to size degradation is very dependent on the rock strength, the rock formation, handling methods, and rock sizes. In areas where size degradation is significant, the riprap grading should be evaluated at the placement site, and the amount of size degradation should be anticipated by the supplier and transporter. See Note 3.

8.3 Stockpiles should be constructed to minimize the segregation of dumped rock. Stockpiles should be formed by a series of layers or truckload dumps, where the rock essentially remains where it is placed. Contamination with soil or mud should be avoided.

9. Placement Equipment

9.1 Special purpose equipment such as clam shells or orange peels provide the best placement and most compact layers of riprap.

9.2 Backhoes or other equipment outfitted with rock buckets are popular tools for riprap placement, but have some shortcomings: For large riprap, rock buckets do not hold a sufficient quantity to place a full layer thickness during each pass of the equipment. Equipment operators tend to smooth the riprap surface with the bucket by using it as a hammer to pound the rock into the layer, or as a rake to pull the rock into place. Adjusting the rock after placement tends to unravel the layer's integrity, which is characterized by an increase in the amount of voids and number of floaters.

9.3 The use of bulldozers and front-end loaders is discouraged for placing riprap. Track-mounted bulldozers that travel on top of riprap, can crush the rock and tear apart the interlocking integrity of the placed riprap layer. Wheel-mounted front-end loaders have a tendency to spin their wheels and tear apart the interlocked integrity of the rock layer. Front-end loaders generally offer poor visibility of the area in front of the bucket which creates problems for the operator, since riprap cannot be spread like soils and aggregates.

9.4 Dump trucks should be equipped with bottom-hinged tailgates if rock is placed directly into position with the trucks. The bottom hinged tailgates allow the load of rock to slide en masse from the truck; and they reduce the drop height.

10. Foundation Preparation

10.1 The foundation surface should be reasonably smooth to match tolerances normally obtained by rough grading with bladed equipment. Foundation areas may need to be excavated or properly filled to meet lines and grades for the revetment.

11. Placement of Bedding

11.1 Bedding should be spread in such manner as to avoid disturbance to the subgrade. Placing the bedding by methods that tend to segregate the particle sizes or cause mixing of the separate layers should not be permitted. Placement should begin at the bottom of the area to be covered and continue up slope. Compaction of bedding material is not required, but the surface should be finished to present an adequately even surface, free from mounds or windrows.

11.2 *Placement of Bedding on Geotextile*—When bedding material is placed on geotextile, the overlying sand and aggregate layers should be spread uniformly over the geotextile to the full lift thickness by methods that do not tear, puncture, or reposition the fabric. Generally, the minimum practical thickness to avoid snagging the geotextile with the blade or bucket of heavy equipment is 150 to 200 mm (6 to 8 in.). Thicker layers may be required to control rutting or shearing below heavy equipment. Sudden braking and sharp turning should be avoided. Tracked equipment should minimize all unnecessary turning to prevent the tracks from tearing the geotextile. Construction equipment should not be operated directly upon the geotextile.

12. Placement of Geotextiles

12.1 Issues related to placement of riprap on geotextiles include (*1*) survivability of the fabric, (*2*) clogging potential of the geotextile, and (*3*) minimizing seam overstress or displacement of overlaps. These issues lead to some conflicting criteria, which must be balanced based on the site conditions.

12.2 *Survivability*—Geotextiles should be selected to withstand installation stresses in accordance with AASHTO M 288, which provides some specific guidelines for drop heights and rock size. The geotextile should be placed in such a manner that placement of the overlying materials will not excessively stretch or tear the geotextile. Anchoring can increase strain in stiff fabrics since it will cause the fabric to stretch as rock deforms the subgrade, and will increase the susceptibility to tearing and puncturing, particularly due to large rocks placed on sand or soft cohesive subgrades without a cushion layer. Stiff geotextiles (typically woven and heat-bonded nonwoven fabrics) should not be anchored in a key trench at the top of the slope until the riprap has been placed up to that location, or experience shows that the geotextile does not tension during riprap placement.

12.3 *Clogging Potential*—Geotextiles that are installed loosely tend to lift up from the subgrade and clog much faster and more severely than geotextiles that are maintained in tight contact with the subgrade. To minimize clogging potential, geotextiles should be confined. For all installations, geotextile should be placed without wrinkles or folds on a smooth graded surface in intimate contact with the soils. For installations where filtration is critical, riprap should be placed on a cushion layer of bedding material, since the large rocks in riprap gradations allow the fabric to wrinkle and fold on the subgrade in the pores spaces between the rocks. For high elasticity geotextiles (needle punched non-wovens), formation of wrinkles during placement of riprap can be reduced by anchoring in the geotextile in key trenches before the rock is placed.

12.4 *Seams and Overlaps*—The number of seams and overlaps should generally be minimized by selective orientation of geotextile panels, within the limitations of maintaining a consistent pattern. Seams on slopes and butt end seams should be shingled so that runoff and channel flow passes over the fabric. Sewn, welded or glued seams are desirable for shoreline protection (or where flow reversal occurs). Overlaps, measured in place after rock placement, are normally a minimum of 300-mm (12-in.). Larger overlaps measured before coverage may be necessary if the geotextile tends to wrinkle when the riprap is placed on it, or for large riprap without a cushion layer.

13. Placement of Riprap

13.1 *Construction Methods*—Riprap should be placed in a systematic manner. Riprap should be placed to its full course thickness in one operation in such manner as to minimize segregation of rock sizes and avoid displacing underlying material. Rearranging of individual rocks may be allowed to the extent necessary to obtain a well-graded distribution of rock sizes. Final finish of the slope should be performed as the material is placed. Equipment used for placement should have the capacity to hold enough rock to deposit a full layer thickness in each pass. Placement should typically begin at the bottom of the area to be covered and continue up slope. Subsequent loads of material should be placed against previously placed material in such a manner as to ensure a relatively homogenous mass. Placing riprap in layers usually results in unstable material and a high void content. Placing riprap by dumping it into chutes, allowing it to roll downhill, or pushing it into place is likely to cause segregation. Operating equipment directly on the completed riprap protection system is generally not allowed due to concerns for rock breakage, tearing apart the interlocking integrity of the riprap layer, and damage of geotextile (if used).

13.2 *Riprap Layer Requirements*—Riprap should be placed in a manner which will produce an interlocked, well-graded mass of rock, with the minimum practicable percentage of voids, and well distributed large rocks. The underlying bedding or geotextile should not be visible. A desirable finished surface is free from pockets of small rocks and clusters of larger rocks. Rockss that are unstable or not interlocked are referred to as "floaters." Floaters do not contribute to the integrity of the placed riprap layer. Some agencies require hand adjustment using pinch bars (steel rods) to dislodge floaters.

13.3 *Surface Tolerances*—The finished surface tolerance for the riprap layer should generally not deviate from the lines and grades shown by more than half (½) the maximum D_{50} stone size of the gradation range. Loose pieces, or pieces that are out of tolerance should be worked to interlock and stabilize them within the riprap layer.

13.3.1 *Chinking*—The surface of the rock can be smoothed for traffic or overlying surfaces by chinking. Chinking is generally undesirable because the fine material may not interlock with the riprap and the chinking material is susceptible to erosion and downstream sedimentation.

13.3.2 *Keying or Plating*—A relatively smooth surface of riprap can be obtained by pounding the rock surface with the flat portion of a bucket or special tool to "key in" the stones and create a "plated" appearance. Since this can result in significant breakage and degradation of the riprap, it should be considered a separate practice and should not be used unless specifically requested by the customer.

13.4 *Placement of Riprap on Geotextiles*—Riprap should be placed over the geotextile by methods that do not stretch, tear, puncture, or reposition the fabric. Equipment should be operated so as to minimize the drop height of the stone without the equipment contacting and damaging the geotextile. Generally this will be about a 300-mm (12-in.) drop from the bucket to the placement surface. Riprap should be placed so that stones do not roll downhill.

13.5 *Riprap Placement in Water*—Riprap placed in water usually requires close observation and increased quality control to ensure a continuous well-graded uniform rock layer of the required thickness. A systematic process for placing and continuous monitoring to verify the quantity and layer thickness is important. Quality control methods such as those presented in Appendix X1 should be implemented. Riprap cast across the surface of the water will likely cause segregation. In underwater applications, the riprap and associated filters must be placed in a timely manner to avoid scour of the foundation during placement.

14. Quality Assurance

14.1 Predominant items for quality assurance include layer thickness, material gradations, rock durability, rock density, and relative density, of the in-place riprap. The riprap layer should always provide complete coverage so that the filter or subgrade is not visible. Compactness of riprap in place is generally controlled by prescriptive requirements for placement procedures discussed in Sections 9 and 13, but may also be evaluated by field testing. Uniformity of the layer thickness should also be visually inspected. Gradations, durability, and rock density are discussed in Section 6.

14.2 Appendix X1 suggest methods for evaluating the average layer thickness and compactness of the in place riprap. Quantifying the in place density may be investigated for evaluating placement procedures. A quality control system should be implemented to control layer thickness when there is potential for normal variations to exceed the allowable tolerance. If measurement for payment by weight is used, it is desirable to make periodic checks of what the average weight per unit are for completed work. Evaluating the average layer thickness is sometimes used for comparison with design assumptions, or when placing rock below water with obscured visibility.

15. Keywords

15.1 bedding; erosion protection; geotextile; revetment; riprap; scour protection

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL FOR RIPRAP

X1.1 The bulk unit weight of riprap (Eq X1.1) can be calculated from typically available field measurements:

$$\gamma_B = \frac{W}{tA} \quad (X1.1)$$

where:

A = a defined area,
W = the mass of rock placed in area A,
t = the theoretical layer thickness, and
γ_B = the bulk unit weight.

The bulk unit weight will vary, depending primarily on determination of layer thickness. Although the interlaboratory precision is likely poor, the evaluation may be useful for comparison of similar riprap installations with consistent surveying practice.

X1.2 For comparative purposes, the compactness may be measured by void ratio, porosity, or relative density.

$$e = (\gamma_s/\gamma_B) - 1 \quad (X1.2)$$

$$n = 1 - (\gamma_B/\gamma_s) \quad (X1.3)$$

where:

γ_s = unit weight of the rock
e = void ratio
n = porosity

For example, if an area 100 by 100 ft is filled with riprap to a thickness of 3 ft, and the riprap was weighted on a scale at the quarry as 1600 tons, and the rock has a unit weight of γ_s = 160 pcf (specific gravity of 2.56). From Eq X1.1 the bulk unit weight is γ_B = 1600 tons × 2000 lbs/ton/(3 × 100 × 100) = 107 pcf. Then from Eq X1.2, the void ratio is e = (160/107) - 1 = 0.50, and from Eq X1.3 the porosity is n = 1.(107/160) = 0.33.

X1.3 The average layer thickness can be calculated by assuming a bulk unit weight of the riprap, and rearranging Eq X1.1:

$$t = W/\gamma_B A \quad (X1.4)$$

From Eq X1.4 the theoretical layer thickness is t = 3 200 000/(107 · 10 000) = 2.99.

X1.4 It is difficult to determine the bulk unit weight of riprap by volumetric measurements because of the surface effects. If a smaller container is used to determine the riprap density, it will underestimate the density of a large volume. For smaller riprap gradations, it may be sufficient to calculate the unit weight from truck weights and the struck volume of the truck box. Even if a larger amount of testing were completed to determine the density of gradation, and the gradation could be controlled to be very consistent, the density of riprap placed in a layer may vary from rock placed in a large mass. It is usually accurate enough for quality control of layer thickness to assume a void ratio and calculate the bulk unit weight from rearranging Eq X1.5.

$$\gamma_B = \gamma_s/(1+e) \quad (X1.5)$$

From Eq X1.5 the bulk unit weight is γ_B = 160/(1 + 0.50) = 107.

X1.5 Void ratios for riprap gradations specified in Practice D6092 and placed in accordance with this standard and typically in the range of 0.45 to 0.7, although lower void ratio may be obtained with riprap having broader size ranges, or by hand placement. Measurement for payment using these relations must specifically define the unit weight of the riprap or how to determine it.

REFERENCES

(1) *Construction with Large Stone*, Engineering Manual 1110-2-2302, October 24, 1990, US Army Corps of Engineers, Washington, D.C. 20314-1000.

(2) *Design of Coastal Revetments, Seawalls, and Bulkheads*, Engineering Manual 1110-2-1614, June 30, 1995, Army Corps of Engineers.

(3) *Design of Grouted Riprap*, Engineering Technical Letter 1110-2-334, August 21, 1992, Army Corps of Engineers.

(4) *Design of Riprap Revetment*, Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No. 11, Publication No. FHWA-IP-89-016, March 1989.

(5) *Design of Roadside Channels with Flexible Linings*, Federal Highway Administration (FHWA) Hydraulic Engineering Circular (HEC) No. 15, Publication No. FHWA-IP-87-7, April 1988.

(6) Holtz, R. D., Christopher, B. R., and Berg, R. R., *Geosynthetic Design and Construction Guidelines*, U.S. Department of Transportation, Federal Highway Administration Report No. HI-95-038, 1995 (revised April 1998), p. 396.

(7) *Hydraulic Design of Flood Control Channels*, Engineering Manual 1110-2-1601, June 30, 1994, Army Corps of Engineers.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D6825–02 (Reapproved 2008)e[1]) that may impact the use of this standard. (Approved Feb. 1, 2014.)

(1) Revised 3.1 to conform to the D18 Standards Preparation Manual.
(2) Revised 5.1 by adding a hyper-link to the References section and by adding the sources of the recommended publications.
(3) Revised Table 1 for better graphic definition and data alignment to improve ease of use.
(4) Revised 6.1.1 for clarity by adding a hyper-link to the References section.
(5) Revised 6.2 for clarity and ease of understanding.
(6) Revised 6.2.1 for correctness.
(7) Revised 6.3, 7.3, 9.2, 9.3, 12.2, and 12.3 for clarity and ease of understanding.
(8) Revised Appendix X1 by clarifying and adding examples to the calculations section.
(9) Revised the References Section by updating the revision dates to two documents.