# Final Draft of Standard

Formatted/Clean Version

RR

# 6.15 RIPRAP

## Definition

A permanently placed layer of large irregular-shaped stone with an underlining geotextile or granular filter blanket.

## Purpose

To protect the soil surface from erosive forces and/or improve stability of soil slopes that are subject to seepage or have poor soil structure.

## Conditions Where Practice Applies

Riprap is used for the following applications:

- cut-and-fill slopes subject to seepage or weathering, particularly where conditions prohibit establishment of vegetation,
- channel side slopes and bottoms,
- inlets and outlets for culverts, bridges, slope drains, grade stabilization structures, and storm drains
- streambanks and streambeds,
- shorelines subject to wave action.

## Planning Considerations

Riprap is a versatile, highly erosion-resistant material that can be used effectively in many locations and in a variety of ways to control erosion on construction sites.

**GRADED VERSUS UNIFORM RIPRAP**

Riprap is classed as either graded or uniform. Graded riprap includes a wide mixture of stone sizes. Uniform riprap consists of stones nearly all the same size.

Graded riprap is preferred to uniform riprap in most applications because the variation in size allows for settling and forms a dense, flexible cover. Uniform riprap creates more open voids, and cannot adjust as effectively to movement of the stones. Graded riprap is also cheaper to install requiring less hand work for installation than uniform riprap, which must be placed in a uniform pattern. Uniform riprap may give a more pleasing appearance.

Riprap sizes are designated by either the mean diameter or the weight of the stones. The diameter specification is often misleading since the stones are usually angular. However, common practice is to specify stone size by the diameter of an equivalent size of spherical stone.

A method commonly used for specifying the range of stone sizes in graded riprap is to designate a diameter for which some percentage, by weight, will be smaller. For example, “d85” specifies a mixture of stones in which 85% of the stone by weight would be smaller than the diameter specified. Most designs are based on “d50”, or median size stones. Table 6.15a lists some commonly referenced mean diameter stone sizes available within North Carolina.

**Table 6.15a Sizes for Riprap**

| ACCEPTANCE CRITERIA FOR RIP RAP AND STONE FOR EROSION CONTROL | | | |
|---|---|---|---|
| **Class** | **Required Stone Sizes, inches** | | |
| | **Minimum** | **Midrange** | **Minimum** |
| A | 2 | A | 2 |
| B | 5 | B | 5 |
| 1 | 5 | 1 | 5 |
| 2 | 9 | 2 | 9 |

No more than 5.0% of the material furnished can be less than the minimum size specified nor more than 10.0% of the material can exceed the maximum size specified.

Source: NCDOT

When considering riprap for surface stabilization, it is important to anticipate visual impacts, including weed control, hazards from snakes and other animals, danger of slides and hazards to areas below steep riprap slopes, damage and possible slides from children moving stones, and general safety.

Proper stone size selection and surface preparation are essential for successful

long-term functioning of riprap. Adequate compaction of fill areas and proper use of filter blankets are necessary.

Sequence of construction—Schedule disturbance of areas that require

riprap protection so that the placement of riprap can follow immediately after grading. When riprap is used for outlet protection, place the riprap before or in conjunction with the installation of the structure so that it is in place before the first runoff event.

## Design Criteria

**Gradation**—Riprap should be a well-graded mixture with 50% by weight larger than the specified design size. The diameter of the largest stone size

in such a mixture should be 1.5 times the d50 size with smaller sizes grading down to 1 inch.

The designer should determine the riprap size that will be stable for design conditions. Having determined the design stone size, the designer should

select the size or sizes that equal or exceed that minimum size based on riprap gradations commercially available in the area.

**Thickness**—Construction techniques, dimensions of the area to be protected, size and gradation of the riprap, the frequency and duration of flow, difficulty and cost of maintenance, and consequences of failure should be considered when determining the thickness of riprap linings. The minimum thickness should be 1.5 times the maximum stone diameter, but in no case less than 6 inches.

**Quality of stone**—Stone for riprap may consist of field stone or quarry stone. The stone should be hard, angular, of such quality that it will not break down on exposure to water or weathering, and suitable in all other respects for the purpose intended. The specific gravity of the individual stones should be at least 2.5.

**Size of stone**—The sizes of stones used for riprap protection are determined by purpose and specific site conditions.

- **Slope stabilization**—Riprap stone for slope stabilization, not subject to flowing water or wave action, should be sized for stability for the proposed grade. The gradient of the slope to be stabilized should be less than the natural angle of repose of the stone selected. Angle of repose of riprap stones may be estimated from Figure 6.15a

  Riprap used for surface stabilization of slopes does not add significant resistance to sliding or slope failure and should not be considered a retaining wall. The inherent stability of the soil must be satisfactory before riprap is used for surface stabilization. Slopes approaching 1.5:1 may require special stability analysis.

- **Outlet protection**—Design criteria for sizing stone and determining the dimensions of riprap pads at channel or conduit outlets are presented in Practice 6.41, Outlet Stabilization Structure.

- **Channel stabilization and streambank protection**—Design criteria for sizing stone for stability of channels are contained in *Appendix 8.05*.

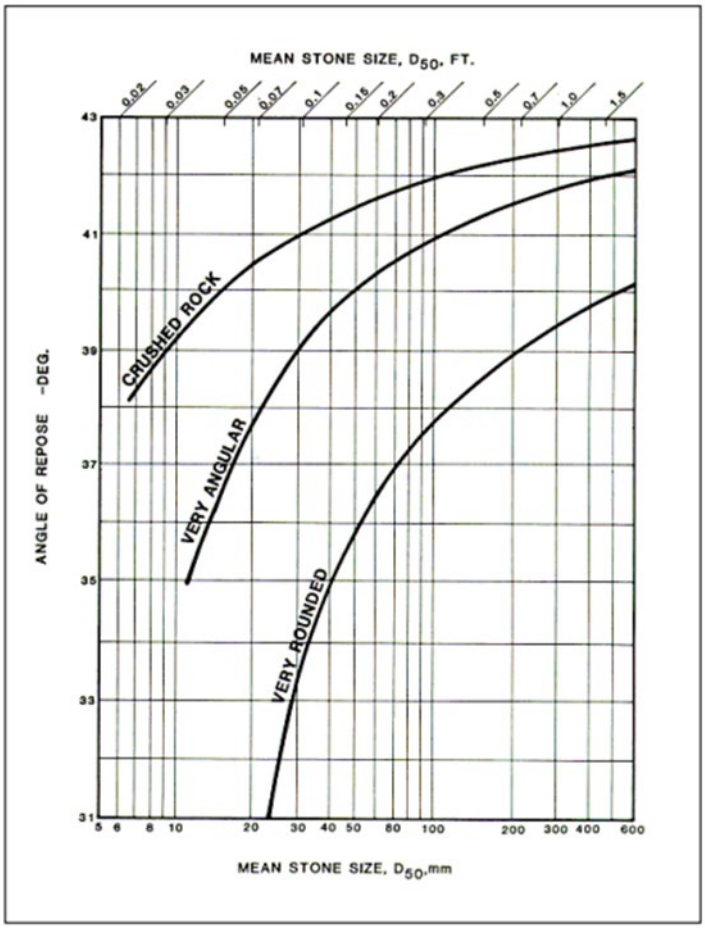


***Figure 6.15a*** *Angle of repose of riprap in terms of mean size and shape of stone (Adapted from FHWA HEC-15, 2005)*

**Filter blanket**—A filter blanket is a layer of material placed between the riprap and the underlying soil to prevent soil movement into or through the riprap.

A suitable filter may consist of a well-graded gravel or sand-gravel layer or a synthetic geotextile manufactured for this express purpose. The design of a gravel filter blanket is based on the ratio of particle size in the overlying filter material to that of the base material in accordance with the criteria below. The designed gravel filter blanket may consist of several layers of increasingly large particles from sand to erosion control stone.

**A gravel filter blanket** should have the following filter-to-base or filter-to-rip-rap relationship for a stable design:

$$\frac{d_{15}\ \text{upper}}{d_{85}\ \text{lower}} \leq 5$$

$$5 \leq \frac{d_{15}\ \text{upper}}{d_{15}\ \text{lower}} \leq 40$$

$$\frac{d_{50}\ \text{upper}}{d_{50}\ \text{lower}} \leq 40$$

In the above relationships, "upper" refers to the overlying material and "lower" refers to the underlying material. The relationships must hold between the filter blanket and base material and between the riprap and filter blanket. More than one layer of filter material may be needed. Each layer of filter material should be at least 6 inches thick.

**A geotextile** may be used with or in place of gravel filters. Selection of geotextile should consider factors such as soil retention, permeability, clogging and survivability. With the exception of problematic soils or high velocity conditions associated with steep channels, geotextile filters may usually be selected based on the apparent opening size (AOS) of the geotextile and the soil type as shown in Table 6.15b.

Detailed design guidance for selecting geotextiles as a riprap filter material in situations where problematic soil environments exist, severe environmental conditions are expected, and/or for critical installations may be found in *Federal Highway Administration, 1998. "Geosynthetic Design and Construction Guidelines," FHWA-HI-95-038.*

**Table 6.15b Maximum AOS for Geotextile Filters (FHWA, 1998)**

| Soil Type | Maximum AOS (mm) |
|---|---|
| Non cohesive, less than 15 percent passing the 0.075 mm (US #200) sieve | 0.43 |
| Non cohesive, 15 to 50 percent passing the 0.075 mm (US #200) sieve | 0.25 |
| Non cohesive, more than 50 percent passing the 0.075 mm (US #200) sieve | 0.22 |
| Cohesive, plasticity index greater than 7 | 0.30 |

Filter blankets should always be provided where seepage is significant,

or where flow velocity and duration of flow or turbulence may cause the underlying soil particles to move through the riprap.

## Construction Specifications

**Subgrade preparation**—Prepare the subgrade for riprap and filter to the required lines and grades shown on the plans. Compact any fill required in the subgrade to a density approximating that of the surrounding undisturbed material or overfill depressions with riprap. Remove brush, trees, stumps, and other objectionable material. Cut the subgrade sufficiently deep that the finished grade of the riprap will be at the elevation of the surrounding area. Channels should be excavated sufficiently to allow placement of the riprap in a manner such that the finished inside dimensions and grade of the riprap meet design specifications.

**Sand and gravel filter blanket**—Place the filter blanket immediately after the ground foundation is prepared. For gravel, spread filter stone in a uniform layer to the specified depth. Where more than one layer of filter material is used, spread the layers with minimal mixing.

**Geotextile**—Place and secure the geotextile directly on the prepared soil foundation in accordance with the manufacturer's installation guidelines. Typically, overlap the edges by at least 12 inches, and space anchors every 3 ft along the overlap. Bury the upstream end of the geotextile a minimum of 12 inches below ground and where necessary, bury the lower end of the geotextile or overlap with the next section as required. See Figure 6.14a, Page 6.14.6.

Take care not to damage the geotextile when placing riprap. If damage occurs remove the riprap and repair the sheet by adding another layer of geotextile with a minimum overlap of 12 inches around the damaged area. If extensive damage is suspected, remove and replace the entire section.

Where large stones are used or machine placement is difficult, a 4-inch layer of fine gravel or sand may be needed to protect the geotextile.

**Stone placement**—Placement of riprap should follow immediately after placement of the filter. Place riprap so that it forms a dense, well-graded mass of stone with a minimum of voids. The desired distribution of stones throughout the mass may be obtained by selective loading at the quarry, and controlled dumping during final placement. Place riprap to its full thickness in one operation. Do not place riprap by dumping through chutes or other methods that cause segregation of stone sizes. Take care not to dislodge the underlying base or filter when placing the stones.

The toe of the riprap slope should be keyed to a stable foundation at its base

as shown in Figure 6.15b. The toe should be excavated to a depth about 1.5 times the design thickness of the riprap and should extend horizontally from the slope.

The finished slope should be free of pockets of small stone or clusters of large stones. Hand placing may be necessary to achieve the proper distribution of stone sizes to produce a relatively smooth, uniform surface. Excavate embankment or channel to accommodate the depth of stone such that the riprap is uniform and level with the finished grade.

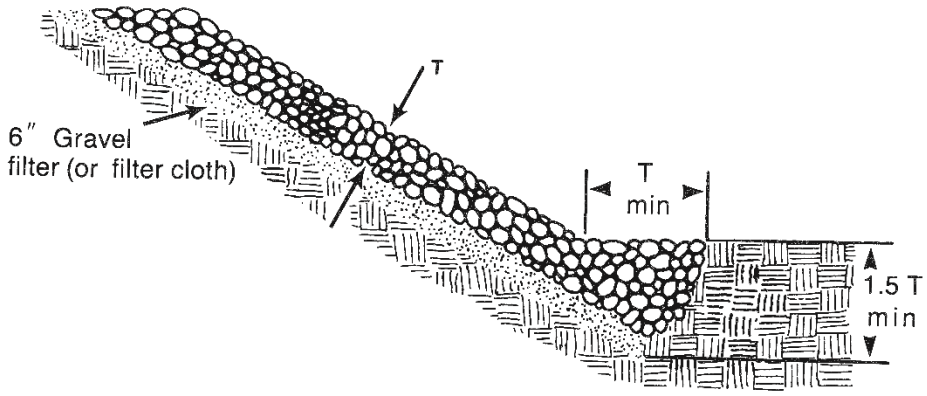


***Figure 6.15b*** *Riprap slope protection (modified from VDH&T)*

## Maintenance

In general, once a riprap installation has been properly designed and installed it requires very little maintenance. Riprap should be inspected periodically for scour or dislodged stones. Control of weed and brush growth may be needed in some locations.

## References

*Runoff Conveyance Measures*

6.31, Riprap-lined and Paved Channels

*Outlet Protection*

6.41, Outlet Stabilization Structure

*Appendices*

8.05, Design of Stable Channels and Diversions

8.06, Design of Riprap Outlet Protection

# CTC Edits to Original Standard

6.15

RR

# RIPRAP

## Definition

A permanently placed layer of large irregular-shaped stone with an underlining geotextile or granular filter blanket.~~A layer of stone designed to protect and stabilize areas subject to erosion.~~

## Purpose

To protect the soil surface from erosive forces and/or improve stability of soil slopes that are subject to seepage or have poor soil structure.

## Conditions Where Practice Applies

Riprap is used for the following applications:

- cut-and-fill slopes subject to seepage or weathering, particularly where conditions prohibit establishment of vegetation,
- channel side slopes and bottoms,
- inlets and outlets for culverts, bridges, slope drains, grade stabilization structures, and storm drains
- streambanks and ~~stream grades~~streambeds,
- shorelines subject to wave action.

## Planning Considerations

Riprap is a versatile, highly erosion-resistant material that can be used effectively in many locations and in a variety of ways to control erosion on construction sites.

**GRADED VERSUS UNIFORM RIPRAP**

Riprap is classed as either graded or uniform. Graded riprap includes a wide mixture of stone sizes. Uniform riprap consists of stones nearly all the same size.

Graded riprap is preferred to uniform riprap in most applications because ~~it~~ the variation in size allows for settling and forms a dense, flexible cover. Uniform riprap ~~is~~creates more open voids, and cannot adjust as effectively to movement of the stones. Graded riprap is also cheaper to install requiring less hand work for installation than uniform riprap, which must be placed in a uniform pattern. Uniform riprap may give a more pleasing appearance.

Riprap sizes are designated by either the mean diameter or the weight of the stones. The diameter specification is often misleading since the stones are usually angular. However, common practice is to specify stone size by the diameter of an equivalent size of spherical stone. ~~Table 6.15a lists some typical stones by weight, spherical diameter, and the corresponding rectangular dimensions. These stone sizes are based upon an assumed specific weight of 165 lb/ft³.~~

A method commonly used for specifying the range of stone sizes in graded riprap is to designate a diameter for which some percentage, by weight, will be smaller. For example, "$d_{85}$" specifies a mixture of stones in which 85% of the stone by weight would be smaller than the diameter specified. Most designs are based on "$d_{50}$", or median size stones. Table 6.15a lists some commonly referenced mean diameter stone sizes available within North Carolina.

~~Riprap and gravel are often designated by N.C. Department of Transportation specifications (Table 6.15b).~~

**Commented [JG1]:** Definition is more consistent with other literature and does not repeat purpose.

**Commented [JG2]:** Odd phrasing. Streambeds or just streams?

~~Table 6.15a~~
~~Size or Riprap Stones~~

| ~~Weight (lb)~~ | ~~Mean Spherical Diameter (ft)~~ | ~~Length (ft)~~ | ~~Rectangular Shape Width/Height (ft)~~ |
|---|---|---|---|
| ~~50~~ | ~~0.8~~ | ~~1.4~~ | ~~0.5~~ |
| ~~100~~ | ~~1.1~~ | ~~1.8~~ | ~~0.6~~ |
| ~~150~~ | ~~1.3~~ | ~~2.0~~ | ~~0.7~~ |
| ~~300~~ | ~~1.6~~ | ~~2.6~~ | ~~0.9~~ |
| ~~500~~ | ~~1.9~~ | ~~3.0~~ | ~~1.0~~ |
| ~~1000~~ | ~~2.2~~ | ~~3.7~~ | ~~1.3~~ |
| ~~1500~~ | ~~2.6~~ | ~~4.7~~ | ~~1.5~~ |
| ~~2000~~ | ~~2.8~~ | ~~5.4~~ | ~~1.8~~ |
| ~~4000~~ | ~~3.6~~ | ~~6.0~~ | ~~2.0~~ |
| ~~6000~~ | ~~4.0~~ | ~~6.9~~ | ~~2.3~~ |
| ~~8000~~ | ~~4.5~~ | ~~7.6~~ | ~~2.5~~ |
| | ~~6.1~~ | ~~10.0~~ | ~~3.3~~ |

~~source: Va. SWCC~~

Commented [JG3]: Table is current for 1992 VA manual (Table 3.19a)

Commented [JG4R3]: Delete. Reference NCDOT Stand. Spec.

Table 6.15a Sizes for Riprap

Commented [JG5]: Table is current for NC Aggregate Association. Riprap mean sizes and classification may vary by state, mostly driven by State DOT specifications due to volume of stone used.

Commented [GJA6R5]: Updated to note original source NCDOT

**RIP RAP MATERIALS**

**ACCEPTANCE CRITERIA FOR RIP RAP AND STONE FOR EROSION CONTROL**

| Class | Required Stone Sizes, inches | | |
|---|---|---|---|
| | Minimum | Midrange | Maximum |
| A | 2 | 4 | 6 |
| B | 5 | 8 | 12 |
| 1 | 5 | 10 | 17 |
| 2 | 9 | 14 | 23 |

No more than 5.0% of the material furnished can be less than the minimum size specified nor no more than 10.0% of the material can exceed the maximum size specified.

Source: NCDOT

When considering riprap for surface stabilization, it is important to anticipate visual impacts, including weed control, hazards from snakes and other animals, danger of slides and hazards to areas below steep riprap slopes, damage and possible slides from children moving stones, and general safety.

Proper ~~slope~~ stone size selection and surface preparation are essential for successful
long-term functioning of riprap. Adequate compaction of fill areas and proper use of filter blankets are necessary.

Commented [JG7]: Slope selection does not seems odd. Stone size selection?

**Sequence of construction**—Schedule disturbance of areas that require riprap protection so that the placement of riprap can follow immediately after grading. When riprap is used for outlet protection, place the riprap before or in

conjunction with the installation of the structure so that it is in place before the first runoff event.

**Gradation**—Riprap should be a well-graded mixture with 50% by weight larger than the specified design size. The diameter of the largest stone size in such a mixture should be 1.5 times the $d_{50}$ size with smaller sizes grading down to 1 inch.

The designer should determine the riprap size that will be stable for design conditions. Having determined the design stone size, the designer should select the size or sizes that equal or exceed that minimum size based on riprap gradations commercially available in the area.

**Thickness**—Construction techniques, dimensions of the area to be protected, size and gradation of the riprap, the frequency and duration of flow, difficulty and cost of maintenance, and consequences of failure should be considered when determining the thickness of riprap linings. The minimum thickness should be 1.5 times the maximum stone diameter, but in no case less than 6 inches.

**Quality of stone**—Stone for riprap may consist of field stone or quarry stone. The stone should be hard, angular, of such quality that it will not break down

**Table 6.15b**

Sizes for Riprap and Erosion Control Stone Specified by the N.C. Department of Transportation

| Riprap | | Erosion Control | |
|---|---|---|---|
| **Class 1** | **Class 2** | **Class A** | **Class B** |
| 5 to 200 lb | 25 to 250 lb | 2" to 6" | 5" to 15" |
| 30% shall weigh a minimum of 60 lbs each | 60% shall weigh a minimum of 100 lb each | | |
| No more than 10% shall weigh less than 15 lb each | No more than 5% shall weigh less than 50 lb each | 10% tolerance top and bottom sizes | |
| | | Equally distributed, no gradation specified | Equally distributed, no gradation specified |

source: North Carolina Aggregates Association

on exposure to water or weathering, and suitable in all other respects for the purpose intended. The specific gravity of the individual stones should be at least 2.5.

**Commented [JG8]:** The granitic rocks have specific gravity of 2.44 – 2.67 with water absorption of 2.57% and 3.17% while the schist has specific gravity of 2.21 and water absorption of 3.63%.
-Journal of Geography and Earth Sciences Vol 7 No 1 June 2019.

**Size of stone**—The sizes of stones used for riprap protection are determined by purpose and specific site conditions.

- **Slope stabilization**—Riprap stone for slope stabilization, not subject to flowing water or wave action, should be sized for stability for the proposed grade. The gradient of the slope to be stabilized should be less than the natural angle of repose of the stone selected. Angle of repose of riprap stones may be estimated from Figure 6.~~15a~~15a~~.~~

  Riprap used for surface stabilization of slopes does not add significant resistance to sliding or slope ~~failure, and~~failure and should not be considered a retaining wall. The inherent stability of the soil must be satisfactory before riprap is used for surface stabilization. Slopes approaching 1.5:1 may require special stability analysis.

- **Outlet protection**—Design criteria for sizing ~~stone, and~~stone and determining the dimensions of riprap pads at channel or conduit outlets are presented in Practice 6.41, *Outlet Stabilization Structure*.

- **Channel stabilization and streambank protection**—Design criteria for sizing stone for stability of channels are contained in *Appendix 8.05*.

**Filter blanket**—A filter blanket is a layer of material placed between the riprap and the underlying soil to prevent soil movement into or through the riprap.

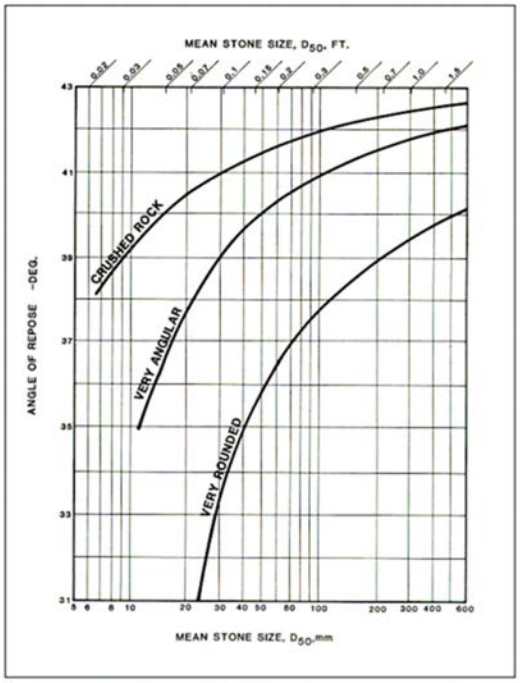


Figure 6.1. Angle of Repose of Riprap in Terms of Mean Size and Shape of Stone

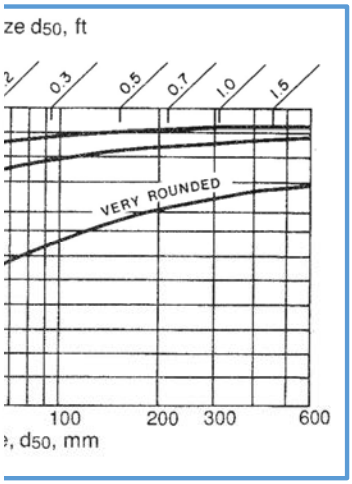


**Figure 6.15a**

A suitable filter may consist of a well-graded gravel or sand-gravel layer or a synthetic ~~filter fabric~~geotextile manufactured for this express purpose. The design of a gravel filter blanket is based on the ratio of particle size in the overlying filter material to that of the base material in accordance with the criteria below. The designed gravel filter blanket may consist of several layers of increasingly large particles from sand to erosion control stone.

**A gravel filter blanket** should have the following relationship for a stable design:

$$\frac{d_{15}\ \text{upper}\sout{\text{filter}}}{d_{85}\ \text{lower}\sout{\text{base}}} \leq 5$$

$$5 \leq \frac{d_{15}\ \text{upper}\sout{\text{filter}}}{}$$

**Commented [JG9]:** Current chart from HEC 15, 2005. Slight differences from pervious table.

**Commented [JG10]:** Geotextile is the current ASTM terminology.

**Commented [JG11]:** Varies from FHWA Circ 15 6.4.3. Revised language clarifies relationship.

$$\frac{d_{15}\ \text{upper}}{d_{15}\ \text{lower}} \leq 40$$

$$\frac{d_{50}\ \text{upper}}{d_{50}\ \text{lower}} \leq 40$$

In the above relationships, "upper" refers to the overlying material and "lower" refers to the underlying material. The relationships must hold between the filter blanket and base material and between the riprap and filter blanket. In these relationships, filter refers to the overlying material, and base refers to the underlying material. These relationships must hold between the filter material and the base material (soil foundation), and between the riprap and the filter. More than one layer of filter material may be needed. Each layer of filter material should be at least 6 inches thick.

**A** synthetic filter fabric**geotextile** may be used with or in place of gravel filters. Selection of geotextile should consider factors such as soil retention, permeability, clogging and survivability. With the exception of problematic soils or high velocity conditions associated with steep channels, geotextile filters may usually be selected based on the apparent opening size (AOS) of the geotextile and the soil type as shown in Table 6.15b.

**Commented [JG12]:** Apparent Opening Size (AOS) is revised term. Current guidance would be FHWA Geosynthetic Design and Construction Guidelines (1998).

Detailed design guidance for selecting geotextiles as a riprap filter material in situations where problematic soil environments exist, severe environmental conditions are expected, and/or for critical installations may be found in *Federal Highway Administration, 1998. "Geosynthetic Design and Construction Guidelines," FHWA-HI-95-038.*

**Table 6.15b. Maximum AOS for Geotextile Filters (FHWA, 1998)**

| Soil Type | Maximum AOS (mm) |
|---|---|
| Non cohesive, less than 15 percent passing the 0.075 mm (US #200) sieve | 0.43 |
| Non cohesive, 15 to 50 percent passing the 0.075 mm (US #200) sieve | 0.25 |
| Non cohesive, more than 50 percent passing the 0.075 mm (US #200) sieve | 0.22 |
| Cohesive, plasticity index greater than 7 | 0.30 |

6.2. The following particle size relationships should exist:

- Filter fabric covering a base with granular particles containing 50% or less (by weight) of fine particles (less than U.S. Standard Sieve no. 200 [0.074mm]):

~~a.~~

| ~~$d_{as}$ base (mm)~~ | ~~EOS* filter fabric (mm)~~ |
|---|---|

~~b. total open area of filter should not exceed 36%.~~

~~• Filter fabric covering other soils:~~
~~a. EOS is no larger than U.S. Standard Sieve no. 70 (0.21mm),~~
~~b. total open area of filter should not exceed 10%.~~
~~**EOS - Equivalent opening size compared to a U.S. standard sieve size.~~
~~No filter fabric should have less than 4% open area, or an EOS less than U.S. Standard Sieve No. 100 (0.15mm). The permeability of the fabric must be greater than that of the soil. The fabric may be made of woven or nonwoven monofilament yarns, and should meet the following minimum requirements:~~
~~• thickness 20 - 60 mils,~~
~~• grab strength 90 - 120 lb, and~~
~~• conform to ASTM D-1682 or ASTM D-177.~~

Filter blankets should always be provided where seepage is significant, or where flow velocity and duration of flow or turbulence may cause the underlying soil particles to move through the riprap.

## Construction Specifications

**Subgrade preparation**—Prepare the subgrade for riprap and filter to the required lines and grades shown on the plans. Compact any fill required in the subgrade to a density approximating that of the surrounding undisturbed material or overfill depressions with riprap. Remove brush, trees, stumps, and other objectionable material. Cut the subgrade sufficiently deep that the finished grade of the riprap will be at the elevation of the surrounding area. Channels should be excavated sufficiently to allow placement of the riprap in a manner such that the finished inside dimensions and grade of the riprap meet design specifications.

**Sand and gravel filter blanket**—Place the filter blanket immediately after the ground foundation is prepared. For gravel, spread filter stone in a uniform layer to the specified depth. Where more than one layer of filter material is used, spread the layers with minimal mixing.

~~**Synthetic filter fabric**~~**Geotextile**—Place and secure the ~~cloth filter~~geotextile directly on the prepared soil foundation in accordance with the manufacturer's installation guidelines. Typically, o~~O~~verlap the edges by at least 12 inches, and space anchor ~~pins~~ every 3 ft along the overlap. Bury the upstream end of the ~~cloth~~ geotextile a minimum of 12 inches below ground and where necessary, bury the lower end of the ~~cloth~~ geotextile or ~~over lap~~overlap with the next section as required. See Figure 6.14a Page 6.14.6.

**Commented [GJA13]:** Will need to be verified after sections are compiled.



Take care not to damage the ~~cloth~~ geotextile when placing riprap. If damage occurs remove the ~~riprap, and~~riprap and repair the sheet by adding another layer of ~~filter material~~geotextile with a minimum overlap of 12 inches around the

damaged area. If extensive damage is suspected, remove and replace the entire section~~sheet~~.

Where large stones are used or machine placement is difficult, a 4-inch layer of fine gravel or sand may be needed to protect the geotextile~~filter cloth~~.

**Stone placement**—Placement of riprap should follow immediately after placement of the filter. Place riprap so that it forms a dense, well-graded mass of stone with a minimum of voids. The desired distribution of stones throughout the mass may be obtained by selective loading at the quarry, and controlled dumping during final placement. Place riprap to its full thickness in one operation. Do not place riprap by dumping through chutes or other methods that cause segregation of stone sizes. Take care not to dislodge the underlying base or filter when placing the stones.

The toe of the riprap slope should be keyed to a stable foundation at its base as shown in Figure 6.15b. The toe should be excavated to a depth about 1.5 times the design thickness of the ~~riprap, and~~riprap and should extend horizontally from the slope.

The finished slope should be free of pockets of small stone or clusters of large stones. Hand placing may be necessary to achieve the proper distribution of stone sizes to produce a relatively smooth, uniform surface. ~~The finished grade of the riprap should blend with the surrounding area. No overfall or protrusion of riprap should be apparent.~~Excavate embankment or channel to accommodate the depth of stone such that the riprap is uniform and level with the finished grade.

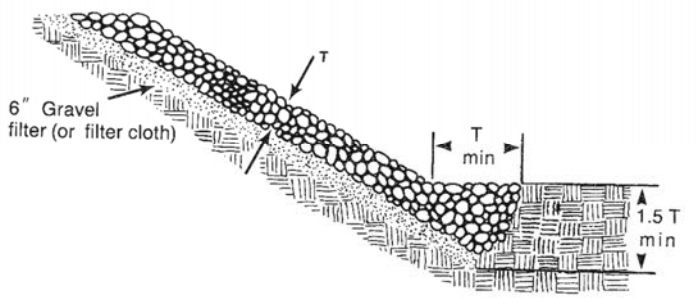


**Figure 6.15b** Riprap slope protection (modified from VDH&T)

In general, once a riprap installation has been properly designed and installed it requires very little maintenance. Riprap should be inspected periodically for scour or dislodged stones. Control of weed and brush growth may be needed in some locations.

## References

*Runoff Conveyance Measures*
6.31, Riprap-lined and Paved Channels

## Maintenance

**Commented [GA14]:** Figure 6.15b will need '(or filter cloth)' edited to '(or geotextile)'.

**Commented [JG15]:** Need to edit Figure 6.15b to replace 'filter cloth' with 'geotextile'.

**Commented [JG16]:** Excavate embankment or channel to accommodate the depth of stone such that the riprap is uniform with the finished grade.

**Commented [JG17R16]:** Adjusted language for clarity.

*Outlet Protection*
6.41, Outlet Stabilization Structure

*Appendices*
8.05, Design of Stable Channels and Diversions
8.06, Design of Riprap Outlet Protection

**Rev.12/93**