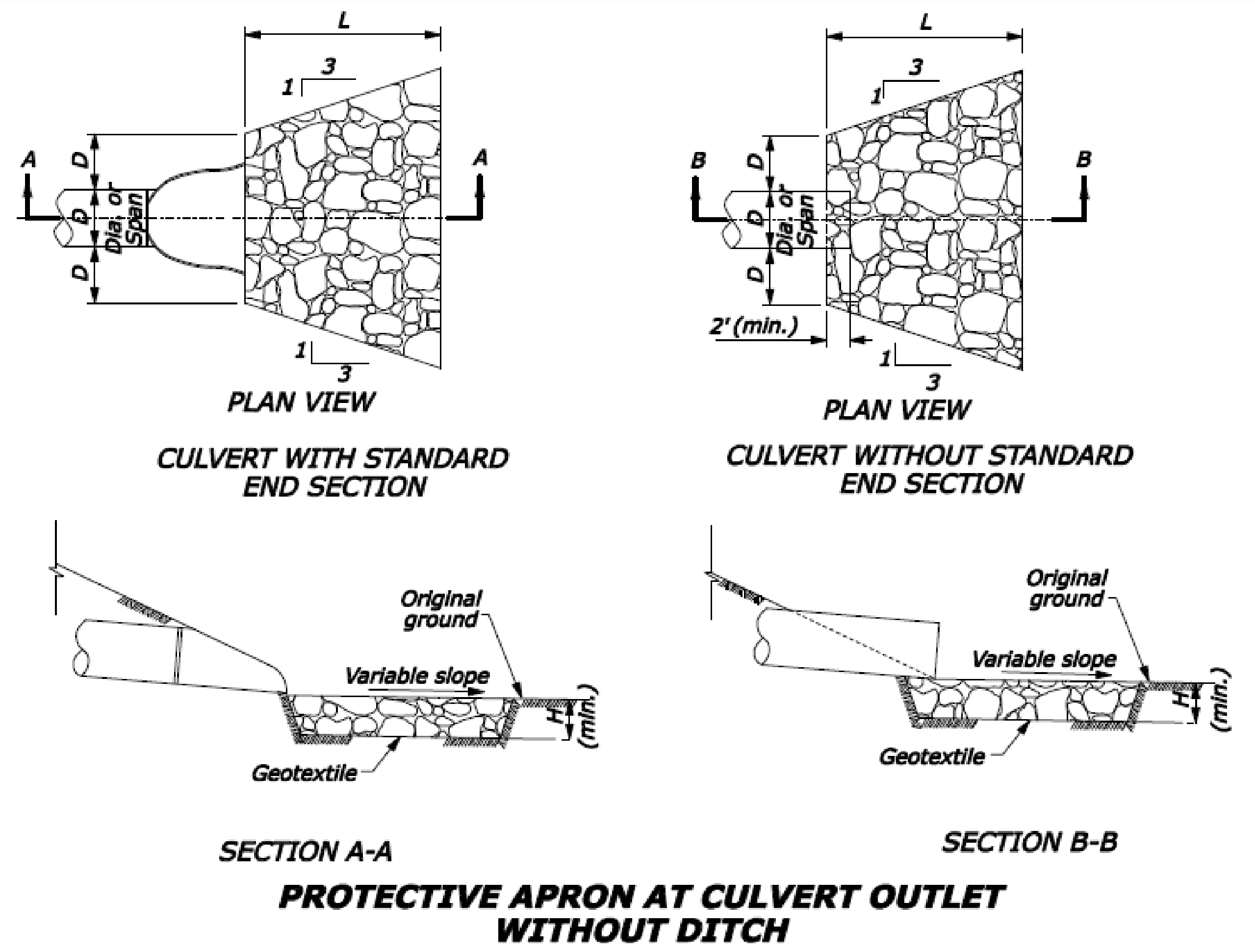
HEC 14: Riprap Apron

10.2 RIPRAP APRON

The most commonly used device for outlet protection, primarily for culverts 60 in (1500 mm) or smaller, is a riprap apron. An example schematic of an apron taken from the Central Federal Lands Division of the Federal Highway Administration is shown in Figure 10.4.



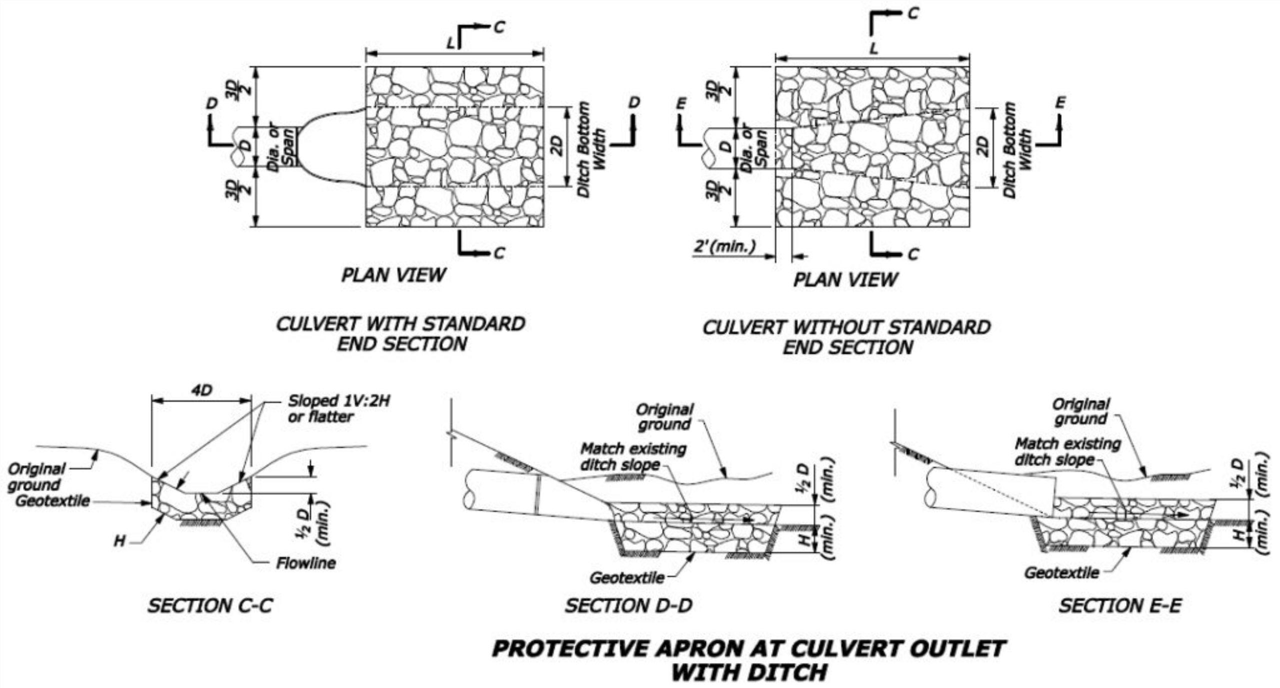


Figure 10.4. Placed Riprap at Culverts (per Central Federal Lands Highway Division Detail C251-50). Click images to enlarge.

They are constructed of riprap or grouted riprap at a zero grade for a distance that is often related to the outlet pipe diameter. These aprons do not dissipate significant energy except through increased roughness for a short distance. However, they do serve to spread the flow helping to transition to the natural drainage way or to sheet flow where no natural drainage way exists. However, if they are too short, or otherwise ineffective, they simply move the location of potential erosion downstream. The key design elements of the riprap apron are the riprap size as well as the length, width, and depth of the apron.

Several relationships have been proposed for riprap sizing for culvert aprons and several of these are discussed in greater detail in Appendix D of HEC-14. The independent variables in these relationships include one or more of the following variables: outlet velocity, rock specific gravity, pipe dimension (e.g. diameter), outlet Froude number, and tailwater. The following equation (Fletcher and Grace, 1972) is recommended for circular culverts:

$$D_{50} = 0.2 \cdot D\left(Q/(\sqrt{g} \cdot D^{2.5})\right)^{4/3}(D/TW) \quad (10.4)$$

where,

- D_{50} = riprap size, m (ft)
- Q = design discharge, m^3/s (ft^3/s)
- D = culvert diameter (circular), m (ft)
- TW = tailwater depth, m (ft)
- g = acceleration due to gravity, 9.81 m/s^2 (32.2 ft/s^2)

Tailwater depth for Equation 10.4 should be limited to between 0.4D and 1.0D. If tailwater is unknown, use 0.4D.

Whenever the flow is supercritical in the culvert, the culvert diameter is adjusted as follows:

$$D' = (D + y_n)/2 \qquad (10.5)$$

where,

- D’ = adjusted culvert rise, m (ft)
- y_n = normal (supercritical) depth in the culvert, m (ft)

Equation 10.4 assumes that the rock specific gravity is 2.65. If the actual specific gravity differs significantly from this value, the D_{50} should be adjusted inversely to specific gravity.

The designer should calculate D_{50} using Equation 10.4 and compare with available riprap classes. A project or design standard can be developed such as the example from the Federal Highway Administration Federal Lands Highway Division (FHWA, 2003) shown in Table 10.1 (first two columns). The class of riprap to be specified is that which has a D_{50} greater than or equal to the required size. For projects with several riprap aprons, it is often cost effective to use fewer riprap classes to simplify acquiring and installing the riprap at multiple locations. In such a case, the designer must evaluate the tradeoffs between over sizing riprap at some locations in order to reduce the number of classes required on a project.

Class	D_{50} (mm)	D_{50} (in)	Apron Length[1]	Apron Depth
1	125	4	4·D	$3.5 \cdot D_{50}$
2	150	6	4·D	$3.3 \cdot D_{50}$
3	250	10	5·D	$2.4 \cdot D_{50}$
4	350	14	6·D	$2.2 \cdot D_{50}$
5	500	20	7·D	$2.0 \cdot D_{50}$
6	550	22	8·D	$2.0 \cdot D_{50}$

[1]D is the culvert rise.

The apron dimensions must also be specified. Table 10.1 provides guidance on the apron length and depth. Apron length is given as a function of the culvert rise and the riprap size. Apron depth ranges from $3.5 \cdot D_{50}$ for the smallest riprap to a limit of $2.0 \cdot D_{50}$ for the larger riprap sizes. The final dimension, width, may be determined using the 1:3 flare shown in Figure 10.4 and should conform to the dimensions of the downstream channel. A filter blanket should also be provided as described in HEC 11 (Brown and Clyde, 1989).

For tailwater conditions above the acceptable range for Equation 10.4 ($TW > 1.0 \cdot D$), Figure 10.3 should be used to determine the velocity downstream of the culvert. The guidance in Section 10.3 may be used for sizing the riprap. The apron length is determined based on the allowable velocity and the location at which it occurs based on Figure 10.3.

Over their service life, riprap aprons experience a wide variety of flow and tailwater conditions. In addition, the relations summarized in Table 10.1 do not fully account for the many variables in culvert design. To ensure continued satisfactory operation, maintenance personnel should inspect them after major flood events. If repeated severe damage occurs, the location may be a candidate for extending the apron or another type of energy dissipator.

Design Example: Riprap Apron (CU)

Design a riprap apron for the following CMP installation. Available riprap classes are provided in Table 10.1. Given:

- $Q = 85$ $ft^{3/s}$
- $D = 5.0$ ft
- $TW = 1.6$ ft

Solution

Step 1. Calculate D_{50} from Equation 10.4. First verify that tailwater is within range.

$TW/D = 1.6/5.0 = 0.32$. This is less than $0.4 \cdot D$, therefore, use $TW = 0.4 \cdot D = 0.4 \cdot 5 = 2.0$ ft.

$D_{50} = 0.2 \cdot D(Q/(\sqrt{g} \cdot D^{2.5}))^{4/3}(D/TW) = 0.2 \cdot 5.0(85/(\sqrt{32.2} \cdot 5.0^{2.5}))^{4/3}(5.0/2.0) = 0.43$ ft = 5.2 in.

Step 2. Determine riprap class. From Table 10.1, riprap class 2 ($D_{50} = 6$ in) is required.

Step 3. Estimate apron dimensions.

From Table 10.1 for riprap class 2,

- Length, $L = 4 \cdot D = 4 \cdot 5 = 20$ ft
- Depth $= 3.3 \cdot D_{50} = 3.3 \cdot 6 = 19.8$ in $= 1.65$ ft

- Width (at apron end) = $3 \cdot D + (2/3) \cdot L = 3 \cdot 5 + (2/3) \cdot 20 = 28.3$ ft

Design Example: Riprap Apron (SI)

Design a riprap apron for the following CMP installation. Available riprap classes are provided in Table 10.1. Given:

- $Q = 2.33\ m^3/s$
- $D = 1.5$ m
- $TW = 0.5$ m

Solution

Step 1. Calculate D_{50} from Equation 10.4. First verify that tailwater is within range.

$TW/D = 0.5/1.5 = 0.33$. This is less than $0.4 \cdot D$, therefore, use $TW = 0.4 \cdot D = 0.4 \cdot 1.5 = 0.6$ m.

$D_{50} = 0.2 \cdot D(Q/(\sqrt{g} \cdot D^{2.5}))^{4/3}(D/TW) = 0.2 \cdot 1.5(2.33/(\sqrt{9.81} \cdot 1.5^{2.5}))^{4/3}(1.5/0.6) = 0.13$ m.

Step 2. Determine riprap class. From Table 10.1, riprap class 2 ($D_{50} = 0.15$ m) is required.

Step 3. Estimate apron dimensions.

From Table 10.1 for riprap class 2,

- Length, $L = 4 \cdot D = 4 \cdot 1.5 = 6$ m
- Depth $= 3.3 \cdot D_{50} = 3.3 \cdot 0.15 = 0.50$ m
- Width (at apron end) = $3 \cdot D + (2/3) \cdot L = 3 \cdot 1.5 + (2/3) \cdot 6 = 8.5$ m