4.3.6 Riprap Apron

Source: TDEC

Definition and Purpose

Riprap aprons are a form of outlet protection placed downstream of drainage infrastructure, typically culverts or channels. They are designed to prevent erosion at the drainage outlet by reducing flow velocity and dissipating energy.

Appropriate Applications

These measures are generally applicable at the outlet of most any storm drain, culvert, paved channel, or slope drain where outlet velocity and shear stress exceed the capacities of downgradient natural materials. Though riprap aprons are typically permanent measures, they can also be applied at the outlet of temporary structures, such as a temporary diversion.

Limitations and Maintenance

Riprap aprons are not an advisable measure when the velocity at the respective outlet exceeds 15 feet per second. Additionally, apron lengths can become excessively long when highly erosive flows are anticipated, which may lead to infringements on property lines (TDOT). Riprap apron lengths greater than 50 feet are less desirable because such structures would add complexity in obtaining environmental permits. In such cases, a stilling basin

(Section 4.3.7) may be more ideal. Conversely, if aprons are too short, they become ineffective and increase the potential for erosion downstream (FHWA, 2006).

Inspect riprap outlet structures after heavy rains to see if any erosion around or below the riprap has taken place or if the stones have been dislodged. Immediately repair all damages. Remove and replace the conventional riprap if the apron is fully clogged with sediment or if sediment is at risk of leaving the site.

Planning and Design Considerations
Outlets, pipes, channels, etc., typically discharge water at velocities capable of causing scour, channel degradation, or embankment failure. A riprap-lined apron functions as a transition structure that dissipates the flow energy, reduces velocity to non-erosive levels, and prevents undermining of the outlet. The apron lining typically consists of loose conventional riprap, or grouted riprap or concrete, depending on site conditions and flow intensity. In locations where very high flows would demand excessive apron lengths, alternatives such as plunge pools or stilling basins offer more compact energy dissipation. Effective planning and implementation of such structures requires constructing the apron at zero grade and extending it downstream until stable hydraulic conditions are reached.

Rock gradation as well as apron dimensions are calculated based on anticipated flow rates from the design storm. If the calculated gradation of stone is not available, round up to the next available D_{50}. Because riprap aprons are typically permanent measures, they should be designed to handle the same design flow rate as the drainage structure they serve. When they are designed as a temporary structure, temporary aprons can be designed using the 2-year, 24-hour or 5-year, 24-hour peak flow rate, depending on the status of the receiving water. Rock gradation (i.e., D_{50}) can be computed utilizing Eqn 22 when using conventional riprap for an apron draining a circular culvert:

$$D_{50} = 0.2 \times D \times \left(\frac{Q}{\sqrt{g} \times D^{2.5}}\right)^{4/3} \times \frac{D}{TW} \qquad \text{(Eqn 22)}$$

where D_{50} is the stone size in which 50% is finer by weight (feet), Q is the design discharge (cubic feet per second), D is the circular culvert diameter (feet), TW is the tailwater depth (feet), and g is acceleration due to gravity (32.2 feet per square second). Use Appendix B of FHWA (2006) if TW computations are required; however, TW should be limited to between $0.4 \times D$ and $1.0 \times D$, using $0.4 \times D$ if TW is unknown (FHWA, 2006). When flow is supercritical [i.e., the Froude Number (Eqn 16, Section 4.3.2) is greater than one), the culvert diameter is adjusted following Eqn 23:

$$D' = \frac{D + y_n}{2} \qquad \text{(Eqn 23)}$$

where D' is the adjusted culvert rise (feet) and y_n is the normal (supercritical) depth in the culvert (feet). Apron dimensions (length and depth) can be obtained from Table 4.3.6-A once the D_{50} has been calculated.

Table 4.3.6-A: Riprap apron length and depth dimensions based on D_{50}. Source: FHWA (2006).

D_{50} (in)	Apron Length[a] (feet)	Apron Depth (feet)
5	$4 \times D$	$3.5 \times D_{50}$
6	$4 \times D$	$3.3 \times D_{50}$
10	$5 \times D$	$2.4 \times D_{50}$
14	$6 \times D$	$2.2 \times D_{50}$
20	$7 \times D$	$2.0 \times D_{50}$
22	$8 \times D$	$2.0 \times D_{50}$

[a]D is the culvert rise.

The width of the apron (at the most upstream end of the apron) should be three times the diameter of the culvert. If runoff is not channeled such that it can only travel in the direction of the length of the apron, the apron width should linearly increase with length (i.e., trapezoidal in shape). The width on each side of the apron should increase by one foot per three feet of apron length. Apron width specifications are shown in Figure 4.3.6-A.
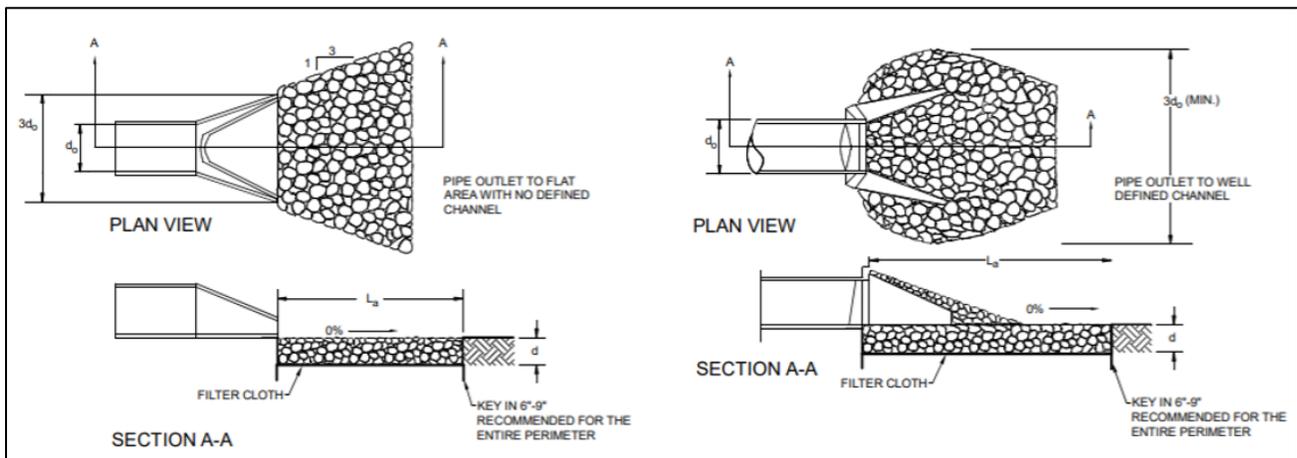

Figure 4.3.6-A. Apron width details. Adapted from VDEQ (2024).

In cases where TW > 1.0 × D and Eqn 22 is not appropriate, consider implementing a stilling basin (Section 4.3.7) or an energy dissipator (Section 4.3.4) upstream of the apron. In the latter case, use Eqn 24 to size the conventional riprap:

$$D_{50} = \frac{0.692}{S-1} \times \frac{V^2}{2 \times g}$$

(Eqn 24)

where S is the specific gravity of the riprap (typically 2.65), and V is the velocity at which water leaves the dissipator (feet per second). Figure 4.3.6-B should be used to determine velocity downstream of the culvert, which is then used to determine the apron length.
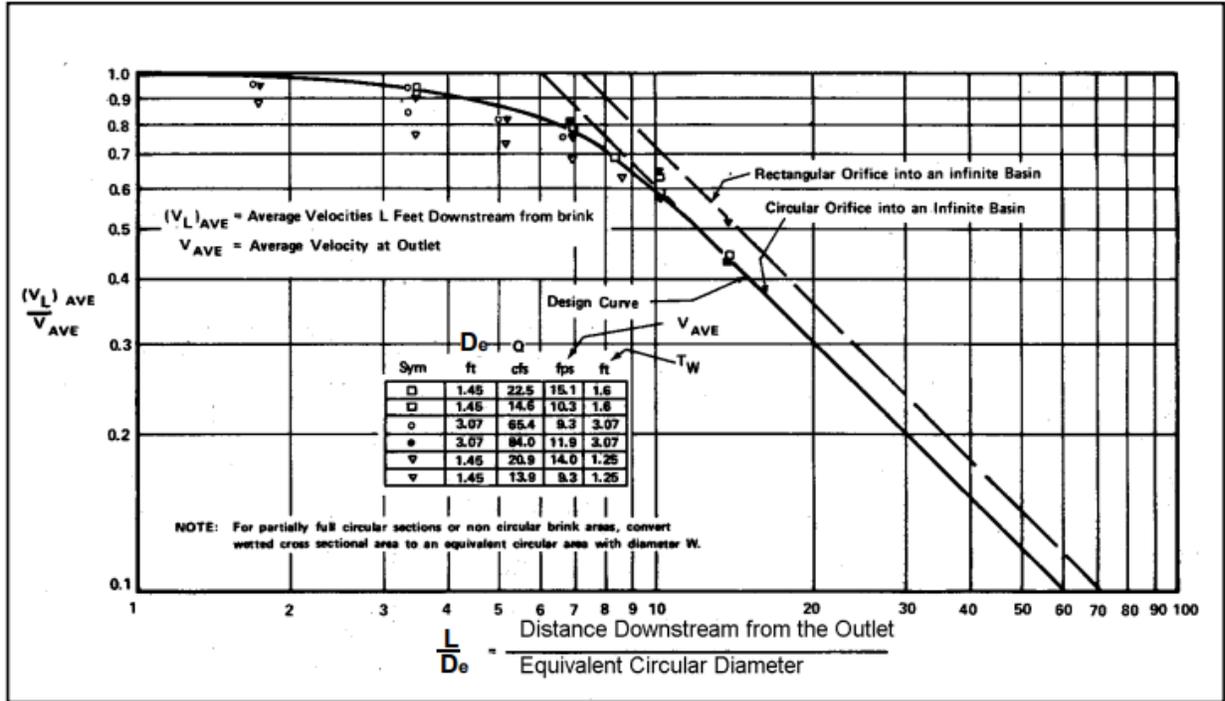

Figure 4.3.6-A: Distribution of centerline velocity for flow from submerged outlets. In this case, it can be used to determine the downstream velocity flow. Source: FHWA (2006).

Non-woven geotextile fabric or stone filter layers should be laid between the soil surface and conventional riprap to prevent piping, settling, and sediment migration as expressed in Section 4.2.6.4 (Hard Armoring). If using a geotextile, it is recommended to meet the requirements found in AASHTO M288 for a Class 2 separation geotextile and lay with such that no voids between the soil surface and fabric are present (ALSWCC, 2018).

Example Application

-Example from FHWA (2006)-

Given:

A design flow rate of 85 ft^3/s, culvert diameter of 5 ft, and tailwater depth of 1.6 ft.

Determine:

The D_{50} and dimensions for a riprap apron.

Solution:

Step 1 – Determine the stone gradation: First, verify that the tailwater is within range. TW/D = 1.6/5 = 0.32. This is less than 0.4 × D, therefore, use TW = 0.4 × D = 0.4 × 5 = 2 ft. Apply Eqn 22.

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

$$D_{50} = 0.2 \times 5 \times \left(\frac{85}{\sqrt{32.2 \times 5^{2.5}}}\right)^{4/3} \times \frac{5}{2}$$

$$D_{50} = 5.2 \text{ inches.}$$

Step 2 – Determine riprap class: This may vary from supplier to supplier. Select the class of riprap that has a D_{50} at least as large as what was calculated in Step 1. For the purposes of this example, assume a supplier has a class of conventional riprap with a D_{50} of 6 in.

Step 3 – Determine apron dimensions: Using Table 4.3.6-A, determine the length, depth, and width (at apron end) of the apron.

Length = 4 × D = 4 × 5 = 20 ft
Depth = 3.3 × D_{50} = 3.3 × 6 = 19.8 in = 1.65 ft
Width = 3 × D + (2/3) × Length = 3 × 5 + (2/3) × 20 = 28.3 ft.

References

ALSWCC. (2018). *Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas*.
FHWA. (2006). *HEC 14: Hydraulic Design of Energy Dissipators for Culverts and Channels.*
TDOT. *Drainage Manual Ch10*.
VDEQ. (2024). *Virginia Stormwater Management Handbook.*