CHAPTER 7

ENERGY DISSIPATION

7.4 Riprap Aprons

7.4.1 Uses

A flat riprap apron can be used to prevent erosion at the transition from a pipe or box culvert outlet to a natural channel. Protection is provided primarily by having sufficient length and flare to dissipate energy by expanding the flow. Riprap aprons are appropriate when the culvert outlet Fr is less than or equal to 2.5.

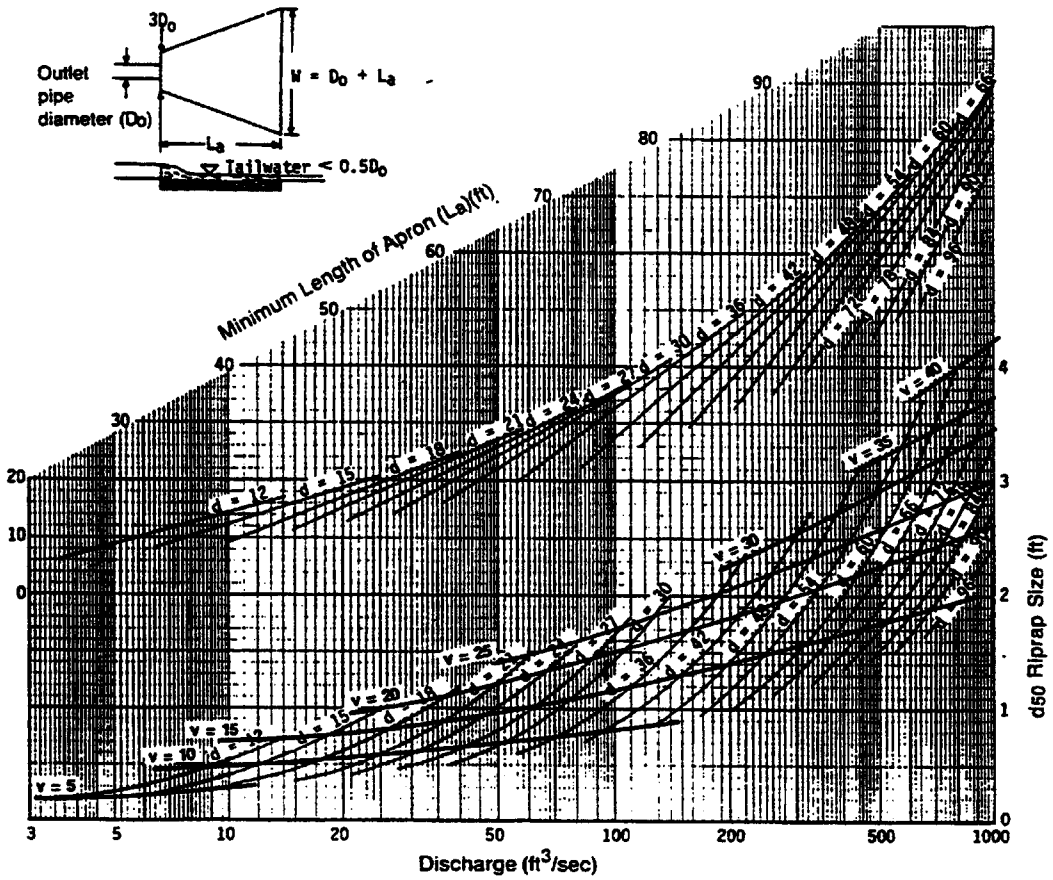
7.4.2 Procedure

The procedure present in this section is taken from USDA, SCS (1975). Two sets of curves, one for minimum and one for maximum tailwater conditions, are used to determine the apron size and the median riprap diameter, d_{50}. If tailwater conditions are unknown, or if both minimum and maximum conditions may occur, the apron should be designed to meet criteria for both. Although the design curves are based on round pipes flowing full, they can be used for partially full pipes and box culverts. The design procedure consists of the following steps:

1. If possible, determine tailwater conditions for the channel. If tailwater is less than one half the discharge flow depth (pipe diameter if flowing full), minimum tailwater conditions exist and the curves in Figure 7.4.2-1 apply. Otherwise, maximum tailwater conditions exist and the curves in Figure 7.4.2-2 should be used.

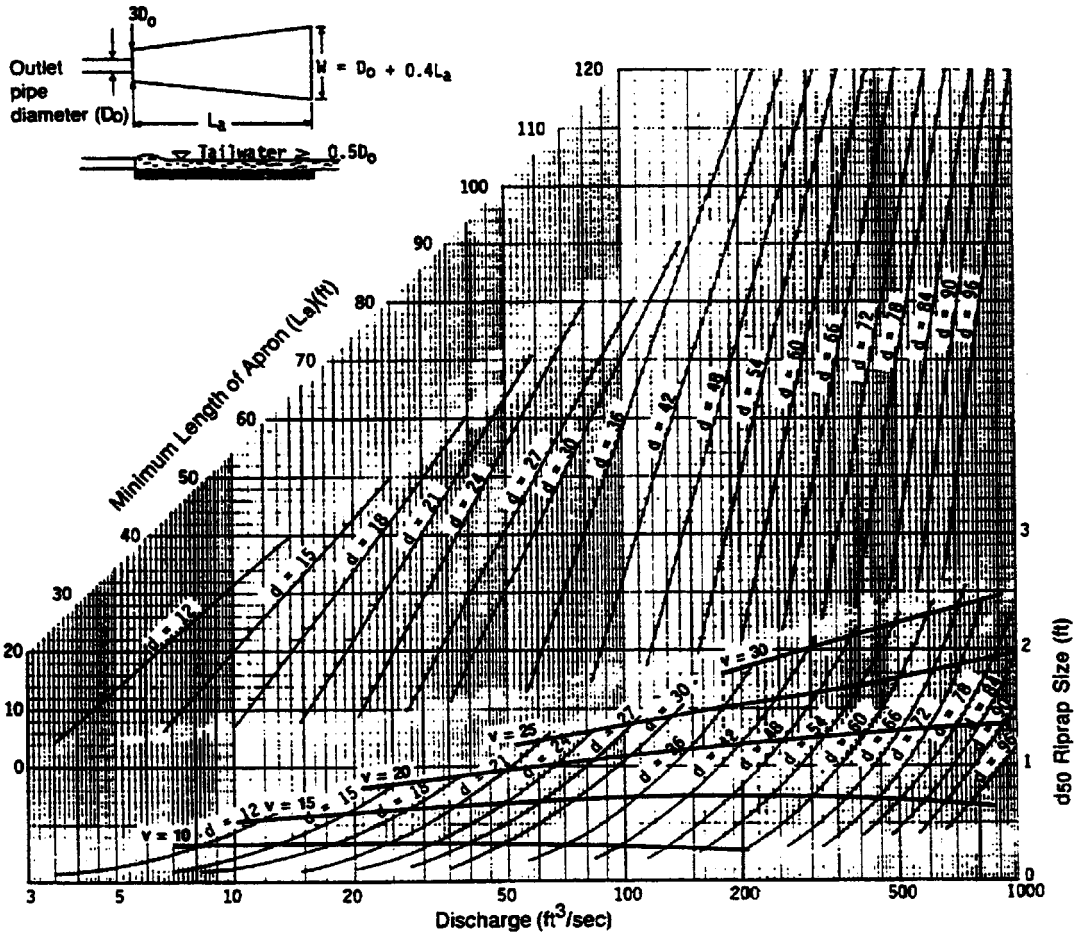
2. Determine the correct apron length and median riprap diameter, d_{50}, using the appropriate curves from Figures 7.4.2-1 and 7.4.2-2. If tailwater conditions are uncertain, find the values for both minimum and maximum conditions and size the apron as shown in Figure 7.4.2-3.

Figure 7.4.2-1
Design of Riprap Apron Under Minimum Tailwater Conditions



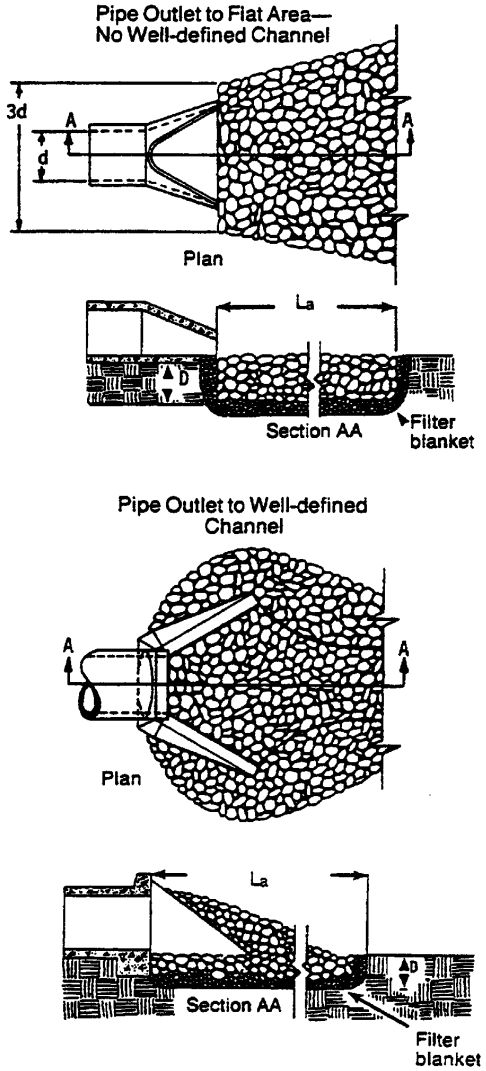
Curves may not be extrapolated.

Figure 7.4.2-2
Design of Riprap Apron Under Maximum Tailwater Conditions



Curves may not be extrapolated.

Figure 7.4.2-3
Riprap Apron



Notes

1. L_a is the length of the riprap apron.
2. D = 1.5 times the maximum stone diameter but not less than 6".
3. In a well-defined channel extend the apron up the channel banks to an elevation of 6" above the maximum tailwater depth or to the top of the bank, whichever is less.
4. A filter blanket or filter fabric should be installed between the riprap and soil foundation.

2.1 For pipes flowing full: Use the depth of flow, d, which equals the pipe diameter, in feet, and design discharge, in cfs, to obtain the apron length, L_a, and median riprap diameter, d_{50}, from the appropriate curves.

2.2 For pipes flowing partially full: Use the depth of flow, d, in feet, and velocity, v, in feet/second. On the lower portion of the appropriate figure, find the intersection of the d and v curves, then find the riprap median diameter, d_{50}, from the scale on the right. From the lower d and v intersection point, move vertically to the upper curves until intersecting

the curve for the correct flow depth, d. Find the minimum apron length, L_a, from the scale on the left.

2.3 For box culverts: Use the depth of flow, d, in feet, and velocity, v, in feet/second. On the lower portion of the appropriate figure, find the intersection of the d and v curves, then find the riprap median diameter, d_{50}, from the scale on the right. From the lower d and v intersection point, move vertically to the upper curve until intersecting the curve equal to the flow depth, d. Find the minimum apron length L_a, using the scale on the left.

3. If tailwater conditions are uncertain, the median riprap diameter should be the larger of the values for minimum and maximum conditions. The dimensions of the apron will be as shown in Figure 7.4.2-3. This will provide protection under either of the tailwater conditions.

7.4.3 Design Considerations

The following items should be considered during riprap apron design:

1. The maximum stone diameter should be 1.5 times the median riprap diameter. $d_{max} = 1.5 \times d_{50}$, d_{50} = median stone size in a well-graded riprap apron.

2. The riprap thickness should be 1.5 times the maximum stone diameter or 6 inches, whichever is greater.
   Apron thickness = $1.5 \times d_{max}$
   (Apron thickness may be reduced to $1.5 \times d_{50}$ when an appropriate filter fabric is used under the apron.)

3. The apron width at the discharge outlet should be at least equal to the pipe diameter or culvert width, d_w. Riprap should extend up both sides of the apron and around the end of the pipe or culvert at the discharge outlet at a maximum of 2:1 and a height not less than the pipe diameter or culvert height, and should taper to the flat surface at the end of the apron.

4. If there is a well-defined channel, the apron length should be extended as necessary so that the downstream apron width is equal to the channel width. The sidewalls of the channel should not be steeper than 2:1.

5. If the ground downstream of the apron is steep channel erosion may occur. The apron should be extended as necessary until the is gentle enough to prevent further erosion.

6. The potential for vandalism should be considered if the rock is easy to carry. If vandalism is a possibility, the rock size must be increased or the rocks held in place using concrete or grout.

7.4.4 Example Designs

Example 7.4.4-1. Riprap Apron Design for Minimum Tailwater Conditions

A flow of 280 cfs discharges from a 66-inch pipe with a tailwater of 2 ft above the pipe invert. Find the required design dimensions for a riprap apron.

1. Minimum tailwater conditions = 0.5 d_O, d_O = 66 in = 5.5 ft therefore, 0.5 d_O = 2.75 ft.

2. Since TW = 2 ft, use Figure 7.4.2-1 for minimum tailwater conditions.

3. By Figure 7.4.2-1, the apron length, L_a, and median stone size, d_{50}, are 38 ft and 1.2 ft, respectively.

4. The downstream apron width equals the apron length plus the pipe diameter:
   $W = d + L_a = 5.5 + 38 = 43.5$ ft.

5. Maximum riprap diameter is 1.5 times the median stone size:
   $1.5\ (d_{50}) = 1.5\ (1.2) – 1.8$ ft.

6. Riprap depth = 1.5 (d_{max}) = 1.5 (1.8) =2.7 ft.

Example 7.4.4-2. Riprap Apron Design for Maximum Tailwater Conditions

A concrete box culvert 5.5 ft high and 10 ft high and 10 ft wide conveys a flow of 600 cfs at a depth of 5.0 ft. Tailwater depth is 5.0 ft above the culvert outlet invert. Find the design dimensions for a riprap apron.

1. Compute 0.5 d_O = 0.5 (5.0) = 2.5 ft.

2. Since TW = 5.0 ft is greater than 2.5 ft, use Figure 7.4.2-2 for maximum tailwater conditions.
   $v = Q/A = [600/(5)\ (10)] = 12$ ft/s

3. On Figure 7-3, at the intersection of the curve, d_O = 60 in and v = 12 ft/s, d_{50} = 0.4 foot. Reading up to the intersection with d = 60 in, find L_a = 40 ft.
4. Apron width downstream = $d_w + 0.4\ L_a = 10 + 0.4\ (40) = 26$ ft.

5. Maximum stone diameter = 1.5 d_{50} = 1.5 (0.4) = 0.6 ft.

6. Riprap depth = 1.5 d_{max} = 1.5 (0.6) = 0.9 ft.

END OF SECTION 7.4