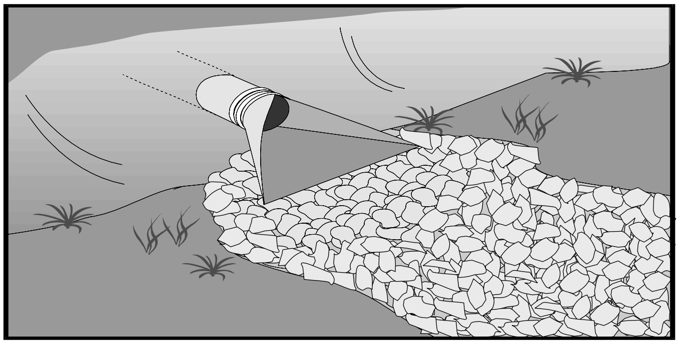
ACTIVITY: Outlet Protection	ES – 25



Targeted Constituents

● Significant Benefit ◗ Partial Benefit ○ Low or Unknown Benefit

● Sediment	○ Heavy Metals	○ Floatable Materials	○ Oxygen Demanding Substances	
○ Nutrients	○ Toxic Materials	○ Oil & Grease	○ Bacteria & Viruses	○ Construction Wastes

Description

Outlet protection for culverts, storm drains, or even steep ditches and flumes is essential to preventing major erosion from damaging downstream channels and drainage structures. Outlet protection can be a channel lining, structure or flow barrier designed to lower excessive flow velocities from pipes and culverts, prevent scour, and dissipate energy. However, effective outlet protection must begin with efficient storm drainage system design that uses adequately sized pipes, culverts, ditches and channels placed at the most efficient slopes and grades. Good outlet protection will significantly reduce erosion and sediment by reducing flow velocities.

Suitable Applications

- Outlet protection is needed wherever discharge velocities and energies at the outlets of culverts, pipes, conduits, channels or ditches are sufficient to erode the immediate downstream reach.

Approach

The design and analysis of riprap protection, stilling basins, impact barriers and other types of culvert outlets is a complex task to accomplish. The first step is to look for ways to reduce the need for outlet protection by efficient storm drainage system design. The last section of pipe (prior to the outlet of a culvert or storm drain) should not be placed at a steeper grade than necessary to adequately convey the design storm. This may require a deeper-than-usual manhole or inlet for the last section of pipe, but any additional costs are usually offset by reduced erosion and settlement due to lower outlet velocities.

In general, temporary outlet protection is usually specified as dumped riprap. See Figure ES-25-1 and Table ES-25-1 for the selection and size of riprap outlet protection for temporary or permanent installations. Permanent riprap protection should be sized by a professional engineer as part of the storm drainage design, using the guidelines in ES-23 to specify sound and durable crushed rock. Riprap outlet protection is usually less expensive and easier to install than concrete aprons or energy dissipators. A riprap channel lining is flexible and adjusts to settlement; it also serves to trap sediment and reduce flow velocities.

Typical energy dissipators are shown in Figure ES-25-2. There have been many types developed over the years by federal and state agencies such as U.S. Army Corps of Engineers and the U.S. Bureau of Reclamation (USBR). Commonly used varieties of stilling basins (for handling hydraulic jumps in addition to dissipating energy) can include USBR Type II, USBR Type III, USBR Type IV, and USBR Type VI. Reference 160 contains procedures and charts for the detailed design of energy dissipating structures using considerations such as specific ranges for the Froude number, depth of flow, roughness, gradient, discharge rate and velocity.

Outlet Velocity

The primary factor in selecting the type of outlet protection is determining the outlet velocity for culverts, which is dependent upon the type of flow profile associated with the design storm. The culvert flow may be controlled by the type of inlet, the throat section, the pipe capacity, or by the type of outlet. The type of control may change from outlet control to inlet control, for example, depending on the flow value. Culvert design is fully described in FHWA Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts (reference 158). For inlet control (including throat section), the outlet velocity is assumed to be normal depth as computed by Manning's equation. For outlet control, the outlet velocity is found by using Manning's equation with the computed tailwater depth or the critical flow depth of culvert, whichever is greater. The entire culvert cross-sectional area is used if the tailwater depth is higher than the top of the culvert opening.

Riprap Aprons

Riprap aprons should not be used to change the direction of outlet flow, for which an impact-type energy dissipator would be more effective. Riprap aprons rely primarily upon a higher Manning's roughness coefficient to slow water velocity into proportions which are manageable by a properly designed channel.

Place a heavy-duty geotextile filter fabric upon prepared subgrade, and carefully anchor to avoid damage or movement. Place riprap without excessive drop heights, avoiding damage by equipment tracks or blades. Dumped rock riprap generally has a higher Manning's roughness coefficient than grouted riprap, and is therefore more effective at slowing stormwater down. However, grouted riprap may be more useful in certain instances. Riprap is generally not adequate at the base of concrete flumes or chutes, and a concrete outlet protection structure is greatly preferred in these instances.

Construct riprap apron at zero percent grade for the specified length L_A and width W_A by using the appropriate D_{50} size of stones interpolated from Table ES-25-1. If a curve is needed within the riprap apron, place within the lower reach of apron and use larger riprap sizes in the curved section. The basic design procedure is:

1. Compute tailwater depth (using normal flow with Manning's equation) for the downstream receiving channel. Select conditions as being Low Tailwater (typically for an undefined channel or greatly oversized channel) or as being High Tailwater (most defined channel shapes). If conditions are unknown, then compute parameters from both sections of table and use the most conservative value.

2. Compute depth of flow in culvert based upon the particular type of culvert flow control. For inlet control, the outlet velocity is assumed to be normal depth as computed by Manning's equation. For outlet control, the outlet velocity is found by using Manning's equation with the computed tailwater depth or the critical flow depth of culvert, whichever value is greater. The entire culvert cross-sectional area is used if the tailwater depth is higher than the top of the culvert opening.

3. Interpolate values for riprap apron length (L_A) and riprap median size (D_{50}) from the appropriate portion of Table ES-25-1. If the culvert is not flowing full, then adjust these values upwards by the following factors. The median riprap size D_{50} is more sensitive than the apron length L_A. The minimum

riprap size D_{50} is 6 inches, which may be specified as TDOT machined Class A-1 riprap as described in ES-23.

Flow depth / Diameter	Increase D_{50} by:	Increase L_A by:
1.00	-----	-----
0.90	-----	-----
0.80	1.10	-----
0.70	1.20	1.05
0.60	1.30	1.10
0.55	1.40	1.15
0.50	1.50	1.20

Energy Dissipators and Stilling Basins

Structural controls, generally made from precast concrete or from pour-in-place concrete, should be used whenever riprap aprons are inadequate. The design of the energy dissipators and stilling basins shown in Figure ES-25-2 are discussed in the FHWA publication HEC-14, Hydraulic Design of Energy Dissipators for Culverts and Channels (reference 160), which can be downloaded at:

http://www.fhwa.dot.gov/bridge/hydpub.htm

Stilling basins are used to convert flows from supercritical to subcritical depths by allowing a hydraulic jump to occur. The stilling basin allows a controlled hydraulic jump to occur within the structure over a wide range of flow conditions and depths. Energy dissipators and stilling basins must be designed by a professional engineer using hydraulic computations. A primary concern for both energy dissipators and stilling basins is whether sediment and trash can accumulate. The designs shown in Figure ES-25-2 have been tested thoroughly over the years and present a good starting point for any type of structural outlet protection. TDOT drawing standards include a riprap basin energy dissipator, based upon procedures in HEC-14.

Maintenance

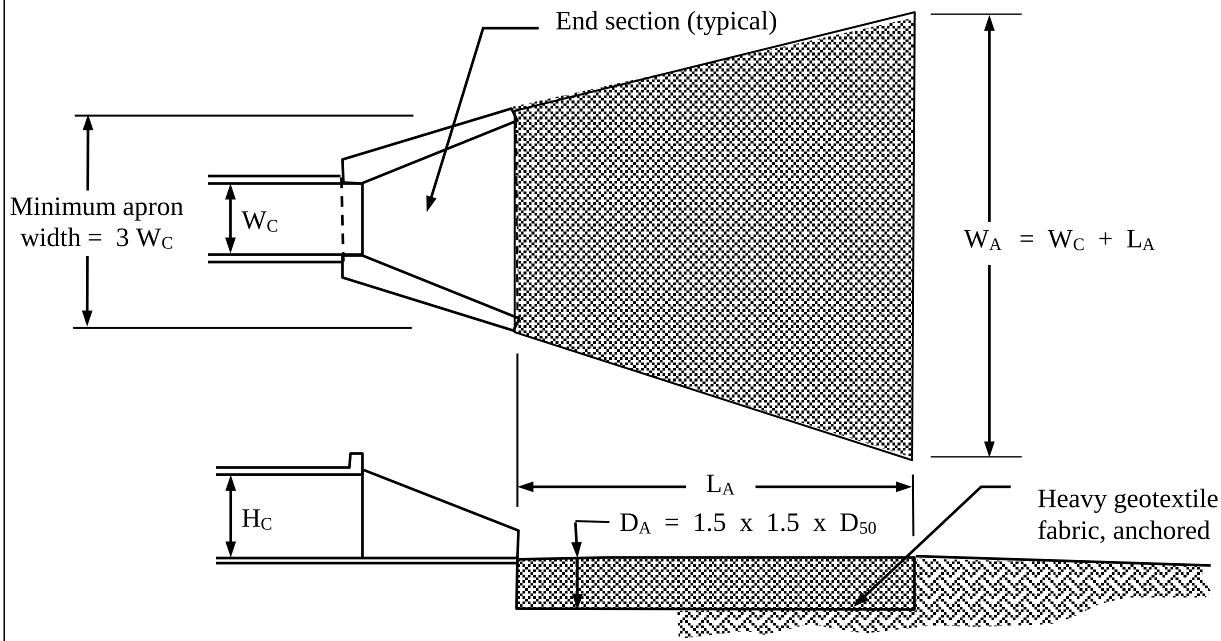
- Inspect outlet protection on a regular basis for erosion, sedimentation, scour or undercutting. Repair or replace riprap, geotextile or concrete structures as necessary to handle design flows. Remove trash, debris, grass, sediment or burrowing animals as needed. Maintenance may be more extensive if smaller riprap sizes are used, as children may tempted to throw or otherwise displace stones and rocks.

Limitations

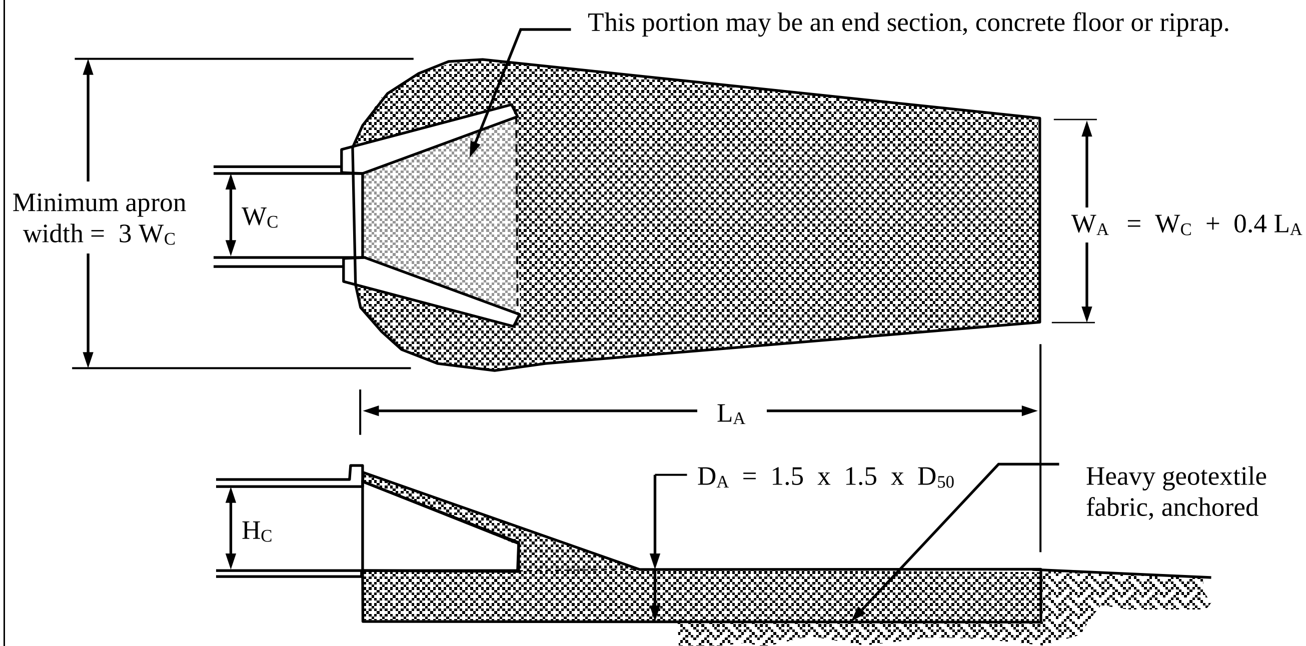
- Riprap outlet protection may occupy a large area. The specified grade for a riprap apron is zero percent. It may be difficult to handle large amounts of riprap, given that designed outlet protection is usually at or near the project boundary or property line. An easement may be necessary to maintain riprap outlet protection.
- Grouted riprap and concrete structures are subject to upheaval from freeze/thaw action. Weepholes and adequately drained foundations are necessary for these types of outlet protection.

References

30, 35, 139, 141, 158, 160, 162, 167, 179 (see BMP Manual Chapter 10 for list)



Tailwater < 0.5 H_C and Assuming Full Culvert Flow (Low Tailwater Conditions)



Tailwater > 0.5 H_C and Assuming Full Culvert Flow (High Tailwater Conditions)

<u>NOT TO SCALE</u>

H_C = height of culvert
W_C = width of culvert
L_A = length of riprap apron
W_A = width of riprap apron at end
D_{50} = median riprap size (Table ES-25-1)
D_{MAX} = maximum size of riprap = 1.5 D_{50}
D_A = depth of riprap apron = 1.5 D_{MAX}

Figure ES-25-1
Riprap Outlet Protection

TABLE ES-25-1
Selecting Riprap Apron Length (L_A) and Riprap Median Size (D_{50})
(for circular culverts flowing full)

This table is intended to select two parameters for the design of riprap outlet protection, based upon outlet velocities that correspond with circular culverts flowing full. Flow values less than the lowest value for the culvert size usually indicate a full-flow velocity less than 5 feet per second, for which riprap is usually not necessary. Flow values more than the highest value for the culvert size usually indicate that a concrete stilling basin or energy dissipator structure is necessary.

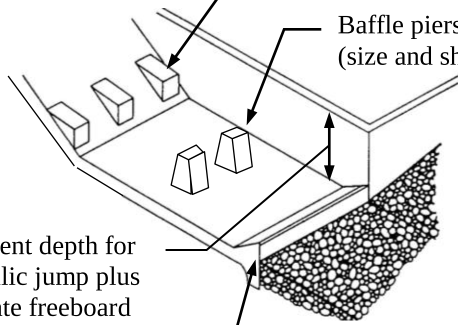
Adjust values upward if the circular culvert is not flowing full based upon outlet conditions. For noncircular pipe, convert into an equivalent cross-sectional area of circular culvert to continue design.

Riprap Aprons for Low Tailwater
(downstream flow depth < 0.5 x pipe diameter)

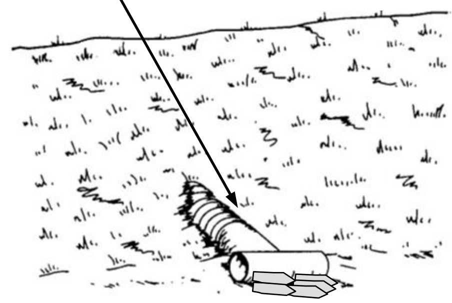
Culvert Diameter	Lowest value			Intermediate values to interpolate from:									Highest value		
	Q	L_A	D_{50}	Q	L_A	D_{50}	Q	L_A	D_{50}	Q	L_A	D_{50}	Q	L_A	D_{50}
	Cfs	Ft	In	Cfs	Ft	In	Cfs	Ft	In	Cfs	Ft	In	Cfs	Ft	In
12”	4	7	2.5	6	10	3.5	9	13	6	12	16	7	14	17	8.5
15”	6.5	8	3	10	12	5	15	16	7	20	18	10	25	20	12
18”	10	9	3.5	15	14	5.5	20	17	7	30	22	11	40	25	14
21”	15	11	4	25	18	7	35	22	10	45	26	13	60	29	18
24”	21	13	5	35	20	8.5	50	26	12	65	30	16	80	33	19
27”	27	14	5.5	50	24	9.5	70	29	14	90	34	18	110	37	22
30”	36	16	6	60	25	9.5	90	33	15.	120	38	20	140	41	24
36”	56	20	7	100	32	13	140	40	18	180	45	23	220	50	28
42”	82	22	8.5	120	32	12	160	39	17	200	45	20	260	52	26
48”	120	26	10	170	37	14	220	46	19	270	54	23	320	64	37

Riprap Aprons for High Tailwater
(downstream flow depth > 0.5 x pipe diameter)

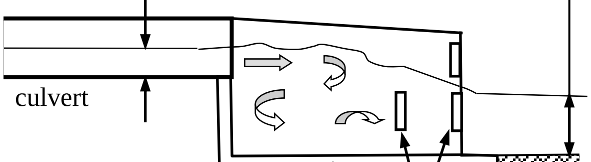
Culvert Diameter	Lowest value			Intermediate values to interpolate from:									Highest value		
	Q	L_A	D_{50}	Q	L_A	D_{50}	Q	L_A	D_{50}	Q	L_A	D_{50}	Q	L_A	D_{50}
	Cfs	Ft	In	Cfs	Ft	In	Cfs	Ft	In	Cfs	Ft	In	Cfs	Ft	In
12”	4	8	2	6	18	2.5	9	28	4.5	12	36	7	14	40	8
15”	7	8	2	10	20	2.5	15	34	5	20	42	7.5	25	50	10
18”	10	8	2	15	22	3	20	34	5	30	50	9	40	60	11
21”	15	8	2	25	32	4.5	35	48	7	45	58	11	60	72	14
24”	20	8	2	35	36	5	50	55	8.5	65	68	12	80	80	15
27”	27	10	2	50	41	6	70	58	10	90	70	14	110	82	17
30”	36	11	2	60	42	6	90	64	11	120	80	15	140	90	18
36”	56	13	2.5	100	60	7	140	85	13	180	104	18	220	120	23
42”	82	15	2.5	120	50	6	160	75	10	200	96	14	260	120	19
48”	120	20	2.5	170	58	7	220	85	12	270	105	16	320	120	20



Typical Stilling Basin At End of Paved Flume or Chute



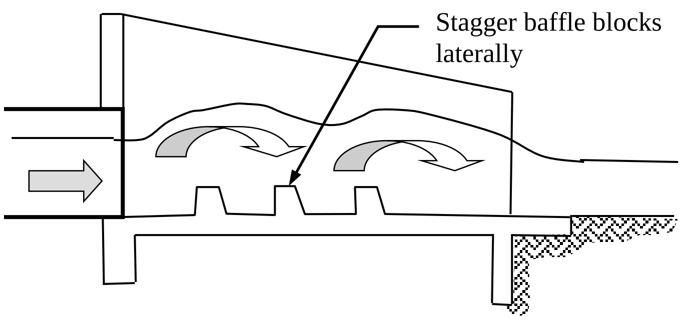
Temporary CMP Energy Dissipator



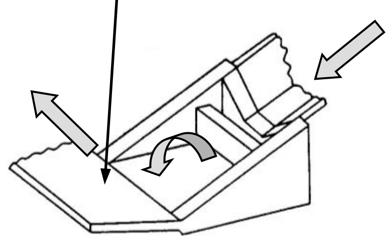
Typical Stilling Basin Using Baffles and Elevation Drop

Notes:

1. This is the basic format for several types of stilling basins. USBR Type II basin does not contain baffle piers, but does have a dentated end sill. USBR Type III basin has baffle piers and a smooth undentated end sill. See HEC-14 for detailed design of concrete structures.
2. Concrete stilling basin should be approximately as wide as the downstream channel. Design baffles to retain sufficient stormwater to act as a plunge pool for a wide range of flow values.



Typical Energy Dissipator – Baffle Blocks Within Headwall



Typical Impact Energy Dissipater (Virginia DOT)

NOT TO SCALE

Figure ES-25-2
Various Energy Dissipaters and Stilling Basins