# CHAPTER 11
# ENERGY DISSIPATORS

**TABLE OF CONTENTS**

11.1 INTRODUCTION........................................................................................................... 2

11.2 DESIGN CRITERIA ........................................................................................................... 2
   11.2.1 Dissipator Type Selection ......................................................................................... 2
   11.2.2 Design Limitations................................................................................................. 5
   11.2.3 Design Options....................................................................................................... 5
   11.2.4 Related Designs ..................................................................................................... 6

11.3 DESIGN PHILOSOPHY..................................................................................................... 6
   11.3.1 Overview................................................................................................................ 6
   11.3.2 Alternative Analysis............................................................................................... 6
   11.3.3 Design Methods..................................................................................................... 7
   11.3.4 Types of Scour ....................................................................................................... 7
   11.3.5 Scour Hazard......................................................................................................... 7
   11.3.6 Dissipator Types ................................................................................................... 8
   11.3.7 Computational Methods........................................................................................ 8

11.4 DESIGN EQUATIONS ..................................................................................................... 8
   11.4.1 General.................................................................................................................. 8
   11.4.2 Approach.............................................................................................................. 9

11.5 DESIGN PROCEDURE ................................................................................................ 11
   11.5.1 Overview.............................................................................................................. 11

11.6 RIPRAP BASIN ............................................................................................................. 15
   11.6.1 Overview.............................................................................................................. 15
   11.6.2 Design Procedure ............................................................................................... 15

11.7 IMPACT BASIN USBR TYPE VI ............................................................................... 20
   11.7.1 Overview.............................................................................................................. 21
   11.7.2 Elements of Design............................................................................................. 21
   11.7.3 Design Procedures ............................................................................................. 25

REFERENCES...................................................................................................................... 29
11.1 INTRODUCTION

The failure or damage of many culverts and detention basin outlet structures can be traced to unchecked erosion. Erosive forces, which are at work in the natural drainage network, are often exacerbated by the construction of a highway or by other urban development. Interception and concentration of overland flow and constriction of natural waterways inevitably results in an increased erosion potential. To protect the culvert and adjacent areas, it is sometimes necessary to employ an energy dissipator.

Energy dissipators are any device designed to protect downstream areas from erosion by reducing the velocity of flow to acceptable limits.

This chapter provides criteria and procedures for designing energy dissipators at our culvert outlets. Most of the design criteria and procedures are based on FHWA Hydraulic Engineering Circular Number 14 (HEC 14), Hydraulic Design of Energy Dissipators for Culverts and Channels.

11.2 DESIGN CRITERIA

11.2.1 Dissipator Type Selection

The dissipator type selected for a site must be appropriate to the location. In this Chapter, the terms internal and external are used to indicate the location of the dissipator in relationship to the culvert. An external dissipator is located outside of the culvert, and an internal dissipator is located within the culvert barrel. Table 11-1 provides limitations for each dissipator type and can be used to determine the alternative types to consider.
Internal Dissipators

Internal dissipators are used where:
- The scour hole at the culvert outlet is unacceptable;
- The right-of-way is limited;
- Debris is not a problem; and
- Moderate velocity reduction is needed.

Natural Scour Holes

Natural scour holes are used where:
- Undermining of the culvert outlet will not occur or it is practicable to be checked by a cutoff wall;
- The expected scour hole will not cause costly property damage; and
- There is no nuisance effect.

External Dissipators

External dissipators are used where:
- The outlet scour hole is not acceptable;
- Moderate amount of debris is present; and
- The culvert outlet velocity is moderate, and corresponding Fr < 3.

Stilling Basins

Stilling Basins are used where:
- The outlet scour hole is not acceptable;
- Debris is present; and
- The culvert outlet velocity is high, and corresponding Fr > 3.

<table>
<thead>
<tr>
<th>Dissipator Type</th>
<th>Froude Number (Fr)</th>
<th>Allowable Debris</th>
<th>Tailwater (TW)</th>
<th>Special Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Silt/ Sand</td>
<td>Boulders</td>
<td>Floating</td>
</tr>
<tr>
<td>Free Hydraulic Jump</td>
<td>&gt; 1</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>CSU Rigid Boundary</td>
<td>&lt; 3</td>
<td>M</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>Tumbling Flow</td>
<td>&gt; 1</td>
<td>M</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Increased Resistance</td>
<td>—</td>
<td>M</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>USBR Type II</td>
<td>4 to 14</td>
<td>M</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>USBR Type III</td>
<td>4.5 to 17</td>
<td>M</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>USBR Type IV</td>
<td>2.5 to 4.5</td>
<td>M</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>SAF</td>
<td>1.7 to 17</td>
<td>M</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>Contra Costa</td>
<td>&lt; 3</td>
<td>H</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Hook</td>
<td>1.8 to 3</td>
<td>H</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>USBR Type VI</td>
<td>—</td>
<td>M</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Forest Service</td>
<td>—</td>
<td>M</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Drop Structure</td>
<td>&lt; 1</td>
<td>H</td>
<td>L</td>
<td>M</td>
</tr>
</tbody>
</table>

TABLE 11.1 Dissipator Limitations (after HEC 14)
### 11.2.2 Design Limitations

#### Ice Buildup

If ice buildup is a factor, it shall be mitigated by:
- Sizing the structure to not obstruct the winter low flow; and
- Using external dissipators.

#### Debris Control

Debris control shall be designed using Hydraulic Engineering Circular No. 9, “Debris-Control Structures" and shall consider:
- Where clean-out access is limited; and
- If the dissipator type selected cannot pass debris.

#### Flood Frequency

The design storm frequency used to design the energy dissipator shall be the frequency used for the culvert design or the 10 year design storm frequency can be used if justified by:
- Low risk of failure of the crossing;
- Substantial cost savings;
- Limited or no adverse effect on the downstream channel; and
- Limited or no adverse effect on downstream development.

#### Maximum Culvert Exit Velocity

The culvert exit velocity shall be consistent with the maximum velocity in the natural channel or shall be mitigated by using:
- Channel stabilization (see Bank Protection, Chapter 17); and
- Energy dissipation.

#### Tailwater Relationship

The hydraulic conditions downstream shall be evaluated to determine a tailwater depth and the maximum velocity for a range of discharges. Open channel hydraulics should be used for culverts with defined channels below the culvert. Lakes, ponds, or rivers shall be evaluated using the high water elevation that has the same frequency as the design flood for the culvert if events are known to occur concurrently (statistically dependent). If statistically independent, evaluate the joint probability of flood magnitudes and use a likely combination.

### 11.2.3 Design Options

#### Material Selection
The material selected for the dissipator shall be based on a comparison of the total cost over the design life of alternative materials and shall not be made using first cost as the only criteria. This comparison shall consider replacement cost and the difficulty of construction and traffic delay.

**Culvert Outlet Type**

In choosing a dissipator, the selected culvert end treatment has the following implications:

- Culvert ends that are projecting or mitered to the fill slope offer no outlet protection;
- Headwalls provide embankment stability and erosion protection. They provide protection from buoyancy and reduce damage to the culvert;
- Commercial end sections add little cost to the culvert and may require less maintenance, retard embankment erosion and incur less damage from maintenance;
- Aprons do not reduce outlet velocity; they increase the time it takes before outlet erosion undercuts the culvert. All large pipe culverts and CBCs require as a minimum a concrete apron at the outlet. The concrete apron shall extend at least one culvert height downstream and shall have a toewall at the end of the apron. The apron and culvert outlet should be at least 6 inches below the normal streambed elevation; and
- Wingwalls are used where the side slopes of the channel are unstable, where the culvert is skewed to the normal channel flow, to redirect outlet velocity or to retain fill.

**Safety Considerations**

Traffic shall be protected from external energy dissipators by locating them outside the appropriate "clear zone" distance per AASHTO Roadside Design Guide or shielding them with a traffic barrier.

**Weep Holes**

If weep holes are used to relieve uplift pressure, they shall be designed in a manner similar to underdrain systems.

**11.2.4 Related Designs**

**Culvert**

The culvert shall be designed independent of the dissipator design (see Culverts, Chapter 9) with the exception of internal dissipators, which may require an iterative solution. The culvert design shall be completed before the outlet protection is designed and shall include computation of outlet velocity.

**Downstream Channel**

The downstream channel protection shall be designed concurrently with dissipator design.

**11.3 DESIGN PHILOSOPHY**

**11.3.1 Overview**

The energy dissipator design approach used in this Chapter is discussed in the following Sections.

**11.3.2 Alternative Analysis**

The designer shall choose alternatives that satisfy:

- Topography; and
- Design policies and criteria.

The designer shall analyze alternatives for:

- Environmental impact;
The designer shall select an alternative that best integrates engineering, economic and political considerations. The chosen dissipator should meet the selected structural and hydraulic criteria and should be based on:

- Construction and maintenance costs;
- Risk of failure or property damage;
- Traffic safety;
- Environmental or aesthetic considerations;
- Political or nuisance considerations; and
- Land-use requirements.

11.3.3 Design Methods

The designer has to choose whether (the choices in bold, all capitals are the methods used in this Chapter):

- To design for LOCAL SCOUR or channel degradation;
- To MITIGATE or monitor erosion problems;
- To use drop structures, internal dissipators, SCOUR HOLES, EXTERNAL DISSIPATORS or STILLING BASINS; and
- To use CHARTS or computer software.

11.3.4 Types of Scour

Local Scour

Local scour is the result of high-velocity flow at the culvert outlet and extends only a limited distance downstream.

Channel Degradation

Channel degradation may proceed in a fairly uniform manner over a long length or may be evident in one or more abrupt drops (headcuts) progressing upstream with every runoff event:

- It should be investigated as an essential part of the site investigation;
- It should be mitigated and included in the initial construction; and
- It is usually controlled by lowering the flowline of the new culvert below predicted channel degradation or sometimes with channel drops.

11.3.5 Scour Hazard

Mitigation

The scour hazard shall be designed by providing protection at the culvert outlet:

- Initial protection shall be sufficient to provide some assurance that extensive damage could not result from one design runoff event;
- Protection should be inspected after major storms to determine if protection must be increased or extended.

Monitoring

The only protection provided is the cutoff walls or culvert end section. The site should be inspected after major storm events to determine if protection is needed.
11.3.6 **Dissipator Types**

**Scour Holes**
Details of the design of scour holes area are as shown below.

**Internal Dissipators**
- Tumbling flow;
- Increased resistance; and
- Broken-back culverts.

This Chapter does not include details of the design of Internal Dissipators. The designer should refer to HEC 14 if design details are needed.

**External Dissipators**
- USBR TYPE VI IMPACT (see HEC-14);
- RIPRAP (see HEC-14);
- CSU rigid boundary (see HEC 14);
- Contra Costa (see HEC 14);
- Hook (see HEC 14); and
- Hydraulic jump (see HEC 14).

**Stilling Basins**
- Saint Anthony Falls (SAF) (see HEC-14);
- USBR Type II (see HEC 14);
- USBR Type III (see HEC 14);
- USBR Type IV (see HEC 14).

**Drop Structures**
- See HEC 14 or Urban Drainage and Flood Control Manual.

11.3.7 **Computational Methods**

**Charts**
Charts are required for a manual solution. Charts required for the design of scour holes, riprap basin, USBR Type VI impact basin and SAF basin are included in this Chapter. Charts required for the design of other types of energy dissipators are found in HEC 14.

**Computer Software**
HY-8 (FHWA Culvert Analysis Software), Version 4.1 or greater contains an energy dissipator module that can be used to analyze most types of energy dissipators in HEC 14.

11.4 **DESIGN EQUATIONS**

11.4.1 **General**
An exact theoretical analysis of flow at culvert outlets is extremely complex because the following data is required:
• Analyzing non-uniform and rapidly varying flow;
• Applying energy and momentum balance;
• Determining where a hydraulic jump will occur;
• Applying the results of hydraulic model studies; and
• Consideration of temporary upstream storage effects.

11.4.2 Approach
The design procedures presented in this Chapter are based on the following:
• Model studies were used to calibrate the equations and charts for scour hole estimating and energy dissipator design.
• HEC 14 is the base reference and contains full explanation of all the equations and procedures used in this Chapter.

Culvert Outlet Conditions
The culvert design establishes the outlet flow conditions. However, these parameters may require closer analysis for energy dissipator design.

Depth, do
The normal depth assumption should be reviewed and a water surface profile calculated if L < 50do. The brink depth (see HEC 14 for curves) should be used for mild slopes and low tailwater, instead of the critical depth.

Area, Ao
The cross sectional area of flow at the culvert outlet should be calculated using (do).

Velocity, Vo
The culvert outlet velocity should be calculated as follows:

\[ V_o = \frac{Q}{A_o} \]  \hspace{1cm} (11.1)

where \( Q \) = discharge, \( \text{ft}^3/\text{s} \).

Froude Number, Fr
The Froude number is a flow parameter that has traditionally been used to design energy dissipators and is calculated using:

\[ Fr = \frac{V_o}{\left( \frac{gd_o}{2} \right)^{0.5}} \]  \hspace{1cm} (11.2)

where \( g \) = gravitational acceleration, 32.2 \( \text{ft}/\text{s}^2 \).

Equivalent Depth, \( d_E \)
Equivalent depth is an artificial depth that is calculated for culverts which are not rectangular so that a reasonable Fr can be determined.

Discharge Intensity, \( DI_c \)
Discharge intensity is a flow parameter similar to Fr that is used for circular culverts of diameter (D) that are flowing full:

\[ DI_c = Q/\left( g^{0.5}D^{2.5} \right) \]  \hspace{1cm} (11.3)

Discharge Intensity Modified, \( DI \)
Modified Discharge Intensity was developed by Abt, Donnel, Ruff, and Doehring, 1985, to generalize data for culvert shape for culverts that are flowing full.

\[ DI = \frac{Q}{(g^{0.5}R_c^{2.5})} \]  \hspace{1cm} (11.4)

where \( Q \) = discharge, \( ft^3/s \); \( R_c = (A_c/P_c) \), \( ft \); \( A_c = \) flow area, \( ft^2 \); and \( P_c \) = wetted perimeter, \( ft \).

**Scour Hole Estimation**

Chapter 5 of HEC 14 contains an estimating procedure for scour hole geometry if no outlet protection is provided. The procedure which was developed by Ruff and Abt at CSU has equations for a number of soil materials and grain sizes (see HEC 14). Abt et al., has further investigated scour at culvert outlets and has published equations that show the effect of culvert shape and slope on outlet scour (Abt, Donnel, Ruff, Doehring, 1985). A consolidated equation which contains shape, slope, and grain size has not been developed. The following equations from reference (Ruff, Abt, Mendoza, Shaikh, and Kloberdanz, 1982) which generalize shape are recommended:

Only scour hole on cohesionless material will be discussed in this Chapter. For scour hole on cohesive soil, the designer can refer to Chapter 5, HEC 14 for details.

The results of the tests made by the US Army Waterways Experiment Station, Vicksburg, Mississippi indicate that the scour hole geometry varies with the tailwater conditions. The maximum scour geometry occurs at tailwater depths less than half the culvert height. The maximum depth of scour, \( d_s \), occurs at a location approximately \( 0.4L_s \) downstream of the culvert, where \( L_s \) is the length of the scour.

Empirical equations defining the relationship between the culvert discharge intensity, time and the length, width, depth and volume of the scour hole are presented below for the maximum or extreme scour case, where \( d_s \) = maximum depth of scour hole, \( ft \); \( L_s \) = length of scour hole, \( ft \); and \( W_s \) = width of scour hole, \( ft \).

\[
\left[ \frac{d_s}{R_c}, \frac{W_s}{R_c}, \frac{L_s}{R_c} \right] = C_s C_h \left( \frac{\alpha}{\sigma^{1/3}} \right) \left( \frac{Q}{\sqrt{gR_c^{2.5}}} \right)^\beta \left( \frac{t}{316} \right)^\theta \]  \hspace{1cm} (11.5)

\[ d_s, W_s \text{ or } L_s = (F_1)(F_2)(F_3)R_c \]  \hspace{1cm} (11.6)

and

\[ F_1 = C_s C_h \left( \frac{\alpha}{\sigma^{1/3}} \right) \]  \hspace{1cm} (11.7)

\[ F_2 = \left( \frac{Q}{\sqrt{gR_c^{2.5}}} \right)^\beta = (DI)^\beta \]  \hspace{1cm} (11.8)

\[ F_3 = \left( \frac{t}{316} \right)^\theta \]  \hspace{1cm} (11.9)

where: \( t = 30 \text{ min or the time of concentration, if longer} \); \( R_c = \) hydraulic radius of the flow at the exit of the culvert; \( \sigma = \) material standard deviation; generally, \( \sigma = 2.10 \) for gravel and 1.87 for sand; \( \alpha, \beta, \theta, C_s \)
and $C_h$ are coefficients, as shown in Tables 11.2 -4; $F_1$, $F_2$ and $F_3$ are factors to aid the computation, as shown in Step 7B, Figure 11.1

### Table 11.2 Coefficients for Culvert Outlet Scour (Cohesionless Materials)

<table>
<thead>
<tr>
<th>Depth, $d_S$</th>
<th>$\alpha$</th>
<th>$\beta$</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.27</td>
<td>0.39</td>
<td>0.06</td>
</tr>
<tr>
<td>Width, $W_S$</td>
<td>6.94</td>
<td>0.53</td>
<td>0.08</td>
</tr>
<tr>
<td>Length, $L_S$</td>
<td>17.10</td>
<td>0.47</td>
<td>0.10</td>
</tr>
<tr>
<td>Volume, $V_S$</td>
<td>127.08</td>
<td>1.24</td>
<td>0.18</td>
</tr>
</tbody>
</table>

### Table 11.3 Coefficient $C_S$ for Outlets Above the Bed

<table>
<thead>
<tr>
<th>$H_S$</th>
<th>Depth</th>
<th>Width</th>
<th>Length</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1</td>
<td>1.22</td>
<td>1.51</td>
<td>0.73</td>
<td>1.28</td>
</tr>
<tr>
<td>2</td>
<td>1.26</td>
<td>1.54</td>
<td>0.73</td>
<td>1.47</td>
</tr>
<tr>
<td>4</td>
<td>1.34</td>
<td>1.66</td>
<td>0.73</td>
<td>1.55</td>
</tr>
</tbody>
</table>

$H_S$ is the height above bed in pipe diameters, m

### Table 11.4 Coefficient $C_h$ for Culvert Slope

<table>
<thead>
<tr>
<th>Slope %</th>
<th>Depth</th>
<th>Width</th>
<th>Length</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>1.03</td>
<td>1.28</td>
<td>1.17</td>
<td>1.30</td>
</tr>
<tr>
<td>5</td>
<td>1.08</td>
<td>1.28</td>
<td>1.17</td>
<td>1.30</td>
</tr>
<tr>
<td>&gt;7</td>
<td>1.12</td>
<td>1.28</td>
<td>1.17</td>
<td>1.30</td>
</tr>
</tbody>
</table>

### 11.5 DESIGN PROCEDURE

#### 11.5.1 Overview

The following design procedures are intended to provide a convenient and organized method for designing energy dissipators by hand. The designer should be familiar with all equations in Section 11.4
before using these procedures. In addition, application of the following design method without an understanding of hydraulics can result in an inadequate, unsafe or costly structure:

Step 1  Assemble Site Data And Project File
   a. See culvert design file for site survey.
   b. Review Section 11.2.2 for applicable criteria.

Step 2  Determine Hydrology
   See culvert design file.

Step 3  Select Design Q
   a. See Section 11.2.3 “Design Limitations.”
   b. See culvert design file.
   c. Select flood frequency.
   d. Determine Q from frequency plot (Step 2).

Step 4  Review Downstream Channel
   a. See culvert design file.
   b. Determine channel slope, cross section, normal depth and velocity.
   c. Check bed and bank material stability.

Step 5  Review Culvert Design
   See culvert design file and obtain design discharge, outlet flow conditions (velocity and depth), culvert type (size, shape and roughness), culvert slope and performance curve.

Step 6  Summarize Data On Design Form.
   a. Use Figure 11-1 “Energy Dissipator Checklist.”
   b. Enter data from Steps 1-5 into Figure 11-1.

Step 7  Estimate Scour Hole Size.
   a. Enter input for scour equation on Figure 11-1.
   b. Calculate \( d_s, W_s, L_s \), using Equation 11.5 or 11.6

Step 8  Determine Need For Dissipator. An energy dissipator is needed if:
   a. the estimated scour hole dimensions that exceed the allowable right-of-way, undermines the culvert cutoff wall or presents a safety or aesthetic problem;
   b. downstream property is threatened; or
   c. \( V_o \) is much greater than \( V_d \).

Step 9  Select Design Alternative.
   a. See Section 11.2.4 “Design Options.”
   b. Calculate Froude number, \( Fr \).
   c. Choose energy dissipator types:
      - if \( Fr > 3 \), design a SAF stilling basin;
      - if \( Fr < 3 \) design a riprap basin;
      - if \( Q < 400 \) cfs and little debris is expected, design a USBR Type VI for each barrel.
      If these are not acceptable or economical, try other dissipators in HEC 14.
Step 10  Design Dissipators
Use the design procedures and charts in Hec 14.

Step 11  Design Riprap Transition
a. Most dissipators require some protection adjacent to the basin exit.
b. The length of protection can be judged based on the difference between $V_o$ and $V_d$. The riprap should be designed using Chapter 17 “Bank Protection” and HEC-11.

Step 12  Review Results
a. If downstream channel conditions (velocity, depth and stability) are exceeded, -design riprap for channel, Step 4; or -select another dissipator, Step 9.
b. If preferred energy dissipator affects culvert hydraulics, return to Step 5 and calculate culvert performance.
c. If debris-control structures are required upstream, consult HEC 9.

Step 13  Documentation
a. See Chapter 4.
b. Include computations in culvert report or file.
SCOUR EQUATIONS

\[
\begin{align*}
\left[\frac{d_s \cdot W_s \cdot L_s}{\text{Re} \cdot \text{Rc} \cdot \text{Rc}}\right] &= C_s C_h \left(\frac{\alpha}{\sigma^{1/3}}\right) \left(\frac{Q}{\sqrt{gR_c^{2.5}}}\right)^{\theta} \left(\frac{t}{316}\right)^{\theta} \\
d_s \cdot W_s \cdot L_s &= \left[C_s C_h \alpha/\sigma^{1/3}\right][\text{DI}]^{\theta}[t/316]^{\theta} \cdot R_c \\
d_s \cdot W_s \cdot L_s &= [F_1][F_2][F_3]R_c
\end{align*}
\]

STEP 7A - EQUATION INPUT DATA

<table>
<thead>
<tr>
<th>FACTOR</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q = Discharge, ft³/s</td>
<td></td>
</tr>
<tr>
<td>A_c = Flow area, ft²</td>
<td></td>
</tr>
<tr>
<td>P_c = Wetted Perimeter, ft</td>
<td></td>
</tr>
<tr>
<td>R_c = A_c / P_c</td>
<td></td>
</tr>
<tr>
<td>DI = Discharge Intensity</td>
<td></td>
</tr>
<tr>
<td>t = time of concentration</td>
<td></td>
</tr>
</tbody>
</table>

STEP 6 - DATA SUMMARY

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Culvert</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height, D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width, B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length, L</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manning’s n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side Slope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discharge, Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth, d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fr = V/(gd)⁰.⁵</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Area, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STEP 7B - SCOUR COMPUTATION

<table>
<thead>
<tr>
<th>Factor</th>
<th>Depth</th>
<th>Width</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>2.27</td>
<td>6.94</td>
<td>17.10</td>
</tr>
<tr>
<td>β</td>
<td>0.39</td>
<td>0.53</td>
<td>0.47</td>
</tr>
<tr>
<td>θ</td>
<td>0.06</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>F₁</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F₃</td>
<td></td>
<td></td>
<td>[F₁][F₂][F₃]R_c</td>
</tr>
</tbody>
</table>

If calculated scour > allowable and:

1. Fr > 3, design a SAF basin
2. Fr < 3, design a riprap basin
3. Q < 400 ft³/s, design a USBR Type VI

Figure 11.1 Energy Dissipator Checklist
11.6 RIPRAP BASIN

11.6.1 Overview

The riprap basin design is based on laboratory data obtained from full-scale prototypical installations. Layout details are shown on Figure 11-5. Following are the principal features of the basin:

- Preshaping and lining with riprap of median size, $d_{50}$.
- Constructing the floor at a depth of $h_s$ below the invert, where $h_s$ is the depth of scour that would occur in a pad of riprap of size $d_{50}$.
- Sizing $d_{50}$ so that $2 < h_s/d_{50} < 4$.
- Sizing the length of the dissipating pool to be $10(h_s)$ or $3(W_o)$, whichever is larger for a single barrel. The overall length of the basin is $15(h_s)$ or $4(W_o)$, whichever is larger.
- Angular rock results were approximately the same as the results of rounded material.

Low Tailwater ($TW/d_o < 7.5D$)

- The high-velocity jet of water emerging from the culvert will drop into the preformed scour hole and will be substantially reduced.
- Riprap may be required for the channel downstream of the rock-lined basin.

High Tailwater ($TW/d_o > 0.75$)

- The high-velocity core of water emerging from the culvert retains its jetlike character as it passes through the basin.
- The scour hole is not as deep as with low tailwater and is generally longer.
- Riprap may be required for the channel downstream of the rock-lined basin.

11.6.2 Design Procedure

Step 1 Determine Input Flow

- $d_o$ or $d_E$, $V_o$, $F_r$ at the culvert outlet ($d_E = \text{the equivalent depth at the brink} = (A/2)^{0.5}$)

Step 2 Check TW

a. If $TW/d_o < 0.75$, TW does not affect design; go to Step 3 and skip Step 6.

b. If $TW/d_o > 0.75$, TW effect must be considered; include Step 6.

Step 3 Determine $d_{50}$

a. Use Figure 11-6.

b. Select $d_{50}/d_E$. Satisfactory results will be obtained, if $0.25 < d_{50}/d_E < 0.45$.

c. Obtain $h_s/d_E$ using Froude number, $F_r$, and Figure 11-6.

d. Check if $2 < h_s/d_{50} < 4$, and repeat until a $d_{50}$ is found within the range.

Step 4 Size Basin

a. As shown in Figure 11-5.

b. Determine length of the dissipating pool, $L_S = 10h_s$ or $3W_o$ minimum.

c. Determine length of basin, $L_B = 15h_s$ or $4W_o$ minimum.

d. Thickness of riprap at the approach section is $3d_{50}$ or $1.5d_{\max}$; at the remainder it is $2d_{50}$ or $1.5d_{\max}$.
CDOT Drainage Design Manual  Energy Dissipators

Figure 11.2  Details Of Riprap Basin Energy Dissipator

NOTE A - IF EXIT VELOCITY OF BASIN IS SPECIFIED, EXTEND BASIN AS REQUIRED TO OBTAIN SUFFICIENT CROSS SECTIONAL AREA AT SECTION A-A SUCH THAT Q_{des} / (CROSS SECTION AREA AT SEC. A-A) = SPECIFIED EXIT VELOCITY.

NOTE B - WARP BASIN TO CONFORM TO NATURAL STREAM CHANNEL. TOP OF RIPRAP IN FLOOR OF BASIN SHOULD BE AT THE SAME ELEVATION OR LOWER THAN NATURAL CHANNEL BOTTOM AT SEC. A-A.
Figure 11.3 Riprap Basin Depth of Scour

\begin{align*}
V_{\text{ave}} &= \text{DESIGN DISCHARGE - } Q \\
& \quad \text{WETTED AREA AT BRINK OF CULVERT}
\end{align*}

\begin{align*}
d_{50} &= \text{THE MEDIAN SIZE OF ROCK} \\
& \quad \text{BY WEIGHT, ROUNDED ROCK} \\
& \quad \text{OR ANGULAR ROCK.}
\end{align*}

\begin{align*}
Y_e &= \text{EQUIVALENT BRINK DEPTH} = d_e \\
& \quad \text{BRINK DEPTH FOR BOX CULVERT} \\
& \quad = (A/2)^{0.5} \text{ FOR NON-RECTANGULAR SECTIONS}
\end{align*}

\text{NOTE: } 2 \leq h_s/d_{50} \leq 4

\text{IF } Tw/Y_e \geq 0.75

\text{RIPRAP MAY BE REQUIRED}
\text{ON BANKS AND CHANNEL BOTTOM DOWNSTREAM}
\text{FROM BASIN. SEE DESIGN EXAMPLE IN TEXT.}

\text{FROUDE NUMBER} = \frac{V_{\text{ave}}}{\sqrt{gY_e}}
CDOT Drainage Design Manual

Energy Dissipators

RIPRAP BASIN

Tailwater, TW

Equivalent depth, d_E

TW/d_E

If TW/d_E > 0.75, calculate riprap downstream using Figure 11-8

D_E = (4A_e/π)^0.5

Note: “D_E,” equivalent diameter, is not equal to “d_E” or “Y_E.”

Figure 11.4 Riprap Basin Design Checklist

11-18
Step 5  Determine $V_B$
   a. Basin exit depth, $d_B = \text{critical depth at basin exit.}$
   b. Basin exit velocity, $V_B = \frac{Q}{W_B(d_B)}$.
   c. Compare $V_B$ with the average normal flow velocity in the natural channel, $V_d$.
The goal of this comparison is that $V_B$ will be the same or lower than the natural channel velocity.
   d. If $TW/d_o \leq 0.75$, go to Step 7.

Step 6  High Tailwater Design
   a. Design a basin for low tailwater conditions, Steps 1 through 5.
   b. Compute equivalent circular diameter $D_e$ for brink area from:
      \[ A = \frac{\pi D}{4} = d_o(W_o) \]
   c. Estimate centerline velocity at a series of downstream cross sections using Figure 11.5.
   d. Size riprap using HEC 11 or the Channels Chapter.

Step 7  Design Filter
   a. Unless the streambed material is sufficiently well graded.
   b. Follow instructions in Section 4.4, HEC 11.
11.7 IMPACT BASIN (USBR TYPE VI)

Note: To be used for predicting channel velocities downstream from culvert outlets where high tailwater prevails. Velocities obtained from the use of this Figure can be used with HEC 11 for sizing riprap.

Figure 11.5 Distribution of Centerline Velocity for Flow from Submerged Outlets
11.7.1 Overview
The USBR Type VI basin was developed by the US Bureau of Reclamation (USBR) and:
- Is referred to as the USBR Type VI basin or hanging baffle;
- Is contained in a relatively small, box-like structure;
- Requires no tailwater for successful performance;
- May be used in open channels as well; and
- Is not recommended where debris or ice buildup may cause substantial clogging.

11.7.2 Elements of Design

Hanging Baffle
Energy dissipation is initiated by flow striking the vertical hanging baffle and being deflected upstream by the horizontal portion of the baffle and by the floor, creating horizontal eddies.

Notches in Baffle
Notches are provided to aid in cleaning the basin. The notches provide concentrated jets of water for cleaning. The basin is designed to carry the full discharge over the top of the baffle if the space beneath the baffle becomes completely clogged.

Equivalent Depth
This depth must be calculated for a pipe or irregular-shaped conduit. The cross section flow area in the pipe is converted into an equivalent rectangular cross section in which the width is twice the depth of flow.

Limitations
Discharges up to 400 ft³/s per barrel and velocities as high as 50 ft/s can be used without subjecting the structure to cavitation damage.

Tailwater
A moderate depth of tailwater will improve performance. For best performance, set the basin so that maximum tailwater does not exceed h₁ + (h₂/2).

Slope
If culvert slope is greater than 15°, a horizontal section of at least four culvert widths should be provided upstream.

End Treatment
An end sill with a low-flow drainage slot, 45° wingwalls and a cutoff wall should be provided at the end of the basin.

Riprap
Riprap should be placed downstream of the basin for a length of at least four conduit widths.
Figure 11.6. Riprap Size Versus Exit Velocity (after HEC 14)
Figure 11.7  USBR Type VI (Impact) Dissipator
USBR TYPE VI BASIN

Project No. ___________________________ Designer ___________________________ Date ________________
Reviewer ___________________________ Date ________________

CHOOSE BASIN WIDTH, W (Figure 11.7) TRIAL 1 FINAL TRIAL CHECK OUTLET VELOCITY, V₀

Equivalent Depth, dₑ
V₀ (ft/s) H_L = (Hₑ/H₀)H₀
H₀ = dₑ + /2g Hₑ = H₀ − H_L
Froude No., Fr dₑ
Hₑ/W V_B = (Q/W)/dₑ
W=Hₑ/(Hₑ/W) (Hₑ)ₜ = dₑ + /2g

BASIN DIMENSIONS (FEET) FROM TABLE 11.2

<table>
<thead>
<tr>
<th>W</th>
<th>h₁</th>
<th>h₂</th>
<th>h₃</th>
<th>h₄</th>
<th>L</th>
<th>L₁</th>
<th>L₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>W₁</td>
<td>W₂</td>
<td>t₁</td>
<td>t₂</td>
<td>t₃</td>
<td>t₄</td>
<td>t₅</td>
</tr>
</tbody>
</table>

Figure 11.8 Impact Basin Type VI Checklist
11.7.3 Design Procedures

Step 1 Calculate Equivalent Depth, \( d_E \)
   a. Rectangular section, \( d_E = d_0 = y_o \)
   b. Other sections, \( d_E = (A/2)^{0.5} \)

Step 2 Determine Input Flow
   a. Froude number, \( Fr = V_o/(gd_E)^{0.5} \)
   b. Specific energy,

Step 3 Determine Basin Width, \( W \)
   a. Use Figure 11.7. Enter with \( Fr \) and read \( H_o/W \)
   b. \( W = H_o/(H_o/W) \)

Step 4 Size Basin
   a. Use Table 11.5 and \( W \)
   b. Obtain the remaining dimensions

Step 5 Energy Loss
   a. Use Figure 11.9
   b. Enter with \( Fr \) and read \( H_L/H_o \)
   c. \( H_L = (H_L/H_o)H_o \)

Step 6 Exit Velocity (\( V_B \))
   a. Exit energy (\( H_E \)) = \( H_o - H_L \)
   b. \( V_B = (Q/W)/d_B \)
Figure 11.9  Energy Loss For USBR Type VI Dissipator
Figure 11.10  Design Curve For USBR Type VI Dissipator

\[ Fr = \frac{V_o}{(g d E)^{1/2}} \]
Table 11.5  Dimensions Of USBR Type VI Basin in reference to Figure 11.7 Dimensions in meters.

<table>
<thead>
<tr>
<th>W</th>
<th>h₁</th>
<th>h₂</th>
<th>h₃</th>
<th>h₄</th>
<th>L</th>
<th>L₁</th>
<th>L₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.79</td>
<td>0.38</td>
<td>0.17</td>
<td>0.43</td>
<td>1.40</td>
<td>0.59</td>
<td>0.79</td>
</tr>
<tr>
<td>1.5</td>
<td>1.16</td>
<td>0.57</td>
<td>0.25</td>
<td>0.62</td>
<td>2.00</td>
<td>0.88</td>
<td>1.16</td>
</tr>
<tr>
<td>2.0</td>
<td>1.54</td>
<td>0.75</td>
<td>0.33</td>
<td>0.83</td>
<td>2.68</td>
<td>1.14</td>
<td>1.54</td>
</tr>
<tr>
<td>2.5</td>
<td>1.93</td>
<td>0.94</td>
<td>0.42</td>
<td>1.04</td>
<td>3.33</td>
<td>1.43</td>
<td>1.93</td>
</tr>
<tr>
<td>3.0</td>
<td>2.30</td>
<td>1.12</td>
<td>0.50</td>
<td>1.25</td>
<td>4.02</td>
<td>1.72</td>
<td>2.30</td>
</tr>
<tr>
<td>3.5</td>
<td>2.68</td>
<td>1.32</td>
<td>0.58</td>
<td>1.46</td>
<td>4.65</td>
<td>2.00</td>
<td>2.68</td>
</tr>
<tr>
<td>4.0</td>
<td>3.12</td>
<td>1.51</td>
<td>0.67</td>
<td>1.67</td>
<td>5.33</td>
<td>2.28</td>
<td>3.08</td>
</tr>
<tr>
<td>4.5</td>
<td>3.46</td>
<td>1.68</td>
<td>0.75</td>
<td>1.88</td>
<td>6.00</td>
<td>2.56</td>
<td>3.46</td>
</tr>
<tr>
<td>5.0</td>
<td>3.82</td>
<td>1.87</td>
<td>0.83</td>
<td>2.08</td>
<td>6.52</td>
<td>2.84</td>
<td>3.82</td>
</tr>
<tr>
<td>5.5</td>
<td>4.19</td>
<td>2.03</td>
<td>0.91</td>
<td>2.29</td>
<td>7.29</td>
<td>3.12</td>
<td>4.19</td>
</tr>
<tr>
<td>6.0</td>
<td>4.60</td>
<td>2.25</td>
<td>1.00</td>
<td>2.50</td>
<td>7.98</td>
<td>3.42</td>
<td>4.60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>W</th>
<th>W₁</th>
<th>W₂</th>
<th>t₁</th>
<th>t₂</th>
<th>t₃</th>
<th>t₄</th>
<th>t₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0.08</td>
<td>0.26</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>1.5</td>
<td>0.13</td>
<td>0.42</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>2.0</td>
<td>0.15</td>
<td>0.55</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>2.5</td>
<td>0.18</td>
<td>0.68</td>
<td>0.16</td>
<td>0.18</td>
<td>0.18</td>
<td>0.16</td>
<td>0.08</td>
</tr>
<tr>
<td>3.0</td>
<td>0.22</td>
<td>0.83</td>
<td>0.20</td>
<td>0.20</td>
<td>0.22</td>
<td>0.20</td>
<td>0.08</td>
</tr>
<tr>
<td>3.5</td>
<td>0.26</td>
<td>0.91</td>
<td>0.20</td>
<td>0.23</td>
<td>0.23</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>4.0</td>
<td>0.30</td>
<td>0.91</td>
<td>0.20</td>
<td>0.28</td>
<td>0.25</td>
<td>0.25</td>
<td>0.10</td>
</tr>
<tr>
<td>4.5</td>
<td>0.36</td>
<td>0.91</td>
<td>0.20</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.13</td>
</tr>
<tr>
<td>5.0</td>
<td>0.39</td>
<td>0.91</td>
<td>0.22</td>
<td>0.31</td>
<td>0.30</td>
<td>0.30</td>
<td>0.15</td>
</tr>
<tr>
<td>5.5</td>
<td>0.41</td>
<td>0.91</td>
<td>0.22</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.18</td>
</tr>
<tr>
<td>6.0</td>
<td>0.45</td>
<td>0.91</td>
<td>0.25</td>
<td>0.36</td>
<td>0.35</td>
<td>0.35</td>
<td>0.19</td>
</tr>
</tbody>
</table>
REFERENCES


