

TDOT DESIGN DIVISION

DRAINAGE MANUAL

CHAPTER IX ENERGY DISSIPATORS

TDOT DESIGN DIVISION

CHAPTER 9 – Energy Dissipator

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CHAPTER 9

Energy Dissipators

SECTION 9.01 – INTRODUCTION

Erosive forces which can be at work in the natural drainage network are often increased by the construction of a highway. Interception and concentration of overland flow and constriction of natural waterways inevitably results in increased erosion potential. In fact, the failure of many highway culverts can be traced to unchecked erosion. To protect the highway and adjacent areas, it is sometimes necessary to employ an energy dissipating device. Throughout the process of selecting and designing an energy dissipator, the designer should keep in mind that the primary objective is to protect the highway structure and adjacent area from excessive damage due to erosion. An effective design will return the flow downstream of the dissipator to a condition which approximates the natural flow regime.

Energy dissipators may be used at a number of locations within a highway drainage system, including outfalls for culverts, storm sewers, detention ponds and steep ditches. However, the predominant use of energy dissipating structures will be at culvert outfalls. Selected energy dissipator shall not impede Section-12 Aquatic Organism Passage (AOP) design requirements. Thus, this chapter concentrates on the use of energy dissipators for culverts. The designer should be able to easily adapt the methods provided in this chapter to the design of dissipators for other drainage features.

Before specifying an energy dissipator for a culvert site, the designer may wish to investigate modifying the vertical alignment of the culvert to reduce the outlet velocity as described in Section 6.04.1.1.1.5 of this Manual. The choice between modifying the culvert alignment or providing an energy dissipator would normally be based on a site-specific consideration of the costs for construction and maintenance presented by each option.

Although energy dissipators cover a wide range in complexity and cost, they can be grouped into two broad categories. One type of energy dissipator acts by forcing a hydraulic jump in the flow stream leaving the culvert. This is accomplished either by increasing the hydraulic

roughness of a segment of the culvert or by directing flows into a basin located at the culvert outfall. The second group of energy dissipators is often referred to as impact basins, even though they are constructed at the stream bed level. Energy is dissipated in these basins as the concentrated flow jet from the culvert outlet impacts on blocks or baffles located on the basin floor. The selection of a particular type of dissipator should be based on consideration of the discharge, velocity of the culvert outflow, TW elevation, an assessment of the erosion hazard, and the amount of right-of-way available. Regardless of what type of dissipator selected the design should offer Aquatic organism passage at normal, mean flow conditions.

SECTION 9.02 – DOCUMENTATION PROCEDURES

The designer will be responsible for documenting the selection process and design computations for each energy dissipator included in the roadway project. In general, the documentation should be sufficient to answer any reasonable question that may be raised in the future regarding the proposed dissipator design. The documentation for each dissipator should be grouped together with the documentation for the individual drainage component that it will serve. For example, the documentation for a dissipator at a culvert outfall should be attached to the design documentation for that culvert.

As appropriate, the following materials should be included in the design documentation:

- The Energy Dissipator Worksheet, Figure 9A-1, which should be clearly labeled with the project description, project station, a description of the drainage feature being served, the date, and the initials of the designer documentation as to the need for an energy dissipator
- All the design forms and computations generated in the design of the selected dissipator type
- Documentation on the computations and assumptions used to design the riprap transition
- Documentation on the review of the design as described in Step 10, Section 9.04.2.1
- Several of the items in the above list may be completed simply by including the output reports from any software which may be used for energy dissipator design

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Each page of hand computation sheets and computer output reports should be clearly labeled with the project description, project station, a description of the drainage feature being served, the date, and the initials of the designer.

SECTION 9.03 – GUIDELINES AND CRITERIA

Design criteria form the basis for the final design configuration. This section presents design standards and guidance for determining the type of dissipator appropriate for a given site. The designers first option shall be always to eliminate the need of a dissipater. Dissipaters shall be used at locations where there are no other options available, the design and installation should not hinder AOP.

9.03.1 ENERGY DISSIPATOR USE

An energy dissipator should be considered for use where:

the culvert outlet velocity computed for the design discharge is 15 feet per second or greater erosion at the culvert outlet will pose an unacceptable risk to the roadway and downstream property (see Section 9.04.1.3 for the method that should be used to estimate this erosion) the need is apparent for any economically justifiable reason

An energy dissipator may not be necessary at sites where the natural stream slope is steep, resulting in a high flow velocity in the natural channel. Furthermore, energy dissipators will generally not be required at sites where the channel is lined with bedrock.

Any energy dissipation structure placed within the clear zone of a mainline roadway should be protected with the proper roadside safety appurtenances.

9.03.2 ENERGY DISSIPATOR DESIGN CRITERIA

An energy dissipator should be designed for the same storm frequency and discharge used to design the facility it serves.

Where practical, the velocity and depth of the flows leaving an energy dissipator should match the natural channel flow regime without altering AOP design withing bank full widths (channel forming follow stage).

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Only the following energy dissipators should be designed and used during the TDOT project development. They should be selected and designed following the guidelines contained in this Manual. Section 9.05 describes software that may be used, or procedures provided in the FHWA publication HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels*.

9.03.3 ENERGY DISSIPATOR SELECTION

A wide variety of energy dissipation devices are available to the designer, each having different applications and limitations. Before calling for an energy dissipator, designers should exhaust all other feasible options. Each culvert site presents a unique set of circumstances.

The designer should exercise care when selecting the option which will best fit the culvert end treatment as well as the overall site without impacting AOP. In general, the selection of the dissipation scheme should be determined based on the following parameters:

Culvert Outflow Froude Number: The Froude Number represents the ratio of the inertial forces to the gravitational forces acting on a given flow. When inertial forces dominate the behavior of the flow, the Froude Number is greater than 1 and the flow is said to be supercritical. Because energy dissipation is normally required when the culvert outlet velocity is very high, the influence of inertial forces will far outweigh gravitational forces, resulting in Froude Numbers much greater than 1.

Velocity: The velocity of flow at the structure outlet should often be evaluated along with the Froude Number when selecting an energy dissipator. In general, erosion protection would not be required where the outlet velocity is less than 5 feet per second. However, the designer may choose to provide some form of erosion protection where highly erodible soils may be present. Riprap linings should be used with caution where the outlet velocity exceeds 12 feet per second.

Debris: For the purposes of designing an energy dissipator, debris is classified into three groups: silt/sand, gravel/boulders, and floating debris. Because of the high flow velocities and turbulence experienced in an energy dissipator, debris transported by the flows can cause abrasion or other damage. In addition, floating debris can be snagged in certain types of dissipators and cause clogging.

Tailwater Effects: Many types of dissipators, particularly those that function by forcing a hydraulic jump, require the presence of a certain depth of tailwater to be effective.

AOP Design Considerations: Dissipator shall not offer any low flow discontinuity inside the channel impacting AOP. Refer to Drainage Manual Chapter 12.

Specific criteria for selecting the type of energy dissipator to be used at a site are provided in Table 9A-1 in the Appendix.

The use of an energy dissipator can represent a significant cost for both construction and for maintenance over the life of the structure. Therefore, the methods described below represent a progressive strategy to ensure the most economical means of erosion protection are provided. Each of the following sections generally represents strategies of increasing complexity and expense.

Commonly there are two types of dissipators that are available internal and external. The type of dissipation is based on site and hydraulic conditions and the designer shall evaluate the best possible type to gain the maximum benefit.

9.03.4 INTERNAL ENERGY DISSIPATORS

In situations where there is limited right-of-way for an energy dissipator at a culvert outlet and where the culvert barrel is not used to capacity due to inlet control, metal or concrete roughness elements may be placed along a section of the downstream end of the culvert to control outlet velocities. These roughness elements are referred to as internal energy dissipators. Because the culvert is flowing partially full with inlet control, it is possible to increase the depth of flow near the culvert outlet without creating additional headwater.

Because internal energy dissipators may require regular maintenance, they should be used only in box culverts of sufficient size to allow for entry by maintenance personnel. They may be used where:

Moderate velocity reduction is required right-of-way is limited access for maintenance is available.

Roughness elements decrease flow velocities by either increasing the flow resistance of the culvert barrel or by a phenomenon known as tumbling flow.

9.03.4.1 TUMBLING FLOW

Tumbling flow (Figure 9-1) is an excellent energy dissipator on steep slopes. It is essentially a series of hydraulic jumps and overfalls that maintain the flow approximately at critical velocity on slopes that would otherwise be characterized by high supercritical velocities. Use of tumbling flow is reasonable for slopes up to 10 or 15 percent. One of the major limitations of tumbling flow as an energy dissipator is that the required height of the roughness elements is closely related to the unit discharge (discharge divided by the width of the culvert). There may be situations where the element height would have to be half the culvert height to maintain tumbling flow. Thus, practical applications of tumbling flow are likely to be limited to low-discharge per unit width (i.e., shallow flow), high-velocity culverts.

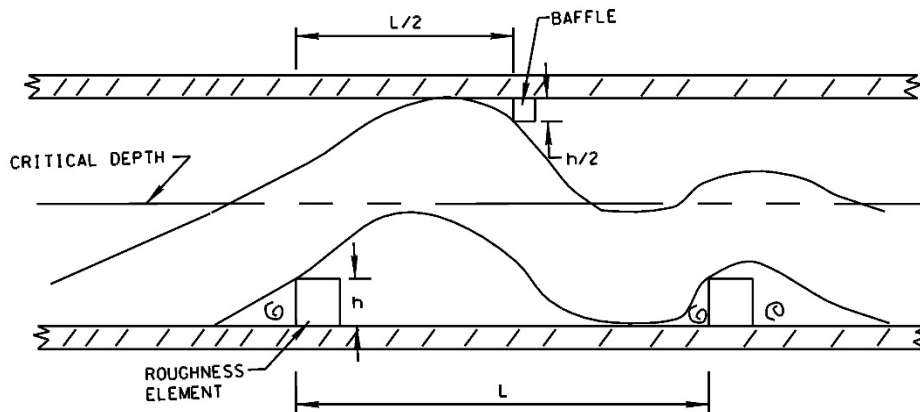


Figure 9-1: Typical Tumbling Flow Energy Dissipator

Tumbling flow can be established rather quickly by using either a very large leading element, or a smaller leading element and a baffle to reverse the flow jet between the first and second rows. The first alternative is not considered to be a practical solution since the element size is likely to be excessive. The baffle has merit since it deflects the so-called "rooster tail" jet back towards the culvert bottom and brings the flow under control very quickly without using a large leading roughness element.

9.03.4.2 INCREASED RESISTANCE

Increased resistance (Figure 9-2) involves using roughness elements to provide greater hydraulic roughness and thus, reduce velocity. Because increasing resistance will also increase the depth of flow, the designer should ensure that the proposed culvert height will be adequate in the roughened section.

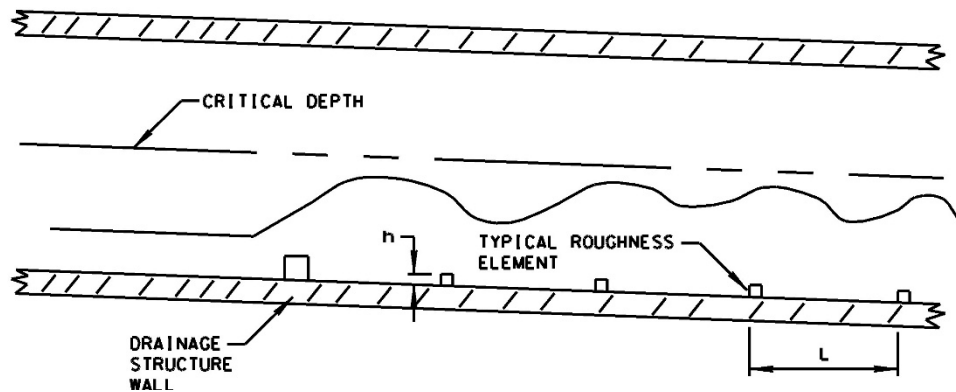


Figure 9-2: Increased Hydraulic Roughness



Figure 9-3: Roughness Elements Inside of a Box Culvert

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Whether roughness elements will represent increased resistance or create tumbling flow is largely dependent on the culvert slope. A roughness element on a steep slope may induce tumbling flow, whereas the same roughness element on a relatively flatter slope would represent increased resistance. Further, tumbling flow essentially delivers the outlet flow at critical velocity while increased resistance will deliver outlet velocities which are still in the supercritical flow regime. The designer should carefully evaluate the depth and velocity of the flows leaving the culvert and provide for any additional required erosion protection in the channel. Although internal energy dissipators may not completely eliminate the need for some form of erosion control at a culvert outlet, they may provide sufficient reduction in outlet velocity or Froude Number to allow a simpler, less expensive form of protection at the outlet.

Although internal energy dissipators will tolerate a moderate quantity of sand and silt, they should not be used in situations where the stream will transport cobbles and boulders or significant amounts of floating debris. These structures do not require a tailwater to operate efficiently.

9.03.5 EXTERNAL ENERGY DISSIPATORS

External energy dissipators are concrete structures placed at the culvert outfall as either stilling basins or impact basins. Structures referenced here are designed to be used at stream bed level. These structures may be used when:

The Froude number of the culvert outflow exceeds the design limits for a basin there is no adequate right-of-way.

Although the FHWA publication HEC-14 provides design information for many these structures, the dissipators described in the following sections are the primary structures to be considered for use on TDOT designs.

The use of these structures will require an individual design to be detailed in the plans. The required structural design should be coordinated with the Hydraulics Section in the Structures Unit in the following manner:

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Following approval of the Line and Grade Plans (Preliminary Plans), the designer should determine the required dimensions of the various elements of the structure using the equations and procedures provided in HEC-14. The designer should also use the equations provided in HEC-14 to estimate the hydrodynamic forces to be used in the structural design.

This information would then be submitted to the Hydraulics Unit, which would be responsible for the detailed structural design. The designer should allow sufficient time for the sizing and preliminary structural design to be completed prior to the Functional Plans Submittal.

9.03.5.1 STILLING BASINS

These basins are flume type drop structures characterized by some combination of chute blocks, baffle blocks, and sills designed to trigger a hydraulic jump in combination with a required tailwater condition. With the required tailwater, velocity leaving a properly designed stilling basin is equal to the velocity in the receiving channel. USBR Type III, Type IV Stilling Basin or Saint Anthony Falls (SAF). Typical roadway culvert cross drain structure should not use stilling basin energy dissipators, therefore there will be no discussion about this type of dissipater in this chapter.

9.03.5.2 IMPACT BASINS

This section contains Impact Basin energy dissipators for culvert outlets that are designed to operate at the streambed level and intended to drain by gravity during normal (mean) flow conditions. This category of dissipators should be favored by designers when applicable due to the ability to reestablish natural flow conditions downstream from the culvert outlet and providing AOP benefits. During the design designers shall provide a low flow channel with the proposed structure and compensate for the impact of embedding (or recessing) pipe or box structures to maintain the natural stream bed within the cross-drain structure.

The preferred streambed level Impact Basin energy dissipators are,

- Colorado State University (CSU) rigid boundary basin
- Contra Costa basin
- U.S. Bureau of Reclamation (USBR) Type VI impact basin

9.03.5.2.1 RIGID BOUNDARY BASIN

The Colorado State University (CSU) rigid boundary basin, illustrated in Figure 9.4, uses staggered rows of roughness elements to initiate a hydraulic jump.

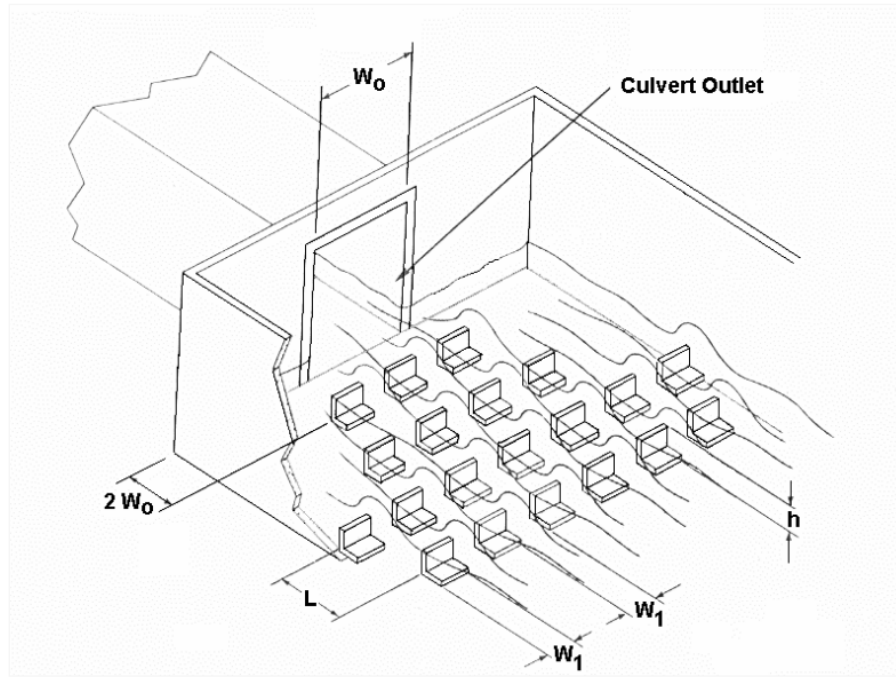


Figure 9-4: Colorado State University Rigid Boundary Basin

Designers may refer to FHWA HEC 14 CHAPTER 9: STREAMBED LEVEL DISSIPATORS for design information.

9.03.5.2.2 CONTRA COSTA BASIN

The Contra Costa energy dissipator was developed at the University of California, Berkeley, in conjunction with Contra Costa County, California. It is intended for use primarily in urban areas with defined tailwater channels. A sketch of the dissipator is shown in Figure 9.5

The dissipator was developed to be self-cleaning with minimum maintenance requirements. It is best suited to small and medium-sized culverts of any cross section where the depth of flow at the outlet is less than or equal to half the culvert height but is applicable over a wide range of culvert sizes and operating conditions. The flow leaving the dissipator will be at minimum energy when operating without tailwater. When tailwater is present, the performance

will improve. To provide AOP thru the dissipater, both baffles and end of slab lip shall have minimum 12" wide 6" high opening (see end view shown below).

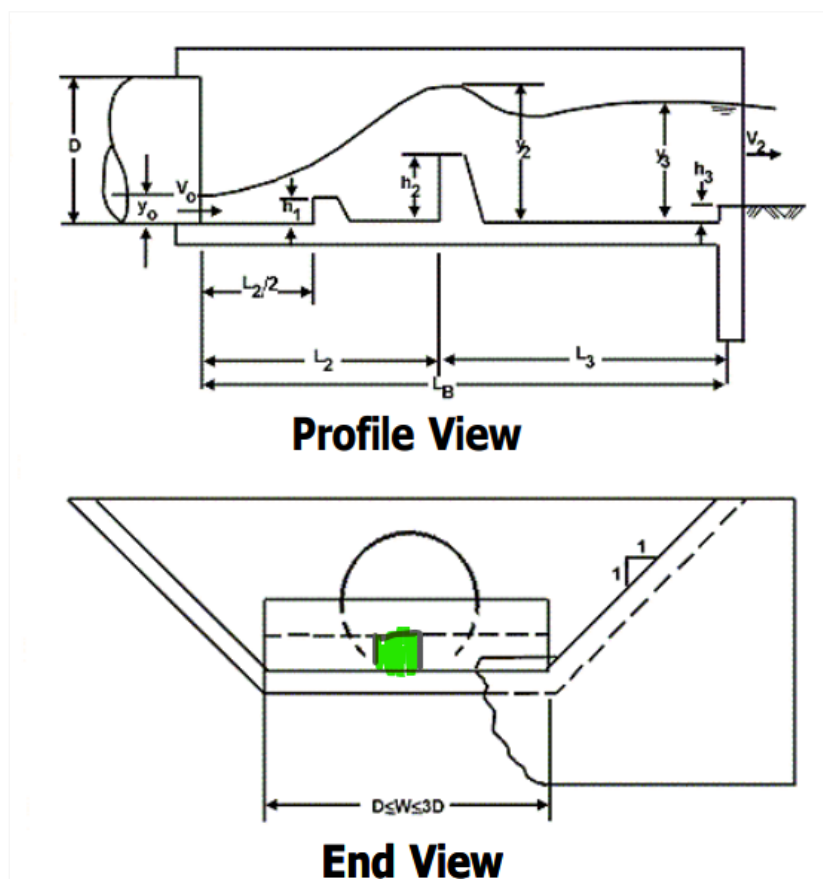


Figure 9-5: Contra Costa Energy Dissipator

Designers may refer to FHWA HEC 14 CHAPTER 9: STREAMBED LEVEL DISSIPATORS for design information.

9.03.5.2.3 USBR TYPE VI IMPACT BASIN

The U.S. Bureau of Reclamation (USBR) Type VI impact basin was developed at the USBR Laboratory as shown in Figures 9-6 and 9-7, is contained in a relatively small box-like structure requires no tailwater for its performance. Inside this box is a vertical baffle which is referred to as a hanging baffle because an opening is provided between the bottom of the baffle and the floor of the box. This type of energy dissipator is attached directly to the culvert outlet in place of a standard endwall.

Energy dissipation is initiated as flow strikes the vertical baffle and is deflected upstream by the horizontal portion of the baffle and by the floor, creating horizontal eddies. Despite its relatively small size, this impact basin yields greater energy dissipation than a hydraulic jump in the same setting.

The baffle is provided with notches which aid in cleaning the basin after prolonged non-use of the structure. If the basin should begin to collect sediment, the notches will provide concentrated jets of water for cleaning. The basin is designed so that the full design discharge can be passed over the top of the baffle should the space beneath it become completely clogged. Although this degrades the performance of the structure, it is acceptable for short periods of time. To provide structural support and aid in priming the device, a short support should be placed under the center of the baffle wall.



Figure 9-6: Typical USBR Type VI Baffled Dissipator

In situations where the culvert entering the basin has a slope greater than 27 percent, the basin should be constructed on a horizontal grade. In addition, the culvert should be provided with a horizontal section at least four culvert widths in length immediately upstream of the dissipator. Although the basin will operate effectively with entrance pipes on slopes up to 27 percent, experience has shown that it is more efficient when the flow jet entering the dissipator is horizontal.

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The end of the basin should be provided with a low sill which, where feasible, should be set at the same elevation as the downstream channel. Where this is not possible, a slot should be placed in the end sill to provide for drainage during periods of low flow. Where needed to retain the roadway embankment, the end of the basin may be provided with an alternate end sill and 45° wingwalls as shown in Figure 9-8. It may also be necessary to provide a cut-off wall. Where the velocities of flows exiting the basin exceed 5 ft/sec, the channel downstream of the basin should be provided with a riprap apron, as described in Section 6.04.3.3.

To prevent cavitation damage, use of the USBR Type VI basin is limited to installations where the discharge is less than 400 cfs. Although tailwater is not necessary for the successful operation of the basin, a moderate depth of tailwater will improve its performance. However, the tailwater depth should not be above half of the height of the baffle, or $h_3 + h_2/2$, as shown in Figure 9-13. This dissipator is not recommended where potential debris may cause substantial clogging.



Figure 9-7: Top of the Baffle in a USBR Type VI Energy Dissipator

SECTION 9.04 – DESIGN PROCEDURES

9.04.1 COMPUTATIONS IN SUPPORT OF ENERGY DISSIPATOR DESIGN

A variety of background information is usually needed to properly design an energy dissipator. A portion of that information may be determined by means of computations that support the

dissipator design. This section discusses the computations that should be completed prior to beginning the selection and design of an energy dissipation scheme.

9.04.1.1 CULVERT HYDRAULIC ANALYSIS

A significant portion of the data needed to design an energy dissipator will be obtained from the culvert design file. Detailed procedures for the design of a new culvert are described in Section 6.05.

9.04.1.2 COMPUTATION OF CULVERT OUTFLOW CONDITIONS

Although the culvert outflow conditions will likely be described in the culvert design file, a few parameters will require a more detailed analysis to support the energy dissipator design:

1. **Outlet Depth (d_o):** The outlet depth is often provided as a part of the hydraulic analysis of the culvert. Where this is not the case, the outlet depth may be determined using the guidance provided in Section 6.05.4 of this Manual.
2. **Area (A_o):** The cross-sectional area of the flow at the culvert outlet should be determined using d_o . This determination may be aided using Table 6A-11.
3. **Top width (T):** The top width of the flow at the culvert outlet may be determined using d_o . Table 6A-11 may also be used in determining this parameter.
4. **Velocity (V_o):** The culvert outlet velocity should be calculated as follows:

$$V_o = \frac{Q}{A_o} \quad (9-1)$$

Where: Q = culvert discharge, (ft³/s)

5. **Equivalent Depth (d_e):** The equivalent depth is used in several computations for non-rectangular culverts. It can be computed as follows:

$$d_e = \left(\frac{A_o}{2} \right)^{0.5} \quad (9-2)$$

6. **Froude Number (Fr):** This parameter is described in Section 9.03.3 and is an important factor in the design of energy dissipators. For rectangular shapes, it is calculated as follows:

$$Fr = \frac{V_o}{(g \times d_o)^{0.5}} \quad (9-3)$$

Where: g = acceleration due to gravity, (32.2 ft/sec²)

d_o = depth of flow at outlet, (ft)

V_o = culvert outlet velocity, (ft/s)

For non-rectangular shapes, the term d_o may be substituted with the equivalent depth, d_e .

9.04.2 DESIGN PROCEDURES

Detailed design procedures for the energy dissipator types described in this Manual are provided in the FHWA document HEC-14, *Hydraulic Design of Energy Dissipators for Culverts and Channels*. This document is available on the Internet from the Federal Highway Administration hydraulics home page. This Manual provides a general procedure for determining whether an energy dissipator is needed and for selecting the type of dissipator, as well as detailed design procedures for the USBR Type VI Impact Basin. When it becomes necessary to perform a design for other types of dissipators, the designer should refer to HEC-14 for detailed guidance and computational procedures. Specific comments and notes helpful in the application of the HEC-14 procedures are provided in the second half of this section.

9.04.2.1 GENERAL DESIGN PROCEDURE

The following design procedure is intended to provide a convenient and organized procedure for manually designing energy dissipators. The designer should be familiar with all the equations in Section 9.04.1 before using this procedure. In addition, application of the following design method without an understanding of the applicable hydraulic principles can result in an inadequate, unsafe or costly structure.

Step 1: Obtain the culvert design file and assemble the required data. This should include:

- Survey data as defined in the TDOT Survey Manual and other site information
- Design storm frequency and discharge (will be the same as used for the culvert design)

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- Tailwater information, including the channel slope, cross section, normal depth and velocity
- Information on the composition of the downstream bed and bank materials
- Information on the proposed culvert design, including the culvert type (size, shape and roughness), outlet flow conditions (see Section 9.04.1.2), culvert slope, and the culvert performance curve

Step 2: Enter the data from Step 1 onto the Energy Dissipator Worksheet provided in the chapter Appendix as Figure 9A-1.

Step 3: Determine the need for an energy dissipator using the criteria presented in Section 9.03.1.

Step 4: Select dissipator design alternatives based on Section 9.03.3. More than one alternative may be possible. The alternate that provides the best overall fit for the site may become apparent as detailed designs are developed for each one.

Step 5: Develop designs for each of the alternates identified in Step 5. Design procedures and forms for each dissipator type are presented in the chapter Appendix.

Step 6: Design the riprap apron. Many dissipators may require a riprap apron between the outlet of the dissipator and the natural channel. This provides for a smooth flow pattern between the dissipator and the channel and provides any final erosion protection that may be required. The length and class of riprap for the apron should be determined based on the procedure provided in Section 6.05.5.

Step 7: Select the cut-off wall depth. Where necessary, energy dissipation structures that are constructed of reinforced concrete should be provided with a cut-off wall of sufficient depth to protect the basin outfall.

Step 9: The need for any structural design of a reinforced concrete energy dissipator should be coordinated with the Hydraulics Unit in the Structures Division. In areas which may be subject to a high-water table the Hydraulics Section should also be consulted with regard to the buoyancy of the structure. If the ground is saturated, and tailwater conditions exist, the

structure may be subject to buoyant forces that are relative in strength to the volume of water displaced by the structure. Flotation of the structure will occur when its weight is equal to or less than the uplift force exerted by the water. Buoyancy analysis should be performed if the possibility of flotation exists.

Step 10: Review the results. At a minimum, the following items should be addressed:

- If the downstream channel conditions (velocity, depth, or stability) are exceeded, provide a riprap apron designed according to Section 6.05.5 or select another type of dissipator.
- If the preferred dissipator affects the hydraulic performance of the proposed culvert, recompute the culvert performance and ensure that the selected dissipator design will still be adequate. Once any needed adjustments are made to the dissipator design, it is not necessary to check the culvert hydraulics any further.
- Ensure that the proposed dissipator will adequately pass debris expected at the site, or that it will not require excessive maintenance.
- Check whether the proposed energy dissipator, and any needed riprap apron, will be contained within the proposed right-of-way. If not, it may be necessary to obtain a permanent drainage easement to accommodate the structure.

9.04.2.2 NOTES ON HEC-14 PROCEDURES

Although the FHWA HEC-14 document provides detailed procedures for the design of the energy dissipators discussed in this Manual, there are points at which specific comments may be helpful in applying these procedures. This section provides suggestions and other guidance information intended to aid the designer in developing energy dissipator designs that are consistent with the guidelines in this chapter.

The only dissipator designs for which a detailed procedure is provided in this Manual are the Saint Anthony Falls stilling basin and the USBR Type VI impact basin.

9.04.2.2.1 HEC-14 PROCEDURES FOR INTERNAL ENERGY DISSIPATORS

The FHWA publication HEC-14 provides design procedures for internal roughness elements which serve to dissipate energy either by producing tumbling flow or by presenting increased

roughness. The Appendix to this chapter provides design computation worksheets for both types of flow in box culverts. Although HEC-14 includes procedures for tumbling flow or increased roughness in round pipes as well as box culverts, the use of roughness elements in round pipes is not recommended due to concerns regarding the maintenance of such structures.

9.04.2.2.2 USBR TYPE VI IMPACT BASIN DESIGN PROCEDURE

The FHWA publication HEC-14 provides a very simple procedure for selecting the dimensions of a USBR Type VI impact basin. However, it does not include detailed instructions for estimating the total energy loss through the structure, nor does it provide specific guidance on the design of any riprap apron that may be required at the outlet. This section presents the HEC-14 method for determining the dimensions of the basin (see Figures 9-6, 9-7, and 9-8) as well as a few additional steps which may be helpful in completing the design.

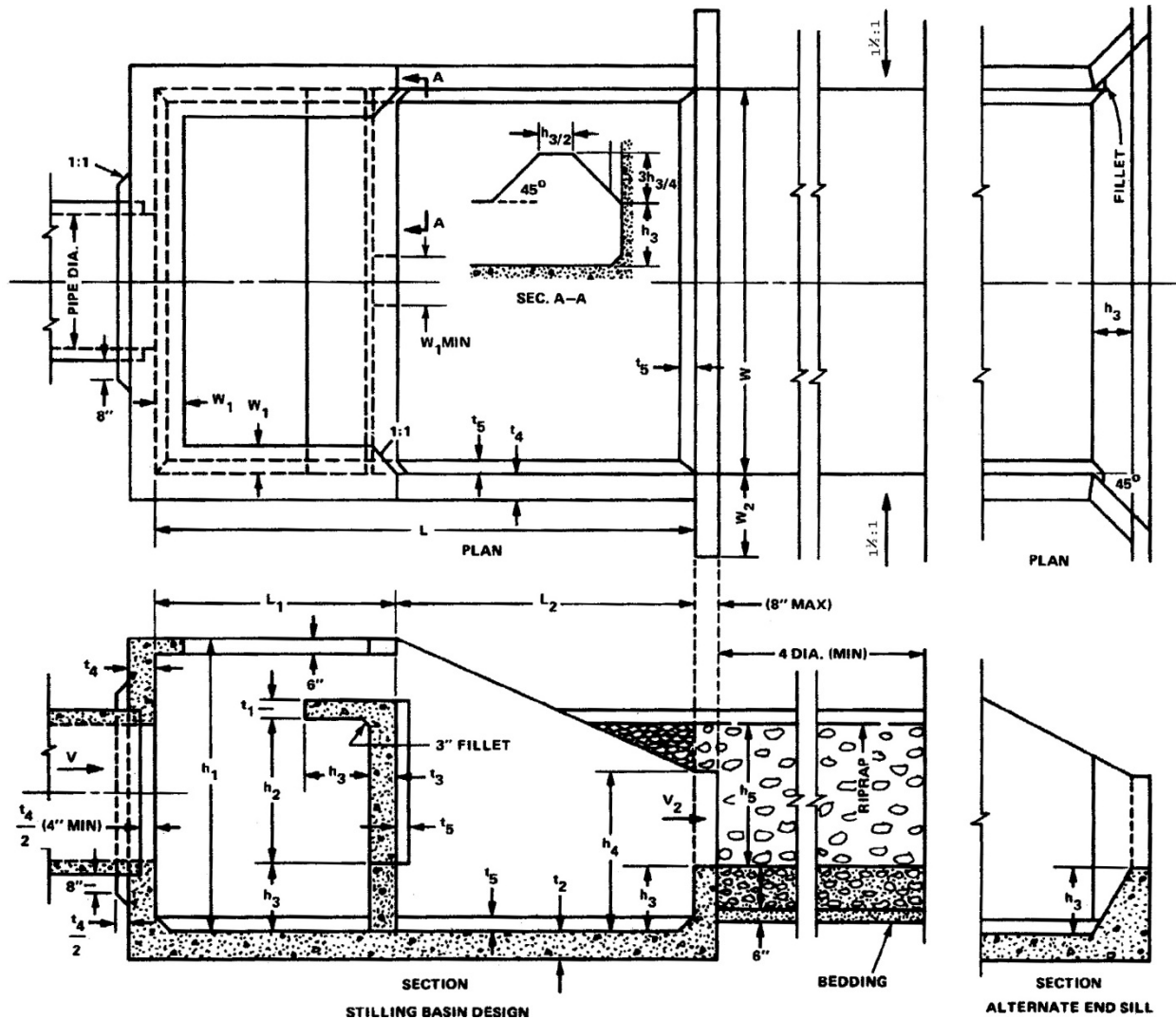


Figure 9-8: Typical USBR Type VI Baffled Dissipator

Reference: USDOT, FHWA, HEC-14 (1983)

Step 1: Determine the depth, d_o , equivalent depth, d_e , velocity, V_o , and Froude Number, Fr_o of the flow at the culvert outlet using the procedures provided in Section 9.04.1.2. In addition, determine the depth of flow (tailwater) in the stream cross section downstream of the basin. This may be computed using the procedure provided in Section 5.06.1.3.4.

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Step 2: Compute the specific energy, H_o , of the culvert outflow using Equation 9-4:

$$H_o = d_o + \frac{V_o^2}{2g} \quad (9-4)$$

Where: H_o = specific energy of culvert outflow, (ft)

d_o = depth of flow at the outlet, (ft)

V_o = velocity of flow at the outlet, (ft/s)

g = acceleration due to gravity, (32.2 ft/sec²)

Step 3: Compute a value for the ratio of the outlet specific energy, H_o , to the width of the basin, W , from Equation 9-5:

$$\frac{H_o}{W} = 0.0348Fr_o^2 + 0.1343Fr_o + 0.1128 \quad (9-5)$$

Where: H_o = specific energy of the culvert outflow, (ft)

W = width of the impact basin, (ft)

Fr_o = Froude Number of the culvert outflow

Determine the required width, W , of the basin by dividing the specific energy computed in Step 2 by the value for H_o / W determined by Equation 9-5. The result should be rounded to the nearest foot.

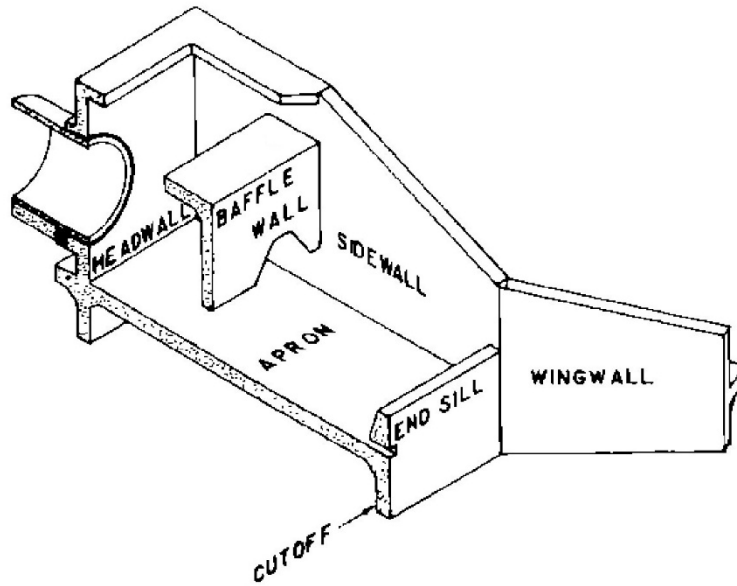


Figure 9-8: “Cut-Away” Isometric View of a Typical USBR Type VI Baffled Dissipator

Reference: USDA, NRCS, TR-49 (1971)

Step 4: Based on the computed value of W in Step 3, obtain values for h_2 and h_3 from Table 9A-2 in the Appendix and verify that Equation 9-6 is true.

$$TW \leq h_3 + \frac{h_2}{2} \quad (9-6)$$

Where: TW = tailwater depth computed in Step 1, (ft)

If Equation 9-6 is not true, the culvert outlet and the basin should be raised such that the height of the tailwater surface above the end sill will make the expression true. This will have the effect of changing the slope of the culvert. Usually, this will require the culvert performance to be reanalyzed, and the procedure will begin again from Step 1.

Step 5: The remaining dimensions of the basin should be determined from Table 9A-2 in the Appendix.

Step 6: Compute a value for the ratio of the head lost, H_L , in the impact basin to the specific energy, H_o , at the culvert outlet from Equation 9-7. Equation 9-7 utilizes the natural log of the Froude Number at the culvert outlet.

$$\frac{H_L}{H_o} = 0.2718 \ln(Fr) + 0.2328 \quad (9-7)$$

Where: HL = head lost in the impact basin, (ft)

H_o = specific energy at the culvert outlet, (ft)

Fr = Froude Number of the culvert outflow

The ratio computed above may then be multiplied by H_o to estimate the total energy lost in the basin.

Step 7: Compute the energy, H_E , at the basin outlet as:

$$H_E = H_o - H_L \quad (9-8)$$

Step 8: Determine the depth of flow, d_E , at the basin outlet. There are three possible values for this depth. The first possible value is based on the energy at the basin outlet and may be estimated from Equation 9-9:

$$H_E = d_E + \frac{\left[\frac{Q}{W \times d_E} \right]^2}{2g} \quad (9-9)$$

Where: H_E = energy at the basin outlet

d_E = depth of flow over end sill, (ft)

Q = design discharge, (ft³/s)

W = basin width at the end sill, (ft)

g = acceleration due to gravity, (32.2 ft/sec²)

This equation should be solved for d_E using trial and error. Typically, two values for d_E will be possible from this expression, one in the supercritical regime and the other in the subcritical regime. The subcritical solution, which will involve the greater value of d_E , should be considered for use.

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The second possible value for d_E is the critical depth of flow across the end sill at the design discharge. This may be computed from the equation:

$$d_{Ec} = \left[\frac{Q}{W\sqrt{g}} \right]^{0.667} \quad (9-10)$$

Where: d_{Ec} = critical depth at the end sill, (ft)

Q = design discharge, (ft³/s)

W = basin width at the end sill, (ft)

g = acceleration due to gravity, (32.2 ft/sec²)

The third possible value for d_E is the depth of flow (tailwater) in the channel cross section downstream of the basin, which was determined in Step 1.

The value to be used for the depth of flow at the end sill may be determined by comparing the tailwater depth with the other possible values for d_E . Where the tailwater depth is greater than d_E , as computed from the energy at the basin outlet, d_E will be equal to TW. Where TW is less than the critical depth, d_{Ec} , the outlet depth will be equal to d_{Ec} . Where TW is between the two values, d_E may be assumed to be equal to the value computed based on energy loss.

Step 9: The flow velocity, V_E , across the basin sill can be computed using Equation 9-11:

$$V_E = \frac{Q}{W \times d_E} \quad (9-11)$$

When V_E is significantly greater than the natural stream flow velocity, erosion protection should be provided in the form of a riprap apron designed in accordance with Section 6.05.5.

Step 10: It is recommended that the basin outlet be provided with a cut-off wall.

SECTION 9.05 – ACCEPTABLE SOFTWARE

The software discussed in the following sections should be used for the design of an energy dissipator unless special circumstances on the project require other software. The TDOT design manager should approve of the use of any other software for these special circumstances.

9.05.1 COMPUTER PROGRAM HY-8

HY-8 is a Windows™ based computer program developed by the FHWA for culvert design.

Energy dissipator design computations using the methods prescribed in HEC-14 are available as a module within HY-8. The program can provide design information for all the dissipator options described in this chapter as well as several other dissipator types discussed in HEC-14. Features of the computer program include:

- design of internal energy dissipators
- design of external energy dissipators
- automatic evaluation of the feasibility of the available dissipator types
- the ability to move seamlessly between the culvert design and energy dissipator design modules
- a convenient means of quickly analyzing a number of dissipator design alternatives for a given site
- output of results to different file formats (.pdf, .rtf or .xls)
- The program is available in the Public Domain from the FHWA Hydraulics internet web page.