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4.3.4 Energy Dissipator



Source: TDOT

Definition and Purpose

Energy dissipators are components of drainage structures that are used to prevent erosion or scouring at the outlet of a pipe or culvert. They are often referred to as “integrated” components of drainage structures, as they are not standalone measures. Components may include roughness elements, baffles, broken-back culvert modifications, weirs, impact basins, and drop structures. These work to dissipate flow energy and reduce erosion potential by creating hydraulic jumps, dispersing flow area, and/or disrupting steep slopes.

Appropriate Applications

An energy dissipator should be considered for use where:

- The required length or dimensions of “external” structural energy dissipators such as level spreaders (Section 4.3.5), riprap aprons (Section 4.3.6), or stilling basins (Section 4.3.7) would be excessive or infeasible due to culvert outlet conditions;
- Culvert outlet velocities and shear stresses exceed erosion resistance thresholds; or
- Erosion at the culvert outlet will pose an unacceptable risk to adjacent or downstream property.

Energy dissipators can be used in series when one may not fully prevent scouring or erosive forces, or in combination with structural energy dissipators. A common dual application is implementing a drop structure followed by a weir.



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Limitations and Maintenance

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 a channel is lined with bedrock. Energy dissipators require routine inspections to ensure they are functioning properly, which may include inspections during and after storm events. Report, correct, and/or replace any malfunctions promptly. Undermining of the concrete apron or slab may occur when transitions from the pipe to the energy dissipator are not seamless. That is, flowing water finds a seam and goes under the concrete slab or other structure, similar to piping. In these cases, water can erode the base stone and cause a structural failure.

Planning and Design Considerations

There are various energy dissipators that can be implemented in drainage (Figure 4.3.4-A). The following summaries provide an understanding of the benefits and drawbacks of such devices and implementation strategies.

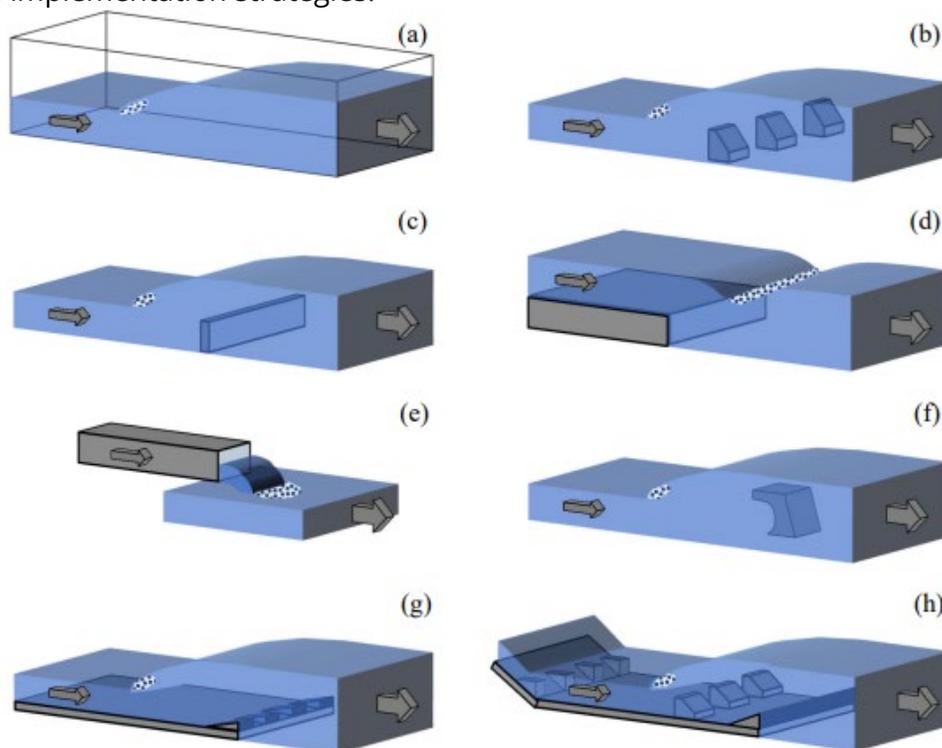


Figure 4.3.4-A: Energy dissipators (a) free hydraulic jump; (b) baffles; (c) sills (weir); (d) drops; (e) plunge basin; (f) counterflow mechanism; (g) flip buckets; and (h) design basins. Source: Admiraal and Zhang (2023).



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Roughness elements or increased resistance is a practical method for reducing kinetic energy in flowing water by enhancing hydraulic resistance. This technique involves the strategic placement of roughness elements like protrusions along the culvert to reduce flow velocities by inducing tumbling flow or increased resistance flow. The distinction between these two flow behaviors is critical in design: steep slopes favor tumbling flow, while flatter slopes benefit more from increased resistance. Tumbling flow consists of repeated hydraulic jumps and overfalls that maintain flow at approximately critical velocity, even in conditions where supercritical velocities would otherwise dominate. While not completely eliminating the need for outlet protection, increased roughness can reduce outlet velocities and Froude numbers enough to allow for simpler, lower-cost measures at the outlet. However, these systems are not suitable for channels expected to carry large debris or coarse sediment such as cobbles and boulders. Proper sizing of the culvert and roughness elements, as well as consideration of flow control (inlet versus outlet control), are essential to achieving effective velocity reduction without compromising culvert capacity. The design of tumbling flow systems must account for the relationship between element height and unit discharge, which can limit their use in high-flow situations. Practical implementation often involves five (or more) rows of roughness elements to establish a cyclical flow pattern without needing to line the entire culvert length (Figure 4.3.4-B). Proper spacing, typically placing the first and last elements a distance of half their length from their respective starting points, is essential for maintaining uniform flow. Design success depends on verifying inlet-controlled drainage structures, evaluating outlet velocity needs, calculating critical flow conditions, and appropriately sizing the elements (FHWA, 2006).

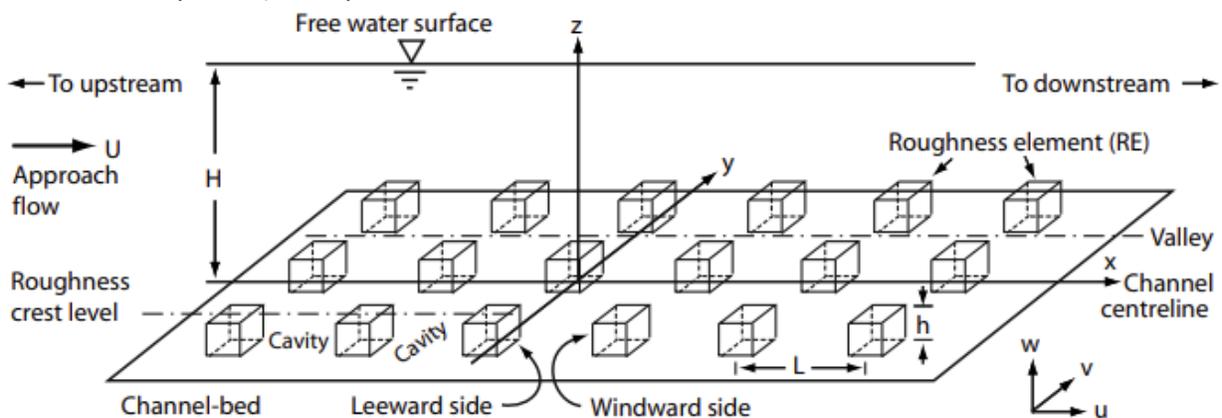


Figure 4.3.4-B: Roughness elements diagram showing the direction of flow, spacing of roughness elements (L), and roughness element height (h). Source: Li & Li (2020).

Baffles are an effective energy dissipation method for high-energy flows in culverts, chutes, or aprons with moderate slopes. These systems use a series of baffles, essentially raised roughness elements, installed along the floor to disrupt the flow, slowing it before and



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accelerating it after each block, thereby reducing overall kinetic energy (Figure 4.3.4-A[b] and 4.3.4-C). When properly designed, this configuration can reduce flow velocities at the apron bottom to one-third of critical velocity. Baffled aprons are particularly useful for preventing excessive acceleration during vertical drops, rather than mitigating high approach velocities. Their performance remains effective with or without downstream tailwater, and they are generally resilient to trash or debris accumulation. Key design parameters include a culvert or chute slope between 25% and 50%, unit discharge under 60 cubic feet per second per foot, and approach velocity below critical velocity. Baffle height should be approximately 0.8 times the critical depth, with width and spacing around 1.5 times the height. Four (or more) rows of baffles are typically sufficient to establish flow control, and additional features such as recessed approaches or conventional riprap at the outlet may be incorporated to further enhance performance and prevent undermining (FHWA, 2006).

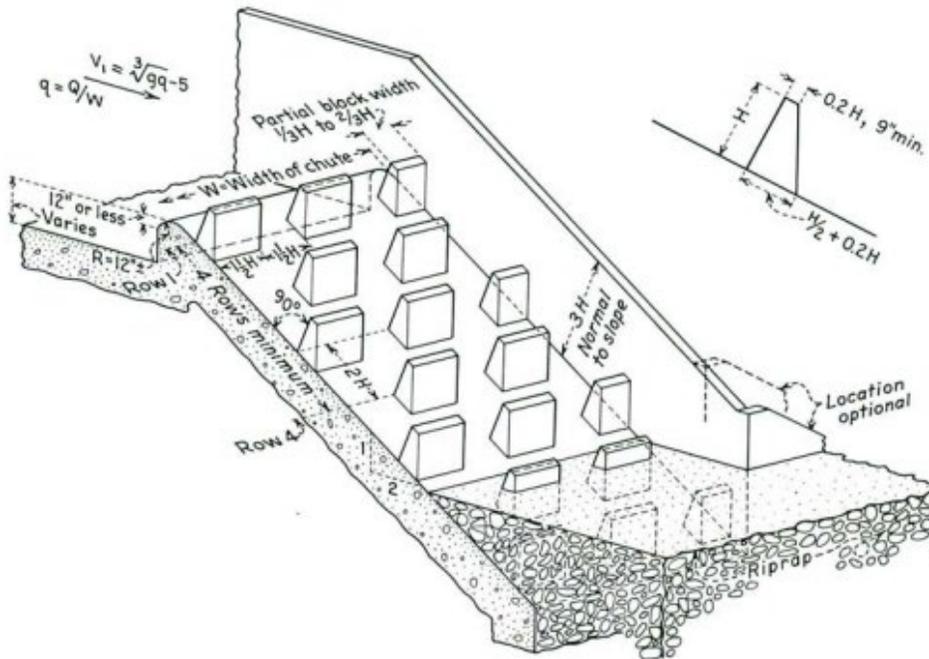


Figure 4.3.4-C: Baffled apron details. Source: Peterka (1978).

Broken-back culverts are used as energy dissipators by promoting the formation of a hydraulic jump within a flat runout section of culvert, thereby reducing the kinetic energy of high velocity flows. These culverts consist of a steep inlet section followed by a horizontal outlet section (Figure 4.3.4-D). A hydraulic jump forms when either the downstream momentum exceeds the upstream momentum, or when the supercritical flow in the steep section decelerates to a Froude number near 1.7 (Eqn 16, Section 4.3.2). The design goal is to ensure that the jump occurs and remains confined within the runout section, where it dissipates energy efficiently and minimizes downstream erosion. Engineers analyze flow



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profiles to determine the location and length of the jump, ensuring it fits within the flat section. This method is particularly useful when external energy dissipation structures are not feasible. Broken-back culverts are best suited for mild slopes and require adequate runout length and tailwater conditions to complete the hydraulic jump internally. If conditions are not ideal, outlet modifications can be used to induce the jump (Thomason, 2019).

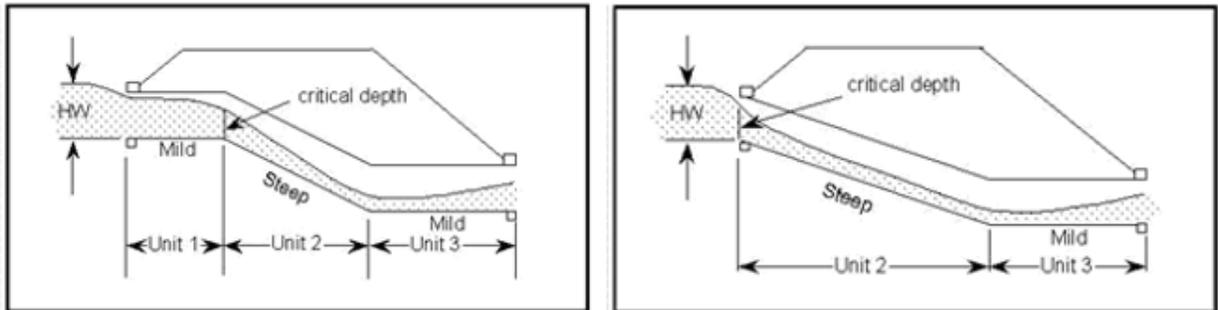


Figure 4.3.4-D: Three-unit broken back culvert diagram (left) and two-unit broken back culvert diagram (right). Source: Thomason (2019).

Weirs can be used as energy dissipators by inducing a hydraulic jump near the outlet of a culvert, effectively reducing the velocity of supercritical flows and minimizing downstream erosion. Typically installed in the horizontal runout section of a broken-back culvert about 10 feet upstream from the outlet, weirs span the full width of the culvert and are designed to trigger a hydraulic jump when the approach Froude number is between 2 and 7 (Eqn 16, Section 4.3.2). As water flows over the weir, it passes through critical depth and becomes supercritical, leading to a hydraulic jump that dissipates energy before the flow exits the culvert (Figure 4.3.4-A[c]). Drain holes in the weir prevent standing water upstream, and its placement allows for easier debris removal. Weirs are particularly effective when there is little or no tailwater and when used in rectangular culverts with weir heights between 0.7 and 4.2 times the upstream flow depth (FHWA, 2006). Their use reduces the need for extensive downstream channel protection.

Impact Basins are compact, engineered structures designed to dissipate the energy of high-velocity stormwater discharges, commonly installed at the outlets of culverts or spillways to prevent downstream erosion. Their primary mechanism involves directing the flow against a vertical hanging baffle, which redirects the water upward and backward, forming turbulent eddies as it interacts with the horizontal baffle section and basin floor; thus, significantly reducing runoff velocity. Unlike traditional hydraulic jumps, impact basins operate effectively without relying on tailwater conditions, although moderate tailwater levels can improve performance. Typical design features include a box-like concrete structure, a vertical baffle



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with cleaning notches, a low-end sill (weir) to help maintain proper water levels, and riprap aprons (Section 4.3.6) downstream to manage residual velocity. Some installations also include wingwalls or a cutoff wall to prevent undermining and promote structural stability. A short support beneath the baffle enhances strength and contributes additional energy dissipation. Horizontal inlet sections are often recommended, even for culverts on moderate slopes, to improve flow orientation and ensure optimal performance. Although impact basins offer reliable energy dissipation across a range of flow conditions, they are not suitable in areas with high debris, and their use is typically limited to discharges under 400 cubic feet per second and velocities below 50 feet per second (FHWA, 2006; TDOT).



Source: TDEC

Drop structures are widely used for energy dissipation and erosion control in channels with steep gradients. Their primary function is to break a steep slope into a series of shorter, milder slopes and vertical drops, preventing the development of high velocity, erosive flows. Unlike methods that slow already fast-moving water, drop structures preemptively control channel slope to ensure high velocities never form. As water falls over the crest of each structure, the resulting kinetic energy is dissipated in a stilling basin (Section 4.3.7) or concrete apron designed to absorb impact, redirect flow, and induce turbulence. Drop structures are typically used in subcritical flow conditions, but considerations for upstream supercritical flow are also possible.

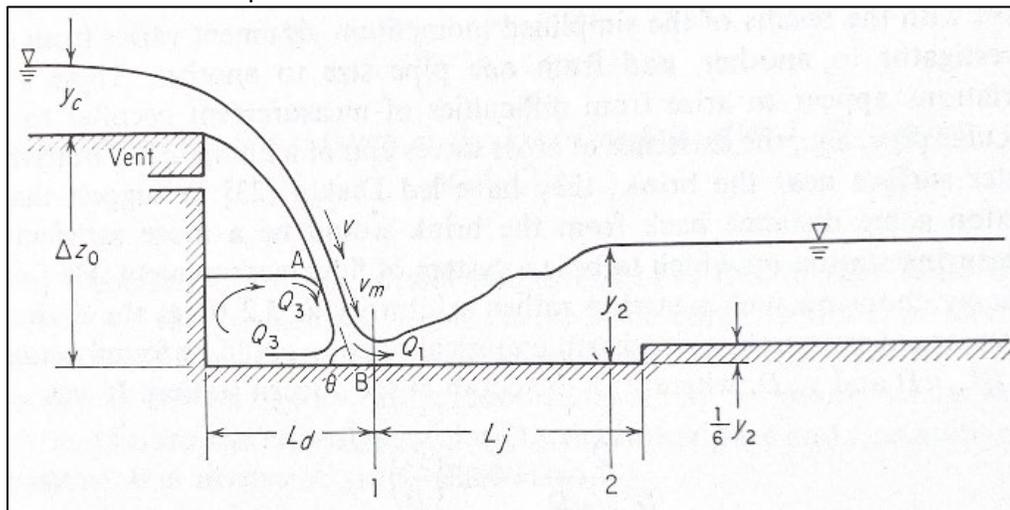


Figure 4.3.4-E: Geometries of a drop structure. Source: Henderson (1966).



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Additional energy dissipators and resources for the design of the dissipators presented herein can be found in FHWA (2006), Admiraal & Zhang (2023), TDOT, and Thomason (2019).

Example Application

No formal design or quantities are required for this measure and therefore are not presented here. For design examples, refer to *HEC-14* by FHWA (2006).

References

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