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Hydraulic Structures - Conduit Outlets

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3.0 CONDUIT OUTLET STRUCTURES

3.1 General

Energy dissipation or stilling basin structures are required to minimize scour damages caused by high exit velocities and turbulence at conduit outlets. Similarly, culverts nearly always require special consideration at their outlets. Outlet structures can provide a high degree of energy dissipation and are generally effective even with relatively low tailwater control. Rock protection at conduit outlets (see the MAJOR DRAINAGE chapter) is appropriate where moderate outlet conditions exist; however, there are many situations where rock basins are impractical. Reinforced concrete outlet structures are suitable for a wide variety of site conditions. In some cases, they are more economical than larger rock basins, particularly when long-term costs are considered.

Any outlet structure must be designed to match the receiving stream conditions. The following steps include an analysis of the probable range of tailwater and bed conditions that can be anticipated including degradation, aggradation, and local scour.

Hydraulic concepts and design criteria are provided in this section for an impact stilling basin and adaptation of a baffle chute to conduit outlets. Use of concrete is often more economical due to structure size or local availability of materials. Initial design selection should include consideration of a conduit outlet structure if any of the following situations exist: (1) high-energy dissipation efficiency is required, where hydraulic conditions approach or exceed the limits for alternate designs (see the MAJOR DRAINAGE chapter); (2) low tailwater control is anticipated; or (3) site conditions, such as public use areas, where plunge pools and standing water are unacceptable because of safety and appearance, or at locations where space limitations direct the use of a concrete structure.

Longer conduits with large cross-sectional areas are designed for significant discharges and often with high velocities requiring special hydraulic design at their outlets. Here, dam outlet and spillway terminal structure technology is appropriate (USBR 1987). Type II, III or IV stilling basins, submerged bucket with plunge basin energy dissipators and slotted-grating dissipators can be considered when appropriate to the site conditions. For instance, a plunge basin may have applicability where discharge is to a wet detention pond or a lake. Alternate designs of pipe exit energy dissipators are provided in this *Manual* that can be matched to a variety of pipe sizes and pipe outlet physical and hydraulic settings.

3.2 Impact Stilling Basin

Most design standards for an impact stilling basin are based on the USBR Type VI basin, often called “impact dissipator” or conduit “outlet stilling basin”. This basin is a relatively small structure that is very efficient energy in dissipating energy without the need of tailwater. The original hydraulic design reference by Biechley (1971) is based on model studies. Additional structural design details are provided by Aisenbrey, et al. (1974) and Peterka (1984).

The Type VI basin was originally designed to operate continuously at the design flow rate. However, it is applicable for use under the varied flow conditions of stormwater runoff. The use of this outlet basin is limited only by structural and economic considerations.

Energy dissipation is accomplished through the turbulence created by the loss of momentum as flow entering the basin impacts a large overhanging baffle. At high flow, further dissipation is produced as water builds up behind the baffle to form a highly turbulent backwater zone. Flow is then redirected under the baffle to the open basin and out to the receiving channel. A check at the basin end reduces exit velocities by breaking up the flow across the basin floor and improves the stilling action at low to moderate flow rates.

The generalized, slightly modified, USBR Type IV Impact Basin design configuration is shown in Figure HS-14, which consists of an open concrete box attached directly to the conduit outlet. The width, *W*, is a function of the Froude number and can be determined using Figure HS-15. The sidewalls are high enough to contain most of the splashing during high flows and slope down to form a transition to the receiving channel. The inlet pipe is vertically aligned with an overhanging L-shaped baffle such that the pipe invert is not lower than the bottom of the baffle. The end check height is equal to the height under the baffle to produce tailwater in the basin. The alternate end transition (at 45 degrees) is recommended for grass-lined channels to reduce the downstream scour potential.

The impact basin can also be adapted to multiple pipe installations. Such modifications are discussed later, but it should be noted that modifications to the design may affect the hydraulic performance of the structure. Model testing of designs that vary significantly from the standard is recommended.

3.2.1 Modified Impact Basins for Smaller Outlets

For smaller pipe outlets a modified version of the USBR Type IV Impact Basin is suggested in this *Manual*. Figure HS-16a provides a design layout for circular outlets ranging in size from 18-inches to 48-inches in diameter and Figure HS-16b for pipes 18-inches in diameter and smaller. The latter was added for primary use as an outlet energy dissipator upstream of forebays of small extended detention basins, sand filters and other structural best management practices requiring energy dissipation at the end of the pipe delivering water to the BMP facility.

Unlike the Type IV impact basin, the modified basins do not require sizing for flow under normal stormwater discharge velocities recommended for storm sewers in this *Manual*. However, their use is limited to exit velocities of 18 feet per second or less. For larger conduits and higher exit velocities, it is recommended that the standard Type IV impact basin be used instead.

3.2.2 Low-flow Modifications

The standard design will retain a standing pool of water in the basin bottom that is generally undesirable from an environmental and maintenance standpoint. As a result, the standard USBR design has been modified herein for urban applications to allow drainage of the basin bottom during dry periods. This situation should be alleviated where practical by matching the receiving channel low-flow invert to the basin invert. A low-flow gap is extended through the basin end check wall. The gap in the check should be as narrow as possible to minimize effects on the check hydraulics. This implies that a narrow and deeper (1½- to 2-foot) low-flow channel will work better than a shallow and wide gap section.

For the modified impact basin illustrated in Figure HS-16a, the downstream geometry recognizes the need for a trickle channel and also provides for a modification when this structure is used upstream of a forebay in an Extended Detention Basin or other BMP requiring energy dissipation at the entrance.

Low-flow modifications have not been fully tested to date. Caution is advised to avoid compromising the overall hydraulic performance of the structure. Other ideas are possible including locating the low-flow gap at one side (off center) to prevent a high velocity jet from flowing from the pipe straight down the low-flow channel. The optimal configuration results in continuous drainage of the basin area and helps to reduce the amount of siltation.

3.2.3 Multiple Conduit Installations

Where two or more conduits of different sizes outlet in proximity, a composite structure can be constructed to eliminate common walls. This can be somewhat awkward since each basin "cell" must be designed as an individual basin with different height, width, etc. Where possible, a more economical approach is to combine storm sewers underground, at a manhole or vault, and bring a single, combined pipe to the outlet structure.

When using a Type IV impact basin shown in Figure HS-14 for two side-by-side pipes of the same size, the two pipes may discharge into a single basin. If the basin's design width for each pipe is W, the combined basin width for two pipes would be $1.5W$. When the flow is different for the two conduits, the design width W is based on the pipe carrying the higher flow. For the modified impact basin shown in Figure HS-16, add 1/2 D space between the pipes and to each outside pipe edge when two pipes discharge into the basin to determine the width of the headwall and extent the width of the impact wall to match the outside edges of the two pipes. The effect of mixing and turbulence of the combined flows in the basin has not been model tested to date.

Remaining structure dimensions are based on the design width of a separate basin W. If the two pipes have different flow, the combined structure is based on the higher Froude number when designing the Type IV basins. Use of a handrail is suggested around the open basin areas where safety is a concern. Access control screens or grating where necessary are a separate design consideration. A hinged rack has been used on a few projects in the District.

3.2.4 General Design Procedure for Type IV Impact Basin

1. Determine the design hydraulic cross-sectional area just inside the pipe, at the outlet. Determine

the effective flow velocity, V, at the same location in the pipe. Assume depth $D = (A_{sect})^{1/2}$ and compute the Froude number = $\frac{V}{(gD)^{1/2}}$

2. The entrance pipe should be turned horizontally at least one pipe diameter equivalent length upstream from the outlet. For pipe slopes greater than 15 degrees, the horizontal length should be a minimum of two pipe diameters.

3. Determine the basin width, W, by entering the Froude number and effective flow depth into Figure HS-15. The remaining dimensions are proportional to the basin width according to Figure HS-14. The basin width should not be oversized since the basin is inherently oversized for less than design flows. Larger basins become less effective as the inflow can pass under the baffle.

4. Structure wall thickness, steel reinforcement, and anchor walls (underneath the floor) should be designed using accepted structural engineering methods. Note that the baffle thickness, t_b, is a suggested minimum. It is not a hydraulic parameter and is not a substitute for structural analysis. Hydraulic forces on the overhanging baffle may be approximated by determination of the hydraulic jet force at the outlet:

   $$F_j = 1.94\ V_{out}\, Q_{des} \quad \text{(force in pounds)} \qquad \text{(HS-15)}$$

   Q_{des} = maximum design discharge (cfs)

   V_{out} = velocity of the outlet jet (ft/sec)

5. Type “M” rock riprap should be provided in the receiving channel from the end check to a minimum distance equal to the basin width. The depth of rock should be equal to the check height or at least 2.0 feet. Rock may be buried to finished grades and planted as desired.

6. The alternate end check and wingwall shown in Figure HS-14 are recommended for all grass-lined channel applications to reduce the scour potential below the check wall.

7. Ideally, the low-flow invert matches the floor invert at the basin end and the main channel elevation is equal to the top of the check. For large basins where the check height, d, becomes greater than the low-flow depth, dimension d in Figure HS-14 may be reduced by no more than one-third. It should not be reduced to less than 2 feet. This implies that a deeper low-flow channel (1.5 to 2.0 feet) will be advantageous for these installations. The alternate when d exceeds the trickle flow depth is that the basin area will not drain completely.

8. A check section should be constructed directly in front of the low-flow notch to break up bottom flow velocities. The length of this check section should overlap the width of the low flow and its dimension is shown in Figure HS-14.