Spillway Design

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Spillways, shown below in figure 1, are defined in the Design of Small Dams as a provision “for storage and detention dams to release surplus water or floodwater that cannot be contained in the allotted storage space…¹. Spillways generally transport excess water that cannot be contained behind a dam to the streambed below it. This action prevents overtopping, which can be particularly destructive in the case of earthfill and rockfill dams, both of which can fail completely when overtopped.

**Spillway Components**

Spillways generally are made up of four components: a control structure, discharge channel, terminal structure, and entrance/outlet channels.

Control structures regulate the flows from the reservoir into the spillway, ensuring that flow will not enter the spillway until the water in the reservoir reaches the designed level, and moderating flow into the spillway once the design level has been reached. Control structures can be sills, weirs, orifices, or pipes.

Discharge channels, also known as waterways, convey flow that passes through the control structure down to the streambed below the dam. Note that conveyance structures are not always present in a spillway design; at times discharge may fall freely after passing through the control structure.

Terminal structures ensure that the flow, which oftentimes acquires a high velocity while traveling down a spillway, will not cause excessive erosion to the toe of the dam, or any other nearby structures. Plunge basins, flip buckets, and deflectors are all examples of terminal structures.

Entrance channels convey water from a reservoir to the control structure. Outlet channels convey flow that has reached the terminal structure to the river channel that resides below the dam.

Entrance and outlet channels are not necessarily a component of all spillways; it is possible for the spillway to transport flow directly from the reservoir to the river channel.

**Spillway Types**

Common types of spillways include: free overflow, ogee, labyrinth, conduit, tunnel, drop inlet, open channel, baffled apron drop, and culvert.

Free overflow or straight drop spillways are spillways in which flow falls freely after passing over the crest of the spillway. For an example of a spillway crest, please refer to figure 2, shown below.

![Figure 2. A spillway with basic components identified.](image)

Ogee spillways are characterized by control structures that consist of ogee shaped crests (crests that are s-shaped when viewed in profile). Ogee spillways can be advantageous, because as stated in *Design of Small Dams*, “For discharges at design head, the flow glides over the crest with no interference from the boundary surface and attains near-maximum discharge efficiency.”

Labyrinth spillways contain additional crest length in the spillway width, as compared to traditional spillways. An example of a labyrinth spillway can be seen in figure 3, shown to the left. Additional crest length allows the spillways to pass a larger discharge than normal, because less head is required. Labyrinth spillways are particularly useful when spillway width is fixed, and the spillway will be dealing with

![Figure 3. Labyrinth spillway. Additional crest length created by triangular folds.](image)

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2 United States Department of Interior-Bureau of Reclamation, pg. 353.
large discharges.

Conduit and tunnel spillways convey flow by means of a closed conduit or closed channel. Most conduit and tunnel spillways only have flow occupying up to 75% of their cross-sectional area, and are aerated to prevent them from acting as siphons between the locations of water transport.

In drop inlet spillways, also known as Shaft or Morning Glory spillways, water flows over a horizontal inlet, down a sloped or vertical shaft, and into the river channel. Drop inlet spillways are advantageous in situations where dams are situated in narrow canyons. They are ideally used in situations where there is a relatively small maximum outflow, because maximum capacity occurs at relatively low heads.

Open channel spillways, also known as Chute or Trough spillways convey water by means of an open channel. It should be noted that channels can be open channel spillways and still possess the characteristics that are necessary for them to be identified as another type of channel, because the designation is applied without reference to the control structure. Open channel spillways are often simple to design, and are frequently used in conjunction with earthfill dams.

Baffled, or apron spillways, shown in figure 4, are used to lower water from level to level, in situations are stilling tanks are not wanted. Baffle piers, which are protrusions along the spillway, obstruct the water’s flow, allowing kinetic energy to dissipate. Baffled spillways generally have slopes that are 2 horizontal units to 1 vertical unit at most, and it is recommended in Design of Small Dams that baffled spillway designs that require a slope steeper than the aforementioned be tested at the model scale before design proceeds.

Culvert spillways are a subset of closed conduit or spillways where the inlet into the spillway is either vertical, or inclined to the upstream or downstream. Additionally, culverts have a profile grade that is (nearly) uniform.

![Figure 4. Baffled spillway at Conconully Dam, in Washington.](image-url)
Design of Ogee Spillways

As mentioned earlier, Ogee spillways are spillways that generally have an S-shaped profile. This profile is advantageous because it can approximate the shape of the jet that travels along its surface, consequently making it easier to obtain ideal discharges. Shown below in figure 5 is a schematic of flow traveling over an ogee spillway, taken from Dr. Pierre Julien’s 11-11-14 handout, entitled CIVE 401-Notes on Spillways.

![Figure 5. Schematic of flow and related quantities as they pertain to an Ogee spillway.](image)

In the case of an Ogee spillway, discharge is given by the following equation:

\[
Q = C \sqrt{2gLH^2}
\]

Eq. 1

where:
- \(Q\) = discharge (L\(^3\)/T)
- \(C\) = variable discharge coefficient
- \(g\) = gravitational acceleration (L/T\(^2\))
- \(L\) = effective length of crest (L)
- \(H\) = head being considered on crest, (including \(h_a\), velocity-of-approach head) (L)
The quantity $h_a$ accounts for friction and other losses in the channel approaching the crest of the Ogee spillway.

However, if the design head and the actual head acting at the crest are the same, and the ogee spillway under consideration has a vertical face upstream, then the ogee crest coefficient, $C_o$ can replace the $C$ in equation 1, leading to the following equation:

$$Q = C_o L H^2$$  

Eq. 2

where:

$Q, L, & H$ are defined as in equation 1a

$C_o = \text{ogee crest coefficient (also called } C_D \text{ in Dr. Julien’s notes)}$

The ogee crest coefficient can be determined using figure 6, shown below.

![Figure 6. Ogee crest coefficient vs. ratio of height of spillway to design head.](image)

At this point in time, the ogee crest coefficient is not particularly versatile, because it only applies to the situation where design head and head acting on the crest are equal in magnitude, and the spillway’s upstream face is vertical. However, figures 7 and 8, which follow below, are charts that are able to address the aforementioned issues, allowing the use of the Ogee coefficient, $C_o$. 

It is possible that due to the placement of the piers and abutments of the dam, the flow over the crest of the spillway could be contracted, in which case, the actual length of the crest is not the effective length, $L$, required for the discharge calculation. In such a situation, effective crest length can be computed using the following equation:

$$L = L' - 2(NK_p + K_a)H$$

Eq. 3

where:
- $L$ = effective length of crest (L)
- $L'$ = net length of crest (L)
- $N$ = number of piers
- $K_p$ = pier contraction coefficient
- $K_a$ = abutment contraction coefficient
- $H$ = head on crest (L)

Pier contraction coefficients, $K_p$, are functions of several factors, including shape and location of the pier’s nose, thickness of the pier design head of the spillway, and the velocity of the approaching flow. Average $K_p$’s vary between 0.0 and 0.02 depending on the shape a pier’s nose. Average $K_a$, the abutment contraction coefficient, varies between 0.0 and 0.2, also depending on the shape of the abutments.
References

Julien, Pierre. *CIVE 401-Notes on Spillways by Prof. Pierre Julien (11-11-14)*.


Figures


Figure 3. United States Department of Interior-Bureau of Reclamation. *Design of Small Dams*, 3rd ed. 1987. Pg. 356

Figure 4. United States Department of Interior, et al. Pg. 360

Figure 5. Julien, Pierre. *CIVE 401-Notes on Spillways by Prof. Pierre Julien (11-11-14)*. Pg. 1

Figure 6. United States Department of Interior, et al. Pg. 370

Figure 7: United States Department of Interior, et al. Pg. 371

Figure 8: United States Department of Interior, et al. Pg. 371

Further Reading

For further information concerning the design of spillways, it is recommended that chapter 9 of the third edition *Design of Small Dams* be consulted. This text is easily found in PDF form on the internet, and covers much that is beyond the scope of this paper. Additionally, chapter 17 of the Hydraulic Design Handbook explores the design process of the various kinds of spillways in greater detail as well. The aforementioned chapter can be found at the following link: [http://www.keu92.org/uploads/Search%20engineering/Spillway%20Design.pdf](http://www.keu92.org/uploads/Search%20engineering/Spillway%20Design.pdf).