CHAPTER 5

SPECIALIZED SPILLWAYS

Section I. Side Channel Spillways

5-l. General. The side channel spillway has certain advantages which make it adaptable to topography where the overflow is most economically returned to the original streambed by a deep, narrow channel or by open channel flow through a tunnel. The conventional side channel spillway consists of an overflow weir discharging into a narrow channel in which the direction of flow is approximately parallel to the weir crest. A typical side channel spillway configuration is shown in Plate 5-la. A modification to the conventional side channel spillway crest includes the addition of a short crest length perpendicular to the channel at the upstream end resulting in an L-shaped crest as illustrated in Plate 5-lb. Preliminary design of side channel spillways can be accomplished using the following procedures. In view of the complex nature of the flow, hydraulic model studies are normally required to ensure adequate and economical details for the final design.

5-2. Crest Design. Crest shape design and discharge determination for side channel spillways are accomplished using the procedures discussed in Chapters 2 and 3. Two crest sections have been connected with a circular arc of radius equal to $0.4H_d$ to form the L-shaped crest (item 65). The crest length in the discharge equation 2-l must be corrected for the loss in effective crest length caused by angularity of flow at the junction of the crest sections. Plate 5-2 gives the loss of effective length as a function of head on the crest and design head. These data are considered suitable for preliminary designs even though some variation would occur with various approach depths and junction configurations.

5-3. Channel Design. The theory of flow in the channel of a conventional side channel spillway was developed by Hinds (item 22) and is based on the law of conservation of linear momentum. The assumption is made that the energy of flow over the crest is dissipated by turbulence as it turns and mixes with the side channel flow and that the only force producing longitudinal motion in the side channel results from gravitation. This theory also assumes that the frictional resistance of the channel is sufficiently small enough to be neglected without seriously affecting the accuracy of the computations. The soundness of this theory has been demonstrated by model investigations and prototype experience. Application of the theory to practical design of such a structure was illustrated by McCormmach (item 30). Hydraulic model studies have demonstrated that the energy of flow over the end section of an L-shaped crest helps in moving water down the side channel. Farney and Markus (item 16) developed a generalization of the Hinds theory to permit consideration of nonuniform velocity distribution and corresponding changes in momentum in the channel caused by flow over the L-shaped crest end section. Design of the channel (chute) downstream from the crest sections should follow procedures outlined in Chapter 4.

Section II. Limited Service Spillways

5-4. General.

a. A limited service spillway is designed to operate very infrequently, and with the knowledge that some degree of damage or erosion will occur during operation. The decision to include a limited service spillway must be based on the premise that the risk of future repair and/or reconstruction is acceptable; however, the risk of sudden, uncontrolled, catastrophic release of water is unacceptable. Limited service spillways include structures classified as emergency and/or auxiliary spillways. Normally, limited service spillways are designed to take every possible advantage of local topography. There is no restriction on alignment and consideration should be given to designing unpaved spillways to blend in with the natural environment; however, topography, geology, and hydrology must be carefully evaluated in order to assure that when the facility does operate, the following conditions will be attained.

(1) The spillway flow and/or resulting erosion will not endanger the dam or dam foundation.

(2) The control of the discharge will remain at the predetermined control section and will not be lost due to erosion.

(3) There will be sufficient time available after a spillway use event to evaluate the resultant conditions and perform repairs or reconstruction prior to the next event.

b. Gates are not normally included with a limited service spillway. Topographical and geological conditions must be extremely favorable if this type of design is to be used, because gates permit greater spillway capacity with a smaller structure, thus increasing the unit discharge and consequently the erodibility of the spillway channel.

5-5. Discharge. Infrequent, short-duration operation of a limited service spillway is highly desirable. Projects on watersheds with relatively short duration floods are the best candidates for this type of spillway; however, projects with a large flood control storage volume to runoff ratio and those with outlet works that have capacity to control floods up to the standard project flood should also be considered. The limited service spillway should not be considered for long-duration use, defined as many days or weeks, unless extreme confidence can be placed in the damage and/or erosion resistance of the facility. The determination of discharge through the limited service spillway will involve the hydraulic theory of open channel flow. When low ogee crest discharge characteristics are involved, the procedures discussed in Chapters 2 and 3 are applicable. When backwater or drawdown computations are performed to analyze the discharge capacity and flow profiles, section-to-section velocity changes should be limited to no more than 10 percent of the velocity near the control section and no more than 20 percent at remaining sections. Two sets of discharge computations are suggested. The first set of computations is to assure that the spillway will have an adequate capacity for passage of the design flood; for this set, the maximum probable energy losses should be assumed. The second set, involving minimum probable energy losses, is used for determination of depths and velocities for the evaluation of erosion and the design of erosion protection.

5-6. Erosion. Evaluation of expected erosion will be the most difficult and critical problem encountered in the design of limited service spillways. The designer must not only decide whether the channel materials will be eroded but also make reasonable estimates pertaining to the rate at which erosion will progress. Extensive exploration, testing of encountered materials, and geological profiles to a depth in excess of any anticipated scour are required to assist in the erosion estimates. Guidance on erosion progression is limited. Suggested permissible velocities for nonscouring channels are given in EM 1110-2-1601. The flow depth and turbulence are other important factors of incipient movement and rate of movement of channel materials; these factors should not be overlooked. Study of the history of erosion in the project area and research of erosion experiences at projects with similar facilities should be undertaken as part of the evaluation of expected erosion. Some additional information on erosion downstream from emergency spillways is given in item 21. WES has investigated scour downstream from emergency spillways and has produced a video report on this subject (item 18).

5-7. Control Section. A positive discharge control section is required for the limited service spillway. This section should be permanently fixed either in a rock cut or by construction of a concrete structure. The simplest type of control structure is a flat concrete slab with sidewalls, placed at a break in grade that will result in critical depth on the slab. A low ogee spillway crest will provide a more positive relation between reservoir elevation and discharge, a reduction in approach channel velocities, and an increase in the efficiency of the spillway. Normally a concrete apron is included downstream from the ogee crest in order to protect the toe of the crest and to align the flow with the erodible exit channel. The location of the control section is usually near the edge of the reservoir and well away from the dam structure. At sites where the channel is located in erodible material, three solutions exist:

a. The control section may be located to provide a long spillway channel with a large portion of the channel at a subcritical slope. This is done in order to ensure that the erosion, or head cutting, will start downstream from the subcritical slope and that the channel length is maximized, in order to maximize the material to be eroded and the time that will be required for the erosion to reach the control section.

b. The control section may be located at the downstream end of a cut or draw in order to maintain subcritical velocities through most of the spillway system. This configuration requires that side slopes of the cut or draw be sufficiently high to contain the design flow at the maximum reservoir elevation, and that the remaining in situ material be sufficiently competent to act as dam structure.

c. The control section located near the center of the channel length is sometimes preferred. At this position the control section is less likely to be lost due to scour than one at the downstream end. When the spillway is sited in a bedrock structure, the most economical configuration may result by placing the control section at the upstream end of the channel and allowing supercritical velocities through most of the channel.

Section III. Shaft Spillways

5-8. General. Shaft spillways include various configurations of crest designs, with or without gates, all of which transition into a closed conduit (tunnel) system immediately downstream from the crest. The closed conduit system on a shaft spillway is in lieu of the open channel chute used on conventional spillways. All configurations of shaft spillways have many of the same disadvantages. This section will present the disadvantages and the design problems involved in designing shaft spillways, one of which is the morning-glory spillway. This spillway may be designed to operate with crest control for a range of reservoir elevations immediately above the crest apex elevation and then conduit control as the reservoir elevation continues to increase. A shaft spillway should be designed in a manner that will prevent flow control shift from the crest to the conduit or outlet when the discharge is greater than 50 percent of the design flow. This recommendation is based on preventing the following hydraulic conditions from occurring when the reservoir is at or near full pool:

a. Unstable flow characteristics during the transition from crest to conduit control, which would occur over an extended period of time, resulting in unacceptable noise, rapid pressure fluctuations, and vibrations.

b. The undesirable change in reservoir elevation-to-discharge relationship associated with conduit or outlet control, wherein the reservoir elevation increases rapidly with comparatively small increases in discharge. This condition could lead to a rapid and unpreventable overtopping of the dam during the peak of a large flood.

Ideally, a shaft spillway should be designed to operate with crest control throughout the entire expected range of discharge. However, the range of expected discharge is based on the current hydrologic data. Spillway design flood flow rates may change due to updated probable maximum precipitation quantities; changes in the basin runoff characteristics could vary significantly with time; and the project operation may be revised at a future date which may result in an increase to the spillway design flood. Any of these factors, separately or in combination, could be sufficient to cause a spillway designed for crest control to shift to conduit control in the upper range of expected discharge. Another condition that could cause the control shift at essentially any discharge is partial plugging of the conduit. Plugging could occur either by external debris (logs and ice) or an internal problem resulting from cavitation damage. Projects incorporating a shaft spillway should consider this feature an outlet works, to be used in conjunction with another form of open channel auxiliary spillway.

5-9. Morning-Glory Outlet. The morning-glory outlet utilizes a crest circular in plan, with outflow conveyed by a vertical or sloping shaft, usually to a horizontal tunnel at approximately streambed elevation. This type structure is especially adaptable to damsites where a portion of the diversion tunnel can be used as the horizontal tunnel. Plate 5-3 shows typical layouts of vertical and sloping shaft designs. Hydraulic design data for the morning-glory outlet are presented in HDC 140-l to 140-l/2. Problems frequently encountered in this type of structure involve vortex action, unstable flow, and cavitation. Local topography may initiate vortex trends in the approach flow to the spillway, resulting in reduced capacity, flow instability, and surges in the spillway shaft and tunnel, as revealed by the USBR studies (items 7, 29, and 75). Posey and Hsu (item 42) performed laboratory studies that indicated the vortex over a submerged circular orifice can reduce the discharge by as much as 75 percent. Piers, fins, vanes, and curtain walls have been used to suppress vortex action. However, model studies are imperative to verify the effectiveness of this type of feature. When the flow control shifts from the crest to the conduit and vice versa, violent surging, originating in the shaft, can cause severe pressure and flow pulsations throughout the structure. Deflectors and vents in the shaft have been used to prevent these surges and pulsations (items 29 and 39). The need for deflectors and vents and verification of their design must be established by a hydraulic model study. The likelihood of cavitation near the point of tangency of the curve connecting the shaft to the horizontal tunnel should be considered.

Section IV. Labyrinth Spillway

5-10. General. The labyrinth spillway is characterized by a broken axis in plan in order to create a greater length of crest compared to a conventional spillway crest occupying the same lateral space. The broken axis forms a series of interconnected V-shaped weirs (see Plate 5-4). Each of the V-shapes is termed a cycle. The spillway shown in Plate 5-4 is a lo-cycle labyrinth spillway. The labyrinth spillway is particularly well-suited for rehabilitation of existing spillways and for providing a large-capacity spillway in a site with restricted width. This is due to significant increase in crest length for a given width. The free-overflow labyrinth spillway can be designed to allow reservoir storage capacity equal to that provided when using a gated spillway, but without increasing the maximum reservoir elevation. This is achieved by the extremely large increase in discharge with a relatively small increase in reservoir stage. The labyrinth spillway hydraulic characteristics are extremely sensitive to approach flow conditions. This requires siting the crest configuration as far upstream into the reservoir as possible in order to achieve approach flow nearly perpendicular to the axis. For additional information on labyrinth spillways, see items 12, 20, and 26. Serious consideration of this type of spillway will require verification of the design by a physical model study.

Section V. Box Inlet Drop Spillways

5-11. General.

a. For small dams, where topographic and foundation conditions permit, the box inlet drop spillway provides an economical means of passing large flows through the dam with relatively small head increases. The concept is similar to that of a labyrinth spillway (Chapter 5, Section IV), in that a folded crest is used to increase crest length within a relatively confined space.

b. Many configurations of box drop inlet spillways have been studied by the USDA (item 9). Two particularly useful types, which are not covered in item 9 are the flush-approach box drop developed by WES for the Tennessee-Tombigbee Waterway (Plate 5-5 and item 3), and the elevated box drop studied by the Agricultural Research Service (ARS) (Plate 5-6 and item 44).

(1) Design Guidance for the Flush-Approach Box Drop Spillway. Although a straight-on flow approach to the box drop (parallel to the stream and at right angles to the dam) is a more common configuration (see item 9), the Tenn-Tom flush-approach box drop is useful in situations where flow approaches the drop laterally rather than straight on. The dimensions of the box inlet drop spillway upstream of a steep chute can be determined from a known discharge and allowable head H or width of chute W, using the calibration data in Plate 5-7. For this data set, with drop length B to chute width ratios B/W range 1 to 4, and drop depth D to chute width ratios D/W range 0 to 1, the abutment radius is equal to three times the width of the chute. If it becomes necessary to increase the radius of the abutments to allow more space for water to approach the box drop from the sides, as will be the case for smaller chutes, the curve in Plate 5-7 labelled "D = 0" should be used for design. This design without a drop will provide a conservative estimate of the discharge rating curve, and the change in the radius of abutments will have little effect on the discharge. A variation on this design, developed by the Nashville District, allows direct determination of chute width for a known discharge and head (see Plate 5-8) when $D/W = 0.6$ and $D/W = 3.0$. This guidance applies to box drop inlet spillways upstream from steep chutes. The slope of the chute will have little effect on the drop structure discharge capacity as long as supercritical flow occurs within the chute; however, the horizontal channel shown in Plate 5-5 could be long enough to cause a backwater effect on the head on the structure during high discharges. Note that the Tenn-Tom box drops were used as drainage structures and not spillways.

(2) Design Guidance for the Elevated Box Drop Spillway. In this spillway type, the drop box protrudes above the surrounding approach elevation. Controlled storage can thus be maintained up to the lip of the box, and a simple gated outlet can be placed through the wall of the box at the stream invert. A generalized elevated drop box spillway is shown in Plate 5-6. Item 44 contains a model study by the ARS of three different drop box configurations.