CVE 471
WATER RESOURCES ENGINEERING

SPILLWAYS

Assist. Prof. Dr. Bertuğ Akıntıuğ

Civil Engineering Program
Middle East Technical University
Northern Cyprus Campus
Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluiceways
General

- Spillway: One of the most **important structural component** of a dam
- Spillway *evacuates the flood wave* from reservoir to river at the downstream.
- It is normally composed of three major components:
  - The **approach facility** admits flow to the spillway.
  - The **discharging conduit** evacuates the flow from the approach facility to an outlet structure.
  - The **outlet structure (tailwater channel)** dissipates the excessive energy of the flow from the discharging conduits and conveys tranquil flow to the downstream.
- For safety, spillways should have sufficient capacity to discharge floods, likely to occur during the lifetime of the dam.
- **Spillway Design Flood** (SDF) can be selected using some prescribed guidelines or from a risk-based analysis.
4. SPILLWAYS

General

- The main idea behind the selection of SDF:
  - For dams having large capacities and constructed near the upstream of settlements, Probable Maximum Flood (PMF) should be considered.
  - For dams located in isolated regions, a reasonable risk can be taken
    - The corresponding design return period and peak discharge of inflow hydrograph can be determined through the frequency analysis
    - Then spillway design discharge is determined from a reservoir routing operation.
    - Return period of floods to be considered in spillway design may range from 100 years for diversion weirs to 15000 years or more (PMF) for earth-fill dams.
4. SPILLWAYS

General

- A more rational approach is proposed by the United States Army Corps of Engineers (USACE) in 1979 for the selection of spillway design flood.

Table 4.1 Hazard classification (USACE, 1979).

<table>
<thead>
<tr>
<th>Hazard classification</th>
<th>Loss of life</th>
<th>Economic loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (III)</td>
<td>None</td>
<td>Minimal</td>
</tr>
<tr>
<td>Significant (II)</td>
<td>Few</td>
<td>Appreciable</td>
</tr>
<tr>
<td>High (I)</td>
<td>&gt;Few</td>
<td>Excessive</td>
</tr>
</tbody>
</table>

Table 4.2 USACE (1979) criterion for SDF.

<table>
<thead>
<tr>
<th>Hazard classification</th>
<th>Large dam</th>
<th>Intermediate dam</th>
<th>Small dam</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>PMF</td>
<td>PMF</td>
<td>0.5PMF-PMF</td>
</tr>
<tr>
<td>Significant</td>
<td>PMF</td>
<td>0.5PMF-PMF</td>
<td>100 yr- 0.5PMF</td>
</tr>
<tr>
<td>Low</td>
<td>0.5PMF-PMF</td>
<td>100 yr- 0.5PMF</td>
<td>50 yr- 100 yr</td>
</tr>
</tbody>
</table>
Overview

- General
- **Types of Spillways**
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluceways
Types of Spillways

- Common types of spillways are as follows:
  1. Straight drop spillway
  2. Overflow (ogee-crest) spillway
  3. Chute spillway
  4. Side channel spillway
  5. Shaft spillway
  6. Siphon spillway
  7. Labyrinth spillway
  8. Baffled chute spillway
  9. Cascade spillway

- Most of the spillways are of overflow types
  - Large capacities,
  - Higher hydraulic conformities, and
  - Adaptable to almost all types of dams.
4. SPILLWAYS

Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluceways
4. SPILLWAYS

Straight Drop Spillways

- Water flows over a relatively thin spillway crest and falls freely to the downstream.
- Usually appropriate for thin dams having almost vertical downstream faces.
- This type of spillways may be economical for low heads as compared with overflow spillways because of saving in concrete.
- Not recommended for high heads because of structural instability problems.
Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluiceways
Overflow Spillways

- Overflow spillways also called oggee-shaped (S-shaped) spillways.
- This type of spillways allows the passage of the flood wave over its crest.
- Widely used on
  - Gravity dams,
  - Arch dams, and
  - Buttress dams.
Overflow Spillways

- The flow depth at the crest is slightly critical than hydrostatic pressure.
- Overflow spillways
  - Controlled (gated, guided)
  - Uncontrolled (ungated, free)
- Almost all recently constructed dams are installed with crest gates to store more water in the reservoir.
Overflow Spillways

- Design discharge

\[ Q_0 = C_0 L H_0^{3/2} \]

- **Q_0**: The design discharge of the spillway which can be determined from the reservoir routing performed for a design inflow hydrograph.

- **C_0**: Spillway discharge coefficient,

- **L**: The effective crest length,

- **H_0**: The total head over the spillway crest, \( H_0 = H + h_a \)

- **h_a** = \( u_0^2 / 2g \) (the approach velocity head)
Overflow Spillways

The effective crest length:

\[ L = L' - 2(NK_p + K_a)H_0 \]

- \( L' \): The net crest length, \( L' = L_t - tN \)
- \( t \): Thickness of the each pier on the crest
- \( N \): Number of bridge piers.
- \( K_p \): Coefficient of contraction in flow induced by the presence of piers.
- \( K_a \): Coefficient of contraction in flow induced by the presence of abutments.
- \( r \): radius of abutment rounding.

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_p )</td>
<td>0.02</td>
<td>Square nosed piers with corners rounded by ( r = 0.1t )</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>Rounded nosed piers</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Pointed nosed piers</td>
</tr>
<tr>
<td>( K_a )</td>
<td>0.20</td>
<td>Square abutments with head wall 90° to the direction of flow</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
<td>Rounded abutments with head wall 90° to the direction of flow when ( 0.1H_0 &lt; r &lt; 0.15H_0 )</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>Rounded abutments where ( r &gt; 0.5H_0 ) and head wall is placed not more than 45° to the direction of flow</td>
</tr>
</tbody>
</table>
Overflow Spillways

- The nose of piers and abutments should be rounded sufficiently to minimize the hydraulic disturbance.
- Piers may extend downstream on the chute as a dividing wall in order to suppress shock waves.
- Abutments are extended towards the reservoir to facilitate gentle flow conditions at the entrance of spillway.
Overflow Spillways

- Spillway discharge coefficient is affected by
  - the geometric features of spillway,
  - hydraulic characteristics of the approaching flow,
  - level of the downstream apron with respect to upstream energy level,
  - the degree of downstream submergence.
4. SPILLWAYS

Overflow Spillways

- Design discharge coefficient, $C_0$

Figure 4.8 Design discharge coefficients for vertical faced crest (USBR, 1987).

Figure 4.9 Discharge coefficients with sloping upstream face (USBR, 1987).
Spillways rarely operated with their design heads since the design head corresponds to very large return periods having relatively small risks.

Therefore, the discharge coefficient for an existing total operating head $H_e$, should be determined.

Figure 4.10 Discharge coefficients for varying heads (USBR, 1987).
Overflow Spillways

- For low spillways, (spillways of diversion weirs) the level of apron and submergence would also affect the flow conditions.
- For a given fixed upstream energy level, the elevation of the apron has a direct influence on the total head available at the downstream.
- The lower the apron elevation, the greater the total available head at the downstream and hence greater the discharge coefficient.
Overflow Spillways

- Submergence imposes a retarding effect to the approaching flow because of lowered available head between the upstream and downstream.
- Therefore, the spillway discharge coefficient for a submerge case, $C_{ms}$, decreases as the submergence is pronounced.
- However, submergence is only critical for low spillways.
- The overall spillway discharge coefficient is obtained by multiplying the effects of each aforementioned case.
- Regression equations of discharge coefficients shown in Figures 4.8-4.13 are valid for the ranges of abscissas given in these figures.
Overflow Spillways

If the gates on the spillway crest are partially open, the discharge over the spillway is determined from

\[ Q = \frac{2}{3} \sqrt{2gCL\left(H_1^{2/3} - H_2^{2/3}\right)} \]

where

- \( C \): discharge coefficient for a partially open gate,
- \( L \): the effective crest length,
- \( H_1 \) and \( H_2 \): Heads

Regression equations of discharge coefficients shown in Figures 4.8-4.13 are valid for the ranges of abscissas given in these figures.
4. SPILLWAYS

Overflow Spillways

Crest Gates

- Additional storage above the spillway crest can be attained by the installation of suitable gates.
- A few meters of water storage above the spillway crest may correspond to a huge volume of additional water.
- A rectangular transverse section is required at the crest on order to accommodate gates properly.
- Common spillway gates:
  - Underflow gates (i.e. vertical lift gate)
  - Tainter (radial) gates
  - Rolling drum gates
4. SPILLWAYS

Overflow Spillways

Crest Gates
4. SPILLWAYS

Overflow Spillways

Crest Gates

Friian Dam

Horseshoe Dam
Overflow Spillways

Spillway Crest Profile

1. The standard overflow spillway crest profile for a vertical upstream face is recommended by USBR (1987).
2. $K \approx 0.5$ and $n \approx 1.85$
3. If the head on the spillway is greater than $H_0$, the pressure over the spillway face may drop below the atmospheric pressure and separation and cavitation may occur.
4. The upstream face of the crest is formed by smooth curves in order to minimize the separation and inhabit the cavitation.

Standard crest profile of an overflow spillway (USBR, 1987)
Overflow Spillways

Spillway Crest Profile

- When the boundary layer thickness, $\delta$, reaches the free surface, fully developed turbulent flow prevails and air entrainment starts.
- Aeration is normally provided when $(\text{kinetic energy}) > (\text{surface tension energy})$.
- Velocities in excess of 10-15 m/s are required for chute aeration.
- The relative boundary layer:

$$\frac{\delta}{x_a} = 0.02 \left( \frac{k_s}{H_a} \right)^{0.10}$$

$\delta$: boundary layer thickness,
$k_s$: the equivalent sand roughness,
$x_a$, $H_a$: dimensions.

- For a smooth spillway face, the headloss over the spillway can be ignored.
Overflow Spillways

Spillway Crest Profile

- A continuous crest profile is proposed by Hanger (1987) for the upstream part of the crest

\[ Y^* = -X^* \ln X^* \quad \text{for} \quad x / H_0 > -0.2818 \]

\[ X^* = 1.3055 \left( \frac{x}{H_0} + 0.2818 \right) \]

\[ Y^* = 2.7050 \left( \frac{y}{H_0} + 0.136 \right) \]

- The application of above equations is present in Example 4.3.
Overflow Spillways

Spillway Crest Profile

- The shape of the crest as well as the approach flow characteristics are important for the bottom pressure distribution of the spillway face.
- At the crest of the spillway, the streamlines have a curvature.
- For heads less than the design head, $H_e < H_0$,
  - the curvature of streamlines is small and
  - the pressure over the spillway crest is greater than atmospheric pressure but still less than hydrostatic pressure.
- When the curvature is large enough under a high head $H_e > H_0$ over the crest, internal pressure may drop below the atmospheric pressure.
- With the reduced pressure over the spillway crest for $H_e > H_0$, overflowing water may break the contact with the spillway face, which results in the formation of vacuum at the point of separation and cavitation may occur.

Development of negative pressure at the spillway crest for $H_e > H_0$
Overflow Spillways

Spillway Crest Profile

- To prevent cavitation, sets of ramps are placed on the face of overflow spillways such that the jet leaves the contact with the surface.
- Ramps are provided at locations where the natural surface air entrainment does not suffice for the concrete protection against cavitation.
- Air is then introduced by suction into the nappe created by the ramp through vertical shafts to increase the negative pressure to atmospheric pressure.
Overflow Spillways

Spillway Crest Profile

ATATURK DAM
Overflow Spillways

Spillway Crest Profile

- Kokpinar Dam carried out extensive experiments to investigate the hydraulic performance of a ramp.
- Its experimental findings indicated that use of a ramp increases the shear length $L_j$ and free surface aeration of the water jet.
- Therefore, it results in higher forced aeration as compared with no ramp case.
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- Excessive turbulent energy at the toe of an overflow spillway can be dissipated by the hydraulic jump.
- To protect the streambed, a stilling basin (energy dissipation basin) having a thick mat foundation (apron) may be formed.
- Energy equation between section (0) and (1)

\[
\begin{align*}
\text{Head loss between } (0) \text{ and } (1) & \\
\Delta h & \approx 0.1u_1^2/(2g)
\end{align*}
\]

Flow condition at the toe of an overflow spillway

\[
\begin{align*}
\text{The sequent depth:} & \\
y_2/y_1 & = \frac{1}{2} \left( \frac{\sqrt{1+8q^2/g^2} - 1}{1+8q^2/y_1^2} \right) = \frac{1}{2} \left( \frac{\sqrt{1+8q^2/g^2} - 1}{1+8q^2/y_1^2} \right)
\end{align*}
\]
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- The strength of the hydraulic jump is measured by the depth ratio, $y_2/y_1$.
- As the depth ratio increases, the hydraulic jump becomes stronger.
- For $F_{r_1}>2$,

$$\frac{y_2}{y_1} = \frac{1}{2} \left( \sqrt{1 + 8F_{r_1}^2} - 1 \right) = \frac{1}{2} \left( \sqrt{\frac{8q_y^2}{g_y^3}} - 1 \right)$$

$$\frac{y_2}{y_1} = \sqrt{2F_{r_1}} - 1$$

- Dimensionless height of the jump $\Delta y = y_2 - y_1$

$$\Delta y = \sqrt{1 + 8F_{r_1}^2} - 3$$

$$\frac{\Delta y}{E_1} = \frac{F_{r_1}^2}{F_{r_1}^2 + 2}$$
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- The energy loss through the hydraulic jump in a rectangular basin is given by

\[
\Delta E = E_1 - E_2 = \frac{(y_2 - y_1)^2}{4y_1y_2}
\]  

(4.14)

- Percent energy loss through the hydraulic jump in a rectangular stilling basin is

\[
\frac{E_1 - E_2}{E_1} = \frac{\Delta E}{E_1} = 1 - \frac{(8F_r^2 + 1)^{3/2} - 4F_r^2 + 1}{8F_r^2(2 + F_r^2)}
\]  

(4.15)

- For \( F_r > 2 \), above equation can be simplified to

\[
\frac{\Delta E}{E_1} = \left(1 - \frac{\sqrt{2}}{F_r}\right)^2
\]  

(4.16)
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- Since the above equations give almost the same results for \( F_{r1} > 2 \), which reflect most of the practical applications, Equation (4.16) can be used for estimating the percent energy loss in stilling basins of rectangular cross-sections.

\[
\frac{E_1 - E_2}{E_1} = \frac{\Delta E}{E_1} = 1 - \frac{(8F_{r1}^2 + 1)^{3/2} - 4F_{r1}^2 + 1}{8F_{r1}^2(2 + F_{r1}^2)}
\]  
(4.15)

\[
\frac{\Delta E}{E_1} = \left(1 - \frac{2}{F_{r1}}\right)^2
\]  
(4.16)

Variation of percent energy loss against Froude number.
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- Hydraulic jumps can be classified according to the value of $F_{r1}$.
  - For ($F_{r1} \leq 1.7$) → Undular jump
  - For ($1.7 < F_{r1} < 2.5$) → Prejump stage
  - For ($2.5 \leq F_{r1} < 4.5$) → Transition stage
  - For ($4.5 \leq F_{r1} < 9.0$) → Well-balanced jump
  - For ($F_{r1} > 9.0$) → Effective jump (highly rough downstream)
## Energy Dissipation at the Toe of Overflow Spillway

- The location of the hydraulic jump is governed by the depth of tailwater.

### Table 4.4 Selection criteria for the stilling basin.

<table>
<thead>
<tr>
<th>Type of basin</th>
<th>$F_{t1}$</th>
<th>Limitations and characteristics</th>
</tr>
</thead>
</table>
| I             | All ranges | - Not economic  
                     - The jump entirely depends on the tailwater and it may sweep away from the basin if $y_2 > y_3$. |
| II            | $\geq 4.5$ | - The basin length is smaller than basin I by 33% and disperses the energy within the basin  
                     - Suitable for high dams  
                     - Its construction is a little complicated because of the formwork of the detented sill and chute blocks. |
| III           | $\geq 4.5$ | - Suitable for small dams and diversion weirs where $u_t < 15 \text{ m/s}$  
                     - The basin length is smaller than basin I by 60%, but it is more difficult to construct because of the form works of the chute blocks, baffle piers, and end sill. |
| IV            | $2.5 < F_{t1} < 4.5$ | - Suitable for small dams and diversion weirs  
                     - The basin length is the same as the length of basin I, but it guarantees the occurrence of the jump within the basin and reduces waves resulting from imperfect jumps |
4. SPILLWAYS

Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- The location of the hydraulic jump is governed by the depth of tailwater.
- $y_2$: Sequent depth
- $y_3$: Tailwater depth at spillway toe.

Table 4.5 Summary of sequent depth and tailwater interference at spillway toe.
4. SPILLWAYS

Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- The location of the hydraulic jump is governed by the depth of tailwater, \( y_3 \).

**Case 1**: (Sequent depth, \( y_2 \)) = (Tailwater depth, \( y_3 \))

A horizontal apron with a certain thickness may be constructed for this case.

Length of the apron, \( L_1 \), is determined from Fig.4.27.
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- The location of the hydraulic jump is governed by the depth of tailwater.

**Case 2:** \( y_3 < y_2 \)

This case should be eliminated since water flows at a very high velocity having a destructive effect on the apron.
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- Case 2:
  - **Chute blocks** channelize the flow and shorten the length of jump and stabilize it.
  - **Baffle piers** dissipate energy by impact effect.
  - Baffle piers are not suitable for very high velocities because of the possibility of cavitation.
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- **Case 2:**
  - The force acting on a baffle pier is

\[ F_p = 2\gamma AE_1 \]

where \( \gamma \): Specific weight of water (kN/m\(^3\)),

A: area of the upstream face of the pier in m\(^2\).

\( E_1 \): The specific energy at section 1 in m.

**Solid of dentated sills** are placed to reduce the length of the jump and control scour downstream of the basin.
Energy Dissipation at the Toe of Overflow Spillway

Case 2:
- To find the stilling basin depth, $\Delta (h_4)$, inserting Equation 4.11 into Equation 4.14

$$\Delta E = \frac{y^3}{2} \left( \frac{1 + \frac{8q^2}{gy_1^3} - 1}{y_1} \right)$$

$$\frac{y_2}{y_1} = \frac{1}{2} \frac{\sqrt{1 + 8r^2}}{\frac{8q^2}{gy_1^3} - 1}$$

To find the stilling basin depth, $\Delta (h_4)$, inserting Equation 4.11 into Equation 4.14.

Applying the energy equation between section 2 and 3, the value of $\Delta$ can be found.
Energy Dissipation at the Toe of Overflow Spillway

**Case 2:**
- The value of $\Delta$ can also be found from

$$\left(\frac{y_3}{y_1}\right)^2 = 1 + 2F_{r1}^2 \left(1 - \frac{y_1}{y_3}\right) + \alpha \left(\alpha - \sqrt{1 + 8F_{r1}^2 + 1}\right)$$

where $\alpha = \Delta/y_1$

- The line of minimum $F_{r1}$
- The length of jump, $L_j$:

$$L_j = 5(y_3 + \Delta)$$

Figure 4.31 Variation of depth ratio, $y_3/y_1$, against Froude number.
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

Case 3: \( y_3 > y_2 \)

- Different modes of energy dissipation may be considered:
  - A long sloping apron (USBR type 5 basin)
  - A culvert outlet (USBR type 6 basin)
  - A deflector bucket (USBR type 7 basin)

- Selection of the best type is normally dictated by
  - The required hydraulic conformity,
  - Foundation conditions, and
  - Economic considerations
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

Case 3: \( y_3 > y_2 \)

A long sloping apron may cause the shift of the jump towards the toe.

It may require large considerable amount of concrete.

The momentum equation may be written between section 1 and 2.

The relationship between the conjugate depths of the jump on a sloping apron is then determined from:

\[
\frac{d_2}{d_1} = \frac{1}{2} \left( 1 + \frac{8F_0^2}{K \tan \theta - \frac{KL \sin \theta}{d_2 - d_1}} \right)
\]

The length of the jump on a sloping apron is greater than on a horizontal bed. Therefore, sloping apron is more expensive.
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

Case 3: \( y_3 > y_2 \)

- A deflecter bucket may be used.

\[ y = x \tan \theta_j - \frac{x^2}{K_j(4E_i \cos^2 \theta_j)} \]

- \( K_j \): factor (unity for theoretical jet).
- \( E_i \): total head at the bucket.

The max. value of \( x \) will be \( 2K_jE_i \) when leaving angle is \( 45^\circ \).

Special care must be taken in case of loose bed material.

Extra measure may be taken to prevent the stream bed erosion induced by the action of inclined jet.
Energy Dissipation at the Toe of Overflow Spillway

Case 4: $y_2 > y_3$
- Sequent depth of the hydraulic jump $y_2$ is greater than the tailwater depth $y_3$ at low flows and smaller at the high flows.
- USBR Type 5 basin with an end sill can be used for this case.

Case 5: $y_3 > y_2$
- Sequent depth of the hydraulic jump $y_3$ is greater than the tailwater depth $y_2$ at low flows and smaller at the high flows.
- USBR Type 2, 3, and 4 basin can be selected for this case.
Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluceways
Chute Spillways

- In case of having sufficient stiff foundation conditions at the spillway location, a chute spillway may be used in stead of overflow spillway due to economic consideration.
- A steep slope open channel is constructed in slabs with 25-50 cm thickness having lengths of approximately 10 m.
- When the horizontal distance between the upstream of the spillway and the tailwater is considerable long, a long steep sloped chute usually follows the overflow spillway until the tailwater.
Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluiceways
Side Channel Spillways

- If a sufficient crest length is not available for an overflow or chute spillways in narrow valleys, floodwater is taken in a side channel.

http://www.britishdams.org/about_dams/sidechannel.htm
4. SPILLWAYS

Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - **Shaft Spillways**
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluiceways
If a sufficient space is not available for an overflow spillway, a shaft spillway may be considered.

In the site of shaft spillway
- Seismic action should be small,
- Stiff geologic formation should be available, and
- Possibility of floating debris is relatively small.

Flow conditions in the spillway:
- Level 1 → a weir flow
- Level 2 → midway between weir flow and pipe flow
- Level 3 → pressurized pipe flow.
Shaft Spillways

- Flow conditions in the spillway:
  - Level 1 → a weir flow

\[ Q = C_s (2\pi R) H_0^{3/2} \]

- \( C_s \): discharge coefficient for a shaft spillway.
- \( H_0 \): total head on the inlet
- \( R \): radius of the shaft inlet

- Variation of shaft discharge with respect to head is given in Figure 4.38.
  - Weir flow with air entrainment takes place until point A.
  - Pressurized pipe flow starts after point B.
  - Part of the curve between point A and B describes the combination of weir and pipe flows.
Shaft Spillways

- When the shaft is completely submerged, further increase in head will not result in appreciable increase in discharge.
- This type of spillway is not suitable for large capacity and deep reservoirs because of stability problems.
- Special designs are required to handle cavitation damage at the transition between shaft and tunnel.
- Repair and maintenance of shaft spillways are difficult.
4. SPILLWAYS

Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - **Siphon Spillways**
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluiceways
Siphon Spillways

- A siphon spillway may be constructed in the body of a concrete dam when space is not available for an overflow spillway.
- It has a limited capacity.
- Discharge $Q = C_d \cdot A \cdot (2gh)^{1/2}$
  
  where
  
  $C_d$: discharge coefficient ($\approx 0.9$)
  
  $A$: flow area of siphon
  
  $h$: the elevation difference between the upstream water level and end of the barrel. When the downstream end is submerged, $h$ is elevation difference between the upstream and downstream water levels.
Disadvantage of siphon spillway:

- A the siphon is primed the flow would result excessive vibrations in the dam body which may cause expansion problems in the joints.
- There is a possibility of cavitation for negative pressures, which is affected by the head between upstream and downstream water levels.
- Repair and maintenance of siphon spillways are difficult.
- There is no siphon spillway application in Turkey.
Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluiceways
Labyrinth Spillways

- A labyrinth spillway is composed of a crest formed by series of staggered walls such that a given discharge can pass under a small head because of the large spillway length afforded.
- Flow conditions around these structures are highly complicated.
- Intensive physical model studies are required to check their performance.

Figure 4.40 Plan and cross-section of a typical labyrinth spillway.
4. SPILLWAYS

Labyrinth Spillways
Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - **Baffled Chute Spillways**
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluceways
Baffled Chute Spillways

- A baffled chute spillway is composed of a chute whose surface is covered by a number of densely spaced baffle blocks.
- The baffle blocks dissipate the kinetic energy of the flowing water effectively.
- A separate stilling basin is not required.
- Special design is needed to maintain sufficiently small velocities at the entrance of a chute.
Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - **Cascade Spillways**
- Selection of Spillway Type
- Bottom Outlets and Sluiceways
Cascade or stepped spillway are recently used as alternative to the conventional overflow spillways for small to medium discharges.

The spillway is composed of series of steps where excessive energy of the flow is dissipated.

Shorter stilling basin is required compared to the conventional overflow spillway.

The spillway face requires higher sidewalls due to the increased turbulence over the steps.

Details of the performance of such structures needed to be investigated through hydraulic model studies.
4. SPILLWAYS

Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluiceways
Selection of Spillway Types

In the selection of a spillway, the following steps are to be considered:

- A spillway with certain dimensions is selected.
- The maximum spillway discharge and maximum lake elevation are determined through reservoir flood routing performed for design conditions.
- Other dimensions are determined.
- Cost of dam and spillway are determined.
- The above steps are repeated for:
  - various combinations of dam height and reservoir capacities using elevation storage relationship of reservoir, and
  - various types of spillways.
- The most economical spillway type and optimum relation of spillway capacity to the height of dam are chosen.
Selection of Spillway Types

- In the economic analysis, following should be considered:
  - repair and maintenance costs,
  - the hydraulic efficiency of each type of spillway.
- Most of the spillways in Turkey are of the controlled overflow type.
- The relation between the length of overflow spillway and the total cost of the dam must be analyzed to achieve an optimum solution.

- Spillway length \[ \overrightarrow{ } \] the cost of the spillway

- Spillway length \[ \overrightarrow{ } \] the water level \[ \overrightarrow{ } \] the cost of the dam

- There is an optimum spillway length, which minimizes the total cost of construction.
Overview

- General
- Types of Spillways
  - Straight Drop Spillways
  - Overflow Spillways
  - Chute Spillways
  - Side Channel Spillways
  - Shaft Spillways
  - Siphon Spillways
  - Labyrinth Spillways
  - Baffled Chute Spillways
  - Cascade Spillways
- Selection of Spillway Type
- Bottom Outlets and Sluceways
Bottom Outlets and Sluceways

- **Bottom outlet**: A pipe located at the lowest allowable elevation of the reservoir.
- For concrete dams: Passes through the dam body.
- For fill dams: Passes through the hillside at one end of the dam.
- Bottom outlets are utilized for:
  - diverting the desired amount of flow downstream,
  - lowering the reservoir level, and
  - flushing the sediment from the reservoir.

Figure 4.42 Bottom outlet aeration (Vischer and Hager, 1999).
Bottom Outlets and Sluiceways

- Problems
  - gate clogging due to floating debris, and
  - gate vibration due to high velocity.
- The bottom outlet needs to be aerated at a location midway between inlet and outlet.
- Generation of free flow conditions in bottom outlets reduces the potential of gate vibration and cavitation damage.

Figure 4.42 Bottom outlet aeration (Vischer and Hager, 1999).
4. SPILLWAYS

Bottom Outlets and Sluceways
4. SPILLWAYS

Bottom Outlets and Sluiceways
4. SPILLWAYS

Bottom Outlets and Sluiceways

Hoover Dam Outlets
Bottom Outlets and Sluceways

Hoover Dam Outlets
Bottom Outlets and Sluiceways
Bottom Outlets and Sluiceways

Hoover Dam Inlets
Bottom Outlets and Sluiceways

Hoover Dam Inlets