CVE 471
WATER RESOURCES ENGINEERING

SPILLWAYS

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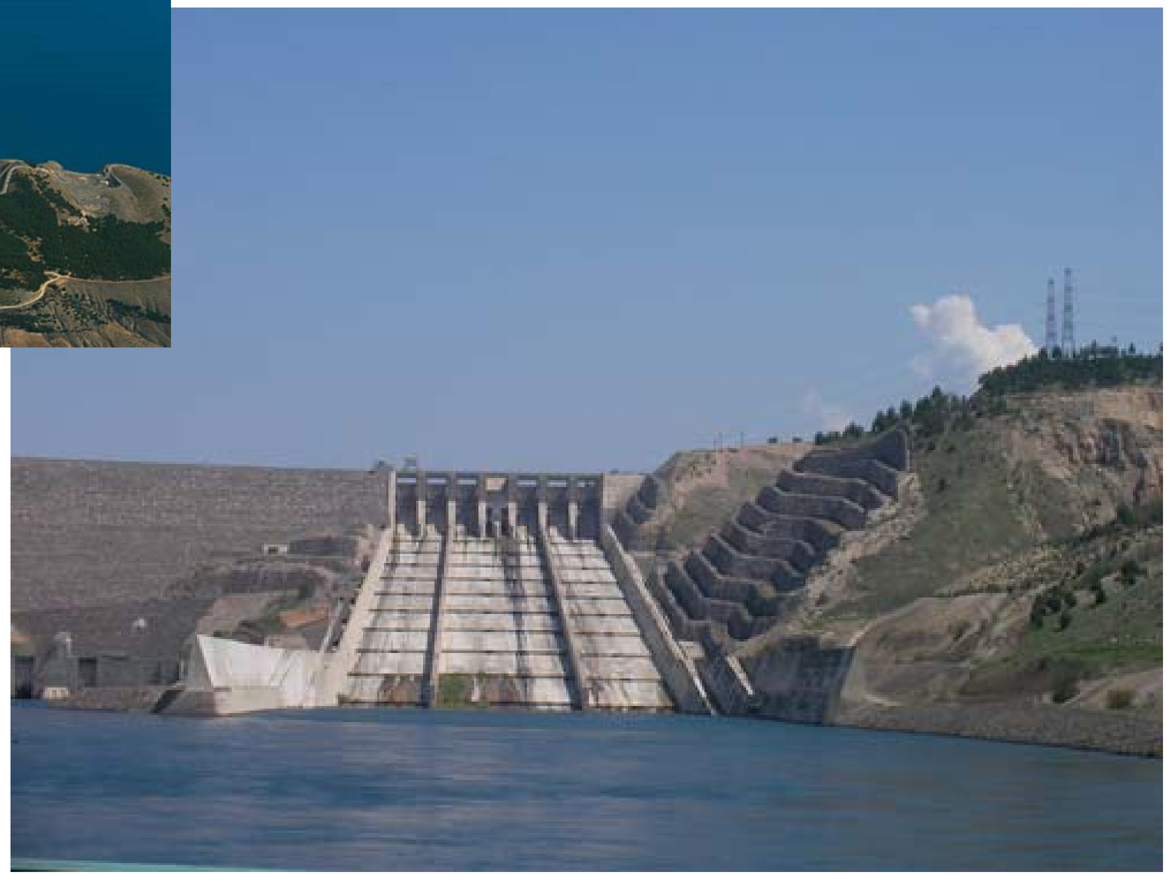
Spillways

Spillways



Ataturk Dam Spillway

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

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.

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.

General

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

Table 4.1 Hazard classification (USACE, 1979).

Hazard classification	Loss of life	Economic loss
Low (III)	None	Minimal
Significant (II)	Few	Appreciable
High (I)	>Few	Excessive

Table 4.2 USACE (1979) criterion for SDF.

Hazard classification	Large dam	Intermediate dam	Small dam
High	PMF	PMF	0.5PMF-PMF
Significant	PMF	0.5PMF-PMF	100 yr- 0.5PMF
Low	0.5PMF-PMF	100 yr- 0.5PMF	50 yr- 100 yr

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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.

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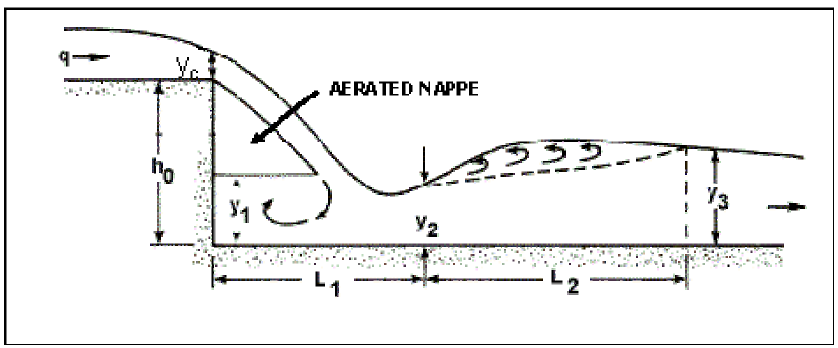
Straight Drop Spillways

- 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.



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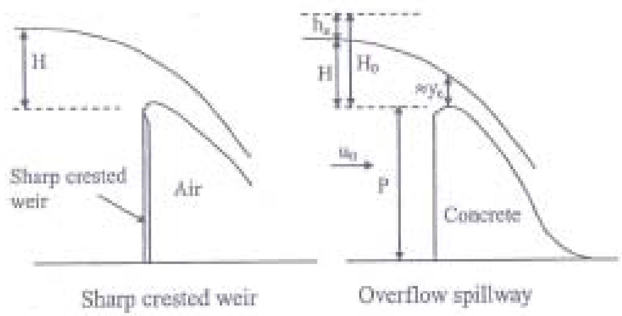
Overflow Spillways

- Overflow spillways also called ogee-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.

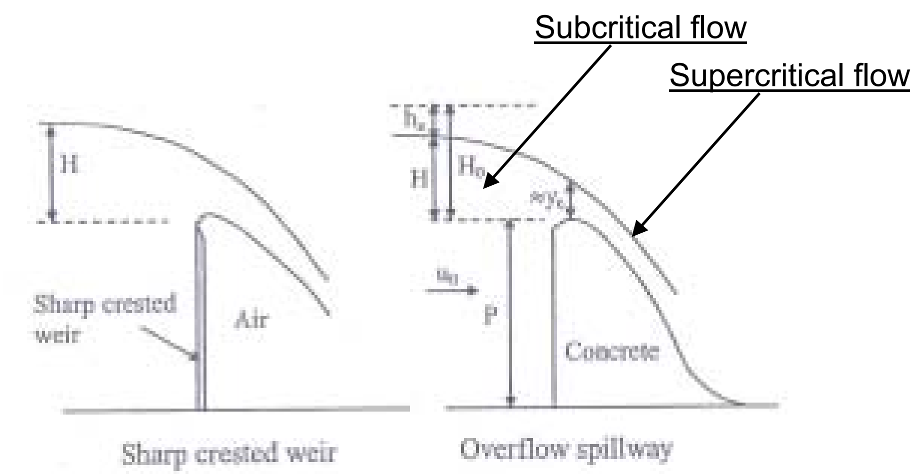


Keban Dam

Hasan Ugurlu Dam

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.



Construction of a small overflow spillway

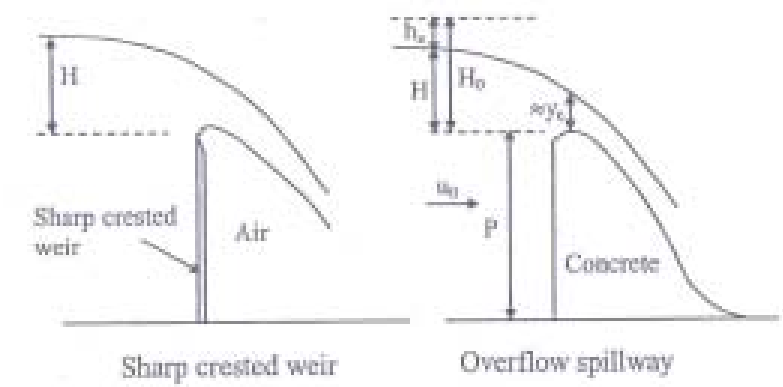
Completed spillway blocks

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:

$$L = L' - 2(NK_p + K_a)H_0$$

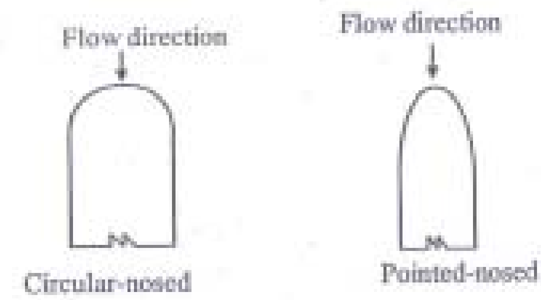


Figure 4.4 Spillway pier shapes.

L': The net crest length, $L'=L_T-tN$

t: Thickness of the each pear 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 4.3 Contraction coefficients due to pier and abutment (USBR, 1987).

Coefficient	Value	Description
K_p	0.02	Square nosed piers with corners rounded by r=0.1t
	0.01	Rounded nosed piers
	0	Pointed nosed piers
K_a	0.20	Square abutments with head wall 90° to the direction of flow
	0.10	Rounded abutments with head wall 90° to the direction of flow when $0.1H_0<r<0.15H_0$
	0	Rounded abutments where $r > 0.5H_0$ and head wall is placed not more than 45° to the direction of flow

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.

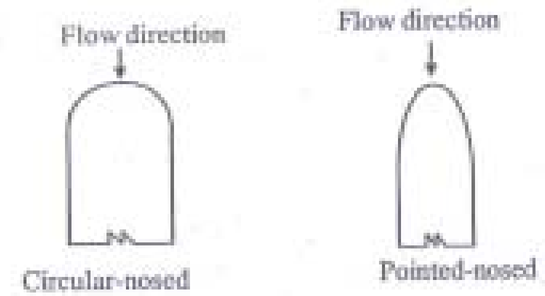
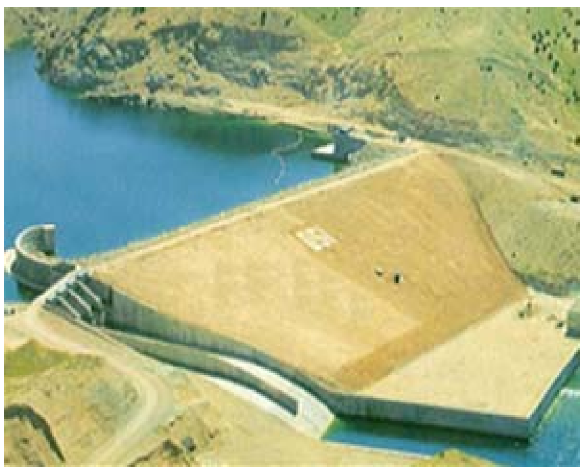


Figure 4.4 Spillway pier shapes.



Kapulukaya Dam

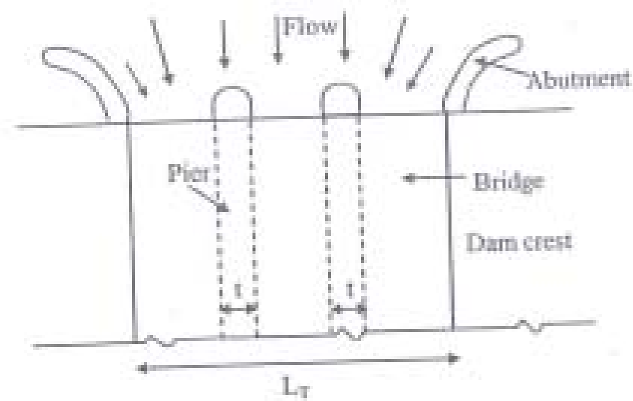


Figure 4.5 Plan view of an overflow spillway.

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.

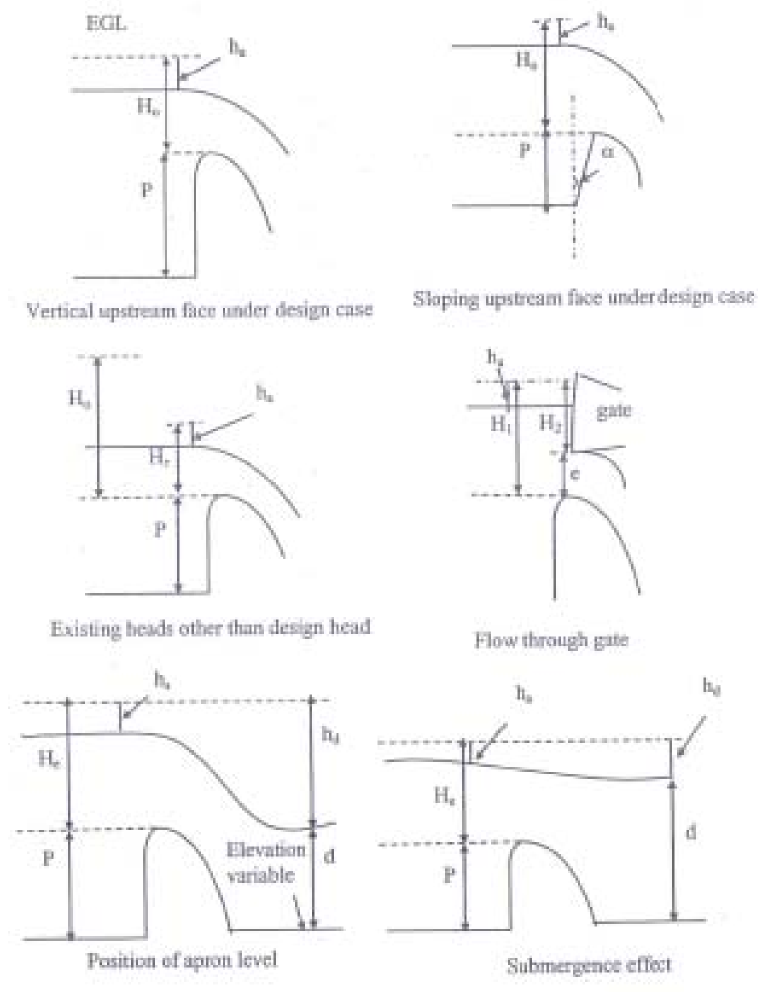


Figure 4.7 Definition sketches for spillway discharge coefficients.

Overflow Spillways

- Design discharge coefficient, C_0

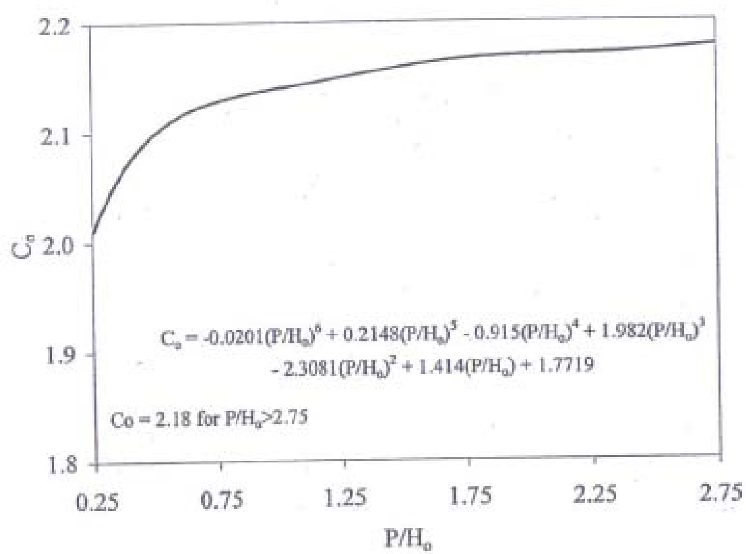


Figure 4.8 Design discharge coefficients for vertical faced crest (USBR, 1987).

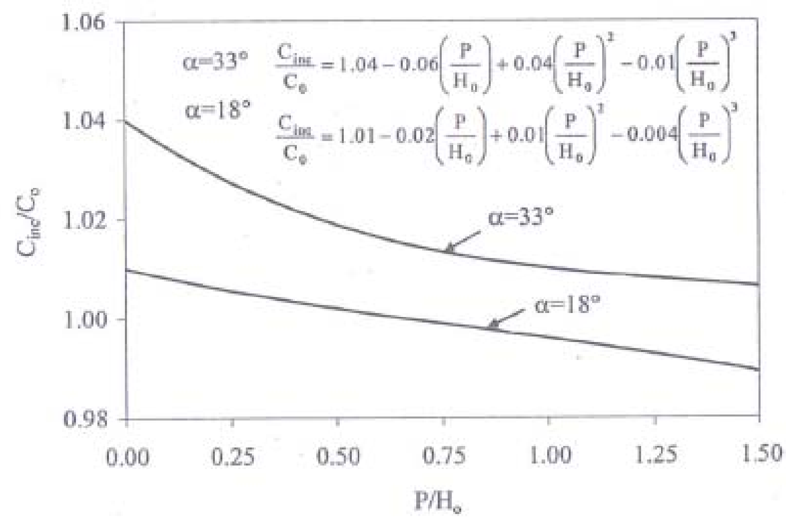


Figure 4.9 Discharge coefficients with sloping upstream face (USBR, 1987).

Overflow Spillways

- 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.

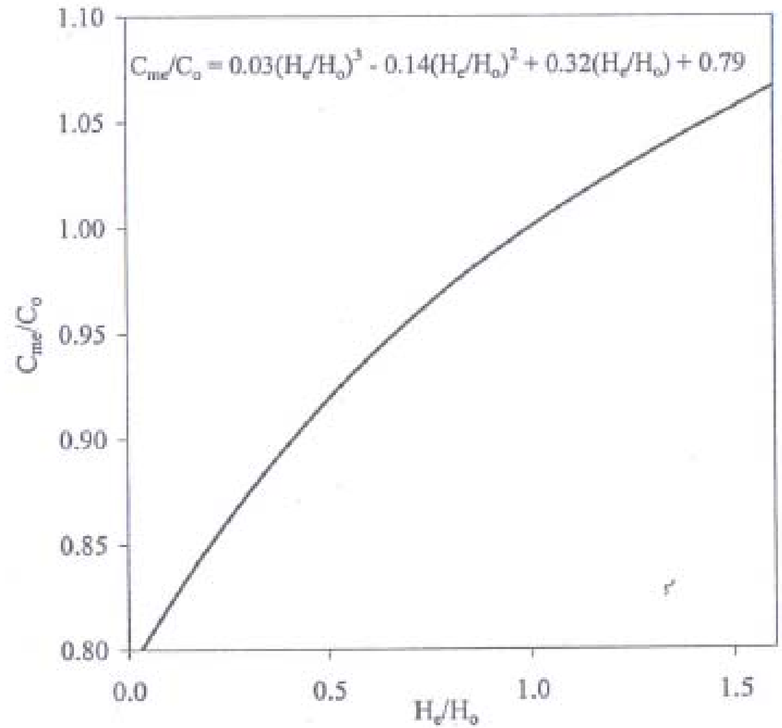
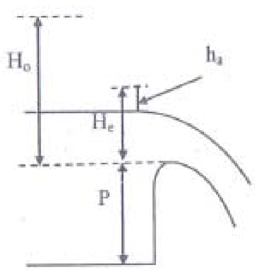


Figure 4.10 Discharge coefficients for varying heads (USBR, 1987).



Existing heads other than design head

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.

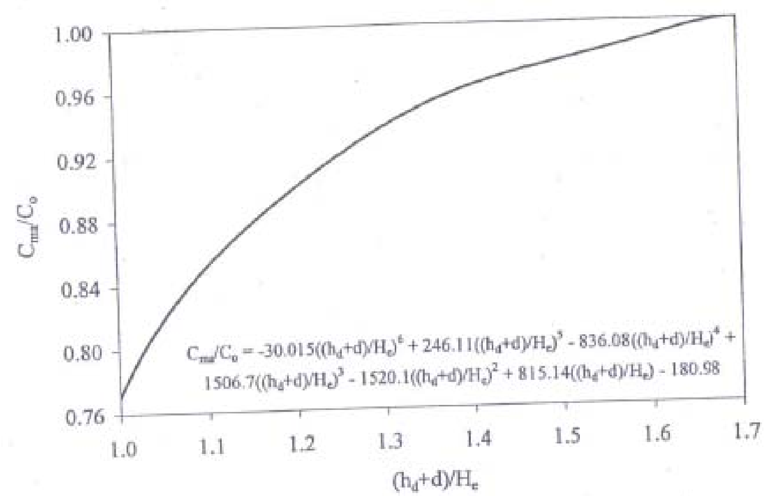
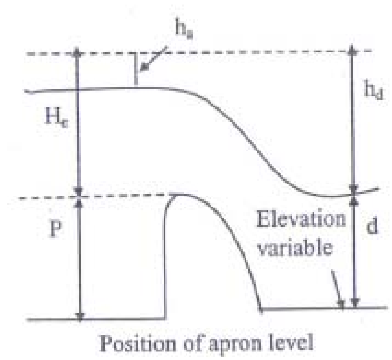


Figure 4.11 Discharge coefficient due to apron effect (USBR, 1987).



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.

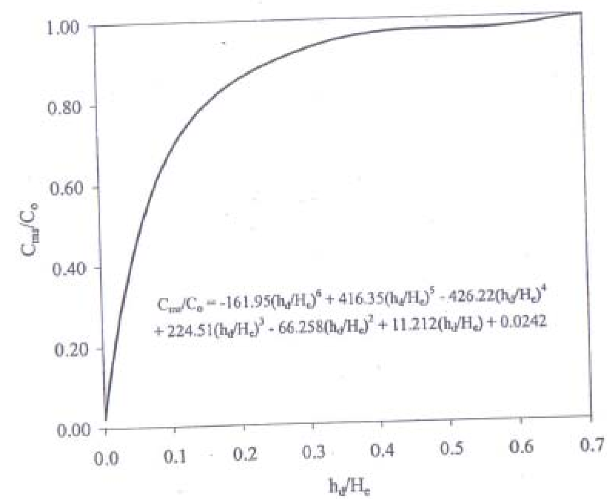
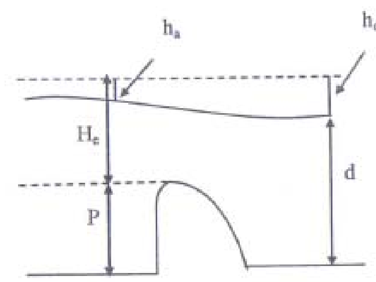


Figure 4.12 Discharge coefficient due to submergence effect (USBR, 1987).



Submergence effect

Overflow Spillways

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

$$Q = \frac{2}{3}\sqrt{2g}\,CL\left(H_1^{2/3} - H_2^{2/3}\right)$$

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.

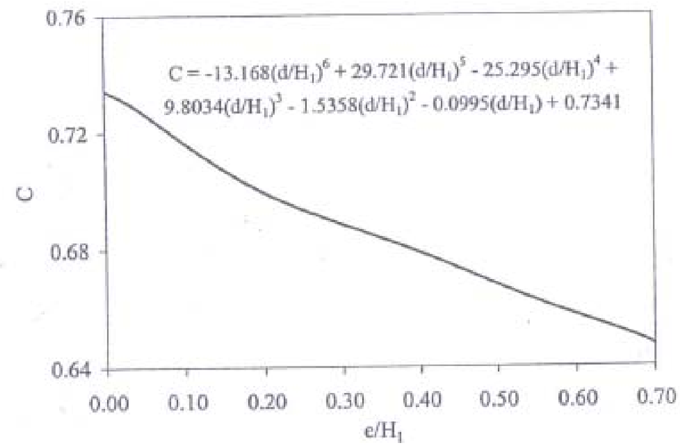
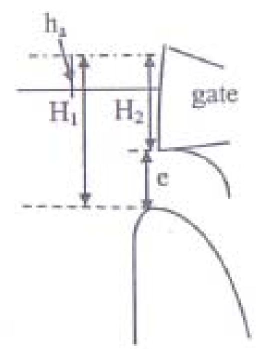


Figure 4.13 Discharge coefficients for flow under gates (USBR, 1987).



Flow through gate

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

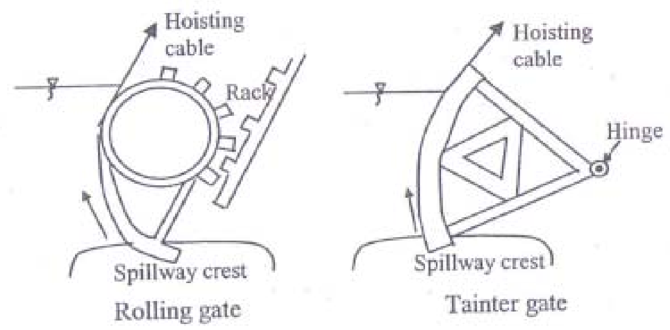


Figure 4.14 Spillway gates.

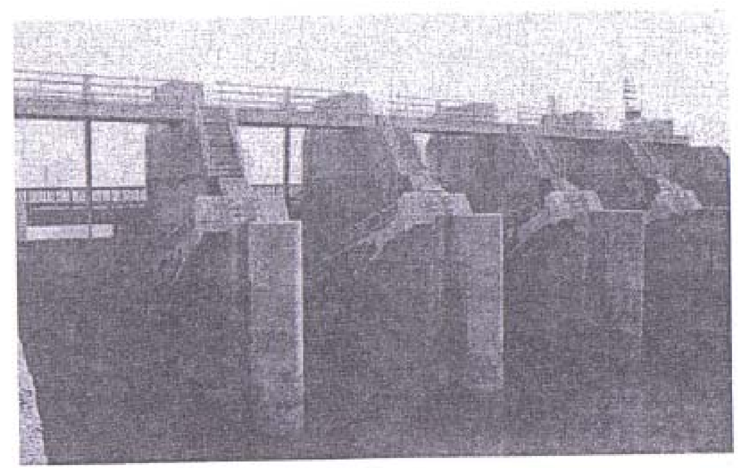


Figure 4.15 Radial gates at spillway crest (Dolsar A.Ş.).

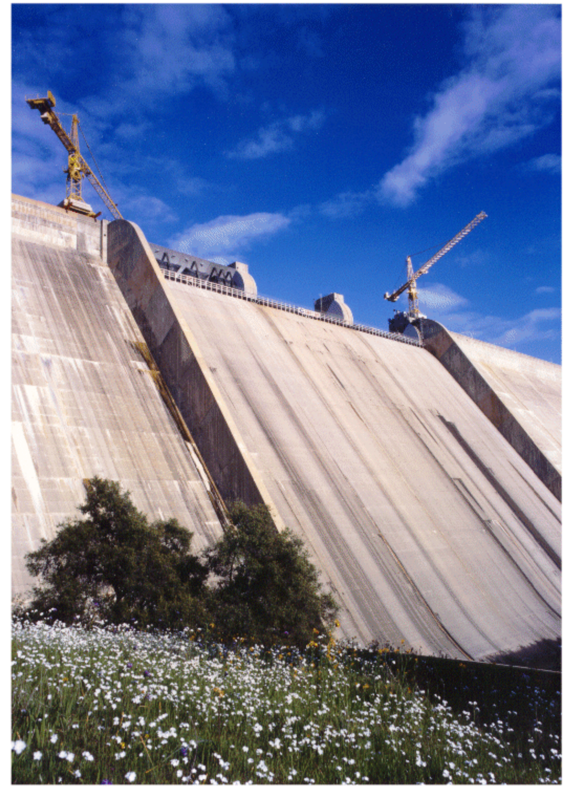
Overflow Spillways

Crest Gates

Overflow Spillways

Crest Gates

Frian Dam

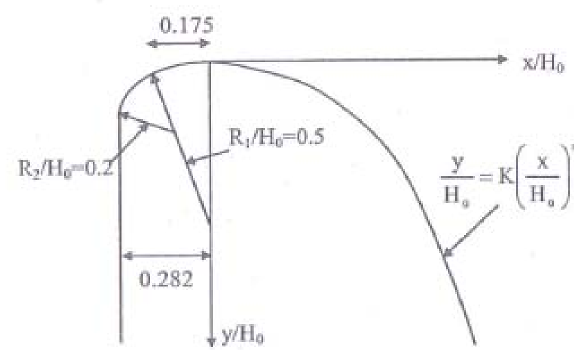


Horseshoe Dam

Overflow Spillways

Spillway Crest Profile

- The standard overflow spillway crest profile for a vertical upstream face is recommended by USBR (1987).
- $K \approx 0.5$ and $n \approx 1.85$
- 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.
- 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, δ, reaches the free surface, fully developed turbulent flow prevails and air entrainment starts.
- Aeration is normally provided when
  (kinetic energy) > (surface tension energy)
- Velocities in excess of 10-15 m/s are required for chute aeration.
- The relative boundary layer:

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

k_s: the equivalent sand roughness,

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

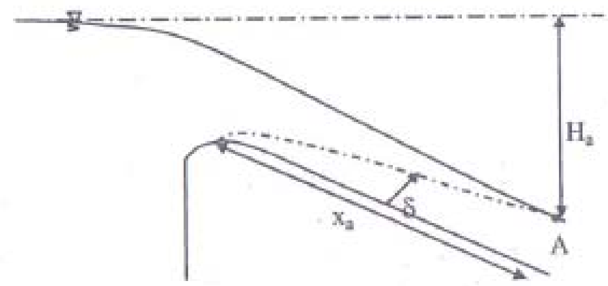


Figure 4.17 Chute aeration.

Overflow Spillways

Spillway Crest Profile

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

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

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

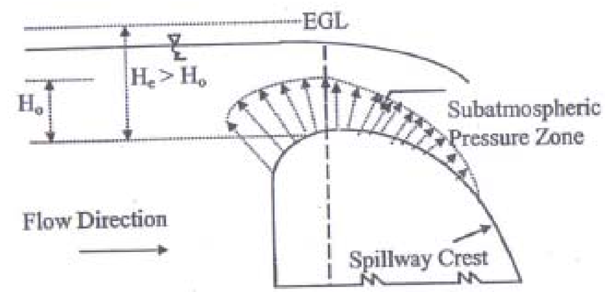
$$Y^* = 2.7050\left(\frac{y}{H_0} + 0.136\right)$$

- 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 $H_e>H_0$

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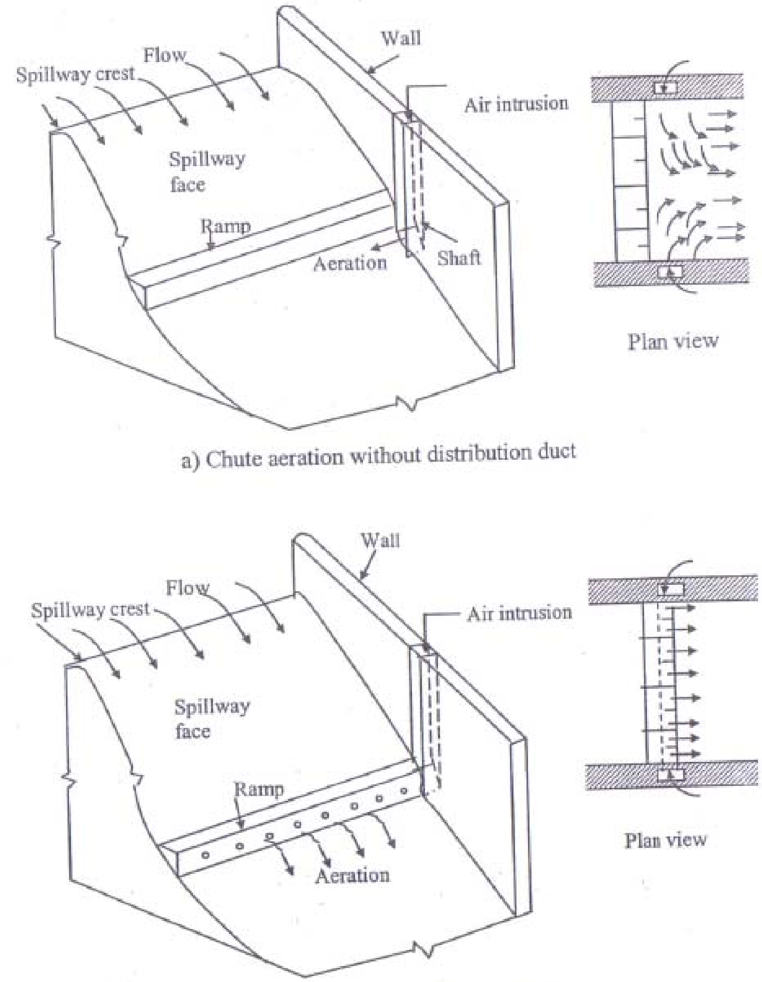
Overflow Spillways

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.



b) Chute aeration with distribution duct

Figure 4.19 Ramp and its aeration on the spillway face.

Overflow Spillways

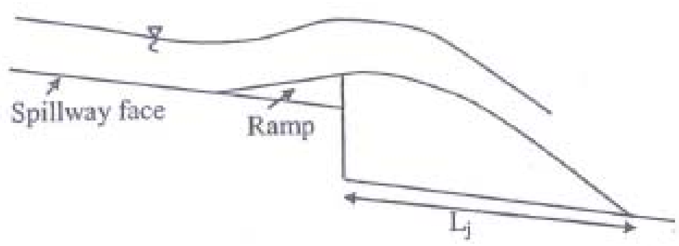
Spillway Crest Profile

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.



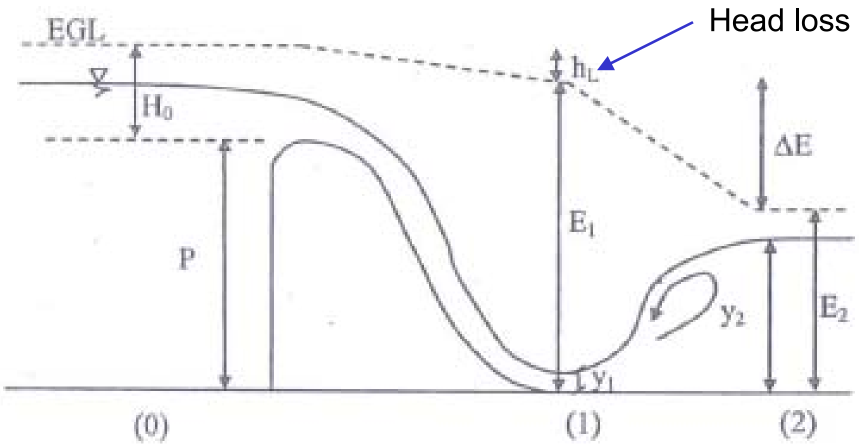
Köpınar Dam

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)

$$P + H_0 = y_1 + \frac{u_1^2}{2g} + h_L$$



Flow condition at the toe of an overflow spillway

$h_L \approx 0.1 u_1^2/(2g)$

y_1=?

$$P + H_0 = y_1 + 1.1\frac{u_1^2}{2g} = y_1 + 1.1\frac{q^2}{2gy_1^2}$$

The sequent depth:

y_2=?

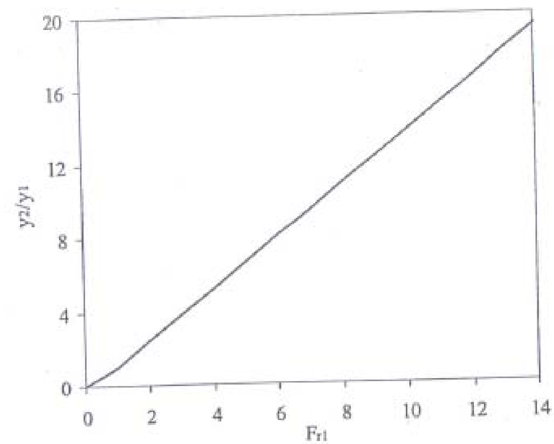
$$\frac{y_2}{y_1} = \frac{1}{2}\left(\sqrt{1+8F_{r1}^2} - 1\right) = \frac{1}{2}\left(\sqrt{1+\frac{8q^2}{gy_1^3}} - 1\right)$$

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 $F_{r1}>2$,

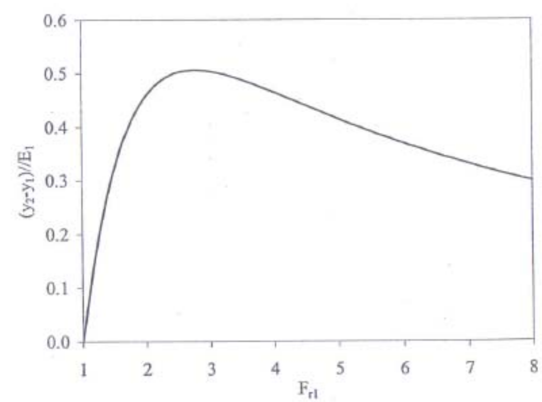
$$\frac{y_2}{y_1}=\frac{1}{2}\left(\sqrt{1+8F_{r1}^2}-1\right)=\frac{1}{2}\left(\sqrt{1+\frac{8q^2}{gy_1^3}}-1\right) \Rightarrow \frac{y_2}{y_1}=\sqrt{2}F_{r1}-\frac{1}{2}$$



Variation of depth ratio of the hydraulic jump against Froude number.

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

$$\frac{\Delta y}{E_1}=\frac{\sqrt{1+8F_{r1}^2}-3}{F_{r1}^2+2}$$



Variation of dimensionless height of the jump against Froude number.

Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

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

$$\Delta E = E_1 - E_2 = \frac{(y_2 - y_1)^3}{4y_1y_2} \qquad (4.14)$$

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

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

- For F_{r1}>2, above equation can be simplifed to

$$\frac{\Delta E}{E_1} = \left(1 - \frac{\sqrt{2}}{F_{r1}}\right)^2 \qquad (4.16)$$

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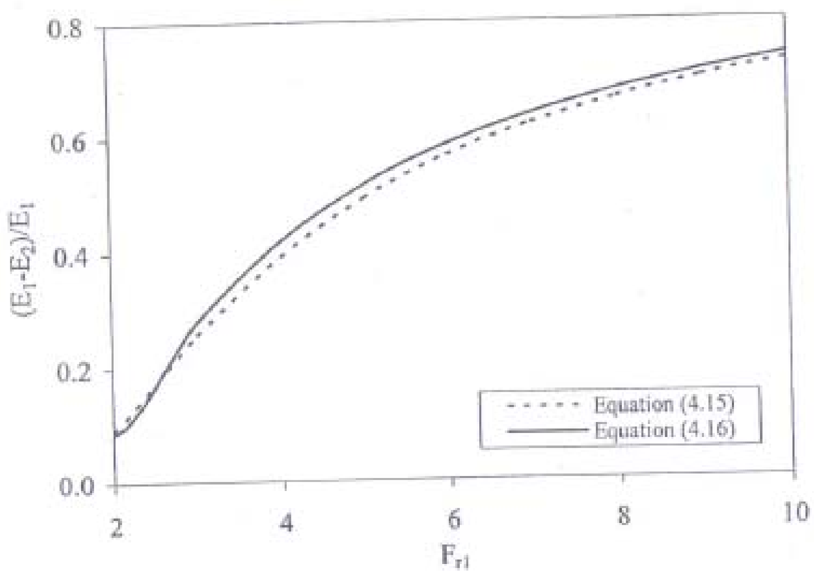
Overflow Spillways

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.



Variation of percent energy loss against Froude number.

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

⇓

$$\frac{\Delta E}{E_1}=\left(1-\frac{\sqrt{2}}{F_{r1}}\right)^2 \quad (4.16)$$

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)

Overflow Spillways

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.

Type of basin	F_{r1}	Limitations and characteristics
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	≥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 dentated sill and chute blocks.
III	≥ 4.5	▪ Suitable for small dams and diversion weirs where $u_1 < 15$ 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	$2.5 < F_{r1} < 4.5$	▪ 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

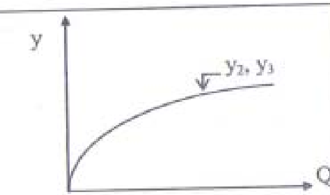
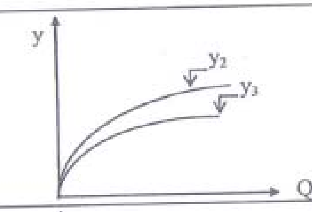
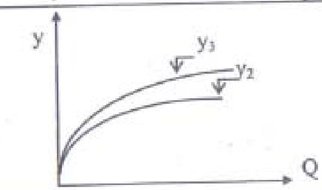
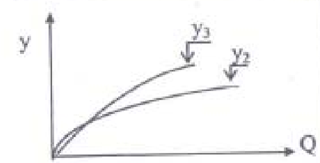
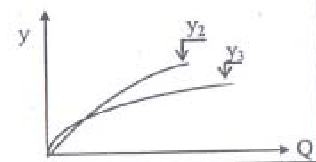
METU NORTHERN CYPRUS CAMPUS

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.

Case	Designation	Remedial measure
1 	y_2 and y_3 coincide at all flows	USBR Type 1 basin
2 	y_2 is always greater than y_3	USBR Types 2, 3, 4 basins
3 	y_3 is always greater than y_2	USBR Type 5 or Type 7 basins
4 	y_2 is greater than y_3 at low flows and smaller at high flows	USBR Type 5 basin with an end sill
5 	y_3 is greater than y_2 at low flows and smaller at high flows	USBR Types 2,3,4 basins

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)

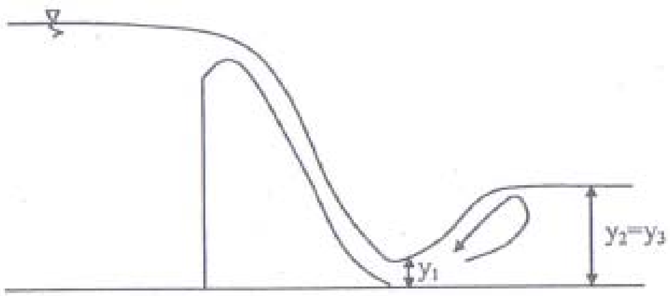


Figure 4.26 Flow conditions for $y_2 = y_3$.

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

Length of the apron, L_l, is determined from Fig.4.27.

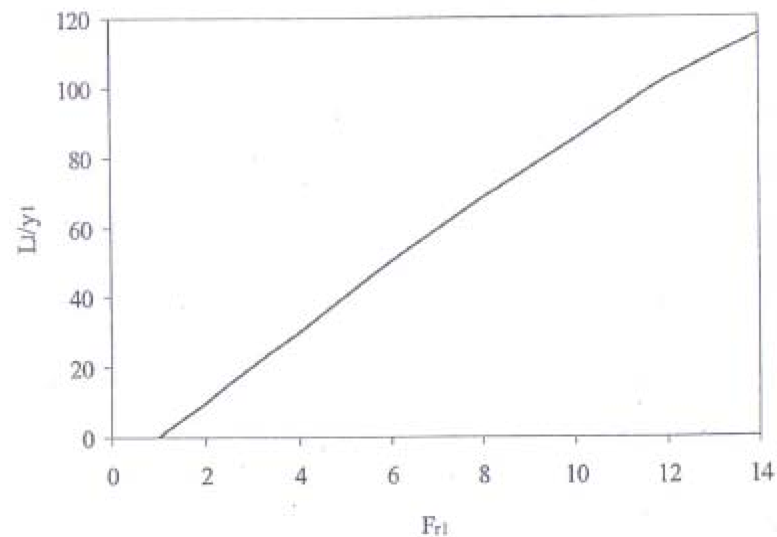


Figure 4.27 Determination of length of the USBR type 1 basin (Peterka, 1964).

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: $y_3<y_2$

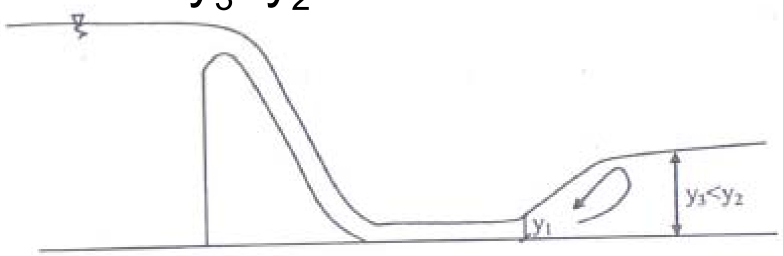


Figure 4.28 Flow conditions for $y_3< y_2$.

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

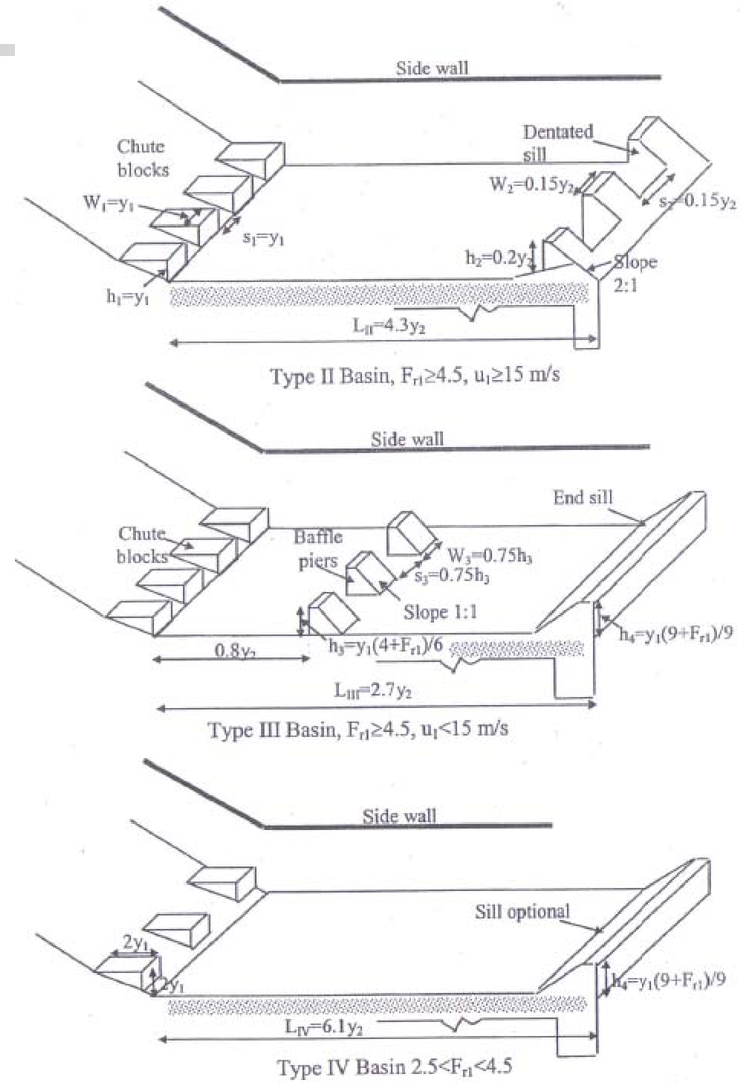


Figure 4.29 Types of the USBR stilling basins (Peterka, 1964; Henderson, 1966).

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.

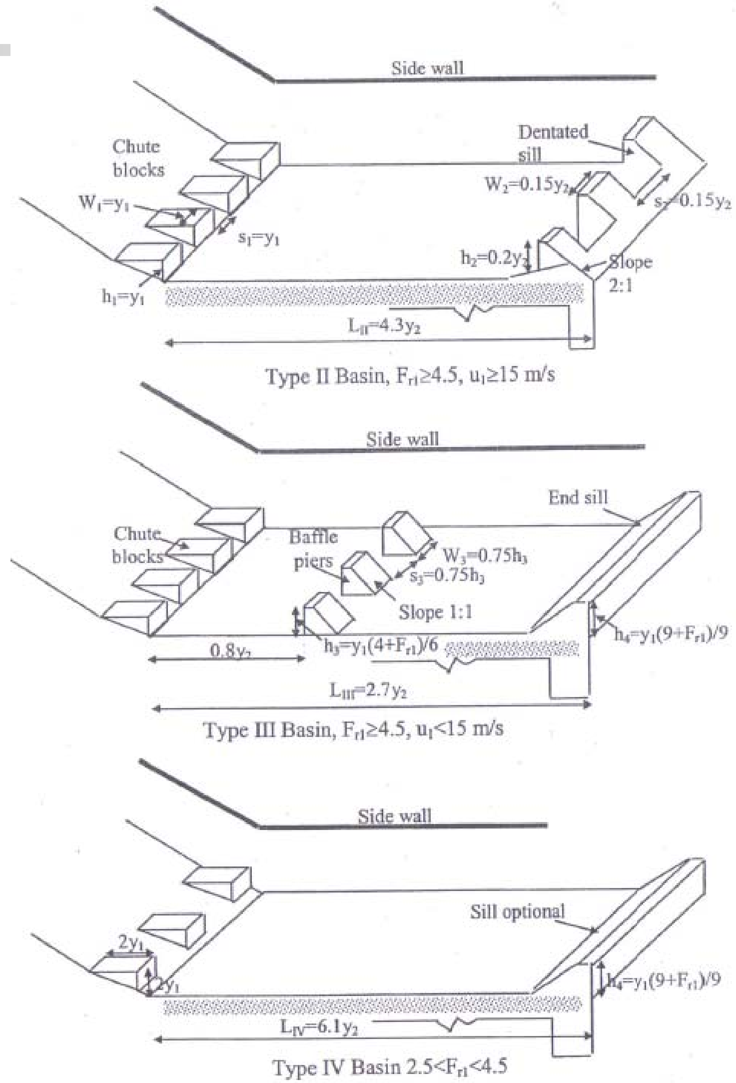


Figure 4.29 Types of the USBR stilling basins (Peterka, 1964; Henderson, 1966).

Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

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

$$F_p = 2\gamma A E_1$$

where γ: Specific weight of water (kN/m³),

A: area of the upstream face of the pier in m².

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.

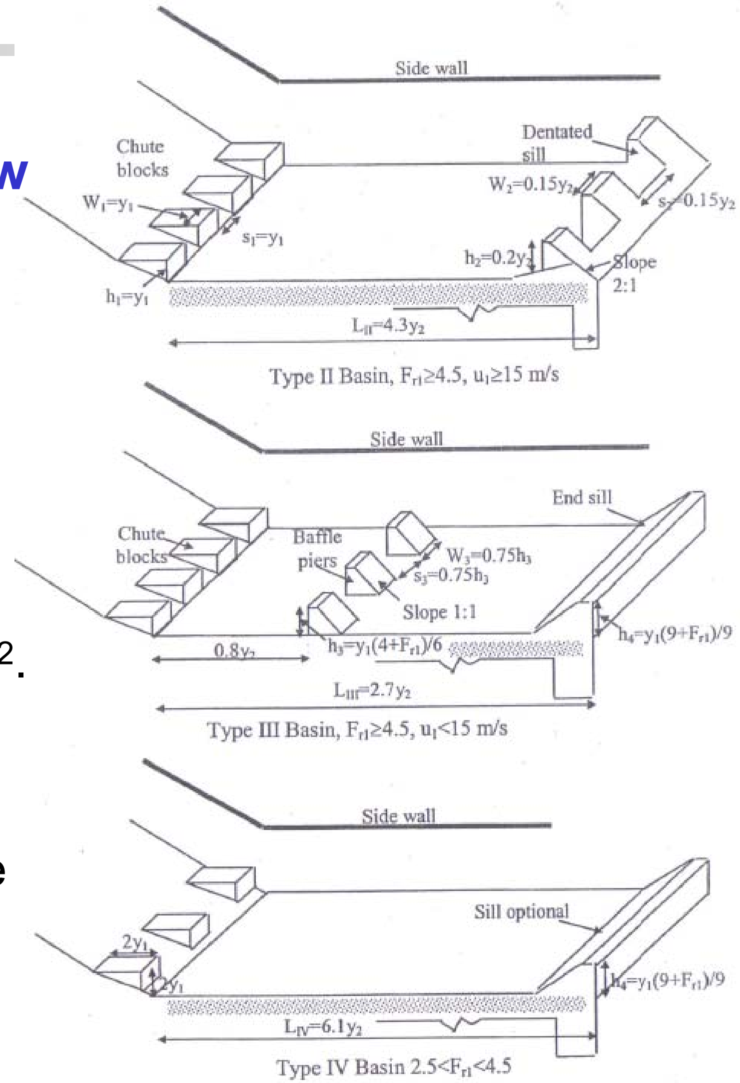


Figure 4.29 Types of the USBR stilling basins (Peterka, 1964; Henderson, 1966).

Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- **Case 2:**
  - To find the stilling basin depth, Δ (h_4), inserting Equation 4.11 into Equation 4.14

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

y_1=?

$$\frac{y_2}{y_1}=\frac{1}{2}\left(\sqrt{1+8F_{r1}^2}-1\right)=\frac{1}{2}\left(\sqrt{1+\frac{8q^2}{gy_1^3}}-1\right)$$

y_2=?

  - Applying the energy equation between section 2 and 3, the value of Δ can be found.

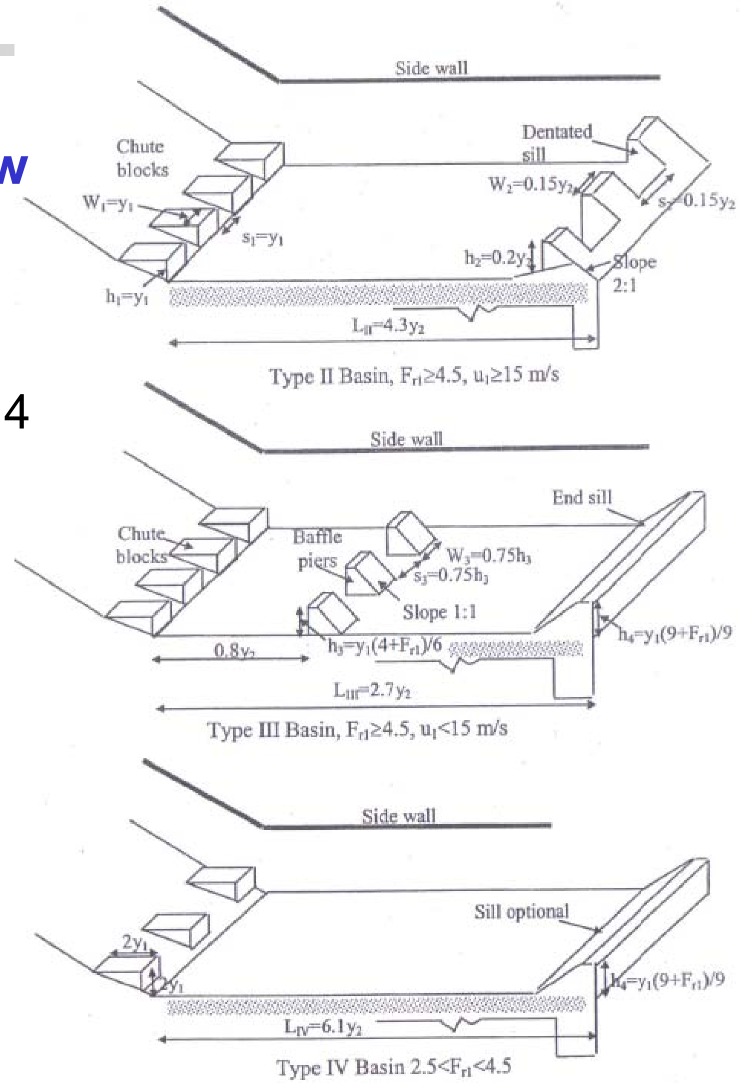


Figure 4.29 Types of the USBR stilling basins (Peterka, 1964; Henderson, 1966).

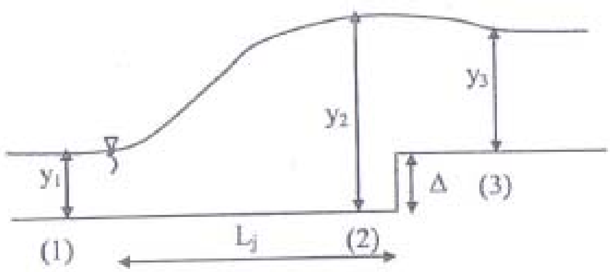
Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

- **Case 2:**
  - The value of Δ 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} $\quad \frac{y_3}{y_1} = F_{r1}^{2/3}$
  - The length of jump, L_j: $\quad L_j = 5(y_3 + \Delta)$

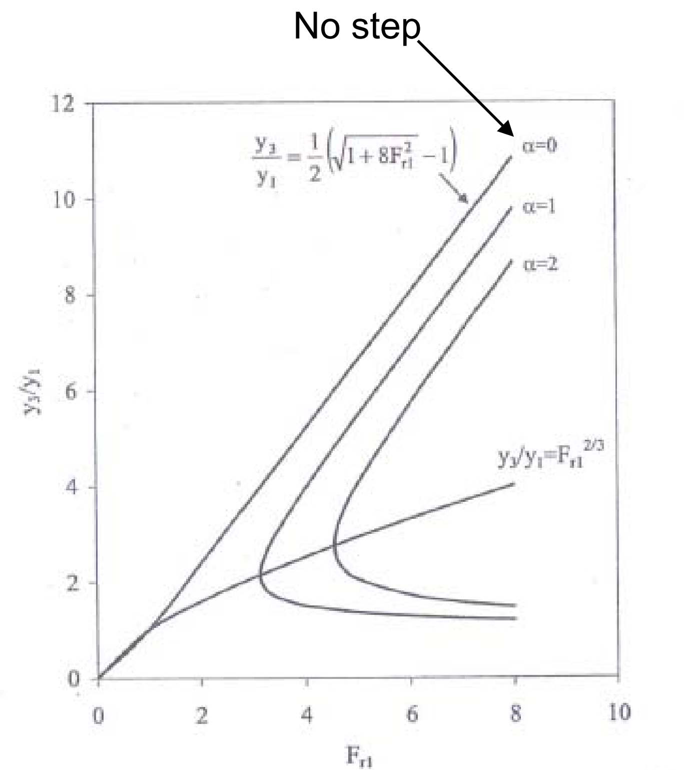
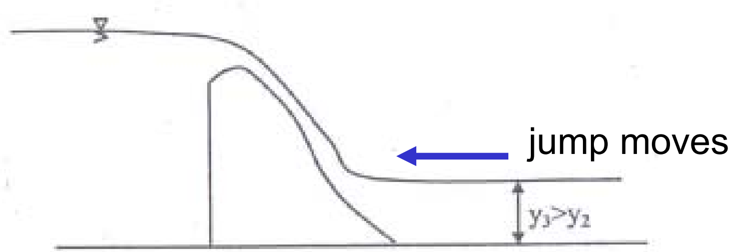


Figure 4.31 Variation of depth ratio, y_3/y_1 against Froude number.

Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

Case 3: $y_3 > y_2$

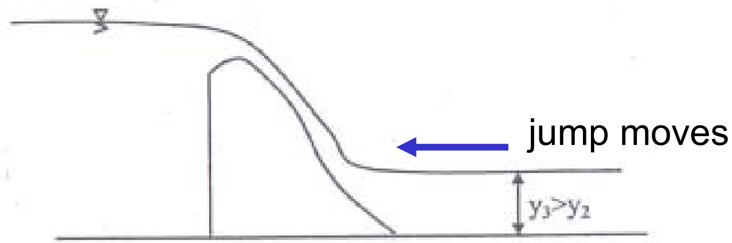


- Different modes of energy dissipation may be considered:
  - A long sloping apron (USBR type 5 basin)
  - A culvert outlet (USBR type 6 basin)
  - A deflector bucket (USBR type 7 basin)
- Selection of the best type is normally dictated by
  - The required hydraulic conformity,
  - Foundation conditions, and
  - Economic considerations

Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

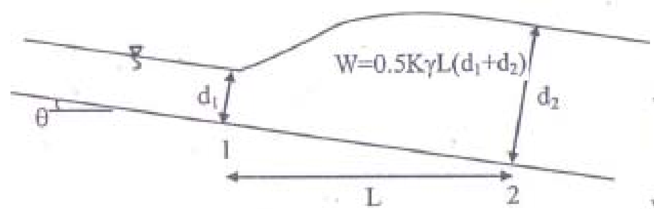
Case 3: $y_3 > y_2$



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

- 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:

$$\frac{d_2}{d_1} = \frac{1}{2}\left(\sqrt{1 + \frac{8F_{r1}^2}{\cos\theta - \frac{KL\sin\theta}{d_2 - d_1}}} - 1\right)$$



$$\frac{L}{y_2} = 6.1 + 4\tan\theta$$

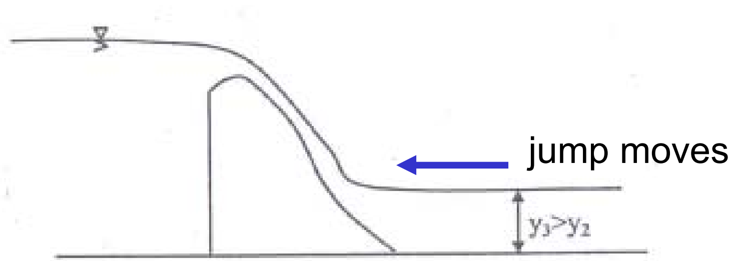
where $y_2 = d_2/\cos\theta$.

Figure 4.33 Definition sketch for hydraulic jump on a sloping apron.

Overflow Spillways

Energy Dissipation at the Toe of Overflow Spillway

Case 3: $y_3 > y_2$



- A **deflector bucket** may be used.

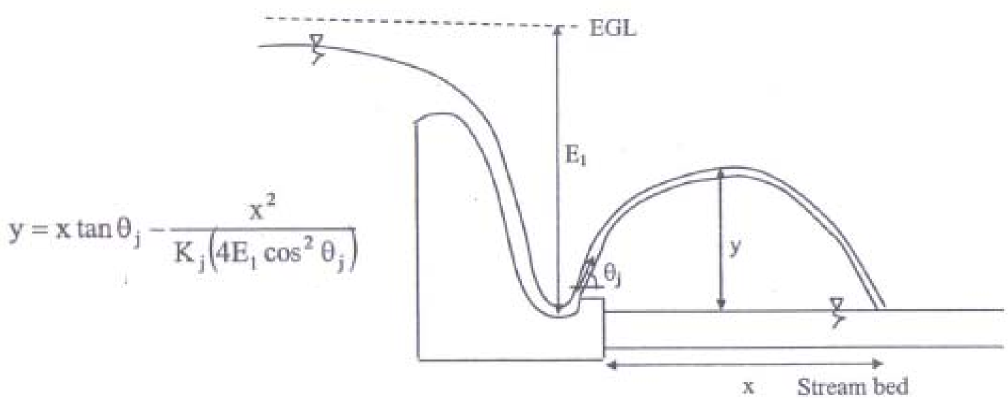


Figure 4.34 Flow conditions for deflector buckets.

K_j: factor (unity for theoretical jet).
E_l: total head at the bucket.

The max. value of x will be $2K_jE_l$ when leaving angle is 45º.

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.

Overflow Spillways

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.

Ataturk Dam


Keban Dam

METU NORTHERN CYPRUS CAMPUS

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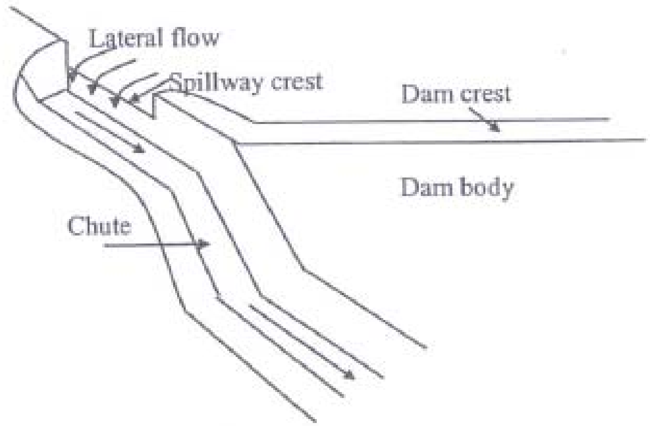
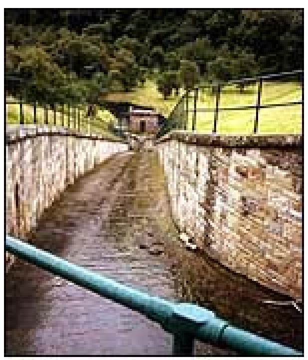
Side Channel Spillways

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



Side channel spillway

Side channel spillway at Hope Dam in Scotland



spillway chute from side channel to river

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

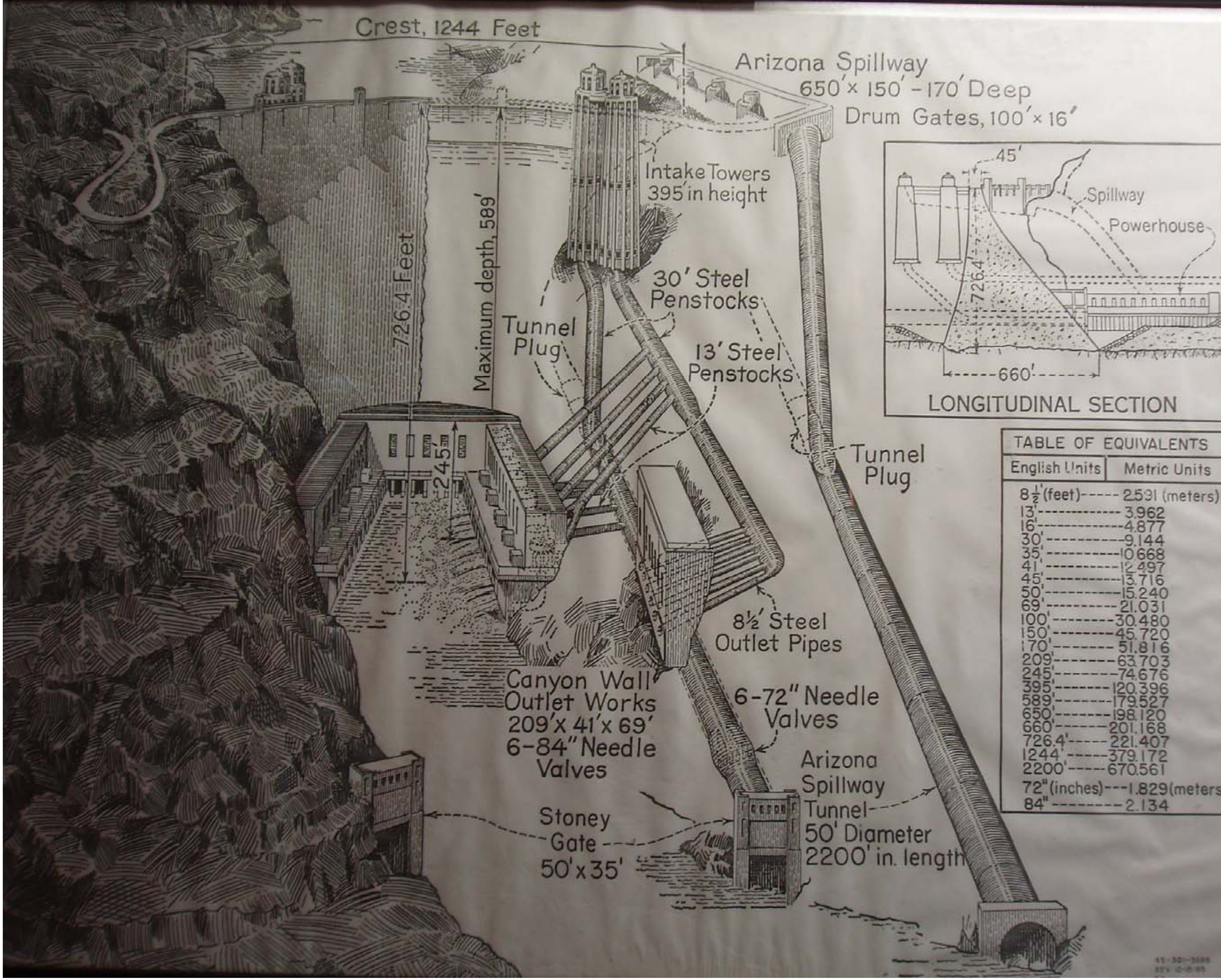
Hoover Dam side channel spillway

Side Channel Spillways

Hoover Dam Overflow Tunnels (spillways), USA

Side Channel Spillways

Hoover Dam Overflow Tunnels (spillways), USA



LONGITUDINAL SECTION

TABLE OF EQUIVALENTS	
English Units	Metric Units
8½' (feet)	2.531 (meters)
13'	3.962
16'	4.877
30'	9.144
35'	10.668
41'	12.497
45'	13.716
50'	15.240
69'	21.031
100'	30.480
150'	45.720
170'	51.816
209'	63.703
245'	74.676
395'	120.396
589'	179.527
650'	198.120
660'	201.168
726.4'	221.407
1244'	379.172
2200'	670.561
72" (inches)	1.829 (meters)
84"	2.134

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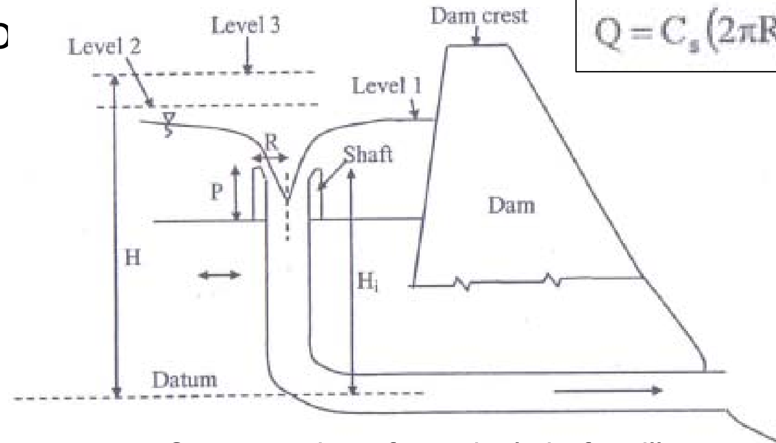
Shaft Spillways

- If a sufficient space is not available fo 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.

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



Cross-section of a typical shaft spillway

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.

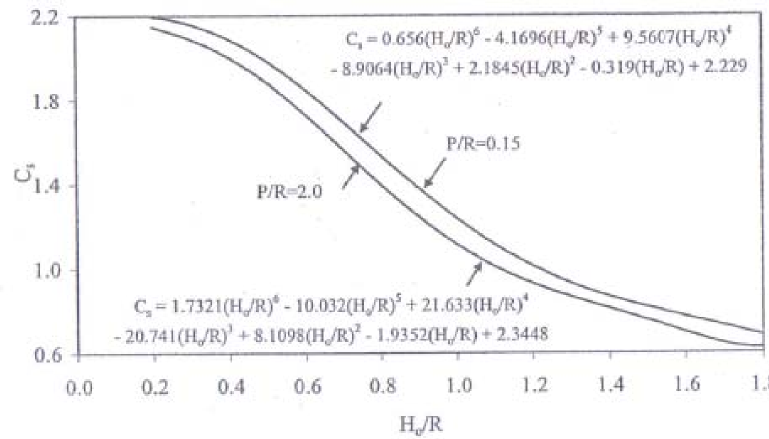


Figure 4.37 Discharge coefficient for shaft spillways (USBR, 1987).

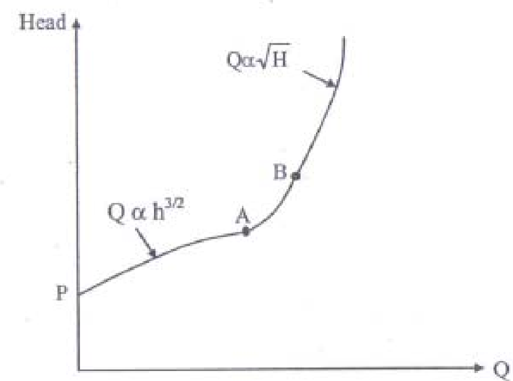
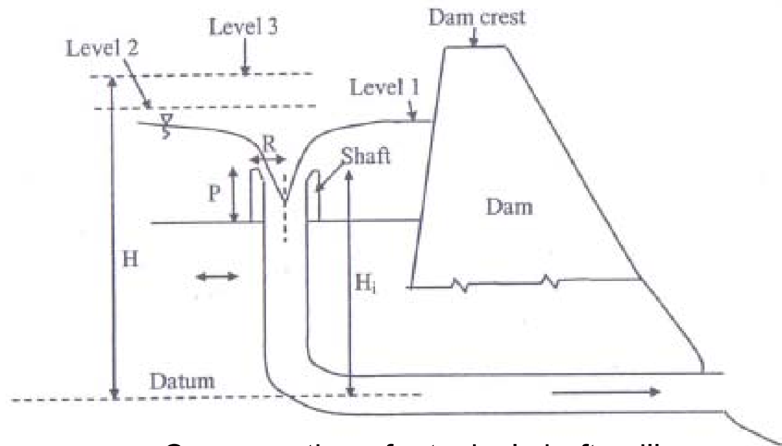


Figure 4.38 Flow conditions in a shaft spillway.

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.
- **Video of Ladybower Dam spillway**



Cross-section of a typical shaft spillway

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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 $Q = C_d A (2gh)^{1/2}$

  where

  C_d: discharge coefficient (≈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.

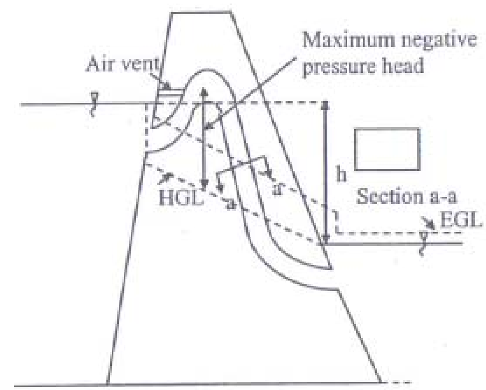
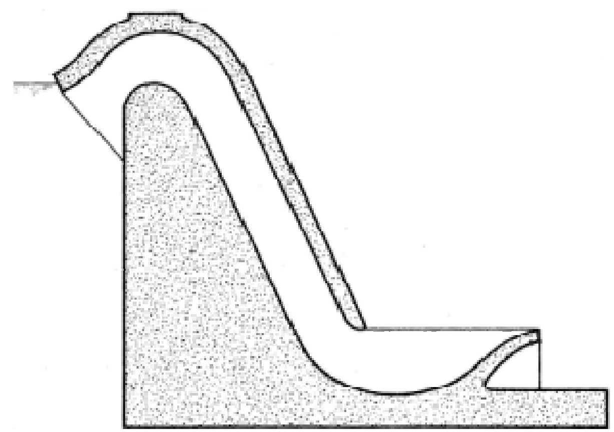


Figure 4.39 Cross-section of a typical siphon spillway.



Cross-section of a typical siphon spillway

Siphon Spillways

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.

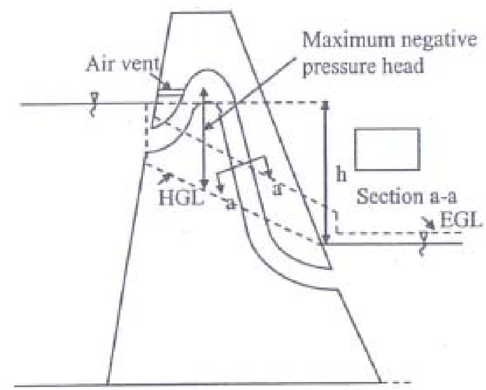
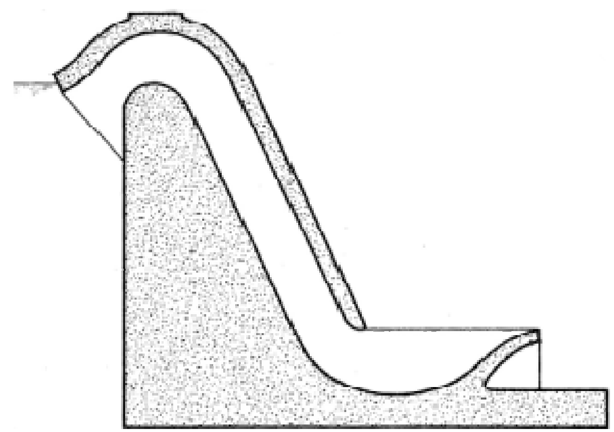


Figure 4.39 Cross-section of a typical siphon spillway.



Cross-section of a typical siphon spillway

METU NORTHERN CYPRUS CAMPUS

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Labyrinth Spillways

- A labyrinth spillway is composed of a crest formed by series of this 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.

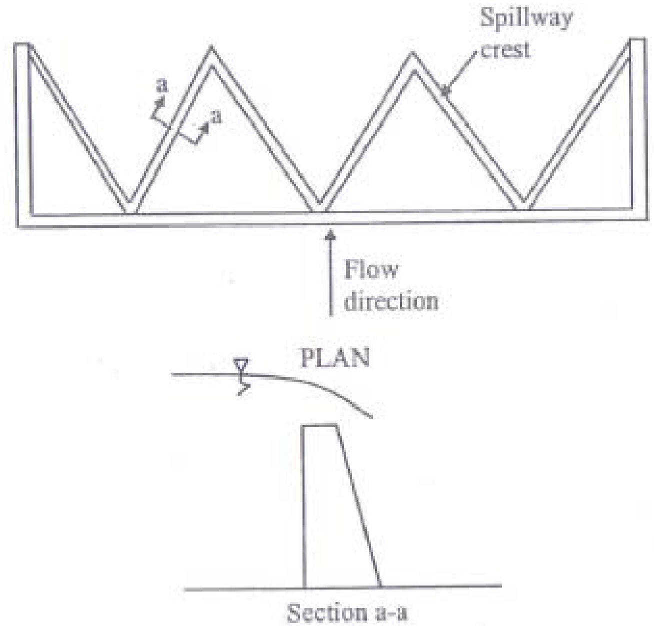
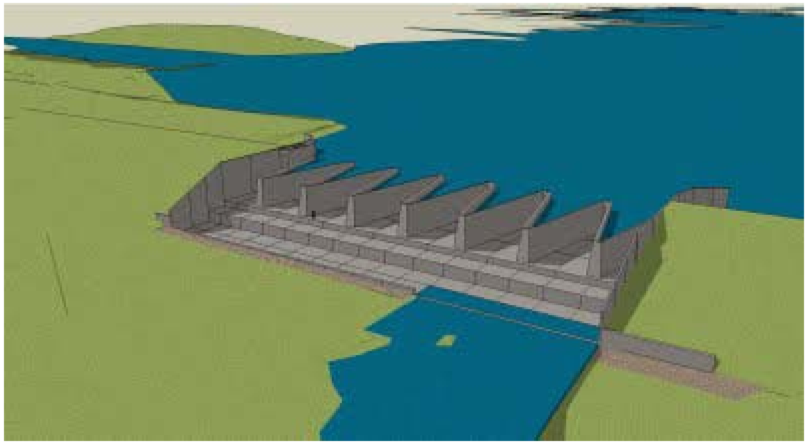
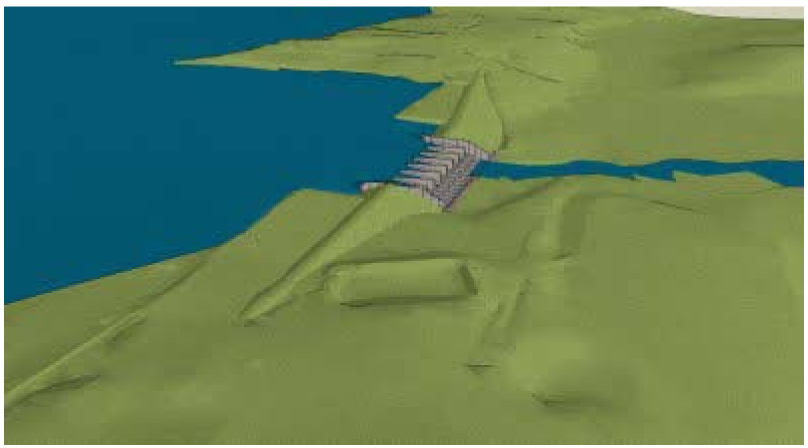


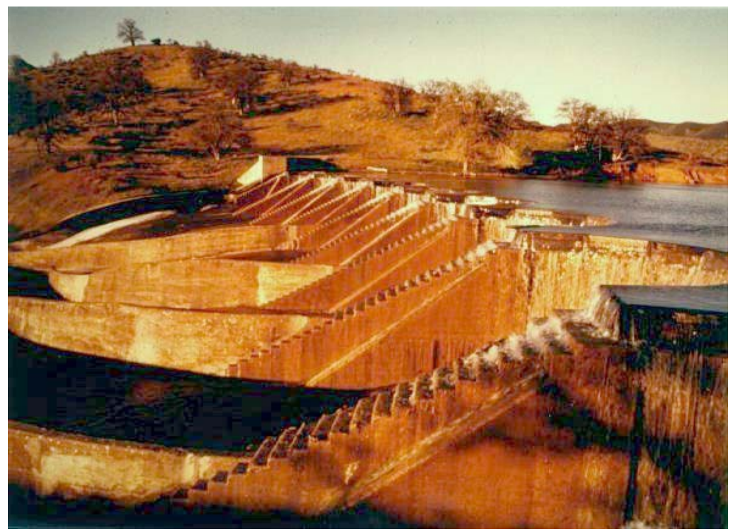
Figure 4.40 Plan and cross-section of a typical labyrinth spillway.

METU NORTHERN CYPRUS CAMPUS

Labyrinth Spillways







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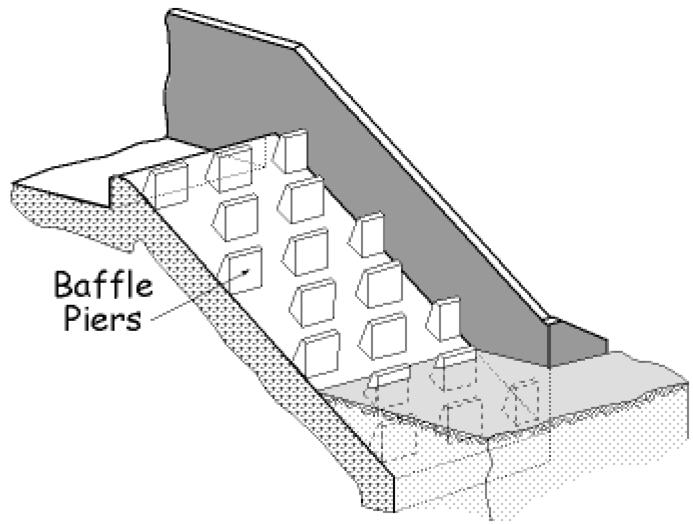
Baffled Chute Spillways

- 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 Sluceways

Cascade Spillways

- 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 compare 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 mode studies.

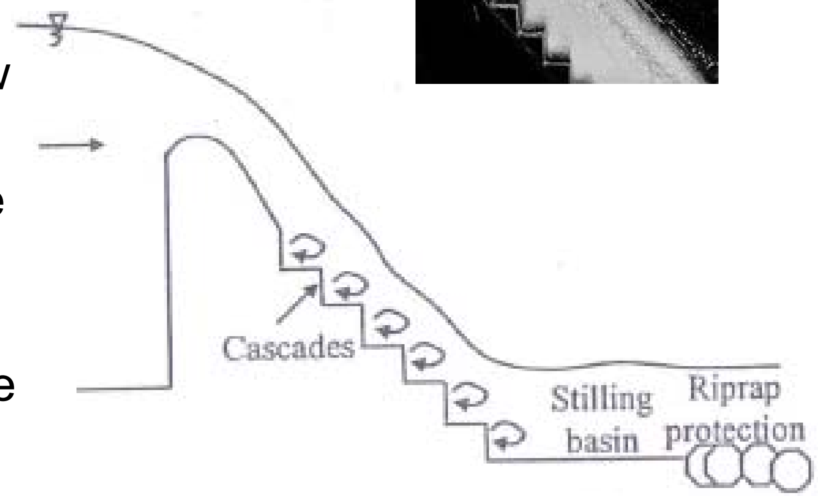


Figure 4.41 A cascade spillway.

Overview

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

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 ⇗ the cost of the spillway ⇗
- Spillway length ⇗ the water level ⇘ the cost of the dam ⇘
- There is an optimum spillway length, which minimizes the total cost of construction.

Overview

- General
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- 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.

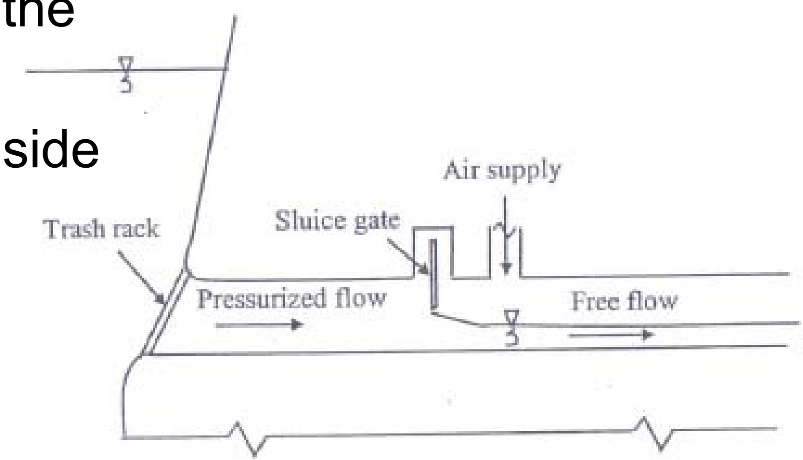


Figure 4.42 Bottom outlet aeration (Vischer and Hager, 1999).

Bottom Outlets and Sluceways

- 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.

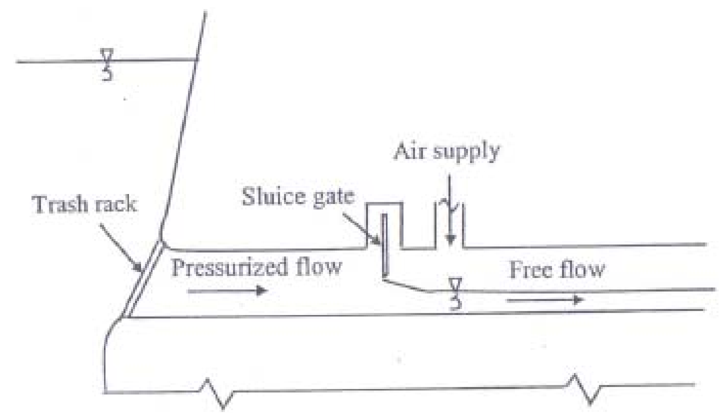
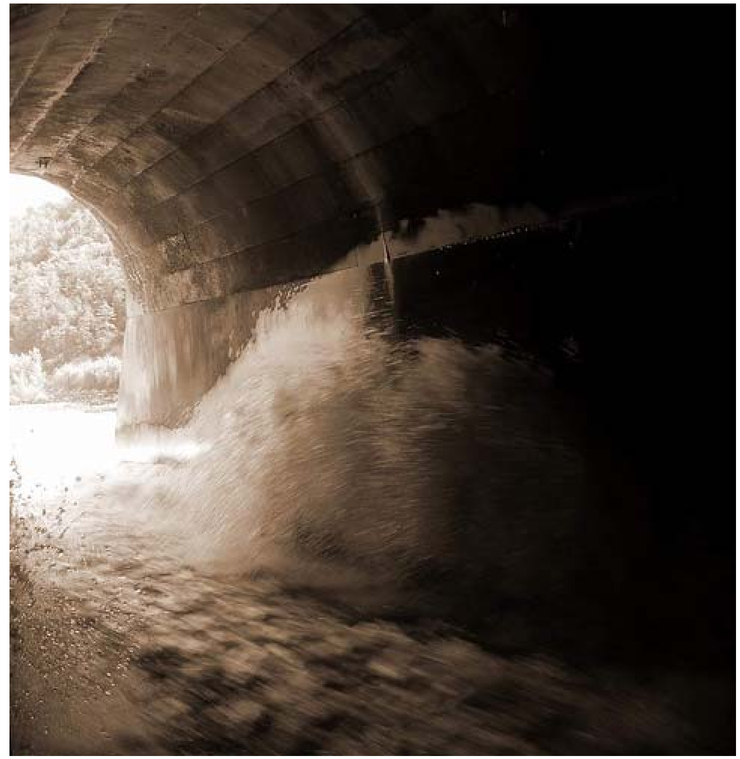


Figure 4.42 Bottom outlet aeration (Vischer and Hager, 1999).

Bottom Outlets and Sluceways



Bottom Outlets and Sluceways

Bottom Outlets of Hoover Dam

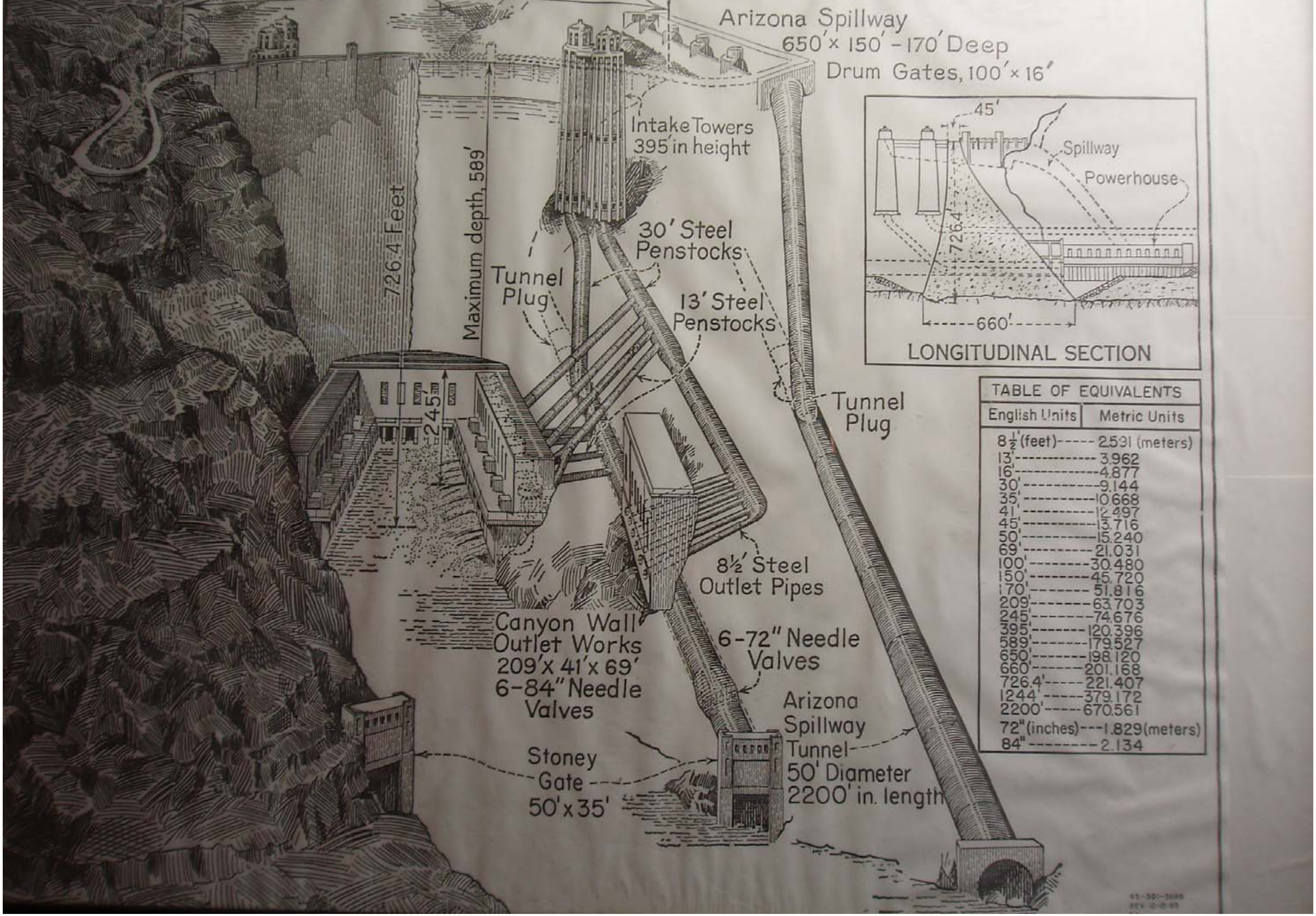
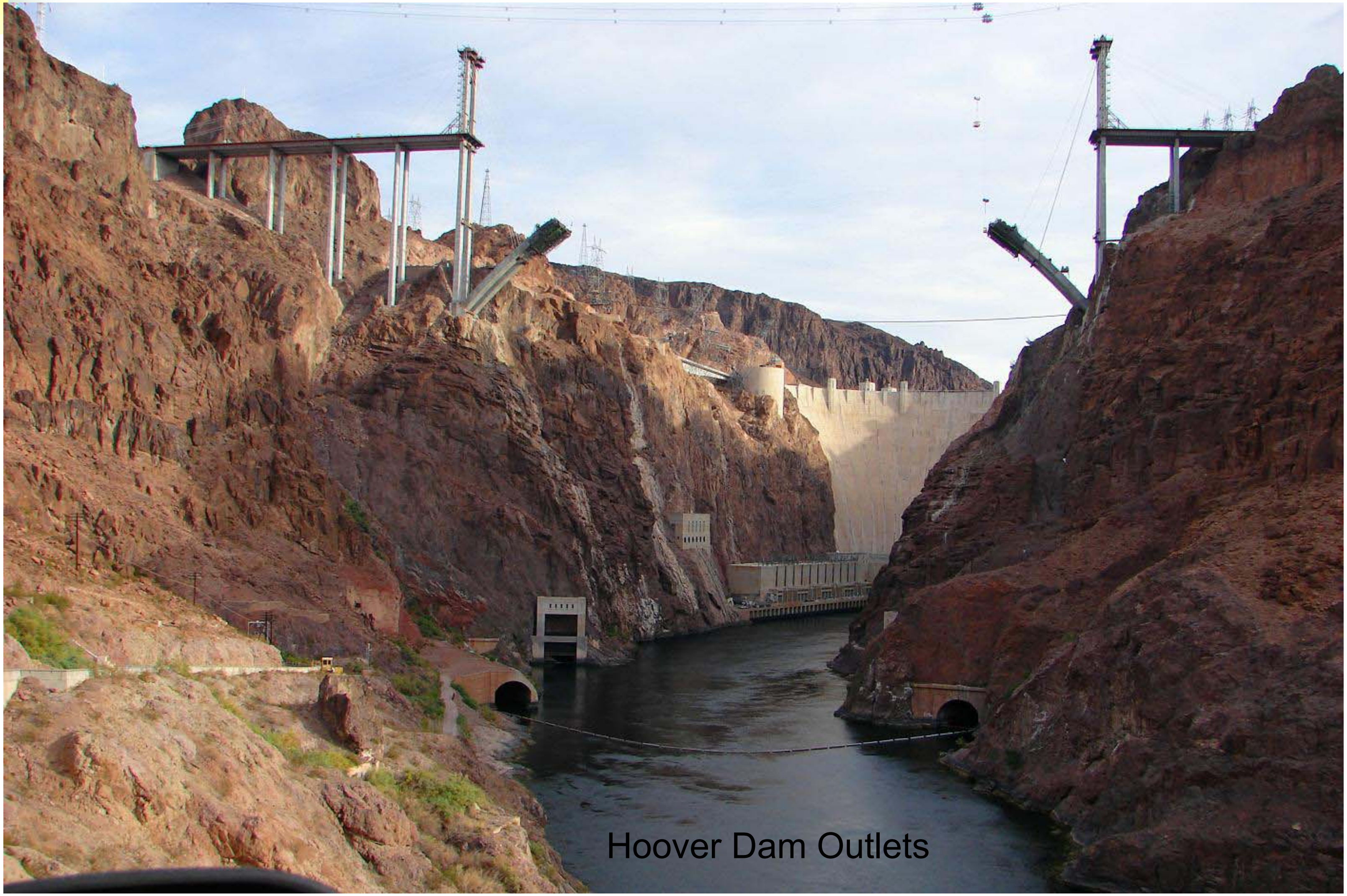


TABLE OF EQUIVALENTS

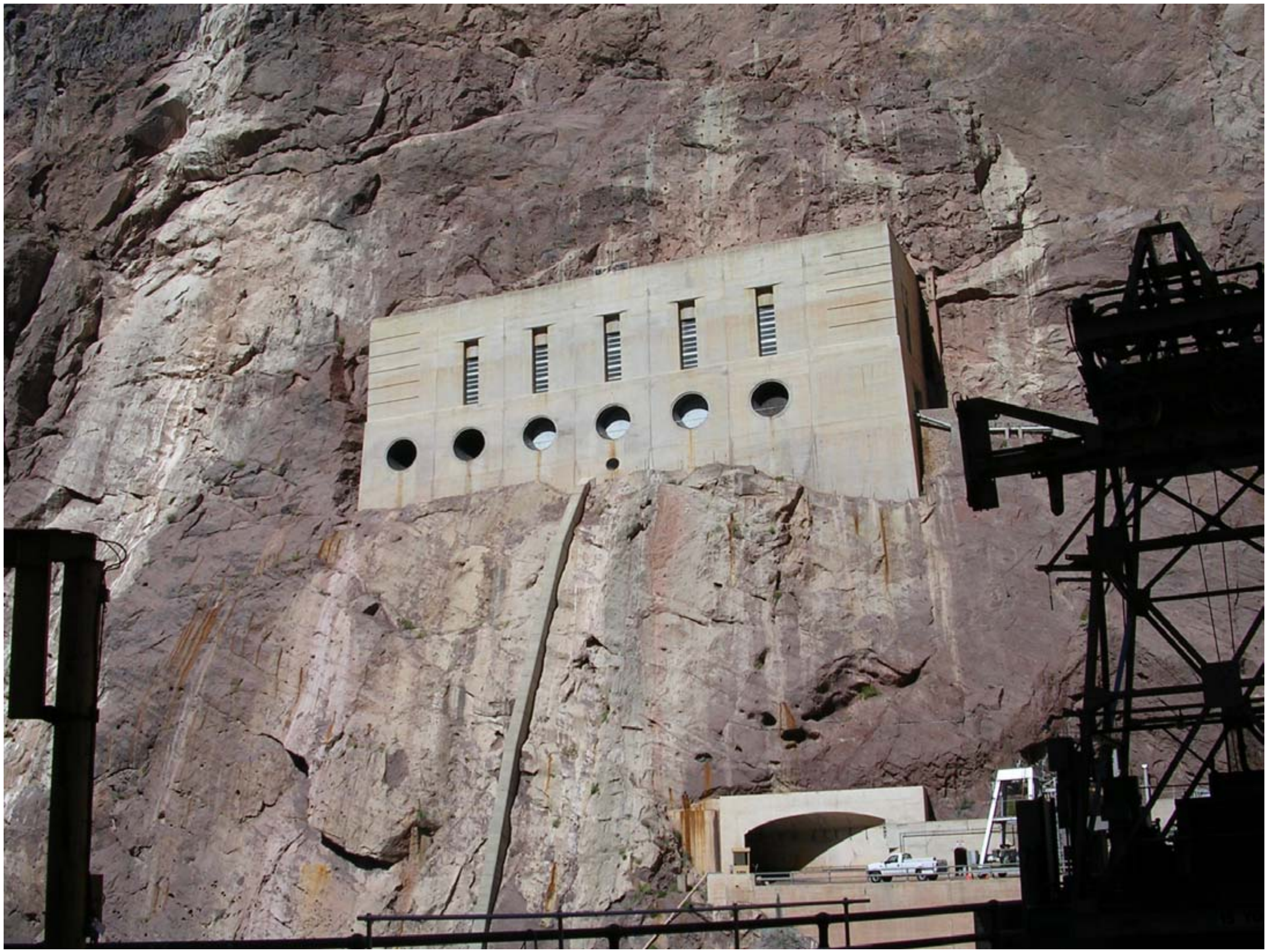
English Units	Metric Units
8½' (feet)	2.531 (meters)
13'	3.962
16'	4.877
30'	9.144
35'	10.668
41'	12.497
45'	13.716
50'	15.240
69'	21.031
100'	30.480
150'	45.720
170'	51.816
209'	63.703
245'	74.676
395'	120.396
589'	179.527
650'	198.120
660'	201.168
726.4'	221.407
1244'	379.172
2200'	670.561
72" (inches)	1.829 (meters)
84"	2.134

Bottom Outlets and Sluceways



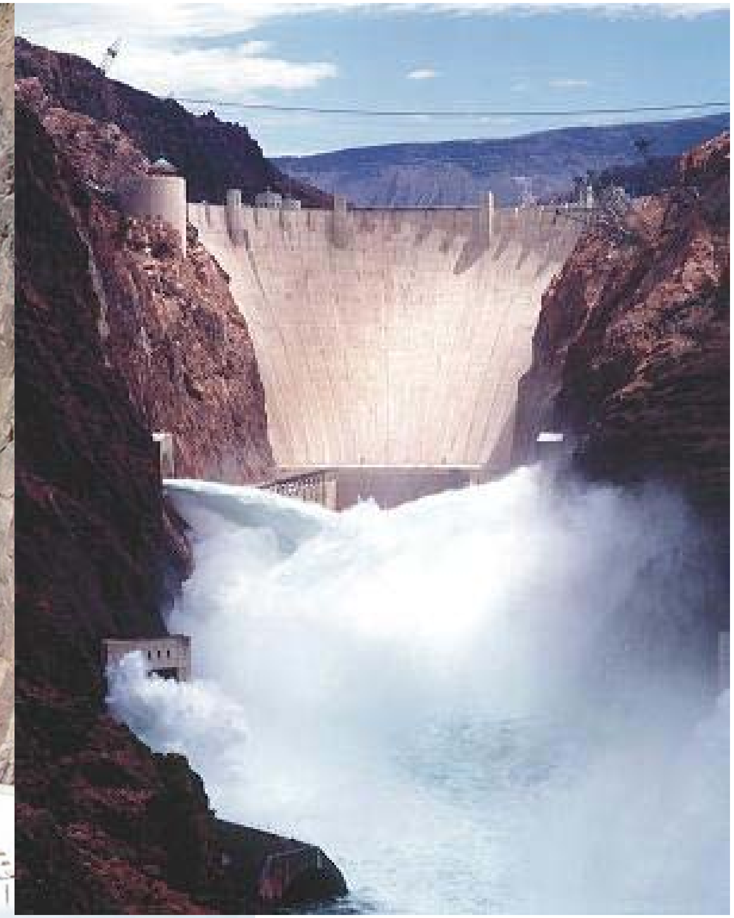
Hoover Dam Outlets

Bottom Outlets and Sluceways



Hoover Dam Outlets

Bottom Outlets and Sluceways



Hoover Dam Outlets

METU NORTHERN CYPRUS CAMPUS

Bottom Outlets and Sluceways

Hoover Dam Inlets

Bottom Outlets and Sluceways

Hoover Dam Inlets