Wollo University
Kombolcha Institute of Technology

Department of Hydraulic and Water Resources Engineering

Lecture on Hydraulic Structures-II (HWRE-3132)
(For G_3-HWRE)

Chapter-Two
Spillways & Energy Dissipaters

2. Spillways and Energy Dissipaters

2.1. <u>Spillway Structures</u>:

- ***Spillway-*** *is a structure constructed to pass surplus flood water on the D/S of reservoir and Dam.*
- *The choice of design is a function of the nature of the site, the type of dam and the overall economics of the scheme.*
- *The importance of a safe spillway can not be exaggerated, many failures of dams have been caused by improperly designed spillways or by spillways of insufficient capacity.*
- ***A spillway** may be located either **within the body of the dam** or **at one end of the dam** or **entirely away from the dam** as an independent structure.*

2.1.1 Essential Requirements of a Spillway

- ✓ *The spillway must have sufficient capacity.*
- ✓ *It must be hydraulically and structurally adequate.*
- ✓ *It must be so located that it provides safe disposal of water i.e., spillway discharge will not erode or undermine the D/S toe of the dam.*
- ✓ *The bounding surface of spillway must be erosion resistant to withstand high scouring velocity created by the drop from reservoir surface to tail water.*
- ✓ *Usually some devices are needed for energy dissipation on the D/S side of spillway.*

2.1.2 Spillway Capacity

- *The required capacity of a spillway, i.e. the maximum outflow rate through the spillway, maybe determined by flood routing and requires the following data:*
  - *i. Inflow Hydrograph*
  - *ii. Reservoir capacity curve*
  - *iii. Discharge curve*
- *However the required capacity of a spillway depends on the following factors:*
  - *a) Inflow flood*
  - *b) Available storage capacity*
  - *c) Discharge capacity of outlet works*
  - *d) Whether gated or un-gated spillway*
  - *e) Possible damage if a spillway of adequate capacity is not provided.*

2.1.3 Components of a Spillway

- ***Essential components a spillway are composed of the following structures:***

- ✓ *Control structure: regulates and controls the outflow from the*
- ✓ *Discharge channel /waterway/ conveyance structure: it conveys the water safety from the reservoir downward to the river (next to the control structure).*
- ✓ *Terminal structure/energy dissipater: provided to dissipate the high energy of flow from spillway before the flow is returned to the river. It is provided on the d/s of the spillway.*
- ✓ *Entrance/approach/channel: required to draw water from the reservoir and convey it to the control structure.*

2.1.3 Types of Spillway

- ***Spillway may be classified:***

1) *According to their function (or based on the time when the spillway comes into operation) as:*

   a) ***Main or service spillway:*** *is the one which comes into operation and is designed to pass the entire spillway design flood.*

   b) ***Auxiliary spillway:*** *It is provided as a supplement to the main spillway and its crest is so located that it comes into operation only after the floods for which the main spillway is designed is exceeded. Thus it is provided in conjunction with the main spillway.*

   c) ***Emergency spillway:*** *It is also provided in addition to main spillway but it comes into operation only during emergency which may arise at any time which may not have been considered in the normal design of main spillway.*

…….*types of Spillway*

- ***Some of the situations which may lead to emergency are:***
  - ✓ *An enforced shut down of the outlet works*
  - ✓ *A malfunctioning of spillway gates*
  - ✓ *The necessity of bye passing the regular spillway because of damage or failure of some part of the structure*
  - ✓ *Further an emergency may also arise if a recurring flood occurs before a previous flood is evacuated by the main spillway and outlet works.*
- ➢ *Emergency spillways are also provided in the saddles or depressions if available.*
- ➢ *It is often provided as breaching section*
- ➢ *The breaching section is also called* ***fuse plug spillway.***

…….types of Spillway

2) *According to flow through the spillway:*
   - a) ***controlled or gated spillway***
   - b) ***un controlled or un-gated spillway***
3) *Based on prominent features pertaining to the various components of the spillway (hydraulic criteria):*
   - a) ***Free over-fall or straight drop spillway***
   - b) ***Over flow or Ogee spillway***
   - c) ***Chute or open channel or trough spillway***
   - d) ***Side channel spillway***
   - e) ***Shaft or morning glory spillway***
   - f) ***Conduit or tunnel spillway***
   - g) ***Siphon spillway***

…….*types of Spillway*

a) *Free over fall or straight drop spillway*:

- ✓ *Is low height narrow crested weir having its down face vertical or nearly vertical.*
- ✓ *The over flowing water may be discharged as in the case of a sharp crested weir.*
- ✓ *Water flowing over the crest drops as a free jet clearly away from the down stream face of the spillway.*
- ✓ *Occasionally the crest of this spillway is extended in the form of an overhanging lip to direct small discharges away from the downstream face.*

…….*types of Spillway*

Figure 2.1: Free over fall or straight drop spillway

…….*types of Spillway*

b) Over flow or Ogee spillway:

- ✓ *Overflowing water in this case is guided smoothly over the crest of the spillway and is made to glide over the down stream face of the spillway.*
- ✓ *The profile of the ogee weir is generally confined to the lower nappe that would be obtained for maximum head over spillway.*
- ✓ *The control structure is a weir which is ogee or S shaped.*

❑ ***The shape of such a profile depends upon the :***

- ✓ *Head*
- ✓ *The inclination of U/S face of the overflow section and*
- ✓ *The height of the overflow section above the floor of the entrance channel.*

➢ *The ogee profile should provide maximum possible hydraulic efficiency, structural stability and economy and also avoid the formation of objectionable sub-atmospheric pressure at the crest.*

…….*types of Spillway*

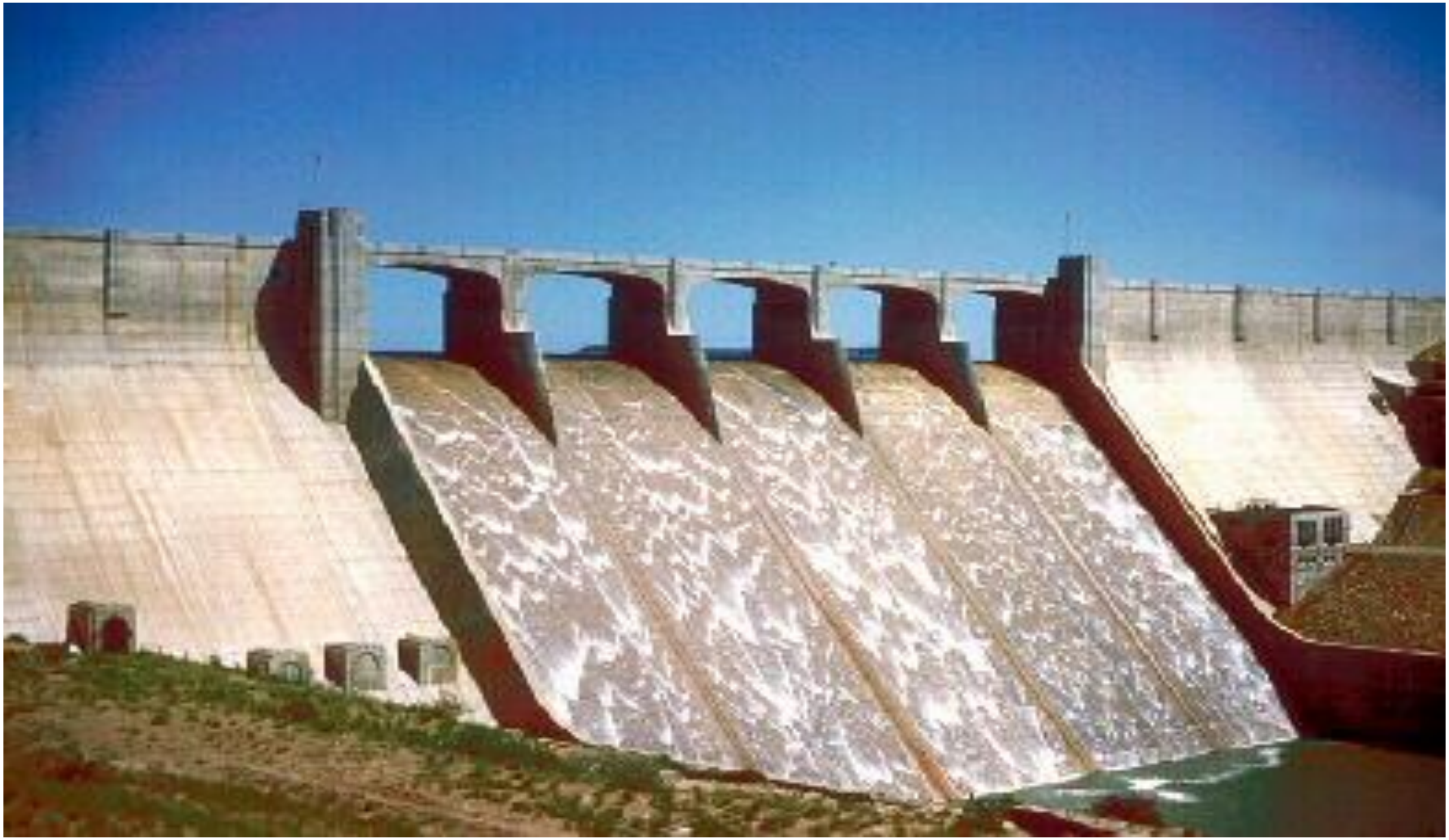


Figure 2.2: Ogee spillway

- ***The ogee profile may be categorized into three groups:***

(i) Overflow dams with vertical U/S face:

- *The following equation as given by U.S. corps of engineers may be used for finding coordinates (X,Y) for the D/S profile;*

$$X^{1.85} = 2\,(H_d)^{0.85} * Y$$

- *Where, X & Y are coordinates as shown in the figure and Hd is the design head;*
- *For U/S profile following coordinates with origin at crest are recommended.*

…….types of Spillway

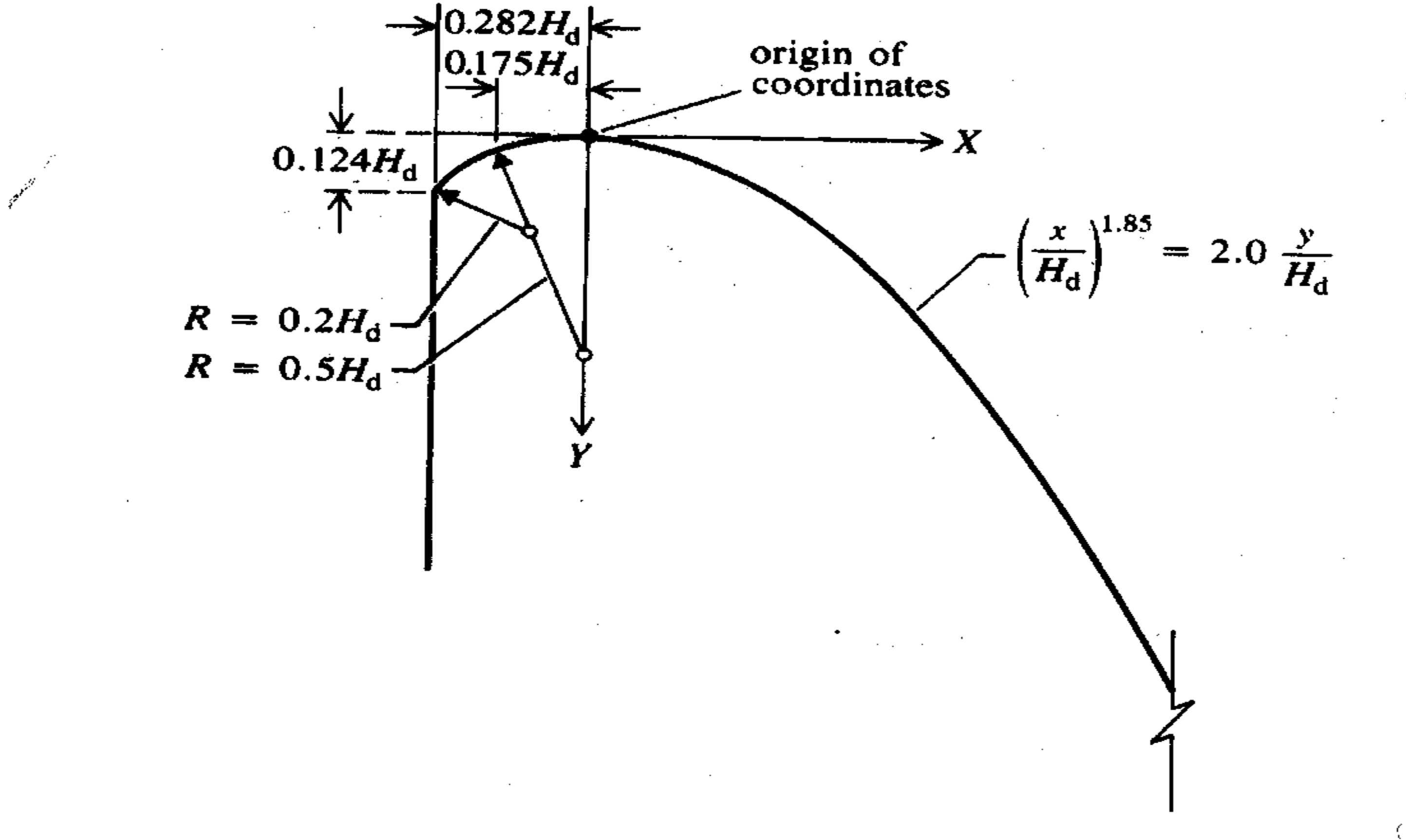


Figure 2.3: Profile of a vertical u/s face over flow section

(ii) Over flow dams with sloping U/S face:

- *The D/S profile may conform to the following equation:*

$$X^n = K (H_d)^{n-1} Y$$

- ✓ *Where, n & K are variable parameters which depends on the inclination of U/S face of the dam, H_d is the design head.*
- ✓ ***Values of constant K, n , R_1, R_2, a and b are given below:***

Shape of U/S face	K	n	R_1/H_d	R_2/H_d	a/H_d	b/H_d
Vertical	2.000	1.850	0.5	0.20	0.175	0.282
3V: 1H	1.936	1.836	0.68	0.21	0.139	0.237
3V: 2 H	1.939	1.810	0.48	0.22	0.115	0.240
3V: 3H	1.873	1.776	0.45	0.00	0.119	0.000

…….types of Spillway

- *The curved profile of the crest section is continued till it meets tangentially the straight sloping portion of the overflow dam section (spillway).*
- *The slope of the d/s face of the overflow dam usually varies in the range of 0.7(H):1(V) to 0.8:1 and is basically decided on the basis of stability requirements.*
- *The location of the point of tangent depends upon the slope of the d/s face, where the value of dy/dx for the curved profile and the straight segment must be equal at the end of the sloping surface of the spillway.*

…….types of Spillway

- *The curved profile of the crest section is continued till it meets tangentially the straight sloping portion of the overflow dam section (spillway).*
- *The slope of the d/s face of the overflow dam usually varies in the range of 0.7(H):1(V) to 0.8:1 and is basically decided on the basis of stability requirements.*
- *The location of the point of tangent depends upon the slope of the d/s face, where the value of dy/dx for the curved profile and the straight segment must be equal at the end of the sloping surface of the spillway.*

U/S profile of the Weir Crest

- *Vertical U/S face: The u/s profile should be tangential to the vertical face and should have zero slope at the crest axis to ensure that there is no discontinuity along the surface of the flow.*
- *The u/s profile should conform to the following equation:*

$$y = \{0.724\,(x + 0.270\,H_d)^{1.85} / (H_d)^{0.85}\} + 0.126\,H_d - 0.4315(H_d)^{0.375}(x + 0.270\,H_d)^{0.625}$$

- *Alternatively the u/s slope may be considered to consist of compound circular curve with values of:*

$R_1 = 0.50\,H_d$, *and* $R_2 = 0.20\,H_d$

- *The chord length up to R1, and R2 is given as:*

$a = 0.175\,H_d$, *and* $b = 0.282\,H_d$

Discharge Computation Over Ogee Crest:

- *The discharge over ogee spillway is computed from the basic equation of weir given below:*

$$Q = C_d L_e H^{1.5}$$

Where,

Q = Discharge in cumecs

C_d = Coefficient of discharge, its value varies from 2.1 to 2.5

H = Head of over flow in meters including velocity of approach head.

$H = H_d + H_a$

L_e = Effective length of overflow crest in meters

$L_e = L - 2(N*k_p + k_a)*H$

L = Net length of the crest

N = Number of piers

k_p = Piers contraction coefficient

k_a = Abutment contraction coefficient

…….types of Spillway

- *Values of pier contraction coefficient kp and abutment contraction coefficient ka for d/t pier condition and abutment conditions respectively are listed on the table below:*

Pier Contraction coefficient k_p		**Abutment Contraction coefficient k_a**	
Pier condition	k_p	*Abutment condition*	ka
Square nosed piers with corners Rounded on a radius equal to 0.1 of pier thickness	***0.02***	Rounded abutment where $R>0.5H_d$ & wall is placed not more than 45° to direction of flow	***0.0***
Rounded nose piers	***0.01***	Rounded abutment with head wall at 90^0 to the direction of flow when: $0.5H_d \geq R \geq 0.15H_d$	***0.10***
Pointed nose piers	***0.0***	Square abutment with head wall at 90° to the direction of flow	***0.2***

…….types of Spillway

- ***The discharge coefficient is influenced by a number of factors:***
  1) *Height of spillway above stream bed or depth of approach*
  2) *relation of the actual crest shape to the ideal nappe shape*
  3) *upstream face slope*
  4) *downstream apron interference, and*
  5) *down stream submergence*
  6) *Ratio of actual total head to the design head*
  7) *effect of head due to velocity of approach*

Height of spillway or Effective depth of approach:

- ✓ *With increase in height of spillway the velocity of approach decreases and the coefficient of discharge increases.*
- ✓ *Model tests indicate that the coefficient of discharge becomes fairly constant when height of spillway > 3.0 Hd, where Hd is the design head including the head due to velocity of approach.*

- ***Various text books give a plot of C_d versus H_d which is reproduced here in the table as:***

P/H$_d$	C$_d$	P/H$_d$	C$_d$	P/H$_d$	C$_d$
0.0	1.7	0.1	1.875	0.2	1.97
0.3	2.025	0.4	2.06	0.5	2.09
0.6	2.12	0.7	2.135	0.8	2.15
0.9	2.16	1.0	2.17	1.5	2.185
2.0	2.195	2.5	2.2	3.0 4.0	2.205 2.210

- ✓ ***When u/s face is inclined the above C_d values gets multiplied by a factor from 0.995 (for $P/H_d = 1.5$) to 1.04 (for $P/H_d = 0.2$) where, P is the height of spillway.***

…….types of Spillway

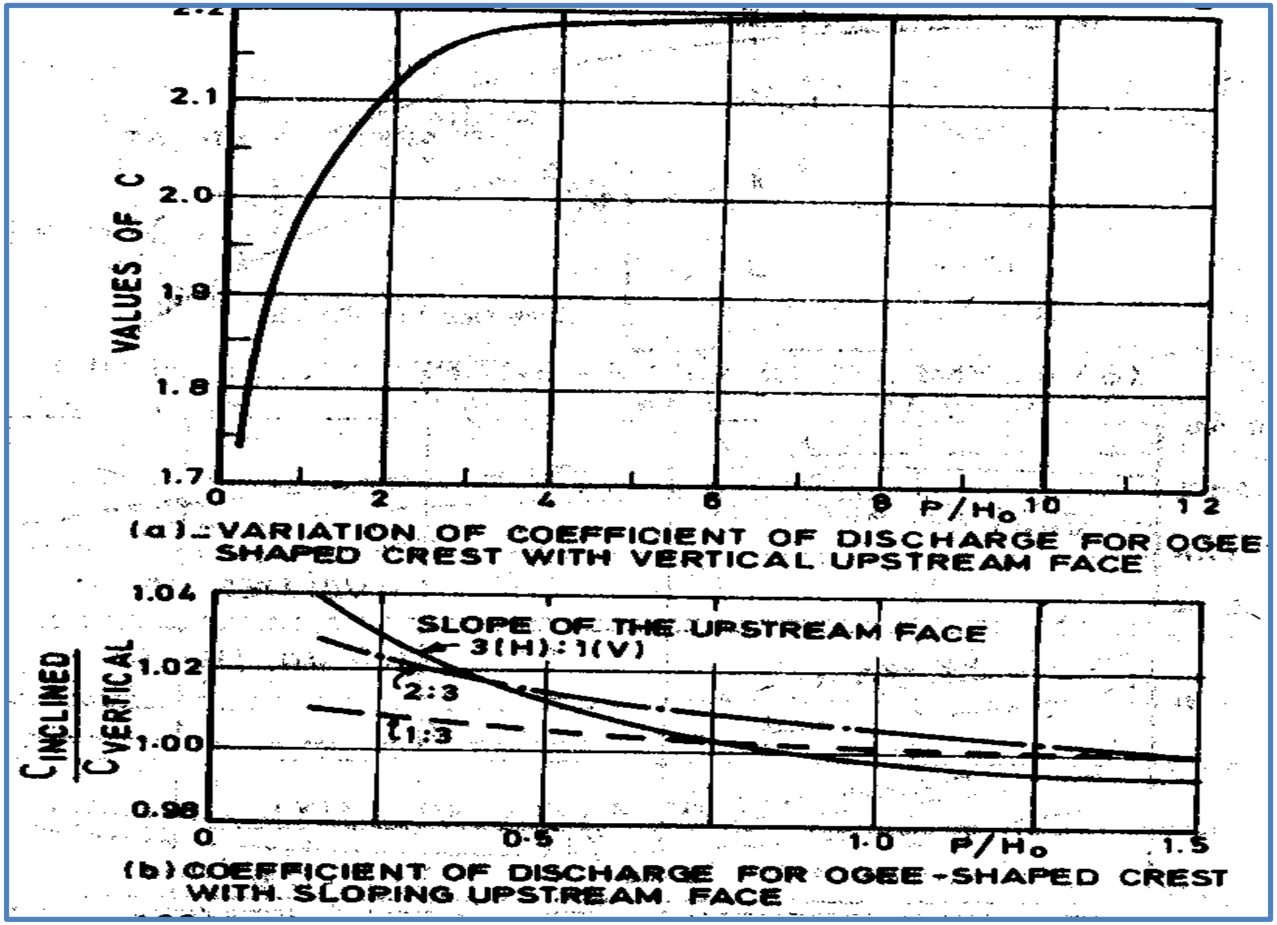


Figure 2.4: Variation of coefficient of discharge for vertical u/s face (a) and sloping u/s face (b) ogee shaped crest

❑ ***Negative Pressure over spillway surface*** **:**

- ✓ *$H > H_d$ the pressure on the crest will be negative (sub atmospheric) may lead to cavitation. Model tests show that till $H < 1.25\ H_d$ there is no harmful cavitation effect.*
- ✓ *$H < H_d$ the pressure on the crest is positive. Lower nappe of the jet attaches itself to the boundary. Also when $H > H_d$ lower nappe may leave the boundary for some distance on d/s face and may attach again as the air mass in between the boundary and the lower nappe gets sucked out. This may lead to the vibration of the structure.*

➢ ***Avoid negative pressure as:***

- ✓ ***It increases overturning moment at the crest***
- ✓ ***It increases the force required for lifting of the gates***
- ✓ ***It causes decrease in the capability for automatic control***
- ✓ ***It causes vibration which extends all over the structure. The vibration also causes cracks in the mortar of stone lining of the crest.***

c) Chute Spillway or Trough Spillway :

- ✓ *An ogee spillway is mostly suitable for concrete gravity dam when the spillway is located within the body of dam.*
- ✓ *For Earth & Rock-fill dam, a separate spillway is generally constructed in a flank or saddle, away from main valley.*
- ✓ *Some times even for gravity dams a separate spillway is required because of the narrowness of the valley.*
- ✓ *In such circumstances a separate spillway may have to be provided.*
- ✓ ***The trough spillway or chute spillway** is the simplest type of spillway which can be easily provided independently and at low costs.*
- ✓ *It is lighter & adoptable to any type of foundation and hence provided easily on Earth & Rock-Fill dam.*
- ✓ *It is also called at times **Waste Weir**; if it is constructed in continuation of the dam at one end, it may be called **a Flank weir**; if it is constructed in a natural saddle in the bank of the river separated from the main dam by a high ridge it is called **a Saddle Weir**.*

…….types of Spillway

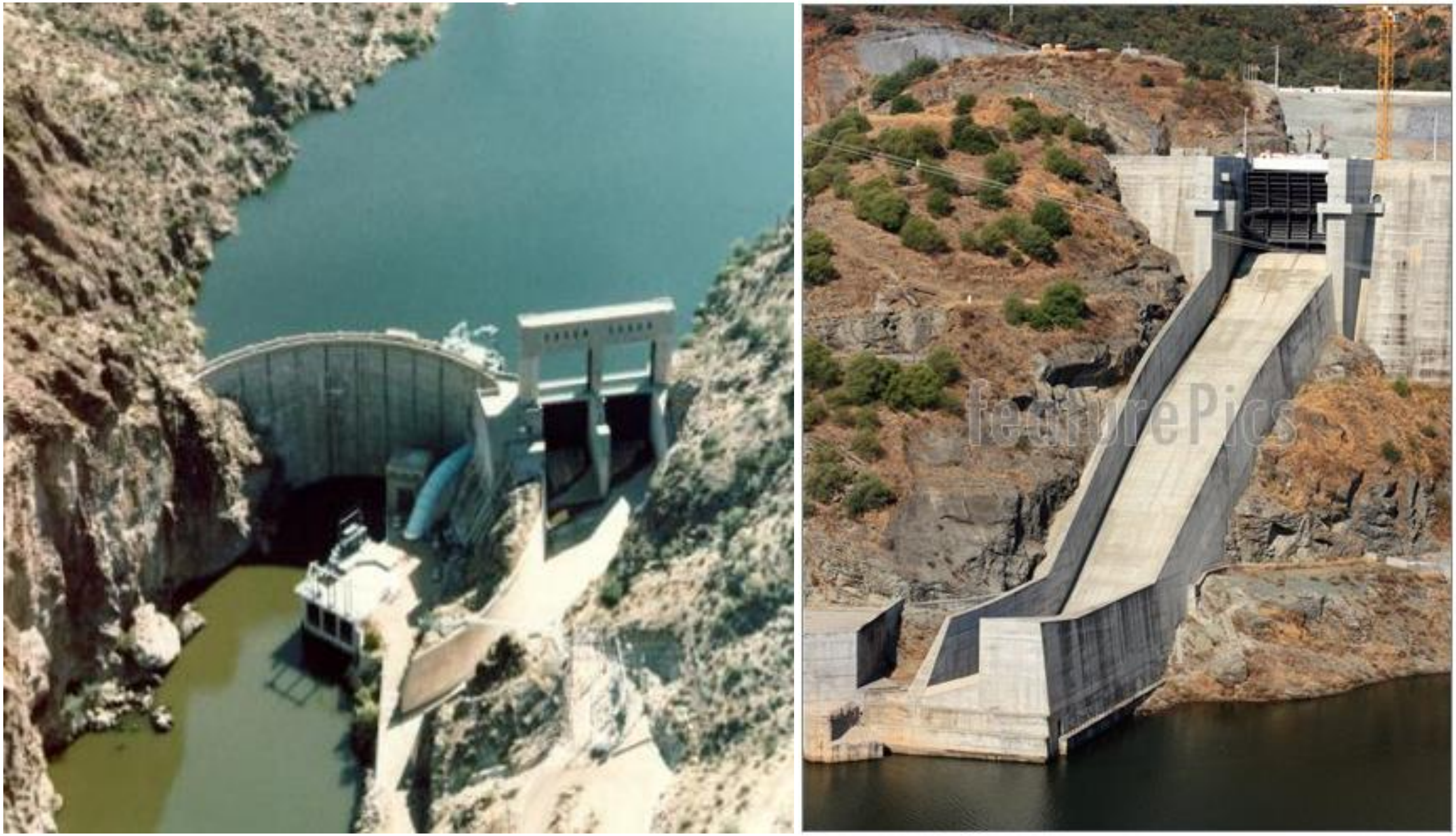


Figure 2.5: Chute Spillway

…….types of Spillway

- ***A chute spillway*** *essentially consists of a steeply sloping open channel placed along a dam abutment or through a flank or saddle.*
- *It leads the water from the reservoir to the downstream channel below the base of the channel is usually made of reinforced concrete slabs 25 to 50 cm thick.*
- *Light reinforcement of about 0.25% of concrete area is provided in the top of the slab in both directions.*
- *The chute is some times of constant width but is usually narrowed for economy and then widened near the end to reduce the discharging velocity.*
- *Expansion joints are usually provided in the chutes at intervals of about 9to 12m in either direction.*
- *The expansion joint s should be made water tight so as to avoid any under seepage and its troublesome effects.*
- *Under drains are also provided, so as to drain the water which may seep through the trough bottom and side walls.*
- *Slope of chute can conform to available topography leading to minimum excavation, but the slope should be steep enough to maintain supercritical flow to avoid unstable flow conditions.*

…….types of Spillway

d) Side Channel Spillway:

- ✓ The crest of the control weir is placed along the side of the discharge channel
- ✓ The crest is approximately parallel to the side channel at the entrance,
- ✓ Thus the flow after passing over the crest is carried in a discharge channel running parallel to the crest.
- ✓ Water flows over the crest into the narrow trough of the discharge channel opposite the weir; it turns approximately at right angle and then continues in the discharge channel.

❑ **The side channel spillway is usually constructed:**

  - ✓ In a narrow canyon where sufficient space is not available for an overflow spillway;
  - ✓ And where there is neither a suitable saddle, nor there is a availability of a wide flanks to accommodate a chute spillway.

- ➢ The crest of a side channel spillway is usually an ogee- shaped section made of concrete.
- ➢ Sometimes it consists of a flat concrete pavement laid on an earthen embankment or the natural ground surface.

…….types of Spillway

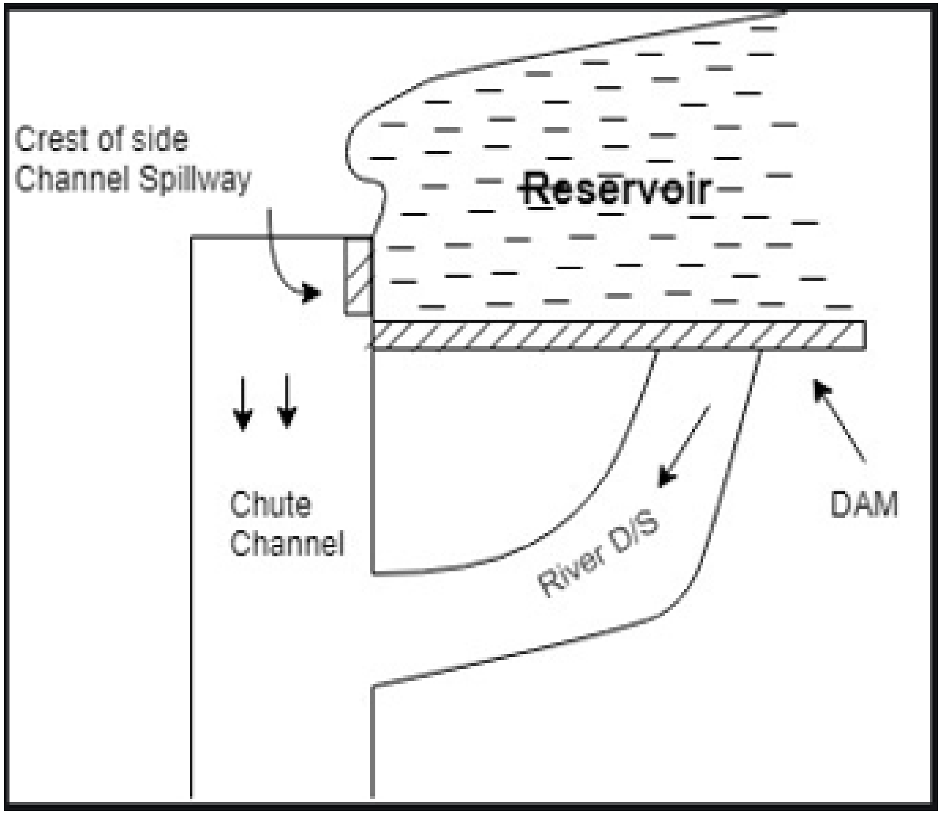


Figure 2.6-a: Layout of side channel spillway

Figure 2.6-b: A typical side channel spillway

…….types of Spillway

e) Saddle Siphon Spillway :

- ✓ *A siphon spillway is a closed conduit system formed in the shape of an inverted U, positioned so that the inside of the bend of the upper passage way is at normal reservoir storage level.*
- ✓ *Occupies less space and regulates the reservoir level within narrow limits.*
- ✓ *The initial discharge of the spillway, as the reservoir level rises above normal pool level is similar to How the over a weir .*
- ✓ *Symphonic action takes place after the air in the bend over the crest has been exhausted.*
- ✓ *Continuous flow is maintained by the suction effect due to the gravity pull of the water in the lower leg of the siphon.*
- ✓ ***Priming** : the action of the siphon spillway from the moment the water just begins to flow over the crest to the instant when the siphon duct starts running full.*

…….types of Spillway

SIPHON SPILLWAYS

- It is designed by the principle of a siphon.
- When water rises over the FRL then water start spilling.
- There is a air vent for removing the entrapped pressure from the water.

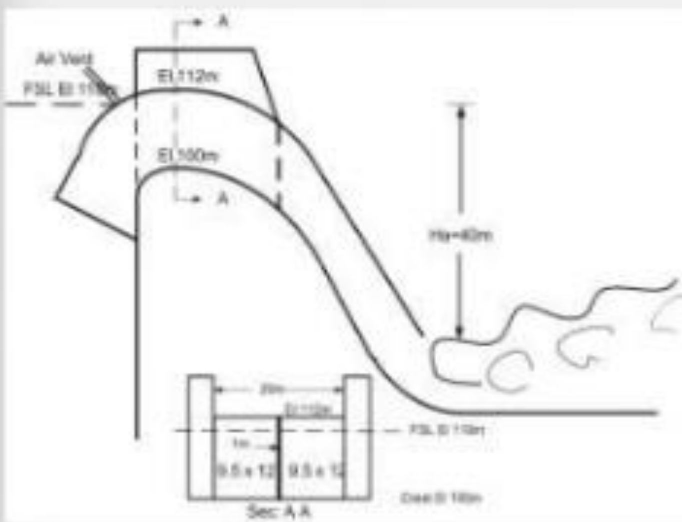


Figure 2.7: Siphon Spillway

f) Shaft Spillway :

- ✓ *Shaft spillway is one in which the water enters over a horizontally positioned lip, drops through a vertical shaft , and then flows to the downstream river channel through a horizontal or nearly horizontal conduit or tunnel.*
- ✓ *The structure is made up of three elements namely an overflow control weir, a vertical transition, and a closed discharge channel.*
- ✓ *A shaft spillway with a funnel shaped inlet is called 'Morning Glory' or Glory Hole spillway.*
- ✓ *Depending upon the type of crest, the shaft spillway can either be standard crested or flat crested.*

…….types of Spillway

Figure 2.8: Shaft Spillway

2.2 Energy Dissipaters

- *The water flowing over the spillway acquires a lot of kinetic energy by the tine it reaches near the toe of the spillway due to the conversion of potential energy in to kinetic energy.*
- *In hydraulic engineering numerous devices like stilling basins, baffled aprons, and vortex shaft etc., are known under the collective term* ***energy dissipaters.***
- ✓ *Their purpose is to dissipate hydraulic energy*
- ✓ *These are also called downstream protection works and occupies a vital place in design of spillways, weirs and barrages.*
- ✓ *The problem of designing energy dissipaters is one essentially of reducing the high velocity flow to a velocity low enough to erosion, abrasion of hydraulic structures, generation of tail water waves or scouring.*

…….energy dissipaters

- *There are several methods of dissipating the energy of shooting flow of water. They can be classified as below:*

1) ***Hydraulic Jump type Stilling Basin*** **:**
   - i. ***Horizontal apron type***
   - ii. ***Sloping apron type***
2) ***Jet Diffusion & free jet stilling basin*** **:**
   - i. ***Jet diffusion basin***
   - ii. ***Interacting jet diffusion basin***
   - iii. ***Free jet stilling basin***
   - iv. ***Hump stilling basin***
   - v. ***Impact stilling basin***
3) ***Bucket type energy dissipaters*** **:**
   - i. ***Solid roller bucket type***
   - ii. ***Slotted roller bucket type***
   - iii. ***Sky jump Bucket type (trajectory or shooting or flip)***

…….energy dissipaters

- ***Energy dissipation process can be achieved in five separate stages some of which may be combined or may be absent;***
  - *i. On the spillway surface*
  - *ii. In a free falling jet*
  - *iii. At impact into a Down stream pool*
  - *iv. In the stilling basin*
  - *v. At he out flow into a river*
- ***Factors affecting the design of energy dissipaters***
  - *i. Nature of foundation*
  - *ii. Magnitude of flood & their occurrence*
  - *iii. Velocity of flow*
  - *iv. Orientation of flow*
  - *v. Depth discharge and its relationship at the site of structure*
- ✓ ***Last factor is most important.***

1) Hydraulic Jump :

- ***Relationship of tail water curve(TWC) to Jump height curve(JHC)***
- *Hydraulic jump can form in a horizontal rectangular channel when the following relation is satisfied between the pre-jump depth (y_1) and post–jump depth (y_2).*

$$y_2 = \frac{y_1}{2}\left[-1+\sqrt{1+8\,F_r^{\,2}}\right]$$

- *Where,* y_1 *= pre-jump (initial) depth*
  y_2 *= post- jump (sequent) depth*
  Fr= Froude number of the incoming flow
- *For a given discharge intensity q over a spillway,* y_1*, will be equal to* $\mathbf{q/v_1}$; *and* v_1 *(mean velocity of incoming flow) is determined by the drop* H_1 *, if head loss is neglected.*
- *Hence, for a given discharge intensity and given height of spillway,* y_1 *is fixed and thus* y_2 *is also fixed.*
- *The values of* y_2*, corresponding to different values of q may be obtained by actual gauge discharge observations and plot of* y_2*, versus q prepared, known as Tail water Rating curve (T.W.R.C.)*

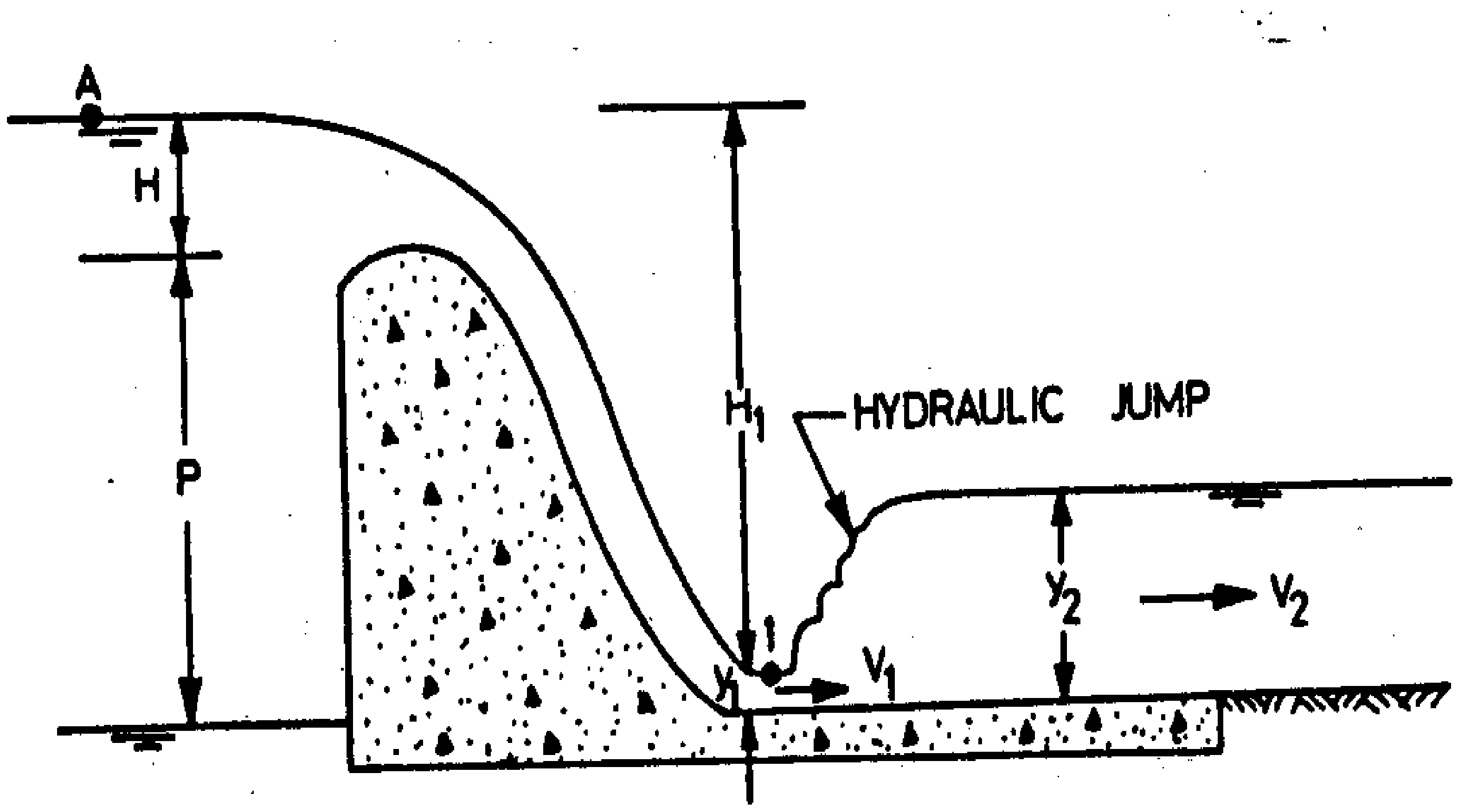


Figure 2.9: Relationship of tail water curve to jump height curve

.......energy dissipaters

- *Plot of y_2 versus q may be made which is known as jump height curve (J.H.C). If J.H.C and T.W.R.C are plotted on the same graph, five possibilities exist regarding the relative positions of these curves;*

1) *T.W.R.C. ($y_{2'}$) coinciding with y_2 curve for all discharges*
2) *T.W.R.C. ($y_{2'}$) lying above the y_2 curve for all discharges*
3) *T.W.R.C. ($y_{2'}$) lying below the y_2 curve for all discharges*
4) *T.W.R.C ($y_{2'}$) lying below the y_2 curve for smaller discharges and lying above y_2 curve for larger discharges*
5) *T.W.R.C. ($y_{2'}$) lying above the y_2 curve for smaller discharges and lying below the y_2 curve for larger discharges*

- *See your handout notes on the details of those five possibilities exist regarding the relative positions of these curves!*

2) Stilling Basin :

- ✓ *A stilling basin consists of a short, level apron at the foot of the spillway.*
- ✓ *It must be constructed of concrete to resist scour.*
- ✓ *The function of the basin is to decelerate the flow sufficiently to ensure the formation of a hydraulic jump within the basin.*
- ✓ *The jump dissipates much of the energy, and returns the flow to the subcritical state.*

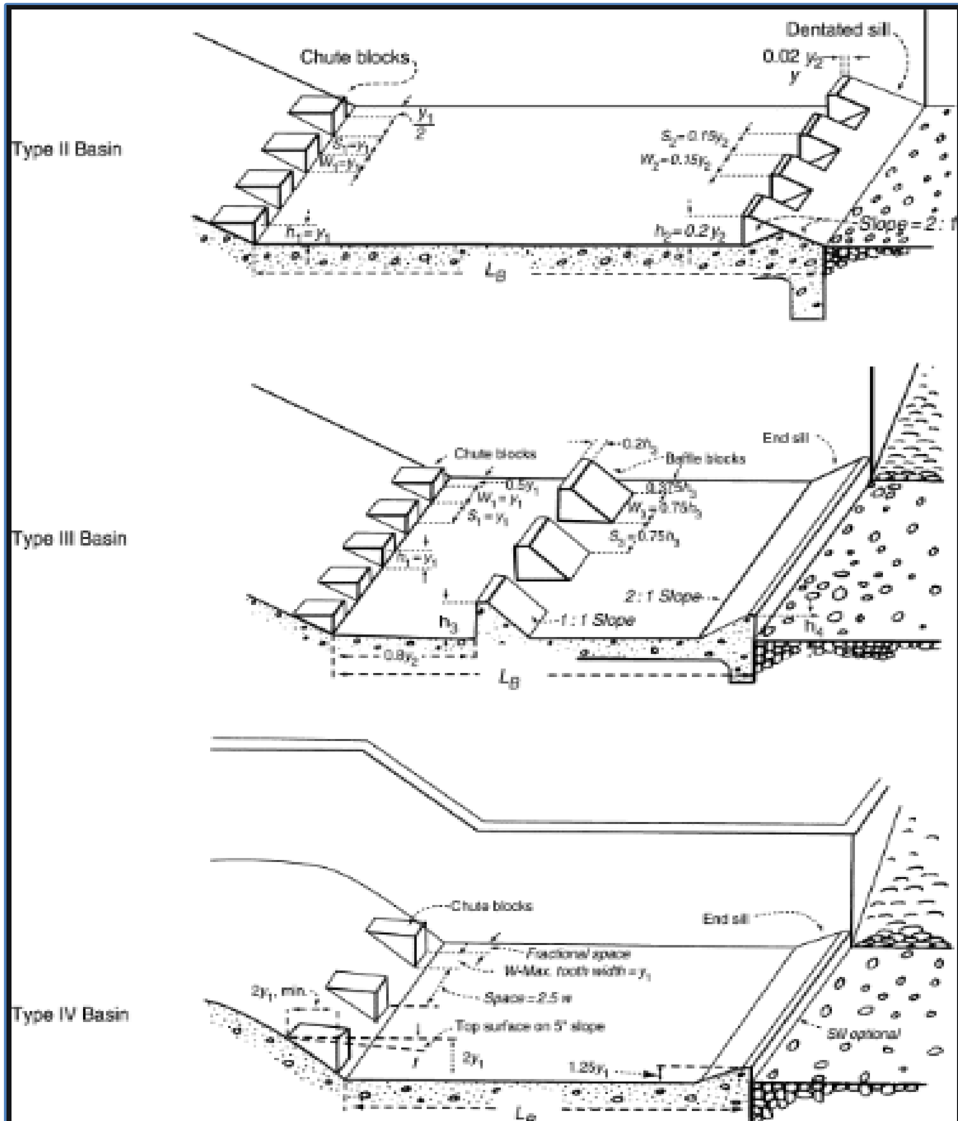
➢ ***Hydraulic Jump Stilling Basin :***

- ✓ *The passage of water from a reservoir into the downstream reach involves a number of hydraulic phenomena.*

➢ *The energy dissipation process is in the following stages, all of which may be combined.*

1) *On the spillway surface*
2) *In the stilling basin*
3) *At the outflow into the river*

…….energy dissipaters



1) *Type II Basin :Fr >4.5*

2) *Type III Basin : Fr>4.5*

3) *Type IV Basin : 2.5<Fr<4.5*

Figure 2.10: Stilling Basin

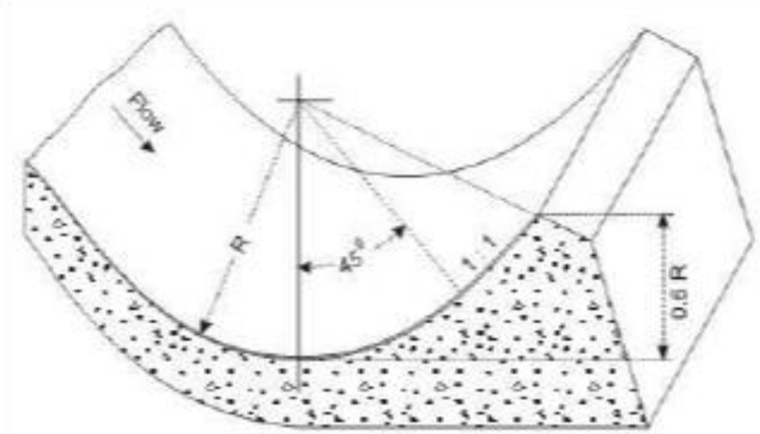
3) Bucket type energy dissipaters :

- *Bucket type energy dissipaters consist of an upturned bucket provided at the toe of the spillway.*
- *The bucket type energy dissipaters may be used only for overflow type spillways.*
- *This type of energy dissipation becomes more economical than the method of stilling basins when the Froude number F1 of the incoming flow exceeds 10,*
- *because in such cases the difference between initial and sequent depths being large a long and stilling basin would be required.*
- *Moreover the bucket type energy dissipaters may be used with any tail water condition.*
- *However, this type of energy dissipater may be used only when the river bed is composed of stiff rock.*

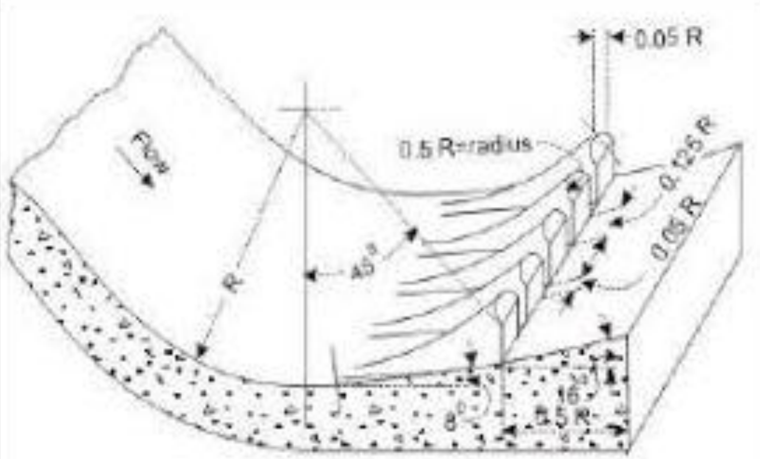
…….*energy dissipaters*

- *The bucket type energy dissipaters are of the following three types:*
  - ✓ *Solid roller Bucket*
  - ✓ *Slotted roller Bucket*
  - ✓ *Ski jump (or flip or trajectory bucket)*
- *The solid or slotted roller bucket may be used where the tail water depths are too large as compared to the sequent depths required for the formation of the hydraulic jump.*
- *Both these buckets remain submerged in tail water and hence these are also termed as submerged bucket type energy dissipaters*
- *A ski jump bucket may be used where the tail water depth, is less than sequent depth required for the formation of hydraulic jump and the river bed is composed of stiff rock.*

…….energy dissipaters



(A) SOLID BUCKET



(B) SLOTTED BUCKET

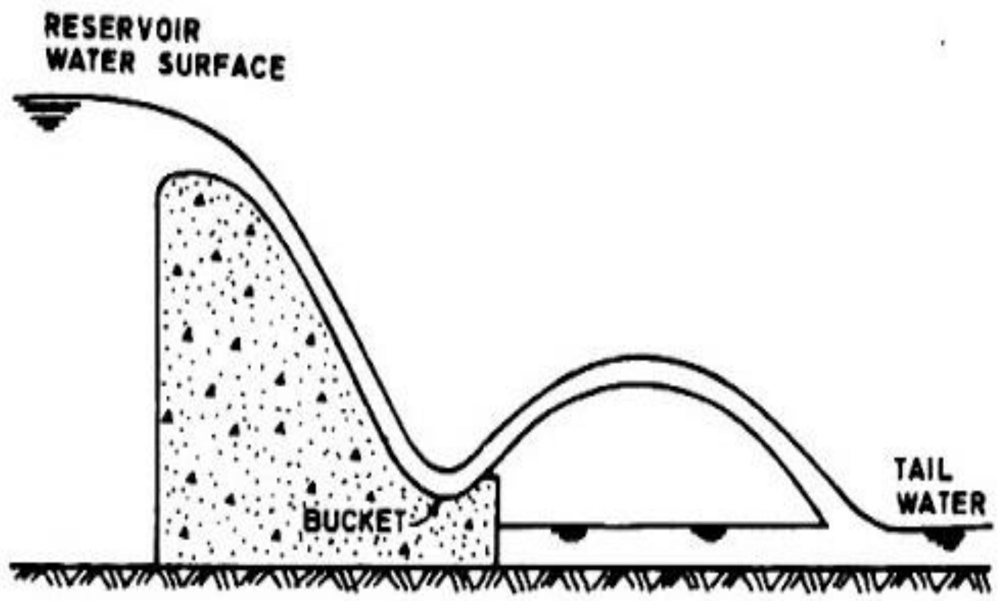


Fig. 11.6 Trajectory bucket

Figure 2.11: Bucket Type Energy Dissipaters

THANK YOU !!!

WATER IS LIFE!

NO DROP OF WATER WOULD JOIN THE SEA WITH OUT BENEFITING THE MAN!