Jump High Curve (JHC)

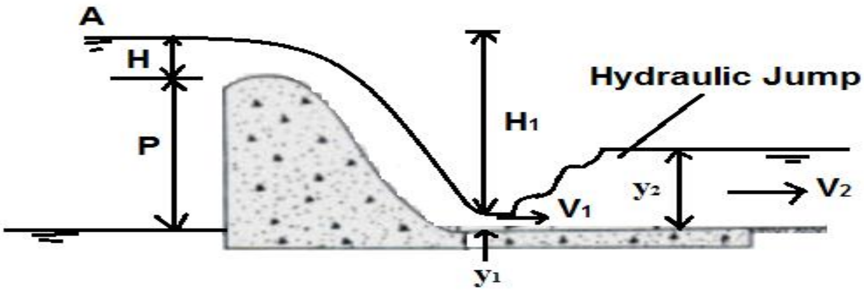
A hydraulic jump will occur in a rectangular open channel if the following equation between the initial depth y_1 and the sequent depth (post jump depth) y_1 is satisfied (See any text of Fluid Mechanics).

$$y_2 = \frac{y_1}{2}[\sqrt{1+8Fr_1^2} - 1 \text{................}(1)$$

Where:

$$Fr_1 = \frac{V_1}{\sqrt{gy_1}}$$

The mean velocity V_1 of the incoming flow for an ogee-shaped spillway can be determined by applying the Bernoulli equation to points A and 1 (Fig. below). Neglecting losses and the velocity of approach,



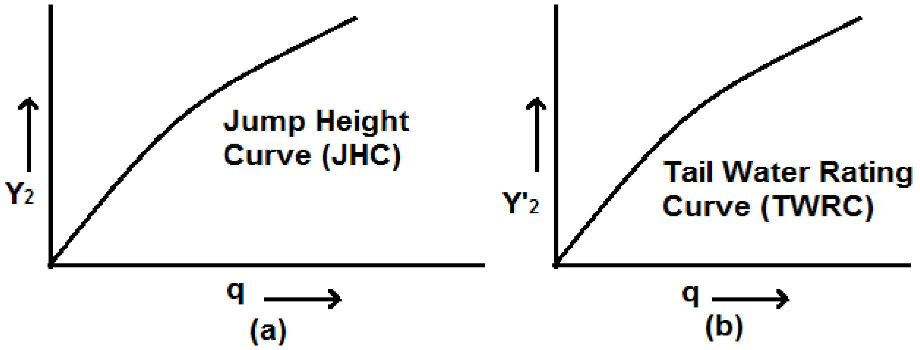
Characteristics of Hydraulic jump

$$P + H = y_1 + \frac{V_1^2}{2g} \text{.............}(2)$$

The mean velocity of flow V_1 at the toe of spillway is equal to (q/y_1). Therefore,

$$P + H = y_1 + \frac{(q/y_1)^2}{2g} \text{.............}(3)$$

By substituting the values of P,H, and q, the value of y_1 can be found from above equation. Thus the value of y_1 is determined for a given discharge intensity q over the spillway. The corresponding value of the sequent depth y_2 can be determined from Eq. b. Likewise, for different values of the discharge intensity; the values of the sequent depth y_2 can be computed. A plot is then made between the discharge intensity q as the abscissa and the corresponding value of the sequent depth y_2 as ordinate [Fig. below (a)]. The curve is known as the jump height curve (*JHC*) or jump rating curve (*JRC*).



Jump Rating Curve

Tail water rating curve

The tail water rating curve (TWRC) gives the relation between the tail water depth y_2' (i.e. the actual water depth in the river on the downstream) as ordinate and the discharge intensity q as abscissa [Fig. 2 (b)]. The actual tail water depth corresponding to any discharge intensity q depends upon the hydraulic characteristics of the river downstream. The values of y_2' corresponding to different values of q are obtained by actual stream gauging. If there is a suitable control somewhere downstream of the spillway where the depth of water and discharge can be accurately measured, the tail water depth y_2' at the spillway can also be determined by backwater computation. While plotting the tail-water rating curve, an allowance for channel retrogression, which is likely to occur, must be made.

Location of a Hydraulic Jump:

For a given discharge intensity (q), the sequent depth y_2 and the tail water depth y_2' are fixed. The location of hydraulic jump will depend upon the relative magnitudes of y_2 and y_2', and hence on the JHC and TWRC. There are five cases, depending upon the relative positions of JHC and TWRC, as discussed below.

Case-1 JHC and TWRC coincide throughout In this case; the JHC and TWRC curves coincide for all discharges [Fig. 3 (a)]. As the tail water depth y_2' is exactly equal to the sequent depth y_2 required for the formation of hydraulic jump, a perfect jump is formed just at the toe of the spillway as shown in Fig.1. However, this case indicates a highly idealized condition, which rarely occurs in practice.

Case-2 TWRC always lower than JHC In this case, the tail water rating curve (TWRC) is below the jump height curve JHC for all discharges [FIG. 3 (b)]. Such a condition occurs when the tail water is carried away quickly due to a rapid or a fall somewhere on the downstream of the spillway. In this case, the jump will be located at a point on the downstream of the toe of spillway. The high velocity jet would sweep down the toe and scour the river bed. Therefore, severe erosion may occur in the portion of the river between the spillway and the section where the hydraulic jump is formed.

Case-3 TWRC always higher than JHC In this case, the tail water rating curve is above the jump height curve for all discharges [Fig.3 (c)]. This condition usually occurs when the river cross-section on the downstream of the spillway is narrow and therefore the tail water backs up. The hydraulic jump in this case is located upstream of the toe on the spillway face. The hydraulic jump is drowned or submerged, and the high velocity jet dives under the tail water. The energy dissipation in a drowned hydraulic jump is not good.

Case-4 TWRC lower than JHC at low discharges, but higher at high discharges

In this case, the tail water rating curve is lower than the jump height curve at low discharges, but it becomes higher at a particular discharge and then remains higher than the jump height curve [Fig.3 (d)].

It is a combination of cases 2 and 3. The hydraulic jump is formed further downstream of the toe at low discharge, as in the case 2; but at higher discharges, it is drowned, as in the case 3.

Case-5 TWRC higher than JHC at low discharges, but lower at high discharges.

It is also combination of cases 3 and 2. However, in this case, at low discharges, the jump is drowned; whereas at high discharges, it is formed further downstream of the toe [Fig. 3 (e)].

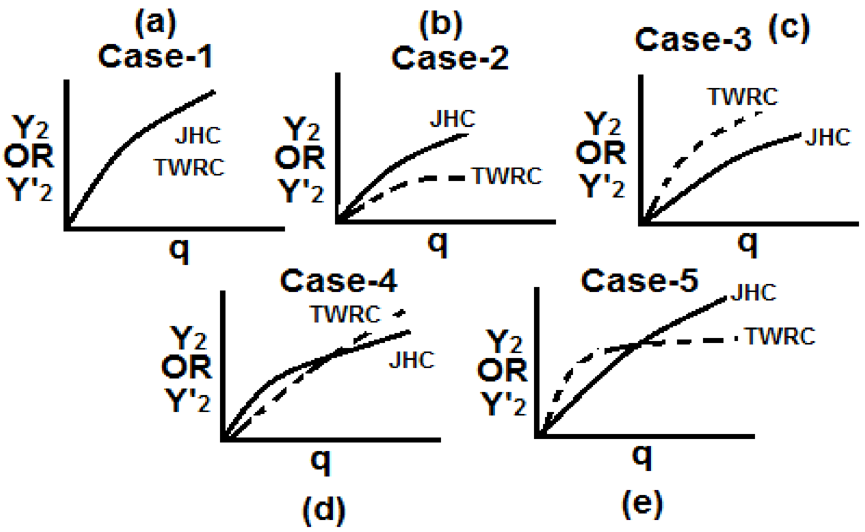


Fig.3

Measure Adopted For Dissipation of Energy:

Various measures are adopted at or near the toe of the spillway so that a perfect jump is formed for the dissipation of energy. The measures adopted will depend upon the relative positions of the tail water rating curve (TWRC) and the jump height curve (JHC). Measures are discussed separately for all the five cases discussed in the preceding section.

Case-1 In this case, the tail water rating curve and jump height curve concide for all discharges. There is no need of any special measure for the formation of hydraulic jump, as a perfect jump will always form at the toe. A horizontal apron is however provided on the downstream of the toe for the protection of the river bed (Fig.4). The length of a horizontal apron is taken equal to the maximum length of the hydraulic jump. Sometimes, baffle blocks are also constructed on the horizontal apron for dissipation of energy. However, if the baffle blocks are placed too near the toe, they may be subjected to cavitation and abrasion.

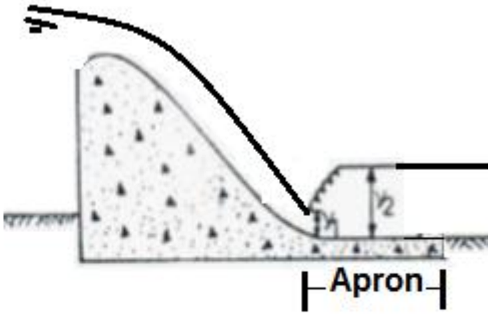


Fig.4

If may be noted that the case-1 rarely occurs in practice. However, by suitably choosing the length of the spillway, the TWRC and JHC may be made to coincide to some extent.

Case –2 As the tail water rating curve is lower than the hydraulic jump curve, the hydraulic jump forms at a certain section downstream of the toe. The following measures are adopted:

- A depressed horizontal apron is formed by excavating the river bed on the downstream of the toe of the spillway to increase the tail water depth [Fig.5 (a)]. The length and depth of the apron should be such that, for all discharges, the jump is confined to the apron. Sometimes, the depressed apron is made sloping instead of horizontal.

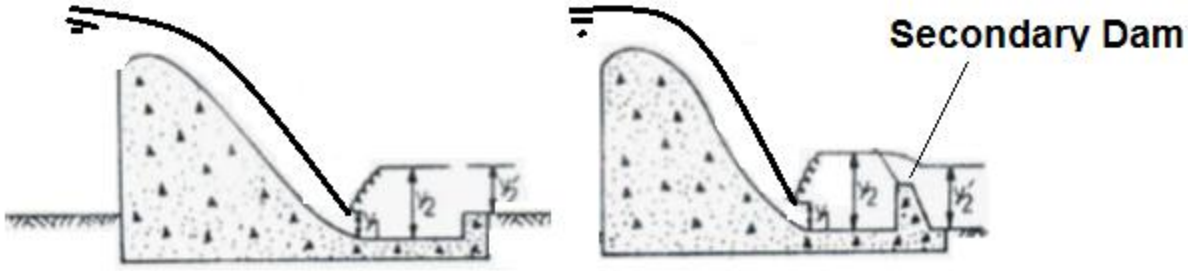


Fig.5

- (ii) A low secondary weir (or dam) is constructed downstream of toe to raise the tail water [Fig.5(b)].
- A stilling basin is formed on the downstream of toe and a sill or baffle wall is provided at the end of the stilling basin. The length and depth of the stilling basin should be sufficient to contain the hydraulic jump for all discharges.
- If the river bed consists of solid rock, a ski jump bucket can be provided which throws the water up so that it strikes the bed at a safe distance away from the toe.

Case-3 In this case, the tail water rating curve is higher than the jump height curve and the hydraulic jump is drowned, the following measures are adopted.

- A sloping apron is constructed above the river bed level extending from the spillway surface to the toe [Fig.6 (a)]. The sloping apron raises the level of the point where the hydraulic jump is formed. The slope of the apron should be such that a perfect jump will form somewhere on the sloping apron for all discharges. A large quantity of concrete is however required for the construction of the sloping apron.

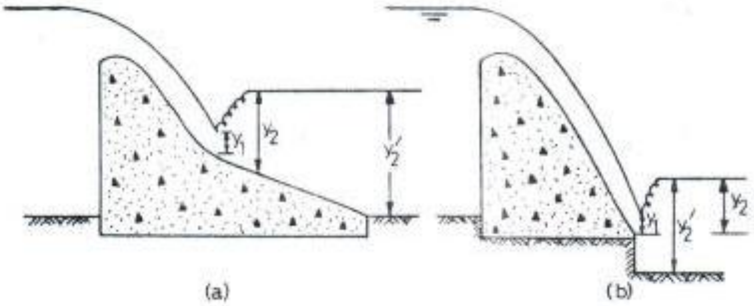


Fig.6

- The river bed may be excavated to provide a drop in the river bed to lower the tail water [Fig.6(b)].
- A roller bucket is provided near the toe, which forms rollers for the dissipation energy.

Case-4 In this case, the tail water rating curve is lower than the jump height curve at low discharges but higher at high discharges. Thus at low discharges, the hydraulic jump is shifted to a downstream point; but for high discharge, it is shifted upstream of the toe and the jump is drowned.

The following measures are adopted.

- A sloping apron is provided which lies partly above and partly below the river bed level so that a perfect jump will form in the lower portion of the apron at low discharges and in the higher portion of the apron at high discharges (Fig.7).

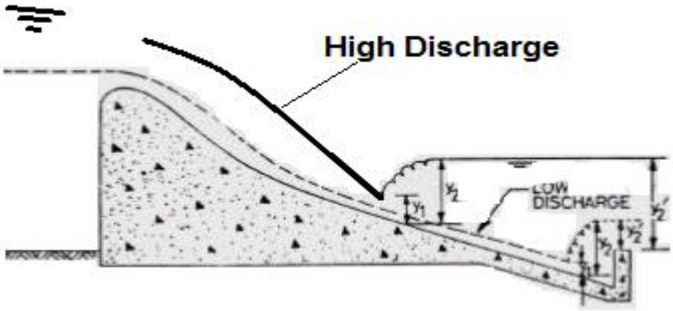


Fig.7

- A low secondary dam (or a sill) with a stilling basin is provided downstream of the toe to raise the tail water level at low discharges. This arrangement is combined with a sloping apron at a higher level for developing a jump at high discharges (Fig.8). It is found in practice that the low secondary dam has negligible effect at high discharges.
- If the velocity is not greater than 15 m/s, baffle blocks or dentated sills may be constructed to break up the jet and raise tail water level at low discharges to assist jump formation. At high discharges, the high velocity jet dives under the tail water and breaks up and the energy is dissipated in internal turbulence, though jump is not formed.

Case-5 In this case, the tail water depth is higher than jump height curve at low discharges, but lower at higher discharges. The case is similar to case 4 but the range of discharge is different. The following measures are usually adopted.

- A sloping apron is provided which is partly above the river bed level and partly below the river bed level, as in Fig. 2.7. In this case, the jump will form in the upper portion of the apron at low discharges, and in the lower portion, at high discharges.
- A low secondary dam (or a sill) with a stilling basin is provided to increase the depth at high discharges as in Fig.8. However, at low discharges, this arrangement will further increase the tail water depth, which is already quite high. Therefore, at low discharges, the jump will be more drowned and consequently, there will be less dissipation of energy. If this arrangement is not likely to cause much scour, if may be acceptable.

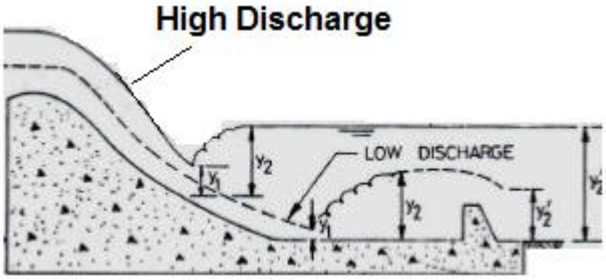


Fig.8