LECTURE NOTES ON

WATER RESOURCES ENGINEERING-II

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CIVIL ENGINEERING

UNIT-V
SPILLWAYS

Spillways are structures constructed to provide safe release of flood waters from a dam to a downstream are, normally the river on which the dam has been constructed.

Every reservoir has a certain capacity to store water. If the reservoir is full and flood waters enter the same, the reservoir level will go up and may eventually result in over-topping of the dam. To avoid this situation, the flood has to be passed to the downstream and this is done by providing a spillway which draws water from the top of the reservoir. A spillway can be a part of the dam or separate from it.

Spillways can be controlled or uncontrolled. A controlled spillway is provided with gates which can be raised or lowered. Controlled spillways have certain advantages as will be clear from the discussion that follows. When a reservoir is full, its water level will be the same as the crest level of the spillway.

This is the normal reservoir level. If a flood enters the reservoir at this time, the water level will start going up and simultaneously water will start flowing out through the spillway. The rise in water level in the reservoir will continue for some time and so will the discharge over the spillway. After reaching a maximum, the reservoir level will come down and eventually come back to the normal reservoir level.

The top of the dam will have to be higher than the maximum reservoir level corresponding to the design flood for the spillway, while the effective storage available is only up to the normal reservoir level. The storage available between the maximum reservoir level and the normal reservoir level is called the surcharge storage and is only a temporary storage in uncontrolled spillways. Thus for a given height of the dam, part of the storage - the surcharge storage is not being utilized. In a controlled spillway, water can be stored even above the spillway crest level by keeping the gates closed. The gates can be opened when a flood has to be passed.

Parameters considered in Designing Spillways

Thus controlled spillways allow more storage for the same height of the dam. Many parameters need consideration in designing a spillway. These include:

1. The inflow design flood hydro-graph
2. The type of spillway to be provided and its capacity
3. The hydraulic and structural design of various components and
4. The energy dissipation downstream of the spillway.
5. The topography, hydrology, hydraulics, geology and economic considerations all have a bearing on these decisions. For a given inflow flood hydro graph, the maximum rise in the reservoir level depends on the discharge characteristics of the spillway crest and its size and can be obtained by flood routing. Trial with different sizes can then help in getting the optimum combination.

Types of Spillways - Classification of Spillways

There are different types of spillways that can be provided depending on the suitability of site and other parameters. Generally a spillway consists of a control structure, a conveyance channel and a terminal structure, but the former two may be combined in the same for certain types. The more common types are briefly described below.

1. **Ogee Spillway:**
   The Ogee spillway is generally provided in rigid dams and forms a part of the main dam itself if sufficient length is available. The crest of the spillway is shaped to conform to the lower nappe of a water sheet flowing over an aerated sharp crested weir.
2. **Chute (Trough) Spillway**

In this type of spillway, the water, after flowing over a short crest or other kind of control structure, is carried by an open channel (called the "chute" or "trough") to the downstream side of the river. The control structure is generally normal to the conveyance channel. The channel is constructed in excavation with stable side slopes and invariably lined. The flow through the channel is super-critical. The spillway can be provided close to the dam or at a suitable saddle away from the dam where site conditions permit.

The chute spillway is ideally suited with earth-fill dams because of:

(i) The simplicity of their design and construction,

(ii) Their adaptability to all types of foundation ranging from solid rock to soft clay, and

(iii) Overall economy usually obtained by the use of large amounts of spillway excavation for the construction of embankment. The chute spillway is also suitable for concrete dams constructed in narrow valleys across a river whose bed is erodible for which ogee spillway becomes unsuitable.

3. **Side Channel Spillway**

   Side channel spillways are located just upstream and to the side of the dam. The water after flowing over a crest enters a side channel which is nearly parallel to the crest. This is then carried by a chute to the downstream side. Sometimes a tunnel may be used instead of a chute.

4. **Shaft (Morning Glory or Glory hole) Spillway**

   This type of spillway utilizes a crest circular in plan, the flow over which is carried by a vertical or sloping tunnel on to a horizontal tunnel nearly at the stream bed level and eventually to the downstream side. The diversion tunnels constructed during the dam construction can be used as the horizontal conduit in many cases. In a shaft spillway, water enters a horizontal crest, drops through a vertical or sloping shaft and then flows to the downstream river channel through a horizontal or nearly horizontal conduit or tunnel. A rock outcrop projecting into the reservoir slightly upstream of the dam would be an ideal site for a shaft spillway.

5. **Siphon Spillway**

   As the name indicates, this spillway works on the principle of a siphon. A hood provided over a conventional spillway forms a conduit. With the rise in reservoir level water starts flowing over the crest as in an "ogee" spillway. The flowing water however, entrains air and once all the air in the crest area is removed, siphon action starts. Under this condition, the discharge takes place at a much larger head. The spillway thus has a larger discharging capacity. The inlet end of the hood is generally kept below the reservoir level to prevent floating debris from entering the conduit. This may cause the reservoir to be drawn down below the normal level before the siphon action breaks and therefore arrangement for de-priming the siphon at the normal reservoir level is provided.

6. **Free Over-Fall Spillway:**

   As the name of the spillway indicates, the flow drops freely from the crest of a free over-fall spillway. At times, the crest is extended in the form of an overhanging lip to direct small discharges away from the downstream face of the overflow section. The underside of the falling water jet is properly ventilated so that the jet does not pulsate. Such a spillway is better suited for a thin arch dam whose downstream face is nearly vertical.Since the flow usually drops into the stream bed, objectionable scour may occur in some cases and a deep plunge pool may be formed. If erosion cannot be tolerated, a plunge pool is created by constructing an auxiliary dam downstream of the main dam. Alternatively, a basin is excavated and it is provided with a concrete apron.When tail water depth is sufficient, a hydraulic jump would form when the water jet falls upon a flat apron. Free over-fall spillways are restricted only to situations where the hydraulic drop from reservoir level to tail water level is less than about six metres.

7. **Tunnel Spillway:**

Tunnel spillway discharges water through closed channels or tunnels laid around or under a dam. The closed channels can be in the form of a vertical or inclined shaft, a conduit constructed in an open cut and backfilled with earth materials, or a horizontal tunnel through earth or rock.

In narrow canyons with steep abutments as well as in wide valleys with abutments far away from the stream channel, tunnel spillways may prove to be advantageous. In such situations, conduit of the spillway can be easily located under the dam near the stream bed.

ENERGY DISSIPATORS

Bucket type energy dissipators This type of energy dissipators includes the following: 1. Solid roller bucket 2. Slotted roller bucket 3. Ski jump (Flip/Trajectory) bucket The shapes of the different types of bucket-type stilling basins have been given in section 4.8.14. Usually the hydraulic jump type stilling basins and the three types of bucket-type energy dissipators are commonly used in conjunction with spillways of major projects. The detailed designs of these are dealt in subsequent sections. Since energy dissipators are an integral part of a dam’s spillway section, they have to be viewed in conjuction with the latter. Two typical examples have been shown in Figures 45 and 46, though it must be remembered that any type of energy dissipator may go with any type of spillway, depending on the specific site conditions.

As water passes over a spillway and down the chute, potential energy converts into increasing kinetic energy. Failure to dissipate the water's energy can lead to scouring and erosion at the dam's toe (base). This can cause spillway damage and undermine the dam's stability

Flip bucket

At the base of a spillway, a flip bucket can create a hydraulic jump and deflect water upwards.

Ski jump

A ski jump can also direct water horizontally and eventually down into a plunge pool or two ski jumps can direct their water discharges to collide with one another.

Stilling basin

Third, a stilling basin at the terminus of a spillway serves to further dissipate energy and prevent erosion. They are usually filled with a relatively shallow depth of water and sometimes lined with concrete. A number of velocity-reducing components can be incorporated into their design to include chute blocks, baffle blocks, wing walls, surface boils or an end sill.

SPILLWAY CREST GATES

Stop-logs/flash boards

A log, plank cut timber, steel or concrete beam fitting into end grooves between walls or piers to close an opening under unbalanced conditions, usually handled or placed one at a time Modern day stop-logs consist of steel frames that may be inserted into grooves etched into piers and used during repair / maintenance of a regular gate .The stop logs are inserted or lifted through the grooves using special cranes that move over the bridge.

Vertical lift gates

These are gates that moves within a vertical groove incised between two piers .The vertical lift gates used for controlling flow over the crest of a hydraulic structure are usually equipped with wheels, This type of gate is commonly used for barrages but is nowadays rarely used for dam spillways. Instead, the radial gates (discussed next) are used for dams. This is mostly due to the fact that in barrage spillways, the downstream tailwater is usually quite high during floods that may submerge the trunnion of a radial gate.

Radial gates

These are hinged gates, with the leaf (or skin) in the form of a circular arc with the centre of curvature at the hinge or trunnion .The hoisting mechanism shown is that using a cable that is winched up by a motor placed on a bridge situated above the piers. Another example of radial gate may be seen in Figure 2, where a hydraulic hoisting mechanism is shown.

Ring gates

A cylindrical drum which moves vertically in an annular hydraulic chamber so as to control the peripheral flow of water from reservoir through a vertical shaft

Stoney gate

A gate which bears on roller trains which are not attached to the gate but in turn move on fixed tracks. The roller train travels only half as far as the gate .

Sector gates

A pair of circular arc gates which are hinged on vertical axis in a lock .These gates are used in navigation locks where ships pass from a reservoir with a higher elevation to one with a lower elevation.

Inflatable gates

These are gates which has expandable cavities. When inflated either with air or water it expands and forms an obstruction to flow thus effecting control .Though these gates have not been commonly used in our country, it is used quite often in many other countries because of its simplicity in operation – However, they suffer from possible vulnerability from man-made damages.

Falling shutters

Low head gates installed on the crest of dams, barrages or weirs which fall at a predetermined water level. Generally these are fully closed or fully open, that is, fallen flat, which are shown to operate using a hoist. However, in some weirs, falling shutters have been provided earlier that are manually operated. In many of the older weir installations constructed during the preindependence period were equipped with falling shutters, some of which are still in use today

Float operated gates

A gate in which the operating mechanism is actuated by a float that is pre-set to a predetermined water level .These may be used as escape in canals or even in dams to release water if it goes above a certain level considered dangerous for the overall safety of the project.

Two-tier gates

A gate used in two leaves or tiers which can be operated separately, but when fully closed act as one gate. These types of gates are used to reduce the hoist capacity or the lift of the gate. Such a gate has been installed in the canal head regulator of the Farakka barrage.

Vertical gate

Similar to that used for crest type gates ,but usually for deep-seated purposes like controlling flow to hydropower intake either the ones with roller wheels ,or the sliding-type without any wheels are used.

Deep-seated radial gates

These are low level radial outlet gates. These gates have sealing on top apart from on all sides. They are located at sluices in the bottom portion of dam .The hoisting arrangement is usually at the top but could also be provided near the elevation of top seal to reduce hoist stroke.

PROFILE OF OGEE SPILLWAY

The overflow type spillway has a crest shaped in the form of an ogee or S-shape (Figure 5). The upper curve of the ogee is made to conform closely to the profile of the lower nappe of a ventilated sheet of water falling from a sharp crested weir (Figure 6). Flow over the crest of an overflow spillway is made to adhere to the face of the profile by preventing access of air to the underside of the sheet of flowing water. Naturally, the shape of the overflow spillway is designed according to the shape of the lower nappe of a free flowing weir conveying the discharge flood. Hence, any discharge higher than the design flood passing through the overflow spillway would try to shoot forward and get detached from the spillway surface, which reduces the efficiency of the spillway due to the presence of negative pressure between the sheet of water and spillway surface. For discharges at designed head, the spillway attains near-maximum efficiency. The profile of the spillway surface is continued in a tangent along a slope to support the sheet of flow on the face of the overflow. A reverse curve at the bottom of the slope turns the flow in to the apron of a sliding basis or in to the spillway discharge channel. An ogee crest apron may comprise an entire spillway such as the overflow of a concrete gravity dam (Figure 7), or the ogee crest may only be the control structure for some other type of spillway

Crest shape The ogee shaped crest is commonly used as a control weir for many types of spillwaysOverflow (Figure 5), Chute (Figure 8), Side Channel (Figure 12) etc. The ogee shape which approximates the profile of the lower nappe of a sheet of water flowing over a sharp-crested weir provides the ideal form for obtaining optimum discharges. The shape of such a profile depends upon the head, the inclination of the upstream face of the flow section, and the height of the overflow section above the floor of the entrance channel (which influences the velocity of approach to the crest). The ogee profile to be acceptable should provide maximum possible hydraulic efficiency, structural stability

Ogee crested control structures are also sensitive to the upstream shape and hence, three types of ogee crests are commonly used and shown in Figure 21. These are as follows:

1. Ogee crests having vertical upstream face
2. Ogee crests having inclined upstream face
3. Ogee crests having over hang on up stream face

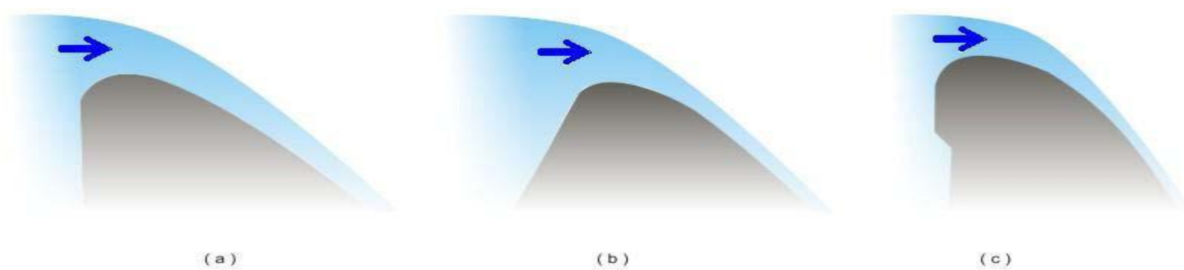

FIGURE 21. Ogee crest control weirs with
(a) Vertical upstream face
(b) Inclined upstream face
(c) Overhangs on the upstream

However, the same general equations for the up stream and down stream quadrants are applicable to all the three cases, as recommended by the Bureau of Indian Standards code IS: 6934-1998 "Hydraulic design of high ogee over flow spillways-recommendations" and are outlined in the following paragraphs.

1. Ogee crests with vertical upstream face

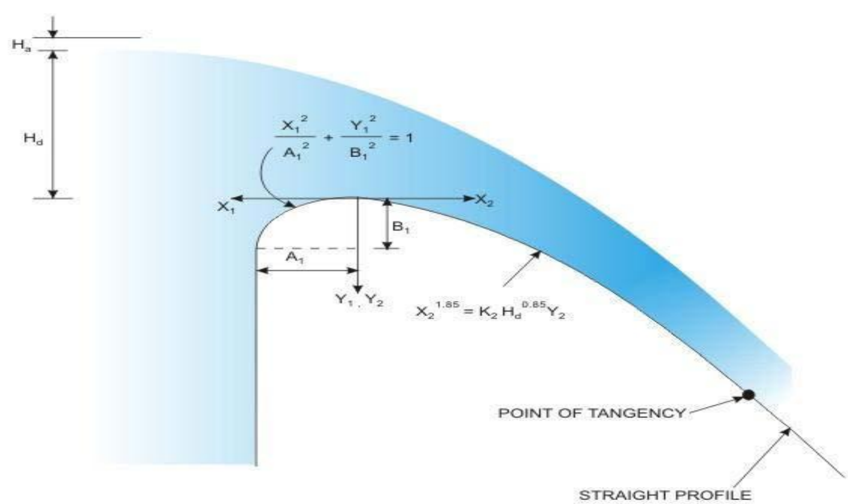

FIGURE 22. Ogee crest shape with vertical upstream wall . Coefficients to be determined from Figure 21

The downstream profile of the ogee crest may confirm to the following equation:

$$x^{1.85} = K \; H^{0.85} Y$$

2. *Ogee crests with sloping up stream face*

In this case, the desired inclination of the upstream face is made tangential to the same elliptical profile as provided for a crest with a vertical face. The downstream face equation remains unchanged.

3. *Ogee crests with overhang*

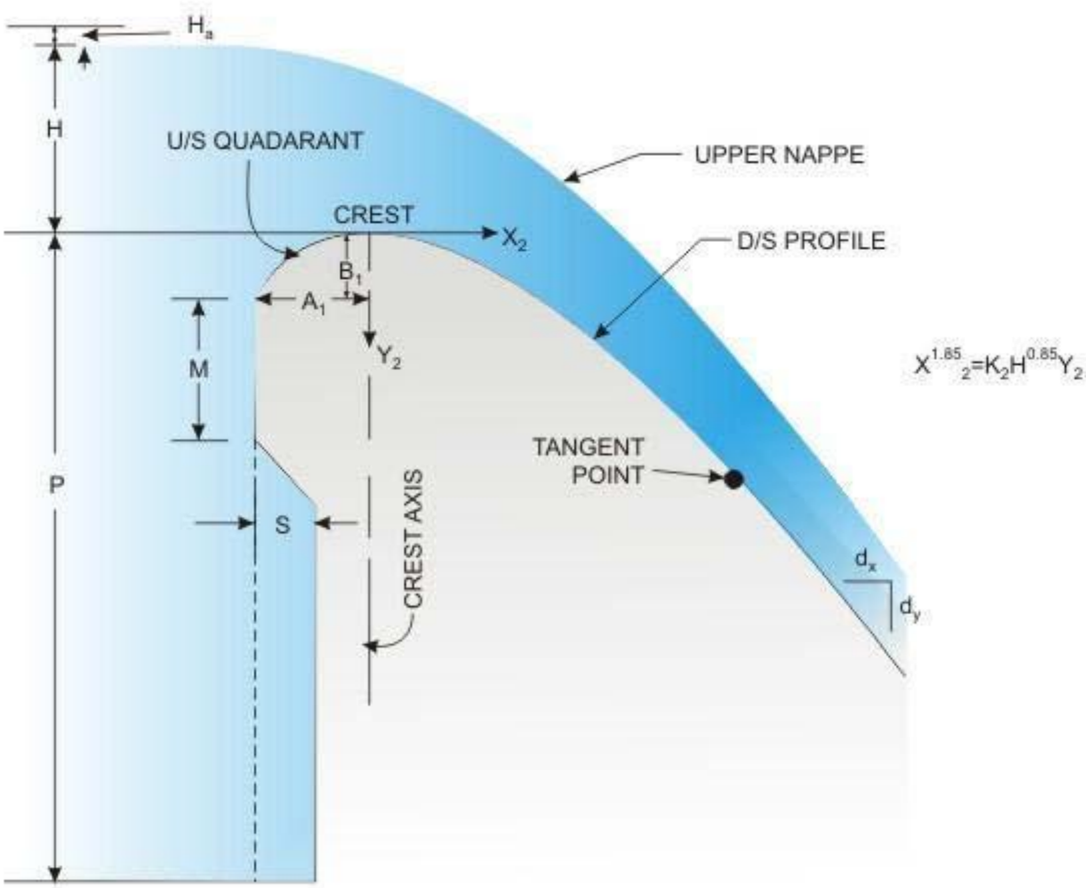

FIGURE 24. Overhang details of ogee crest