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CRITERIA FOR HYDRAULIC DESIGN OF SLUICES IN CONCRETE AND MASONRY DAMS

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0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 20 November 1985, after the draft finalized by the Spillways Including Energy Dissipators Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Sluices are provided in the body of the dam to release regulated supplies of water for a variety of purposes which are briefly listed below:

a) River diverson;

b) Irrigation;

c) Generation of hydro-electric power;

d) Water supply for municipal or industrial uses;

e) To pass the flood discharge in conjunction with the spillway;

f) Flood control regulation to release water temporarily stored in flood control storage space or to evacuate the storage in anticipation of flood inflows;

g) Depletion of the reservoir in order to facilitate inspection of the reservoir rim and the upstream face of the dam for carrying out remedial measures, if necessary;

h) To furnish necessary flows for satisfying prior right uses downstream; and

j) For maintenance of a live stream for abatement of stream polation, preservation of aquatic life, etc.

0.3 The flow through a sluice may be either pressure flow or free flow along its entire length or a combination of pressure flow in part length and free flow in the remainder part.

0.4 In the formulation of this standard due weightage has been given to International co-ordination among standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. This has been met by deriving assistance from the following publication:

EM-1110-2-1602 Hydraulic design of reservoir outlet works, U.S. Army Corps of Engineers.

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1. SCOPE

1.1 This standard lays down the criteria for hydraulic design of sluices in concrete and masonry dams.

1.2 It does not cover the hydraulic design of openings for penstocks.

2. TYPES OF SLUICES

2.1 Sluices may be classified depending upon their purpose, their hydraulic operation or their alignment. The first two types have been described in **0.2** and **0.3**. Based upon their alignment, sluices may be classified as under.

2.1.1 *Straight Barrel Sluice* — The barrel of this sluice is kept nearly horizontal between the entry and exit transitions (*see* Fig. 1a). This sluice has the advantage of having minimum length due to which lesser friction losses take place.

2.1.1.1 Horizontal sluices are generally used under the following conditions:

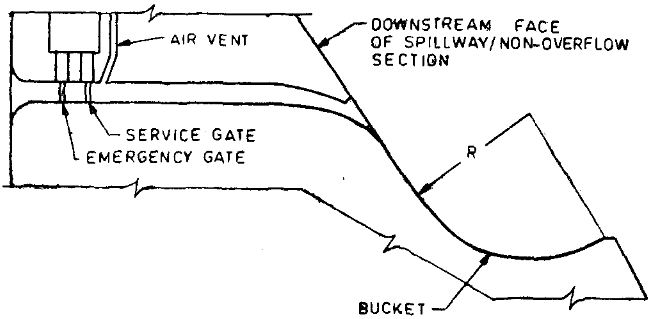
a) When the sluices are drowned at the exit; and

b) When they have to be located at or near the river bed level, for example, in construction sluices for river diversion.

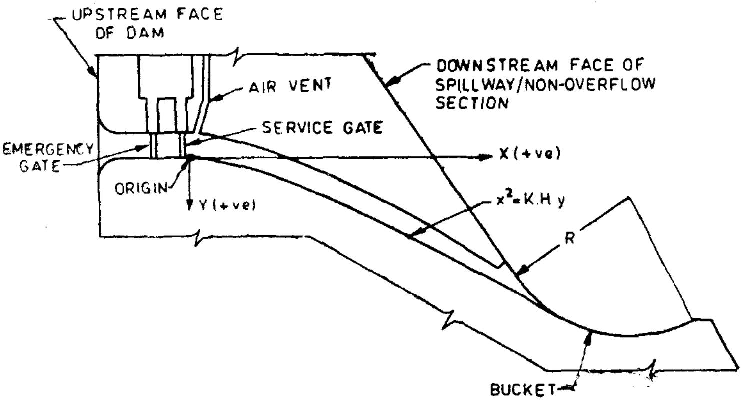
2.1.1.2 The width of the sluice barrel is generally kept uniform throughout the length except in the entry transaction.

2.1.1.3 If the sluice is designed for pressure flow conditions then the top profile of the sluice may be given a slight constriction in accordance with **3.4.1**. On the other hand, if free flow conditions prevail then no such constriction is required.

2.1.2 *Trajectory Type Sluice* — The barrel of this sluice is generally kept horizontal downstream of the entry transition up to the service gate to facilitate resting of the latter. Beyond the service gate the bottom of the sluice conforms to the parabolic path of the trajectory and meets the downstream face of the dam section tangentially (*see* Fig. 1).



1A Straight Barrel Sluice



1B Trajectory Type Sluice

FIG. 1 TYPE OF SLUICE

2.1.2.1 The equation of the bottom profile after the service gate shall be:

$$x^2 = k.H.y$$

where

k = coefficient (A value of about 4 is generally used depending on the distance available to accommodate this curve in the reach between the service gate and the downstream face of the spillway/non-overflow section).

H = head at the centre line of the gate opening.

x, y = co-ordinates of any point on the profile (*see* Fig. 1b).

In case the trajectory profile defined by the above equation would not permit meeting the downstream face tangentially, the adjustment of profile may be effected alternatively by introducing a small tilt in the co-ordinate axes through a small transition zone just downstream of service gate.

2.1.2.2 The width of the sluice is kept uniform throughout the length except in the entry transition.

2.1.2.3 The height of the sluice is gradually reduced from downstream of the service gate to the exit in order to ensure pressure flow in the sluce. The constriction shall be in accordance with **3.4.1**.

3. DESIGN CONSIDERATIONS

3.1 Fixation of Size and Number of Sluices — The size and number of sluices required to pass the desired discharge at a predetermined reservoir elevation may be found based on the type of flow required to be maintained in the sluice, that is, either pressure flow or free flow or a combination of both. The sluice dimensions shall be so proportioned as to provide a minimum of two number of sluices but simultaneously to permit inspection and repair of the same.

3.1.1 *Pressure Flow in the Sluice* — For pressure flow conditions, the following basic relation may be used:

$$H_T = h_L + h_V$$

where

H_T = total head needed to overcome various head losses to produce discharge;

h_L = the cumulative losses of the system in terms of velocity head; and

h_V = velocity head at the sluice exit.

For a free discharging sluice H_T shall be measured from the reservoir water surface to the centre of the sluice at the exit. If the outflowing jet is supported on a downstream floor the head shall be measured to the point of greatest contraction and if the sluice is submerged at the exit then the head shall be measured to the tail water level. The losses shall consist of trashrock losses, entrance losses, friction losses, gate or valve losses, bend losses, expansion and contraction losses. They may be expressed in terms of velocity head. The above equation may be re-written in a simplified form as follows:

$$H_T = K_L . \frac{v^2}{2\,g}$$

$$\text{Then } Q = a_1 \sqrt{\frac{2g\, H_T}{K_L}}$$

where

K_L = constant, which is obtained after considering all the losses in the system;

v = velocity in the portion of the sluice where the cross sectional area is a_1;

a_1 = cross sectional area of the sluice, where the velocity is V;

g = acceleration due to gravity; and

Q = discharge to be passed through the sluice at a predetermined reservoir elevation.

3.1.2 *Free Flow (Open Channel Flow) in the Sluice*

3.1.2.1 When open channel flow is controlled by regulating gates, the following relation shall be used.

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

where

Q = discharge to be passed through the sluice;

g = acceleration due to gravity;

L = width of the sluice;

H_1, H_2 = heads (including the velocity of approach) up to the bottom and top of the gate, respectively; and

C = coefficient of discharge (*see* Table 1).

TABLE 1 COEFFICIENT OF DISCHARGE, *C*, FOR CONDUIT ENTRANCES
(*Clause* 3.1.2.1)

Particulars	Coefficient of Discharge, *C*		
	Maximum	Minimum	Average
Gate in thin wall—unsuppressed contraction	0·70	0·60	0·63
Gate in thin wall—bottom and sides suppressed	0·81	0·68	0·70
Gate in thin wall—corners rounded	0·95	0·71	0·82

3.1.2.2 When there is high tail water either due to canal water supply level or downstream ituences in the streambed, the regulating gate opening may be either partly or entirely submerged. For the unsubmerged part of the gate opening the discharge shall be calculated according to **3.1.2.1**. However, for the submerged part of the gate opening discharge shall be calculated by the following relation:

$$Q = C.A. \sqrt{2gH}$$

where

Q = discharge through submerged portion of the gate opening,

A = area of the submerged portion of the sluice,

H = difference between upstream and downstrem water levels, and

C = coefficient of discharge for submerged orifice or tube flow. (Its value generally varies between 0·62 to 0·81).

3.1.3 For calculating the size of the sluice and plotting the water surface profile maximum losses should be considered. However, minimum losses shall be considered for the design of the energy dissipation arrangements for the flow through sluices.

3.2 Shape of Sluices — Generally rectangular gates are preferred. Therefore, the shape of sluices is also normally kept rectangular. Generally the height of the sluice is kept as 1·5 times the width. However, circular shapes may also be provided when small diameter openings (less than one metre) are required to be regulated by valves.

3.3 Entry Transitions — The efficient functioning of a sluice depends to a great extent on the design of its entry transitions. To obtain the best inlet efficiency, the shape of the entrance should simulate that of a jet discharging into air. A bell mouth entrance which conforms to or slightly encroaches upon the free jet profile will provide the best entrance shape. Elliptical entrances have been found to be suitable.

3.3.1 For a rectangular or square sluice the entrance transition may be defined by the following equation

$$\frac{x^2}{D^2} + \frac{y^2}{(0{\cdot}33\ D)^2} = 1$$

where D is the vertical height of the sluice (downstream of the entrance curve) for top and bottom curves and the horizontal width of the sluice (downstream of the entrance curve) for the side curves.

3.3.2 For a rectangular entrance with bottom placed even with upstream floor, the side curves at the entrance may be defined by the above equation. However, the top contraction curve may be given by the following equation:

$$\frac{x^2}{D^2} + \frac{y^2}{(0{\cdot}67\ D)^2} = 1$$

where D is the vertical height of the sluice downstream of the entrance transition.

3.3.3 For a circular entrance the entry transition is given by the following equation:

$$\frac{x^2}{(0{\cdot}5\ D)^2} + \frac{y^2}{(0{\cdot}15\ D)^2} = 1$$

where D is the diameter of the sluice downstream of the entrance transition.

3.4 Exit of the Sluice — The exit of the sluice shall be tangential to either the downstream face of the spillway/non-overflow section or the bucket or it may be upturned (*see* Fig. 2).

3.4.1 In order to ensure the pressure flow conditions throughout the length of the sluice and to avoid negative pressures the section of the sluice should be constricted at the exit so as to give reduced cross-sectional area commensurate with the increase in the velocity of flow. A constriction of 10 to 15 percent in flow area is generally found adequate by effecting constriction in the roof profile only.

3.4.2 When the exit of the sluices is not drowned, the top profile of the sluices is given a small turn of about 1·0 to 1·5 metres normal to the downstream face of the spillway/non-overflow section. This helps in the aeration of the sluice (*see* Fig. 2).

3.4.3 In case of an upturned exit, the shape and dimensions of the profile may be best worked out on the basis of the model studies. It has to be used with caution in spillway/non-overflow sections because the flow from the sluice may damage the energy dissipation arrangements of the spillway or the downstream face of the spillway/non-overflow section, if it falls over them. Alternatively, a jet disperser of suitable shape, based on model studies may be provided.

3.4.4 In case the sluices are located in a spillway section, then no separate energy dissipation arrangements are necessary. However, if they are provided in a non-overflow section, then separate energy dissipation arrangements may have to be provided.

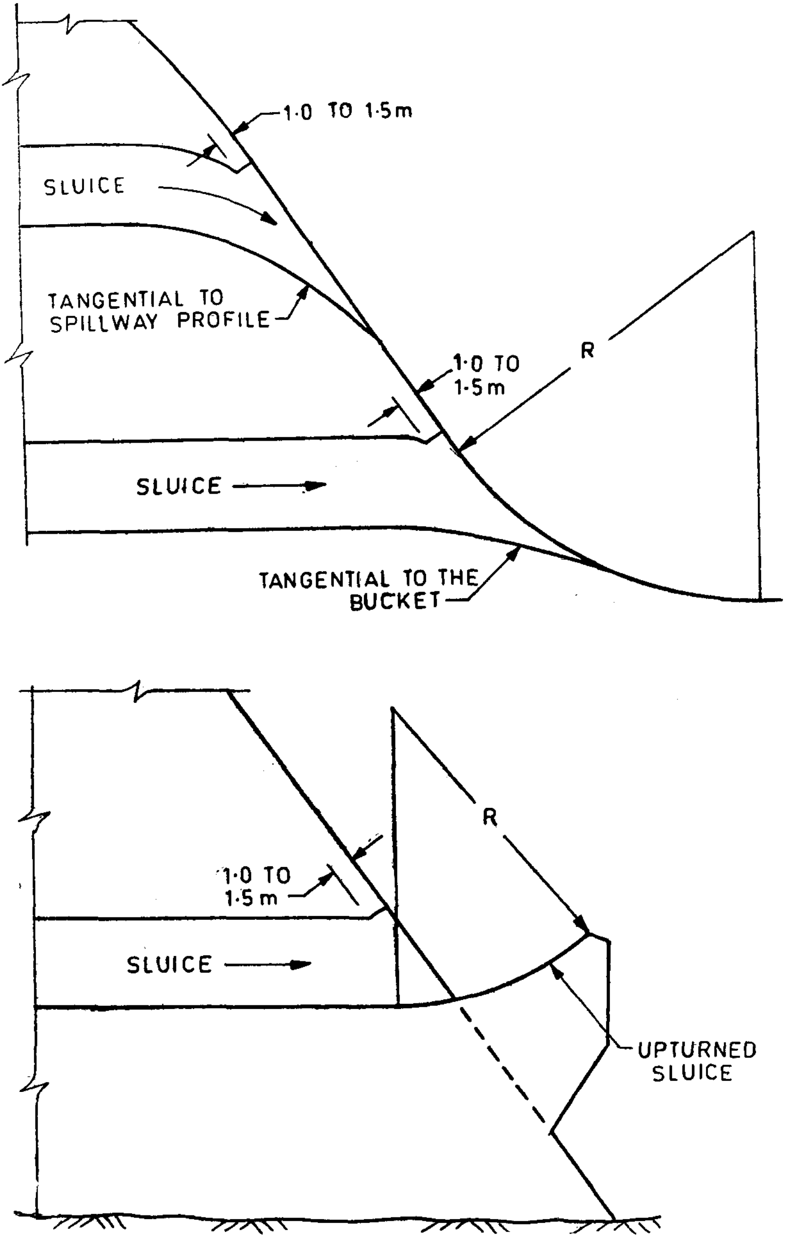
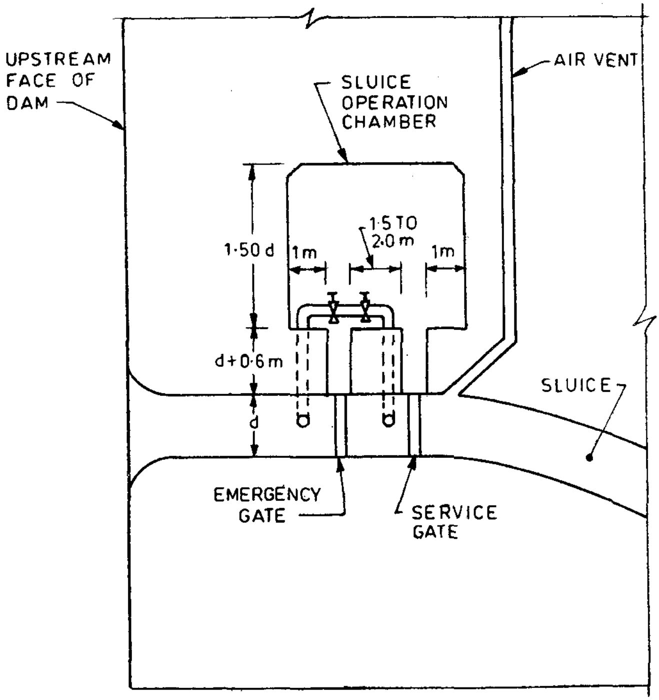


FIG. 2 TYPES OF SLUICE EXIT

3.4.5 In case the spillway and sluice run together then either sluice eyebrow deflectors may be provided on the exit of the sluice or aeration be provided at the exit end.

3.5 Control Devices — The flow through sluices is controlled by either gates or valves. Generally, two sets of gates, that is, emergency and service gates are provided. In case of construction sluices, the flow is generally uncontrolled and only stoplogs are provided for the eventual plugging of the sluices. Where the construction sluices are required to be closed under flowing water, provision of emergency gates may be considered.

3.5.1 The control (service) gates shall be located as far upstream as possible. The operation and servicing may be done from operation galleries/chambers in the dam (*see* Fig. 3). In order to repair the gates without emptying the reservoir should they become inoperative, the usual practice is to install a guard or emergency gate further upstream in the sluices. These emergency gates may be placed either at the entrance or inside the sluice and operated from galleries.



NOTE — The above dimensions are suggestive only. These may be changed to meet local requirements.

FIG. 3 A TYPICAL ARRANGEMENT WITH GATES OPERATION FROM OPERATION CHAMBER (DETAILS OF GATES AND HOISTS NOT SHOWN)

3.5.2 Sometimes when the sluice have to be located at high levels near the crest in the spillway section, where it is not possible to provide a gallery for gates operation, the sluices may also be located in thick spillway piers in which the gates are operated from the top of pier (*see* Fig. 4).

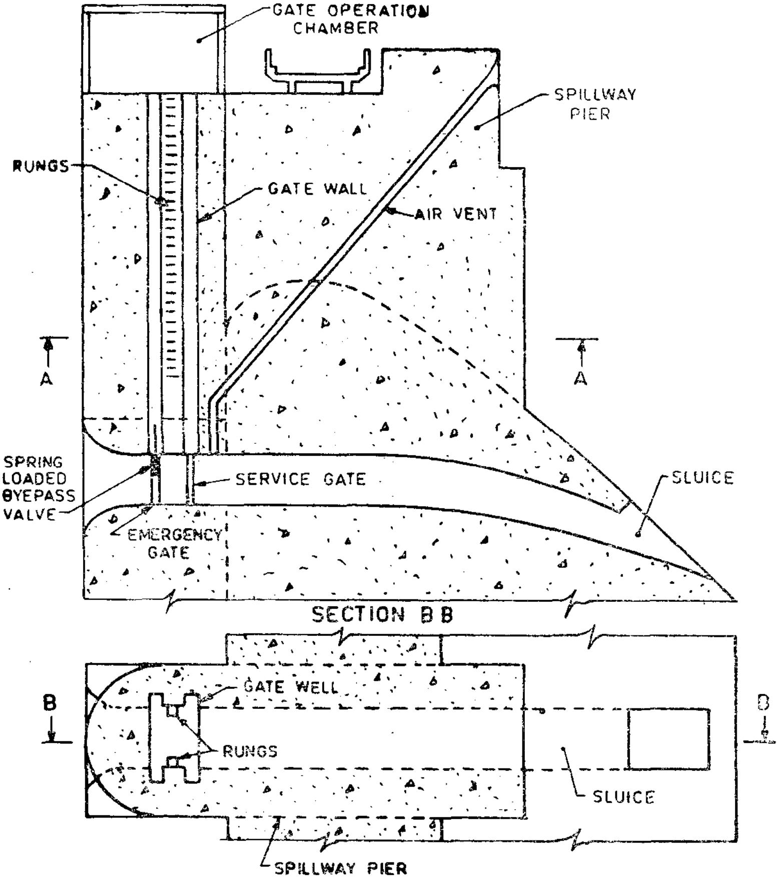


FIG. 4 TYPICAL DETAILS OF SLUICE LOCATED IN THICK SPILLWAY PIER

3.5.3 In case of high heads (more than 30 m) gate controls may also be located near the downstream end of the sluice to minimize possibilities of cavitation.

3.5.4 For better slot hydraulics, the gate slots should be as small as practicable and adequately streamlined.

3.6 Air Vents — Air vents of suitable size should be provided downstream of the control gates to supply air and thereby avoid or minimize cavitation damages. The air demand for calculating the size of air vent may be calculated from the following formulae:

i) For hydraulic jump formation in the conduit

$$\beta = 0{\cdot}006\,6\ (F_{1c} - 1)^{1{\cdot}4}$$

ii) For spray flow

$$\beta = 0{\cdot}20\ F_{1c}$$

iii) For free flow

$$\beta = 0{\cdot}09\ F_{1c}$$

where

$$\beta = \text{air-demand ratio} = \frac{\text{volume flow rate of air}}{\text{volume flow rate of water}}$$

F_{1c} = Froude number at Vena contracta

$= V_{1c}\sqrt{g\,d_{1c}}$

V_{1c} = Velocity of flow at the vena contracta

d_{1c} = Depth of flow at the vena contracta

g = Acceleration due to gravity.

The size of air vents as determined above assume that the maximum air demand occurs at a gate opening of 80 percent fully open and the maximum air velocity in the vent does not exceed 50 m/s. Air vent passages should use generous bend radi and gradual transitions to avoid losses and particularly excessive noise. The air vent intakes should be so located that they are inaccessible to the public and should be protected by grills. The intake entrance average velocity should not exceed 10 m/s. The air vent exit portal should be designed to ensure spread of air across the full width of the conduit. The air vent should terminate into a plenum located in the conduit roof and immediately downstream of the gate. The plenum should extend across the full width of the conduit and should be vaned so that the air flow is evenly distributed.

3.6.1 The size of the air vent should be such that the pressure drop downstream of the gate does not normally exceed 2 m.

3.6.2 Hydraulic jump formation in the sluice should normally be avoided. When unavoidable, sufficient clearance shall be provided above the jump profile to avoid choked jump conditions.

3.6.3 Normally a sluice located in a spillway section should not operate simultaneously with the spillway. However, if it is obligatory to run the sluice in conjunction with the spillway, proper aeration should be ensured at the exit either by running the sluice partially full or by providing a suitable air-vent at the exit of the sluice.

3.6.4 Sometimes a steel liner may also be provided in the sluices near the gates to avoid cavitation damages. In case of control being located at the exit end, the entire length of sluice shall be provided with steel liner.

3.7 Model Studies — Hydraulic model studies are desirable to test the efficacy of the hydraulic design of the sluice and to verify the air-demand. They should be done for the pre-determined minimum reservoir elevation at which the sluice is designed to pass the required discharge and also for higher reservoir elevations under the gate opening necessary to pass the same discharge.