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भारतीय मानक मसौदा

उत्प्लाव वातकों का हाइड्रोलिक डिज़ाइन — दिशानिर्देश

(IS 12804 ***का पहला पुनरीक्षण***)

Draft Indian Standard

HYDRAULIC DESIGN OF SPILLWAY AERATORS — GUIDELINES

(*First Revision of* IS 12804)

Dams and Spillways Sectional Committee, WRD 09	Last date for Comments: **07 December 2024**

FOREWORD
(*Formal clauses of the foreword will be added later*)

Spillways and outlets of high-head dams may be exposed to high-velocity flows and the associated destructive phenomenon of cavitation. The extent of cavitation erosion depends to a large extent on the surface finish of the spillway/outlet. As velocity increases above a certain limit, the surface finish required to prevent cavitation erosion exceeds the tolerance to be expected from standard construction practice. In such cases, the spillway surfaces are usually protected from cavitation damage by introducing air near the flow boundary. Devices called aerators which supply the air are located on the spillway floors.

The procedure outlined in the existing standard (1989) provides the guidelines for preliminary design of aerator for overflow spillway. However, the orifice spillway is a recent development in spillway design for dual purpose of passing the flood and flushing of sediment from the reservoir. The hydraulic characteristics of the orifice spillway are entirely different than the overflow spillway. The hydraulics of orifice spillway changes with varying reservoir levels. The flow is Free flow for reservoir water levels below the roof of the sluice, for higher water levels the flow is orifice flow. Therefore, the design guidelines for aerator on overflow spillway are not applicable to design the aerator on orifice spillway. Aerators on deep-seated orifice spillways with heads more than 50 m are required for mitigating cavitation damage. However, no significant studies have been done for the aerators on orifice spillways except for a few project-specific studies.

This standard was first published in 1989. The first revision of this standard has been brought out to bring the standard in latest style and update with respect to the latest field practices. In revision of this standard, the following major changes have incorporated:

a) The title of the standards has updated as ‘*Hydraulic design of spillway aerators — Guidelines*’.
b) The latest information available for designing the spillway aeration system including need of aerator, types of aerators and its spacing, types of air passages to aerator, jet trajectory calculation, design aspects of aerators and air entrainment mechanism for overflow and orifice type of spillway.
c) While bringing out this revision, assistance has been derived from ‘*Reduction of cavitation on spillways by induced air entrainment, Kells and Smith, Canadian Journal of Civil Engineering, vol. 18, 1991’.* The details for the existing aerators system used worldwide have been given in Annex A for information. It is recommended to further carry out model studies.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS 2 : 2022 *'Rounding off numerical values (second revision)'.* The number of significant places retained in the rounded-off value should be the same as that of the specified value in this standard.

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1 SCOPE

1.1 This standard deals with provision of aeration for spillways to prevent or minimize cavitation damage.

2 TERMINOLOGY

The following terms and definitions shall apply for the purpose of this standard.

2.1 Cavitation

The phenomenon and consequential formation of cavities or pittings caused by sudden vaporization of a flowing liquid in a zone of excessively low pressure.

2.2 Incipient Cavitation

The onset of vaporization is called incipient cavitation.

2.3 Cavitation Index ($\boldsymbol{\sigma}$)

2.3.1 The cavitation index is a parameter enabling prediction of onset of cavitation in a particular flow situation. It may be written in the form

$$\sigma = \left(\frac{p_{\mathrm{o}} - p_{\mathrm{v}}}{\frac{\rho V_0^2}{2}}\right) \qquad \text{............(1)}$$

Where,

σ = cavitation index
p_{o} = pressure (absolute) at some reference point in the flow, N/m^2
p_{v} = vapour pressure (absolute) of the fluid, N/m^2
ρ = mass density of fluid, kg/m^3
V_0 = reference velocity near to the cavitation source, m/s

NOTE: p_{o} needs to be assessed thorugh scaled model studies or from experience in similar projects

2.4 Incipient Cavitation Index ($\boldsymbol{\sigma_{\mathrm{i}}}$)

The cavitation index at the condition of incipient cavitation is called the incipient cavitation index.

2.4.1 While the cavitation index (σ) is relevant to the flow condition, incipient cavitation index (σ) is relevant to the object or surface in question. In general, for the value $(\sigma)>(\sigma_i)$ cavitation will not occur.

2.5. Aerator

A device is installed on the spillway floor to provide air to the flow near the boundary of the flow surface. This includes the ramp, step, offset, groove, and also the air intake conduit in the body of the spillway or the side walls.

3 NEED FOR AERATION

3.1 Spillways of high head dams may be exposed to high velocity flows and the associated destructive phenomenon of cavitation. The inception of cavitation erosion depends to a large extent on the surface finish of the spillway. As velocity increases above a certain limit the surface finish required to prevent cavitation erosion exceeds the tolerance to be expected from standard construction practice with velocities greater than about 25 m/s, protection of flow boundaries by means of streamlining, lining critical areas with steel sheets, using improved surface finishes and/or cavitation erosion resistant material is neither economical nor completely successful. In such cases, entrainment of adequate quantity of air incavitating flow significantly reduces the damage caused by cavitation. The air dispersed throughout the region where cavitation originates is believed to suppress formation of vapourous cavitation and provides cushioning effect. Hence, aeration of high velocity flow is becoming a widely accepted method of preventing cavitation damage in hydraulic structures.

3.2 Based on the experience from the operation of several spillways, the following general guidelines for cavitation protection, based on cavitation index alone are given in Table 1.

Table 1 General guidelines for cacitation protection based on cavitation index
(*Clause* 2.4)

Sl No.	***Cavitation Index*** $(\boldsymbol{\sigma})$	***Cavitation protection***
(1)	(2)	(3)
i)	> 1.80	No surface protection required.
ii)	0.25 – 1.80	Flow surface can be protected by surface treatments including grinding of all roughness elements to specified chamfers.
iii)	0.17 – 0.25	Flow surface can be protected by incorporating design modifications to the chute profile *(e.g.,* reducing convex curvature) or by incorporating aeration devices etc.
iv)	0.12 – 0.17	Flow surfaces can be protected by incorporating aeration devices into the design.
v)	< 0.12	Flow surface probably cannot be protected from cavitation a new design should be selected.

3.3 Minimum air concentration near the solid surface required to mitigate cavitation damage over the spillway surface is about 6 to 8 percent.

4 SPILLWAY AERATION DEVICE

4.1 Description of Device

4.1.1. Types of devices that could be used to introduce air into flowing water on a spillway chute include deflectors or ramps, offsets, steps, grooves, and combinations thereof. The basic types of aeration devices are shown schematically in Fig. 1. An aerator also, requires that a passage may be provided to admit air to the underside of the jet. Wall slots or recesses, lateral wall deflectors or wedges, and air intake conduits are Frequently used for the air admission system. A schematic diagram of an aeration system with a ramp, offset, and air intake conduit is shown in Fig. 2. Another type of system using a ramp, step, and air gallery with a distribution duct is shown in Fig. 3. The zones describing aerator mechanism are shown in Fig.4.

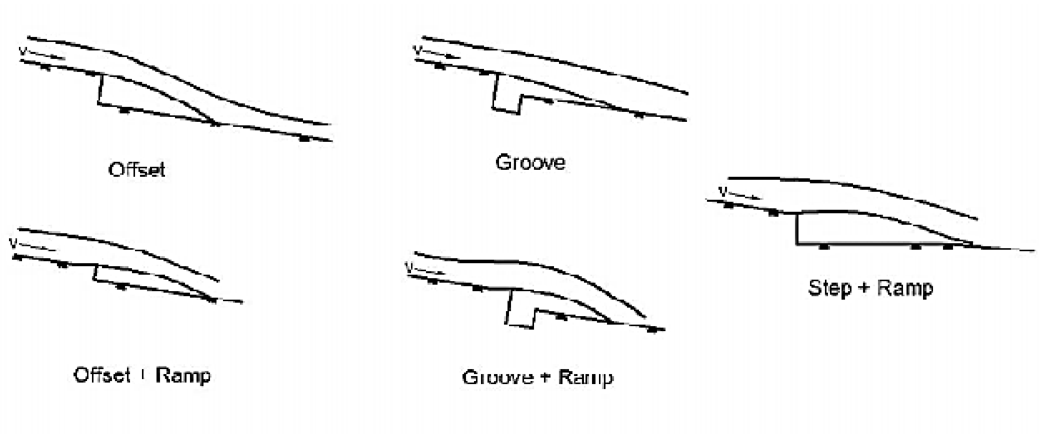

FIG. 1 BASIC TYPES OF AERATION DEVICES

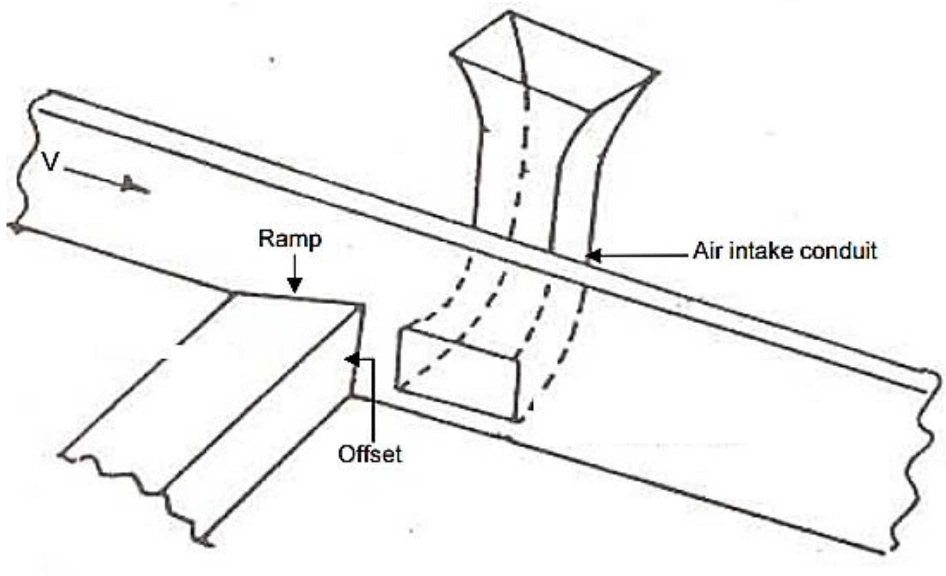

FIG. 2 AERATION SYSTEM WITH INTAKE CONDUIT

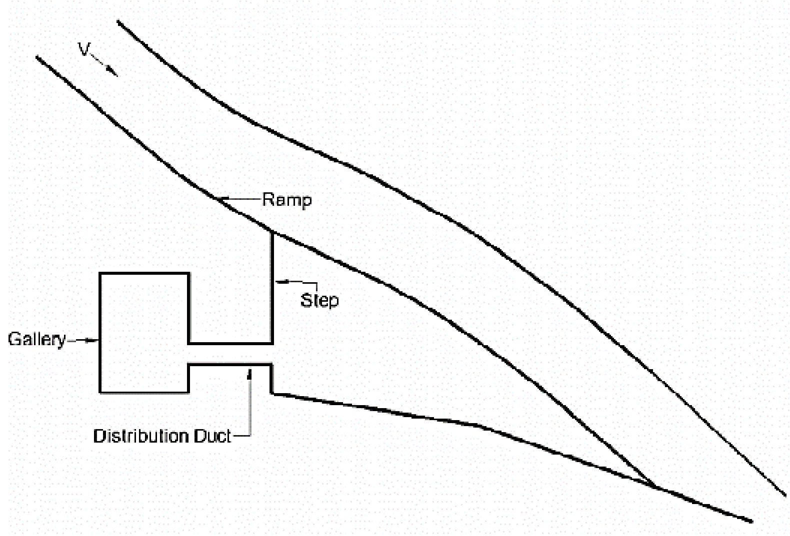

FIG. 3 AERATION SYSTEM WITH GALLERY AND DUCT

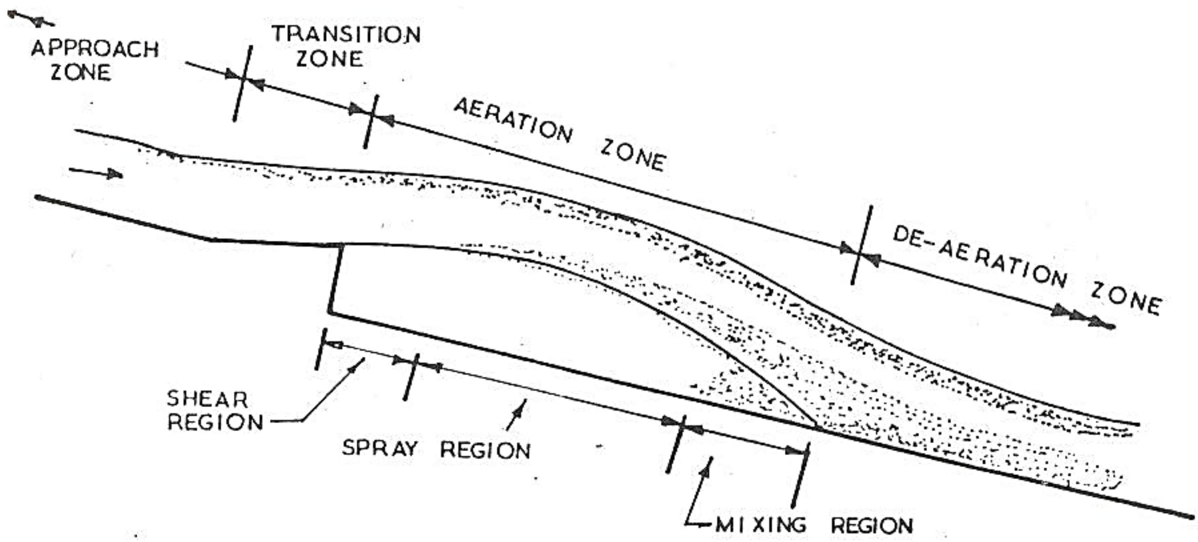

FIG.4 ZONES IN AERATOR MECHANISM

4.2 Hydraulic Action

4.2.1 The hydraulic action of a spillway aerator system consisting of ramp, step, air slot, and air intake system is similar to a water jet pump. The high velocity water jet issuing over the ramp draws some air already trapped in the groove and creates a partial vacuum. The rate of air demand of the jet depends principally on the velocity and length of the trajectory (which is affected by the presence of sub-atmospheric pressure in the groove). The sub-atmospheric pressure in the groove causes some air to be drawn through the atmosphere via the air intake system. The airflow rate through the air intake system is governed by the head loss through the system which in turn determines the magnitude of sub-atmospheric pressure in the cavity and consequently the jet trajectory length. This interaction continues until local equilibrium is established for a given set of conditions. An air velocity of 30m/s could be considered reasonable, however, velocities up to 100m/s may also be allowed at some places with adequate precaution. However, the velocities greater than 60m/s create noise.

5 DESIGN CRITERIA FOR OVERFLOW AND ORIFICE SPILLWAY AERATOR

5.1 General

5.1.1 The procedure for designing an aerator is currently very much state-of-art and subject to changes as advancements are made. Designing an aerator system involves the location of the first aerator, pressure distribution on the spillway surface to decide the location of the second aerator, type, and size of the aerator, volume of air entrained at the aerator, type, and size of the air supply system and spacing between the aerators to maintain a given protection level. The performance of the aerator can be assessed by calculating the jet length, cavity pressures, air entrainment coefficient, and air concentration throughout the length of the spillway. The hydraulic characteristics of the orifice spillway are entirely different from the overflow spillway. Therefore, the design criteria for aerator on overflow spillway are not applicable to aerator on orifice spillway. Present design practice includes the use of empirical relationships developed from model and prototype measurements and a limited amount of theoretical analysis. The guidelines given in the present code may be used for evolving the preliminary design of aerators for overflow and orifice types of spillways which should be checked on a hydraulic model.

5.2 Locating the First Aerator

5.2.1 The aerator should be located first where the potential for cavitation damage is deemed possible i.e. the cavitation index of the flow is less than 0.2. If the bottom air concentration after the impact of the jet of the first aerator falls below the acceptable level of 6 to 8 percent, another aerator is required. The location of the second or subsequent aerators should be decided based on the pressure distribution and air concentration along the bottom profile of the spillway. The same should be checked by conducting hydraulic model studies.

5.3 Aerator Air Intake Configuration

5.3.1 The following are the air supply systems that can be applied in the various projects as per the requirement:

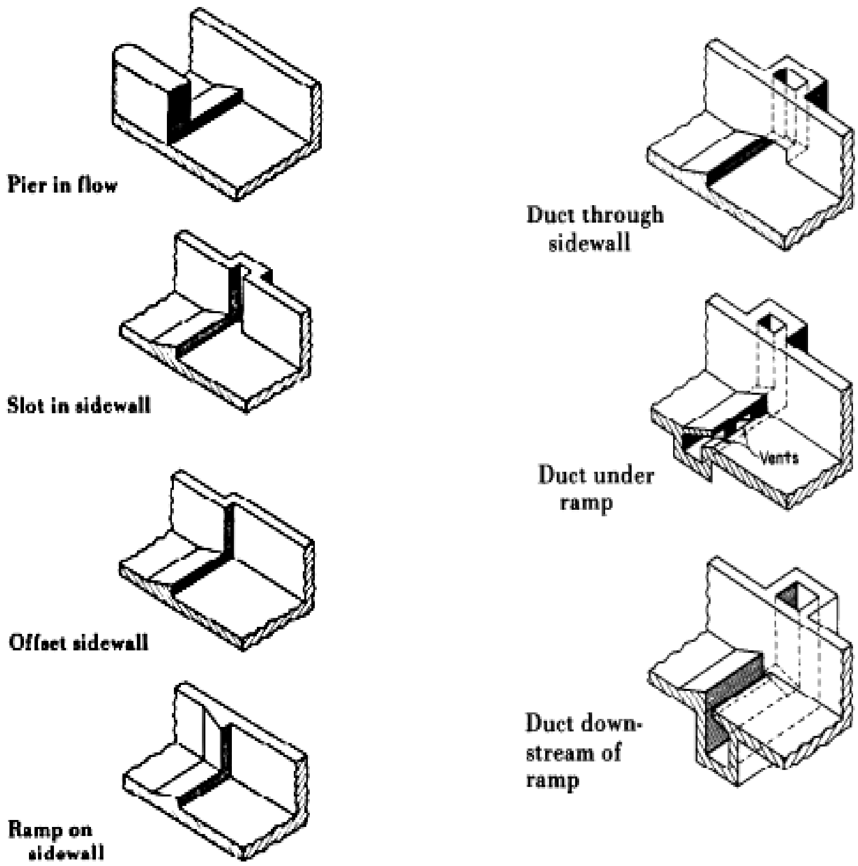

FIG. 5 AIR SUPPLY SYSTEM TO AERATORS

5.3.2 In the absence of any firm and definite guidelines, pertinent dimensions of, the aerator and intake systems can be chosen, at least as a first approximation, by referring to the details of existing installations and finding a parallel case. More refined calculations, if necessary, can be carried out in subsequent trials.

5.3.3 Pertinent dimensions and other details with respect to existing aerator systems of some projects have been given in Annex A.

5.3.4 Relevant notations appearing in the design, calculations are shown in Fig. 6.

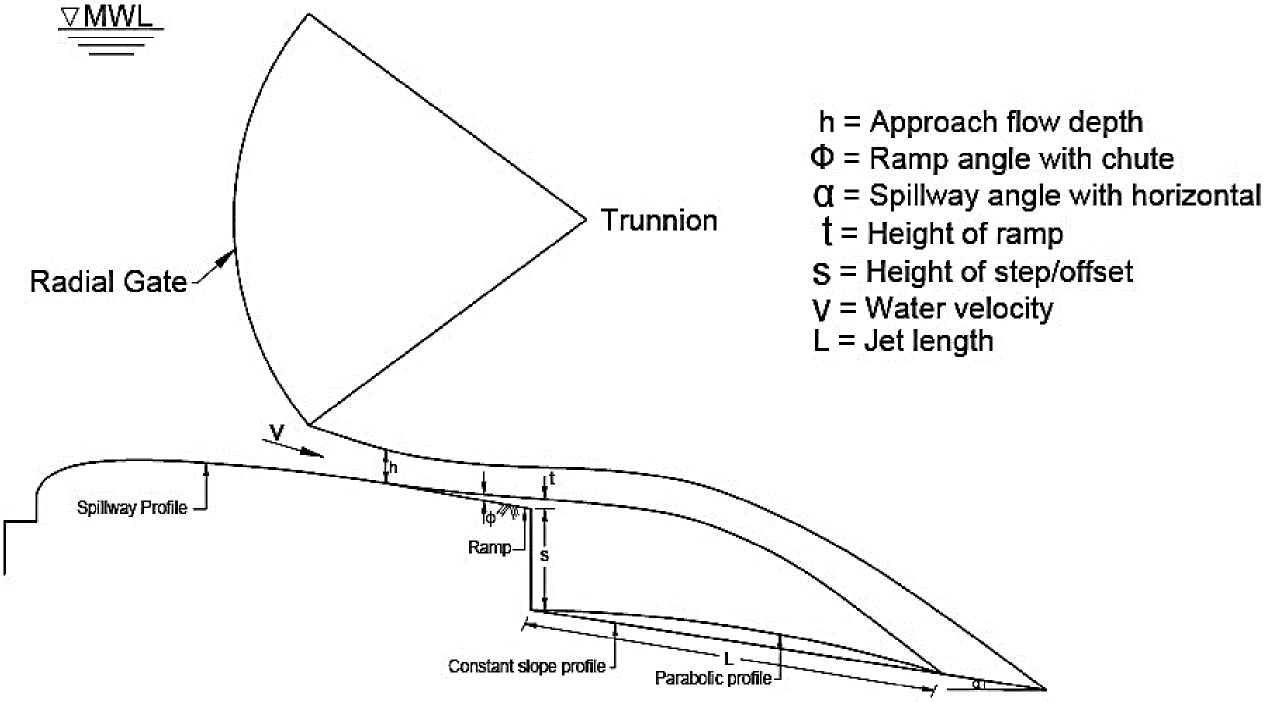

FIG. 6 DEFINITION SKETCH

5.4. Estimation of Desired Air Demand

The quantity of air requirement can be worked out from the following equation:

$$\beta = \frac{Q_a}{Q_w} \quad \text{........(2)}$$

Where,

β = Ratio between quantity of air demand vs quantity of water discharge
Q_a = Quantity of air demand in m^3/s
Q_w = Quantity of water discharge in m^3/s

The value of β for overflow and orifice spillway can be calculated from the equations given in the section **5.5** to **5.10**. By knowing the value of Q_w and β, Q_a can be calculated.

The size of the air vent can be worked out by knowing the quantity of air demand and considering the maximum allowable air vent velocity of 40m/s.

5.5 Estimation of Non-Dimensional Jet Length (λ) for Aerator of Overflow Spillway

$$\lambda = \frac{L}{h} = 0.77F_r(1 + sin\alpha)^{1.5}\left[\sqrt{\frac{s+t}{h}} + F_r tan\varphi\right], \quad \text{for } 0 < \frac{L}{h} < 50 \quad \text{........(3)}$$

Where,

L = Jet length in m
h = approach flow depth in m
F_r = approach flow Froude number $(\frac{\mathrm{V}}{\sqrt{\mathrm{gh}}})$,
α = spillway angle in degrees,
s = height of step/offset in m.
t = height of ramp in m, and
φ = ramp angle in degrees

Equation 3 may be applied to aerators consisting of aerators, offsets, or combinations and is valid for:

a) $5.8 \leq F_r \leq 10.4$,
b) $12^\mathrm{o} \leq \alpha \leq 50^\mathrm{o}$,
c) $0.1 \leq \left(\frac{s+t}{h}\right) \leq 2.1$,
d) $0^\mathrm{o} \leq \varphi \leq$, and
e) $h_\mathrm{s} \approx 0$ where h_s is cavity sub-pressure head

5.6 Estimation of Air Entrainment Coefficient (*β*) for Aerator of Overflow Spillway

$$\beta = \frac{Q\mathrm{a}}{Q\mathrm{w}} = 0.0028\, F_r^2 [1 + F_r \tan \varphi] - 0.1$$, for 0 <*β*< 0.80 .... (4)

Where,

$Q\mathrm{a}$ = air discharge
$Q\mathrm{w}$ = water discharge

Equations 4 may be applied to aerators consisting of aerators, offsets, or combinations and is valid for:

c) $5.8 \leq F_r \leq 16.1$,
d) $0^\mathrm{o} \leq \alpha \leq 50^\mathrm{o}$,
c) $0.06 \leq \left(\frac{s+t}{h}\right) \leq 2.1$,
d) $0^\mathrm{o} \leq \varphi \leq 11.3^\mathrm{o}$, and
e) $h_\mathrm{s} \approx 0$ where h_s is cavity sub-pressure head

5.7 Estimation of Non-Dimensional Jet Length (λ) for Aerator of Orifice Spillway with Parabolic Profile

$$\lambda = \frac{L}{h} = 0.83 * {F_r}^{1.21} * (1 + sin\alpha)^{4.296} * \left(\frac{A_a}{A_w}\right)^{0.129} * \left(\frac{s+t}{h}\right)^{0.201} * (1 + tan\varphi)^{5.393}$$ .... (5)

for 0.72 < λ < 35

5.8 Estimation of Air Entrainment Coefficient (β) for Aerator of Orifice Spillway with Parabolic Profile

$$\beta = 0.01011 * {F_r}^{1.52} * \left(\frac{A_a}{A_w}\right)^{0.4244} * (1 + tan\varphi)^{7.22} * (1 + sin\alpha)^{1.8789} * \left(\frac{s+t}{h}\right)^{-0.4796} \quad ......(6)$$

for $0 < \beta < 0.4$

Where,

A_{a} = area of air vent in m^2
A_{w} = area of water flow in m^2

Equations 5 and 6 may be applied to aerators consisting of ramp, offsets or combinations and are valid for:

a) $2.23 < F_{\mathrm{r}} < 9.81$
b) $0.13 < \left(\frac{s+t}{h}\right) < 1.77 F_{\mathrm{r}}$
c) $10^0 < \alpha < 20^0$
d) $0^0 < \varphi < 3^0$
e) $0.001 < \frac{A_{\mathrm{a}}}{A_{\mathrm{w}}} < 0.32$

5.9 Estimation of Non-Dimensional Jet Length (λ) for Aerator on Orifice Spillway for Constant Slope Profile

$$\lambda = 0.4781 * {F_r}^{1.3464} * (1 + sin\alpha)^{4.7762} * \left(\frac{A_a}{A_w}\right)^{-0.04553} * \left(\frac{s+t}{h}\right)^{0.3265} * (1 + tan\varphi)^{5.3569} \quad ....(7)$$

for $0.72 < \lambda < 48$

5.10 Estimation of Air Entrainment Coefficient (β) for Aerator on Orifice Spillway for Constant Slope Profile

$$\beta = 0.00604 * {F_r}^{1.5151} * \left(\frac{A_a}{A_w}\right)^{0.4686} * (1 + tan\varphi)^{6.4491} * (1 + sin\alpha)^{4.8592} * \left(\frac{s+t}{h}\right)^{-0.3029}$$

........(8)

for $0 < \beta < 0.56$

Where,

A_{a} = area of air vent in m^2
A_{w} = area of water flow in m^2

Equations (7) and (8) may be applied to aerators consisting of ramp, offsets or combinations and valid for

a) 2.23 $< F_r <$ 9.81,

b) 0.13 < (s + t) / h < 1.77,

c) $10^0 < \alpha < 20^0$,

d) $0^0 < \varphi < 3^0$, and

e) 0.03 $< \frac{A_a}{A_w} <$ 0.32

5.11 Aerator Spacing

5.11.1 Design criteria for deciding aerator spacing have not been established yet. Data on aerator spacings of some existing installations given in Annex A would serve to provide useful guidelines. Aerators produce an air-water mixture at the flow boundary. If the concentration of the mixture is large enough, cavitation damage will be prevented. In general, the aerator should be located first where the potential for cavitation damage is deemed possible i.e the cavitation index of the flow is less than 0.2. The pressure in the cavity is nearly atmospheric and increases again at the point of impact. It drops to the hydrostatic pressure after the reattachment of the jet. The high-pressure gradient in this region causes rapid changes in air distribution. As the flow progresses downstream from an aerator, the air concentration decreases because of buoyancy of the bubbles. If the bottom concentration falls below the acceptable level, another aerator is required. The minimum air concentration required to mitigate cavitation damage is about 6 to 8 percent.

5.11.2 The location of the second aerators and subsequent aerators may be decided based on the available length of chute, pressure distribution on the surface, and air concentration along the bottom of spillway surface. While an aerator is desirable at a grade change, installing aerators in vertical bends that are concave upward should be avoided. Aeration shaft should be designed in such a way that minimum head loss should occur in the shaft. The sharp bend should also be avoided in the design. Flow conditions in the vicinity of the aerator must be observed in a hydraulic model to ensure that the groove does not get filled in with water when low discharges are passed down the spillway and ski-action is not initiated.

5.11.3 Care must be taken to construct the aerator surface with steel/ high performance concrete as the sediment laden flow would erode the spillway surface during draw-down flushing. It is important that the dimensions of the geometry of aerator do not change with the passage of time as the air entrainment characteristic of the aerator is very sensitive to the geometry of aerator.

5.11.4 A sample calculation for design of aeration system for an overflow and orifice spillway is given in Annex B.

5.12 Model Studies

Model studies are important in the development of spillway aeration systems. Physical models are useful in obtaining the proper shapes for aeration devices so as to produce satisfactory flow conditions. Parameters such as length of jet, location, and dimensions of the aerator can be optimized using physical models. The necessity of aerator can be identified based on the measured parameters such as pressure, velocity, and estimated cavitation index. Numerical model studies may be used as a complementary tool to reduce the number of alternatives to be studied on the physical model. As indicated in **5.1.1**, the guidelines given above would be useful in preparing a preliminary design of an aerator system. However, the final design should be evolved on the basis of studies on a physical model constructed to an appropriate scale and taking into consideration the scale effects involved in such a model study.

ANNEX A

(*Clause* 5.3.2)

DETAILS OF EXISTING AERATOR SYSTEMS

S.No.	Project Details			Spillway Design Details						Air Supply System Details							Aerator Design Details	
	Name	Country	Height of dam (m)	Type of spillway	Discharge (m^3/s)	Length (m)	Width /diameter (m)	Slope (H:V)	Drop height (m)	Type	No.used	Spacing (m)	Ramp Height (m)	Ramp angle (Degree)	Step/ offset height (m)	First aerator (m)	Intake size/type (m)	Lateral distribution (m)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
i)	Alicura	Argentina	130	Ch	-	537	39	2.86 : 1	141	R/S	4	63	0.17	9.9	-	126	2 intakes of size 1.3 x 3.0 C, SYM	Natural
ii)	Amaluza	Ecuador	-	Ch	-	-	-	0.414 : 1	-	R	-	-	0.06	5.7	-	-	-	-
iii)	Bratsk	Russia	100	Ch	-	100	-	0.8 : 1	90	R	1	-	0.45	11.3	-	39	P	Natural
iv)	Chamera I	India	121	Gr	22000	107	8x10	1.26 : 1	67	G	1	-	-	-	2	41	2 x 2 C, SYM, P	G
v)	Emborcacao	Brazil	-	Ch	-	330	-	5.55 : 1	-	R/S	2	103	0.30, 0.20	7.1	-	-	2x2 AG, G	2 x 2AG,G
vi)	Fengjiashan	China	-	T	1140/725	922	7.2x11	2 : 1, 66.67 : 1	64	R/G, R	2	50	0.60, 0.18	3.8, 7.1	-	84	0.9 C	0.6 x 0.9 G,Natural
vii)	Foz do Areia	Brazil	160	Ch	11000	400	70.6	3.87 : 1	119	R/S	3	72, 90	0.20, 0.15, 0.10	7.1	1.5	146	1.8 x 4.0.C, SYM	Natural
viii)	Glen Canyon	USA	216	T	2 with each 3908	400	12.5	0.7 : 1	175	R/G/S	1	-	0 - 0.18	0 - 7.7	0.31	50	1.2 x 1.2 G, SYM	1.2x1.2 G
ix)	Guri (Chute 1)	Venezuela	150	Ch	6000	140	48	0.8 : 1	130	R, R/S	2	93	1, 0.25	7, 5	2.84	30	P, C, ASYM	Natural, 2 x 4 AG, 6 each of 1.25 x 1.25 D
x)	Guri (Chute 2)	Venezuela	150	Ch	6000	145	51	0.8 : 1, 1.3 : 1, 2.5 : 1	120	R, R/S	2	103	1, 1.5	7, 25	2.2	30	P, AG, SYM	Natural, 2 x 3.1 AG, 6 each of 1.25 x 1.25 D
xi)	Karjan	India	81	Gr	16475	-	17.61	0.8 : 1	79	R	1	-	0.563	8	-	-	2.5 x 3.75, AG, SYM	-
xii)	Laiban	Philippines	-	Ch	2960	397	25	33.3 : 1 to 2.7 : 1	81	R/S, R/G	4	40, 64, 56	0.20, 0.4	5.2, 5.71	-	180	C, C	Natural, AG/0.8 G

xiii)	King Talal	Jordan	-	Ch	2160	-	35	2.78 : 1 *Max.*	-	S, R	2	-	0.74	7.8	1.4	40	W	Natural
xiv)	McPhee	USA	82	Ch	950	303	18.3	9.1 : 1 to 2 : 1	90	R	1	-	0.91	6.4	-	172	1.2 x 1.2 C	0.91 x 1.22 Po
xv)	Narmada Sagar	India	100	Gr	88315	109	495	0.86 : 1	60.3	R	1	-	0.2	2.5	-	15	Pier end	Natural
xvi)	San Roque	Philippines	210	Ch	12800	550	105	4 : 1 *Max.*	110	R/O	7	50, 60	0.5	9.6	0.75	158	1.1 x 2.0 C, SYM	1.8 x 2.0 AG, 0.5 x 1.5 Po
xvii)	Sardar Sarovar	India	165	Gr	65000	300	524.3	0.6 : 1	56.68	R/G	1	-	0.25	4	-	40	2.54 x 2.54	2.54 x 2.54 G
xviii)	Tehri	India	261	Ch	5487	718	39.5	1.94 : 1	41.87	R/G	3	80, 100	0.2	5.71	-	230	1.2 x 1.2 C	1.4 x 1.4 AG
xix)	Toktogul	Russia	-	Ch	-	-	-	0.71 : 1		R/O, R/G	3		0.15, 0.45	9.5	2.0	-	P	Natural, 1.0 AG
xx)	Nurek	Russia	-	T, Ch	2400	-	10	Varies		G/O	8	10 to 15	-	-	0.40	-	1.4 x 1.5 G, C	-
xxi)	Uribante	Venezuela	130	Ch	1100	400	12	6.25 : 1 *Max.*, 2.94 : 1	101	R/S	2	153	0.25, 0.30	4.7, 5	0.40, 0.99	174		0.5 x 1.0 AG, 0.8 x 0.9 AG
xxii)	Ullum	Argentina	-	Ch	2560/1000	225	35	4 : 1	73	R	1	-	1.0	14	-	100	Wall wedge 7.1 m at each side protruding 0.5 in the flow	Natural
xxiii)	Ust-Ilim	Russia	-	Ch	-	-	-	0.7 : 1	-	R	1	-	0.6	9.5	-	35	C	0.5 x 4.5 Po
xxiv)	Yellowtail	USA	-	T	2600	450	9.75	0.7 : 1	150	R/G/S	1		0 to 0.076	0 to 6.3	0.076	100	0.9 x 0.9 G, SYM	0.9 x 0.9 G
xxv)	Subansiri	India	125	Gr	37500	175.5	11.5x14	variable	-	R/S	2	61	0.56	4	2.5	27	2 square ducts (1.5x1.5) each side of span for first aerator and second aerator at pier end	Aeration through shaft at first aerator and natural aeration at second aerator

NOTE –

a) In column (6) where two values are given, the first represents spillway design discharge and the second represents the aerator design discharge.
b) In column (17), the discharge given is that from the spillway crest to the first downstream aerator.
c) Column (18) describes how the air is delivered to the aerator from the atmosphere and whether delivery is from both sides of the chute.
d) Column (19) describes how the air is conducted to the underside of the jet at the aerator. The term 'natural' means that no special appurtenances have been used to distribute the air in the jet cavity void.
e) The list of abbreviations used in the Annex A is given in Table below:

Abbreviation	***Meaning***	***Abbreviation***	***Meaning***
AG	Air gallery	P	Pier
ASYM	Asymmetrical inlet	Po	Portal
C	Air intake conduit	R	Ramp
Ch	Chute	S	Step
D	Distribution duct	SYM	Symmetrical inlet
G	Groove	T	Tunnel
O	Offset	W	Wall wedge

ANNEX B
(*Clause* 5.11.2)

SAMPLE FOR DESIGN CALCULATION OF AERATION SYSTEM

(A) ESTIMATION OF NON-DIMENSIONAL JET LENGTH (λ) AND AIR ENTRAINMENT COEFFICIENT (β) FOR OVERFLOW SPILLWAY

A.1 Input Data:

Approach flow depth h = 3.7 m
Approach flow Froude number F_r = 6
Chute bottom angle $\alpha = 40^o$
Offset height s = 2.45 m
Ramp height t = 0.4 m
Ramp angle $\varphi = 4^o$

A.2 Estimation of Non-Dimensional Jet Length (λ) :

$$\lambda = \frac{L}{h_o} = 0.77 F_r (1 + \sin\alpha)^{1.5} \left[\sqrt{\frac{s+t}{h}} + F_r \tan\varphi \right]$$

$$\lambda = \frac{L}{h_o} = 0.77 * 6 * \ (1 + \sin 40^o\ )^{1.5} \left[\sqrt{\frac{2.45 + 0.4}{3.7}} +\ 6 * \tan 4^o \right]$$

$$\lambda = 0.77 * 6 * \ 2.106 * (0.878 + 0.419)$$

$$\lambda = 12.62$$

A.3 Estimation of Air Entrainment Coefficient (β) :

$$\beta = 0.0028\ F_r^2 [1 +\ F_r \tan\varphi] -\ 0.1$$

$$\beta = 0.0028 * 6^2 * \ \ [1 +\ 6 * \ \tan 4^o\ ] -\ 0.1$$

$$\beta = 0.0028 * 36 * \ \ 1.419 -\ 0.1$$

$$\beta = 0.043$$

(B) ESTIMATION OF NON-DIMENSIONAL JET LENGTH (λ) AND AIR ENTRAINMENT COEFFICIENT (β) FOR ORIFICE SPILLWAY WITH PARABOLIC PROFILE

B.1 Input Data:

Froude number F_r = 7.53
Spillway angle in degrees α = 10^0
Ramp angle in degrees φ = 3^0

Offset height in 'm' s = 1.5 m
Ramp height in 'm' t = 0.25 m
Incoming depth of flow h = 1 m
Area of air vent in m^2 A_a = 0.785
Area of water flow in m^2 A_w = 3.825 m^2

B.2 Estimation of Non-Dimensional Jet Length (λ) :

$$\lambda = 0.83 * {F_r}^{1.21} * (1 + sin\alpha)^{4.296} * \left(\frac{A_a}{A_w}\right)^{0.129} * \left(\frac{s+t}{h}\right)^{0.201} * (1 + tan\varphi)^{5.393}$$

$$\lambda = 0.83 * 7.53^{1.21} * (1 + \sin 10^0)^{4.296} * \left(\frac{0.785}{3.825}\right)^{0.129} * \left(\frac{1.5 + 0.25}{1}\right)^{0.201} * (1 + \tan 3^0)^{5.393}$$

$$\lambda = 0.83 * 11.51 * 1.989 * 0.815 * 1.119 * 1.317$$

$$\lambda = \mathbf{22.82}$$

B.3 Estimation of Air Entrainment Coefficient ($\boldsymbol{\beta}$) :

$$\beta = 0.01011 * {F_r}^{1.52} * \left(\frac{A_a}{A_w}\right)^{0.4244} * (1 + tan\varphi)^{7.22} * (1 + sin\alpha)^{1.8789} * \left(\frac{s+t}{h}\right)^{-0.4796}$$

$$\beta = 0.01011 * 7.53^{1.52} * \left(\frac{0.785}{3.825}\right)^{0.4244} * (1 + \tan 3^0)^{7.22} * (1 + \sin 10^0)^{1.8789} * \left(\frac{1.5 + 0.25}{1}\right)^{-0.4796}$$

$$\beta = 0.01011 * 21.51 * 0.510 * 1.446 * 1.351 * 0.765$$
$$\beta = 0.165$$

(C) ESTIMATION OF NON-DIMENSIONAL JET LENGTH (λ) AND AIR ENTRAINMENT COEFFICIENT ($\boldsymbol{\beta}$) FOR ORIFICE SPILLWAY WITH CONSTANT SLOPE PROFILE

C.1 Input Data:

Froude number F_r = 7.53
Spillway angle in degrees α = 10^0
Ramp angle in degrees φ = 3^0
Offset height in 'm' s = 1.5 m
Ramp height in 'm' t = 0.25 m
Incoming depth of flow in 'm' h = 1 m
Area of air vent in m^2 A_a = 0.785
Area of water flow in m^2 A_w = 3.825

C.2 Estimation of Non-Dimensional Jet Length (λ) :

$$\lambda = 0.4781 * F_r^{1.3464} * (1 + sin\alpha)^{4.7762} * \left(\frac{A_a}{A_w}\right)^{-0.04553} * \left(\frac{s+t}{h}\right)^{0.3265} * (1 + tan\varphi)^{5.3569}$$

$$\lambda = 0.4781 * 7.53^{1.3464} * (1 + sin10^0)^{4.7762} * \left(\frac{0.785}{3.825}\right)^{-0.04553} * \left(\frac{1.5+0.25}{1}\right)^{0.3265} * (1 + tan3^0)^{5.3569}$$

$$\lambda = 0.4781 * 15.15 * 2.148 * 1.075 * 1.20 * 1.315$$

$$\lambda = 26.39$$

C.3 Estimation of Air Entrainment Coefficient (β) :

$$\beta = 0.00604 * F_r^{1.5151} * \left(\frac{A_a}{A_w}\right)^{0.4686} * (1 + tan\varphi)^{6.4491} * (1 + sin\alpha)^{4.8592} * \left(\frac{s+t}{h}\right)^{-0.3029}$$

$$\beta = 0.00604 * 7.53^{1.5151} * \left(\frac{0.785}{3.825}\right)^{0.4686} * (1 + tan3^0)^{6.4491} * (1 + sin10^0)^{4.8592} * \left(\frac{1.5 + 0.25}{1}\right)^{-0.3029}$$

$$\beta = 0.00604 * 21.3 * 0.476 * 1.390 * 2.177 * 0.844$$

$$\beta = 0.156$$