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Indian Standard

CRITERIA FOR ESTIMATION OF AERATION DEMAND FOR SPILLWAY AND OUTLET STRUCTURES

भारतीय मानक

उत्पलाव मार्ग और निकास संरचनाओं की वातन-आवश्यकताओं के आकलन सम्बन्धी मापदण्ड

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BUREAU OF INDIAN STANDARDS
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Price Group 6

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FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards on 25 September 1989, after the draft finalized by the Spillways Including Energy Dissipators Sectional Committee had been approved by the River Valley Projects Division Council.

Cavitation is formation of gas phase within liquid. The successive formation and collapse of cavities causes damage to nearby boundary. The cavitation occurrence is effected by high velocity and discharge concentration. The flood water contains impurities and cannot withstand substantial tensile force (compared to pure water) and therefore ruptures easily. The cavitation damage occurs downstream from the source of cavitation. The irregularities at the boundaries of flow surface are the main cause for cavitation damage. The aeration of high velocity flow prevents cavitation damage in hydraulic structure.

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 or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

CRITERIA FOR ESTIMATION OF AERATION DEMAND FOR SPILLWAY AND OUTLET STRUCTURES

1 SCOPE

1.1 This standard deals with provision of aeration for spillway and oultet structures to overcome the cavitation damages.

2 TERMINOLOGY

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

2.1 Cavitation

Cavitation is formation of gas phase within liquid. The successive formation and collapse of cavities in a stream of flowing liquid which results from pressure changes within the stream caused by changes in the velocity of flow.

2.2 Vaporous Cavitation

During process of cavitation when the void is filled primarily with water vapour, the process is further classified as vaporous cavitation.

2.2.1 *Gaseous Cavitation*

During process of cavitation when the void is filled with gases which have come out of the liquid the process is classified as gaseous cavitation.

2.2.2 *Pseudo Cavitation*

During the process of cavitation if the reduction in pressure is sufficiently low, the cavities/voids may get filled partly with gas(es) and partly with liquid vapour, then it is called pseudo cavitation.

2.3 Incipient Cavitation

In vaporous cavitation, the vaporization first takes place at local weakness in the liquid which are called 'Cavitation nuclei'. The nuclei often found to be are either micro gas bubbles existing freely in the liquid, or a gas pocket in a small crevice present in the solid surface in contact with the liquid, gas bubble with organic skin or a hydro phobic solid. This onset of vaporization is called 'Incipient Cavitation'.

2.4 Pitting

The successive formation of vapour pockets in low pressure areas and subsequent collapse in high pressure areas associated with high velocity flow, frequently causes severe damage to concrete or steel surface. The roughening or formation of pockets in surface due to cavitation is commonly called 'pitting'.

2.5 Cavitation Damage

The sudden reduction of pressure at any point due to the vapour pressure of water is caused in water passage by abrupt changes in boundary which causes a tendency of separation of the flow from the boundary, by constrictions which produce high velocities and low pressures, and by siphons in which pressures are reduced due to elevation. Vapour cavities form as spheres in the low pressure areas and collapse when a higher pressure area is reached in a short distance downstream. The collapse is very rapid and sets up a high pressure shock wave in the water which causes the damage to the nearby boundary.

3 ESTIMATION OF AERATION DEMAND FOR SPILLWAY STRUCTURES

3.1 Cavitation and Associated Damage

3.1.1 The flow of water on overflow section in the spillway causes higher velocities, if the height of overflow section is more than 60 m above the river bed. For higher velocities of water the problem of cavitation becomes more critical. For velocities around 30 m/sec the pressure field becomes much sensitive. The cavitation occurrence is not only related with high velocity but with discharge concentration also.

3.1.2 Pure water can withstand very large tensile forces before it ruptures, but impurities in the water are the points of weakness. Most of flood water contains impurities.

3.1.3 Cavitation damage occurs when vapour bubbles form in the void/partial vacuum created or the high velocity water tends to break away from the concrete surface while jumping over the irregularities.

3.1.4 The surface irregularities include projections/offsets of joints, grooves, etc. All precautions shall be taken to avoid irregularities on the downstream face of overflow section. The projections/offsets shall not be more than 3 mm.

3.1.5 The abrupt variation in the surface smoothness on the alignment and curvature in flow surface can also cause cavitation damage.

3.1.6 The cavitation damage always occurs downstream from the source of cavitation. The right angle break occurs when the damage has destroyed the concrete lining. The cavitation damage occurs usually at all similar type of locations. The floor slabs of the spillway are more vulnerable to cavitation damage than the walls or piers. Cavitation erosion due to pitting are seen as a series of tear drop-shape holes.

3.2 Preventive Measures to Avoid Cavitation Damage

a) The aeration of high velocity flow is becoming a widely accepted method of preventing cavitation damage in hydraulic structures.

b) The air entrained by a high velocity flow affects the compressibility of the airwater mixture. So, when vapour bubbles collapse, the collapsing effect of the bubble should be smaller than those occurring in water without free air.

c) Construction of flow surface produces irregularities that cannot be totally avoided. With the successful adoption of aeration devices, the cavitation damages can be minimized.

3.3 Criteria of Occurrence of Cavitation Damage

3.3.1 As explained in **3.1** irregularities at the boundaries of the flow surfaces are the main causes for the cavitation damage. The following procedure is recommended to find out the occurrence of cavitation damage by comparing the incipient cavitation index (σ) and flow cavitation index (K) for every overflow section of hydraulic structures.

3.3.2 The incipient cavitation index (σ) is given by the formula:

$$\sigma = 1{\cdot}2 \ (h/B)$$

where

h = height of offset, and

B = depth of water flow channel.

The relative height of offset (h/B) shall be less than 0·05.

3.3.3 *Flow Cavitation Index (K)*

Cavitation occurrence is considered to be correlated not only to high velocities but also to the discharge concentration. An index is to be worked out to describe the potential for cavitation on spillway glacies or a chute by using the following equation:

$$K = \frac{d \cos \theta + \frac{d}{g}\frac{v^2}{R} + \frac{P_b}{\gamma} - \frac{P_v}{\gamma}}{v^2/2g} \quad \text{......(1)}$$

where

d = depth of flow in metre,

θ = angle between horizontal and invert in degree,

g = acceleration due to gravity,

R = radius of curvature of invert in metre,

v = velocity of flow in metre/second,

$\frac{P_b}{\gamma}$ = barometric pressure expressed in terms of height of water in metre, and

$\frac{P_v}{\gamma}$ = vapour pressure expressed in terms of height of water in metre.

NOTE — It can be observed from the above equation that the cavitation index decreases as velocity increases and the damage will increase very rapidly with even a small increase in velocity beyond a limiting value.

The radius of curvature 'R' is worked out by using the formula:

$$R = \frac{[\,1+(\,dy/dx\,)^2\,]^{\frac{3}{2}}}{d^2y/dx^2} \quad \text{......(2)}$$

When the value of flow cavitation index (K) is to be calculated in a uniform slope below tangent point of ogee section, then centrifugal form $\frac{dv^2}{gR}$ may be neglected and formula reduced to:

$$K = \frac{d \cos \theta + \frac{Pb}{\gamma} - \frac{Pv}{\gamma}}{\frac{v^2}{2g}} \quad \text{......(3)}$$

3.3.4 If the flow cavitation index (K) is greater than incipient cavitation index (σ), then cavitation will not take place and also no damage will occur. In case the flow cavitation index (K) is less than incipient cavitation index (σ), then cavitation will occur.

3.3.5 Based upon the computation of the flow cavitation index as per **3.3.3** the range of index and its effects are given in Table 1.

3.3.6 Whenever cavitation occurs, it will damage the surface. However, the extent and length of time in which the damage takes place is very important for ascertaining the potential of damage and safety of the structure. The magnitude of cavitation damage occurrence is related to length of time which is given in Table 2 for guidance.

Table 1 Effect of Flow Cavitation Index

(*Clause* 3.3.5)

Range of Flow Cavitation Index *K*	Remarks/Recommendations
i) if $K > 1·7$	No damages, because the structure is free from cavitation
ii) if $1·7 > K > 0·3$	Smoothen all offsets to 1 : 15 chamfer to avoid cavitation damage
iii) if $0·3 > K > 0·2$	Revised design is necessary
iv) if $0·2 > K > 0·12$	Provision of local protection is necessary
v) if $0·12 > K$	Use a completely different concept of design

Table 2 Magnitude of Cavitation Damage

(*Clause* 3.3.6)

Range of Flow Cavitation Index (*K*)	Magnitude of Damage and Period
a) *K* between 1·2 and 0·3	i) Damage can be expected to occur in an accumulative operating time of one year
	ii) Serious damage would occur for accumulative operating time exceeding 10 years
b) *K* between 0·2 and 0·3	i) A minor damage may occur after one month of operation
	ii) Severe damage may occur after one year
c) *K* between 0·2 and 0·12	i) Damage may occur after few hours of operation
	ii) Major damage may occur after one day
d) *K* less than 0·12	The design is to be changed

NOTE — Cavitation indices should be calculated over the expected range of flows as the lowest flow cavitation index frequently occurs at about one-third of the design discharge.

3.4 Aeration Devices

3.4.1 Provision of some aeration arrangement to combat cavitation will be effective and economical as compared to the practice of preventing cavitation erosion by improved cavitation resistant materials. Supply of air content of about 1·5 to 2·5 percent in the bottom layer of flow will minimize the cavitation erosion. If air content is about 7 percent in the water, then the cavitation erosion risk is totally eliminated.

3.4.2 While designing the aeration system, following three important aspects are necessary to be considered:

a) Velocity of air,

b) Correct volume of air, and

c) Spacing between the aerators.

3.4.3 Aeration arrangements for supplying air into the high velocity spillway flows are of following types:

a) Aeration grooves,

b) Ramps, and

c) Steps and combination of ramps and steps or specially designed aeration grooves and ramps.

3.4.4 *Design Criteria of Aeration Groove*

3.4.4.1 The cross-sectional area of the groove should be minimum 0·30 m². Large grooves should maintain a square or near square section. The cross sectional area of the groove should be such that the velocity of air does not exceed the maximum value of air velocity considered for the design.

3.4.4.2 An air velocity of 30 m/s could be considered as reasonable, however, the velocities up to 100 m/s may also be allowed at some places with adequate precaution. However, the velocities greater than 60 m/s create noise.

3.4.4.3 The air groove geometry is influenced by the type of structure into which the groove is to be provided. The groove should be self draining. If the groove is not functioning properly and the groove is filled up with water, it becomes a potential source of damage, which is more dangerous than the irregularities. To avoid above likely phenomena, a ramp is to be provided on upstream of the groove.

3.4.4.4 Considering convenient length of ramp, the height of ramp can be found out by the formula:

$$H = \frac{(So - \text{Tan}\,\phi)\,L}{\sqrt{1+S_0^2}} + \frac{gL^2}{2v^2\,\text{Cos}^2\,\phi\,\sqrt{1+S_0^2}} \quad \ldots(4)$$

where

So = Downstream slope of spillway,

L = assumed ramp length in metre,

V = velocity of flow in m/s at reference, and

ϕ = vertical angle between the ramp and the horizontal.

A typical sketch of the aeration groove is shown Fig. 1.

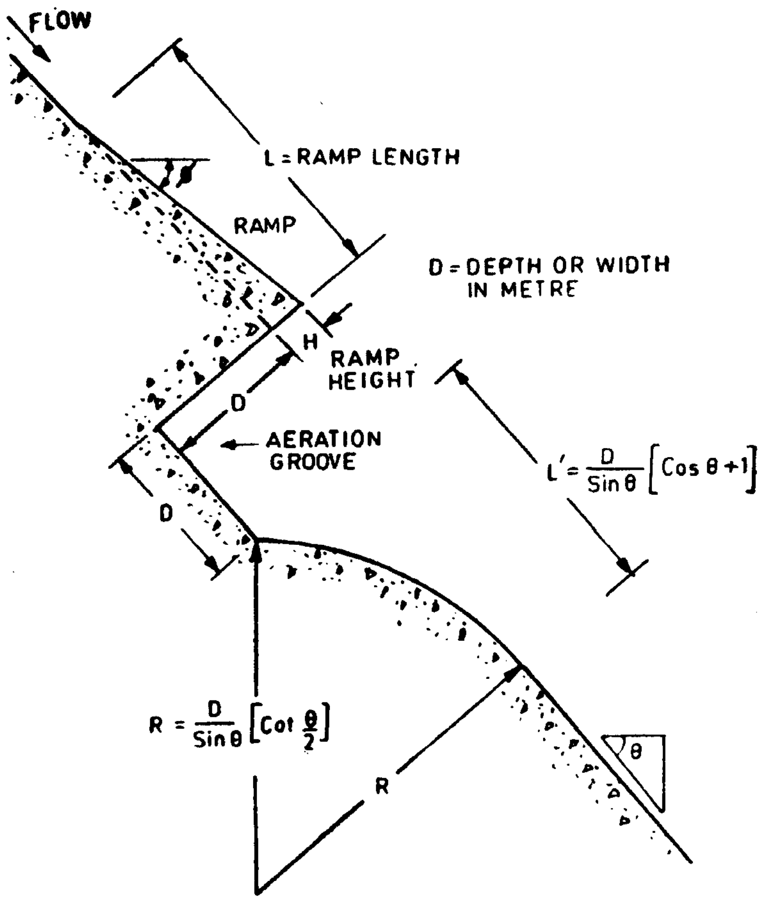


FIG. 1 TYPICAL SECTION OF AERATION GROOVE

3.4.4.5 When the velocity of flow is more than 30 m/s or height of overflow section is more than 60 m, it is desirable to provide artificial air supply by means of aeration devices. The estimation of the air flow rate can be made by assuming a turbulent flow distribution at the location. The air flow discharge (Qa) is estimated by the equation:

$$Qa = \frac{BV^3 \cos^3 \phi \ (So - \tan \phi)^2}{4g} \quad \ldots\ldots (5)$$

where

Qa = air flow discharge in m^3/s,

B = c/c distance of piers in m,

V = velocity of flow in m/s at reference,

ϕ = vertical angle between the ramp and the horizontal,

S_0 = Downstream slope of spillway, and

g = acceleration due to gravity.

3.4.4.6 The geometrical shape of aeration groove for a particular spillway will have to be finalised by model studies only. Whether such aeration grooves are necessary in all the bays of the spillway will also have to be decided from model studies and accordingly provided.

3.4.4.7 The location of aeration groove provided as per requirements as worked out by flow cavitation index (K).

3.4.4.8 The location of aeration grooves, method of air supply arrangement through air ducts, or any other suitable methods may be adopted after the actual model studies are carried out for the project as per site conditions.

3.4.4.9 The amount of air required should also to be ascertained from model studies to compare with the design. The spacing of aeration grooves at different locations can be worked out from the formula:

$$S = 3.5\, d \frac{(d V_m)^{1/4}}{\nu} \quad \ldots\ldots(6)$$

where

S = maximum spacing between air grooves in metre,

d = flow depth in metre,

V_m = mean velocity in m/s, and

ν = kinematic viscosity of water.

NOTE — Kinematic viscosity of water at 20°C is to be taken as 0·000 001 m^2/s.

A sample calculation for design of aeration groove is given at Annex A.

3.4.5 *Design Criteria of Ramps*

3.4.5.1 The principle of providing ramp as aeration device is based on the theory that it causes the nappe to be lifted from the spillway surface and strike it back at some distance downstream. A cavity is created under the nappe which draws in air from outside. As the air is entrained by the flow, local pressure reduction occurs which causes more air from atmosphere to rush in water flow.

3.4.5.2 The air requirement shall be worked out according to the method explained in **3.4.1** or formula given in **3.4.4.5**.

3.4.5.3 Suitable size of ramp is considered and actual model studies are carried out, to find out the air drawing capacity of the nappe per unit width by the formula:

$$qa = C. V. L. \quad \ldots \quad (7)$$

where

qa is the quantity of air drawn m^3/s of the nappe per unit width.

C is a coefficient which lies between 0·01 to 0·04. (The value of C increases with velocity and upstream roughness).

For concrete surface, C may be taken as 0·01.

V is the velocity of the flow at the centre of cavity (trajectory) in m/s.

L is the length of cavity in to be found from experiment.

3.4.5.4 The height and length of ramp is to be finalised from the model studies for the different flow conditions by comparing air requirement as per design for avoiding cavitation damage and actually air drawing capacity due to provision of ramp.

3.4.5.5 The ideal location of ramp shall be near the downstream pier touching point on spillway, where water flow have separation and exposed to atmosphere just downstream of pier. If the ramps are to be located other than as explained above, then artificial means of air supply will have to be made to meet the requirement of aeration.

3.4.5.6 A typical sketch of ramp on spillway is shown in Fig. 2.

4 ESTIMATION OF AIR DEMAND FOR OUTLET STRUCTURES

4.1 General

Under certain conditions of outlet gate operation, the pressure in a conduit may fall considerably below atmospheric pressure. Sub-atmospheric pressure, approaching the vapour pressure of water, may cause dangerous destructive cavitation damage in the downstream. To avoid the cavitation damage, air supply is necessary according to **3.2** (a) and **3.2** (b).

4.2 Large reductions in pressure can be avoided by providing air vents through which air will discharge into the conduit when a low pressure exists. The vents usually open through the conduit roof immediately downstream from the service gate. The size of the air vent is governed by Froude number and discharge.

4.3 The air discharge which must be supplied through air vents is dependent upon the rate of air entrained by high velocity flow and upon the rate of air discharged at the conduit exit above the air-water mixture. These factors are variable and are influenced by the hydraulic and structural features of the conduit, and method of conduit operation. When conduit discharge is not influenced by tail water conditions and hydraulic jump does not form in the conduit, the jet coming out from a small gate opening forms a fine spray or mist which fills the conduit and is dragged along the conduit by the underlying high velocity flow producing a blast of air and spray from the exit portal. But at large gate openings a hydraulic jump is formed in the conduit and the jet will entrain air. Further air discharge at the top of the conduit will be entrained by the turbulence of the jump and pumped by the jump action into the conduit down stream. Both conditions of air flow in the conduit result in reduced pressure at downstream of gate and at the vent exit, resulting in air discharge through the vent. The maximum air velocity in the vent should not exceed 60 m/s.

4.4 Estimation of Air Demand

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

i) $$\beta = \frac{Qa}{Qw} \quad \ldots\ldots(8)$$

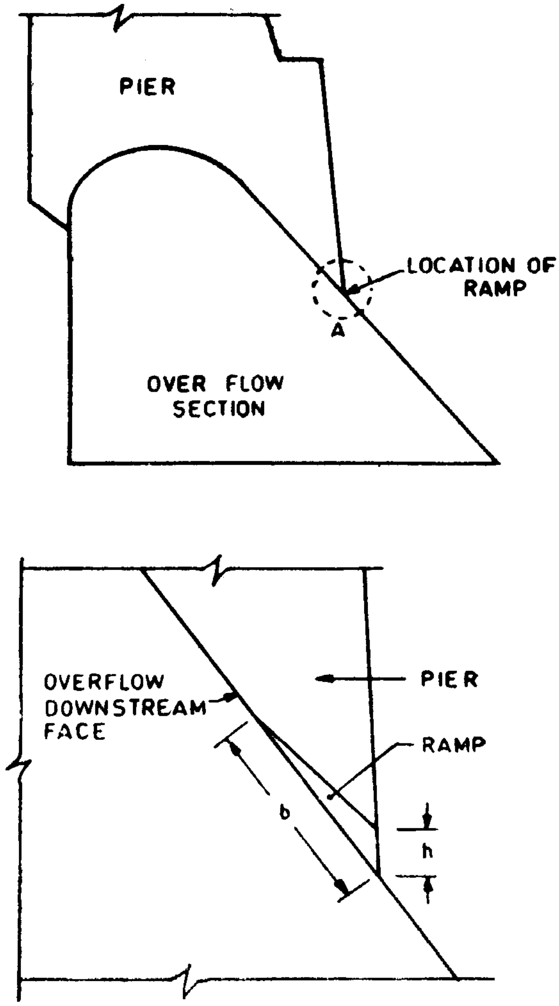


FIG. 2 RAMP DETAILS AND LOCATION OF SPILLWAY

where

β is the ratio between quantity of air requirement vs quantity of water discharge through conduit,

Qa is the quantity of air in m^3/s,

Qw is the quantity of water discharge through outlet in m^3/s,

ii) $\beta = 0.03\ (Fr - 1)\ 1.06$ ......(9)

where

Fr is the Froude = number at vena contracta of gate opening.

Alternatively, the β can be obtained directly from the graph of Fig. 3.

iii) By the known gate size of outlet and head of water, the discharge through outlet gate is worked out by:

$$Qw = C\, Go \sqrt{2gH^1} \qquad ......(10)$$

where

C is discharge coefficient or contraction coefficient (can be obtained from the graph of Fig. 4).

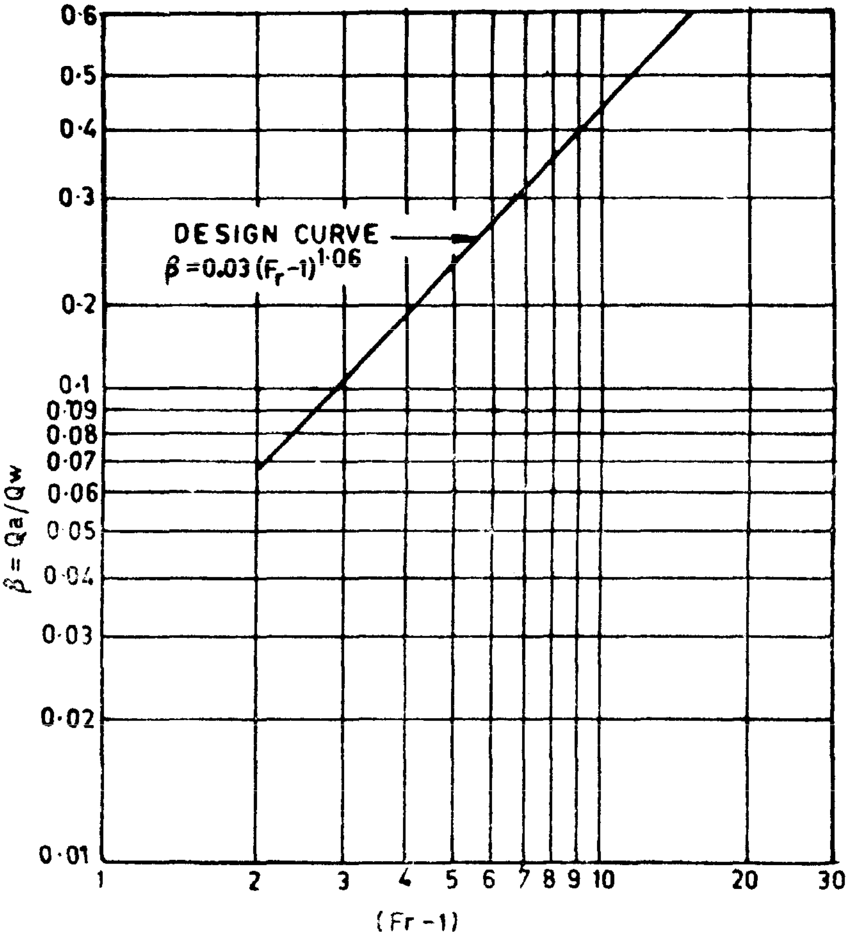
Go is the gate opening above invert in m,

B is the width of the gate opening in m,

H^1 is the height between energy head elevation — (invert elevation + $C\,Go$).

iv) Quantity of air required is given by:

$$Qa = \beta\, Qw \qquad ...\ (11)$$



NOTE — $F_r = V_r \sqrt{gy}$ (Froude number)
Vr = Water Velocity at Vena Contracta
y = Depth at Vena Contracta
Qa = Air Demand m³/s
Qw = Water Discharge m³/s

FIG. 3 GRAPH FOR DETERMINATION OF β

4.4.2 The size of air vent can be worked out by knowing the quantity of air, to be supplied from the equation 11 and considering the maximum air vent velocity at 40 m/s.

Therefore area of air vent $\frac{Qa}{40}$ in m² ......(12)

A typical calculation for estimation of air requirement and size of air vent is given at Annex B.

4.4.3 Details regarding air vent are shown in Fig. 5.

4.5 Corrective Measures to Minimize Cavitation Damages in Outlet Structures

4.5.1 Improvement of water passage to minimize the possibility of the occurrence of cavitation by stream lining of conduit entrances, rounding of downstream corners of gate slots, and using conservative bend radii.

4.5.2 Increasing the pressure or raising the hydraulic grade line at disturbance may be accomplished either by restricting the exit end of an outlet conduit, or by increasing the cross sectional area in such localities as gate passages to decrease the velocity and increase the pressure.

4.5.3 Introducing air at low pressure area to alleviate negative pressure conditions. In the design of high head outlet conduits, it is often desirable to combine any two or all three of the above corrective measures.

4.6 High head outlet of more than 75 m shall be finalised after model studies are carried out.

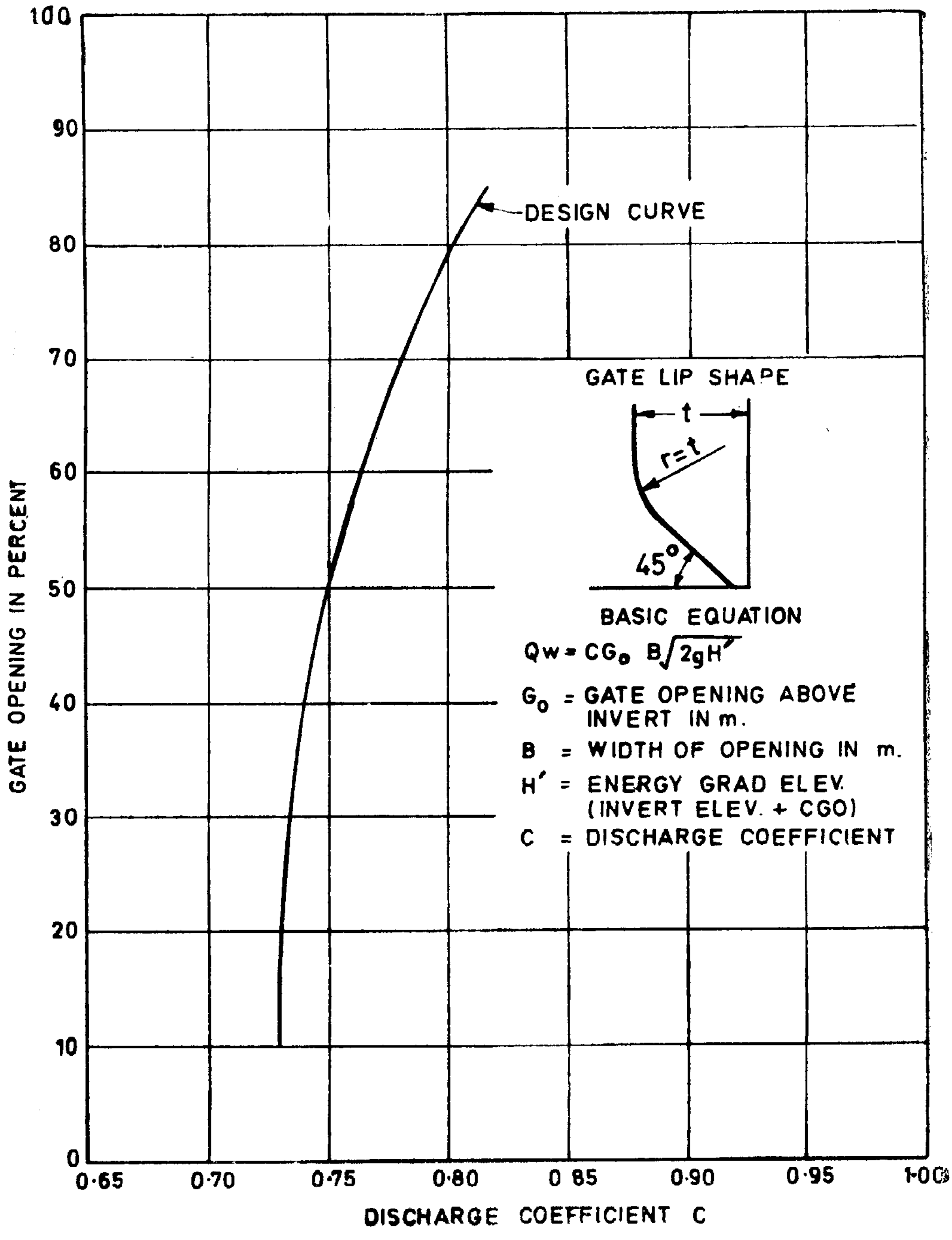


FIG. 4 GRAPH FOR DETERMINATION OF DISCHARGE COEFFICIENT

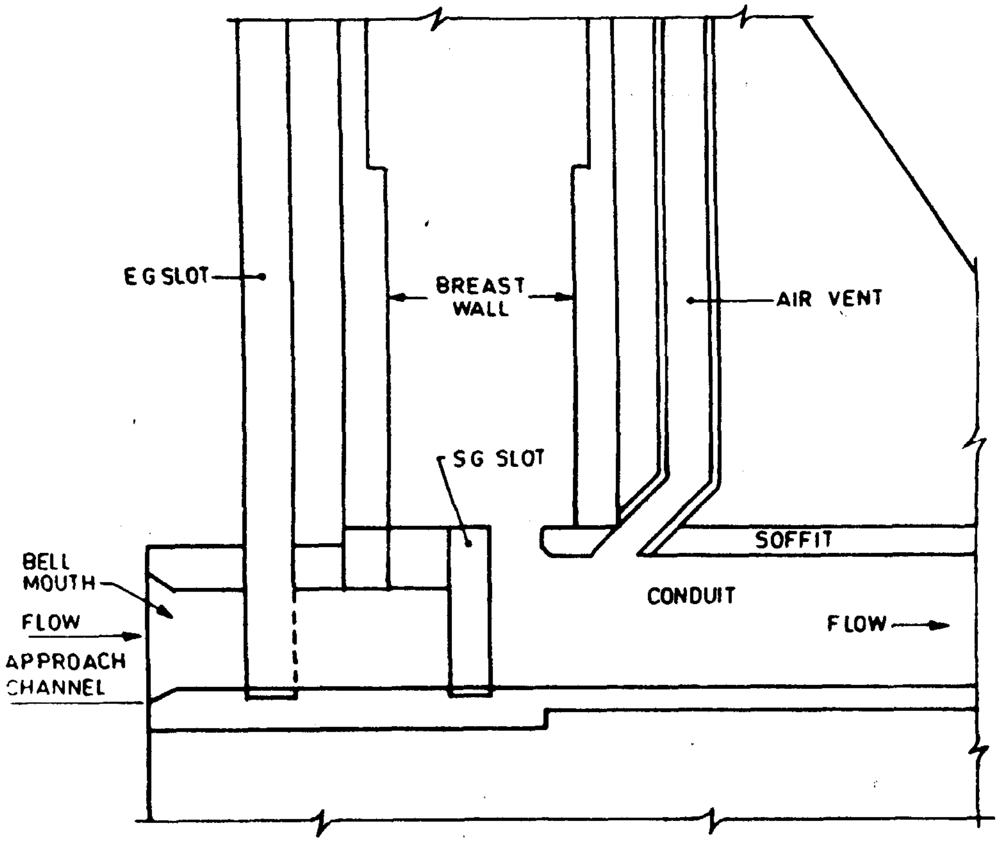


FIG. 5 TYPICAL INLET PORTION AIR VENT AND CONDUIT

ANNEX A

(*Clause* 3.4.4.9)

DESIGN OF AERATION GROOVE WITH RAMP ON UPSTREAM

A-1 DATA

Reservoir maximum water level ......140·21 m

Intensity of discharge in the spillway (q) .. ...135 m^3/s

A-1.1 Necessity of Aeration

Flow cavitation index to be found out at R.L. Reduced level 80·00 m.

(According to **3.3.3** equation 3)

$$K = \frac{d \cos\theta + \frac{P_b}{\gamma} - \frac{P_v}{\gamma}}{v^2/2g}$$

Head H = MWL − RL under consideration

(MWL = maximum water level)

$= 140·21 - 80·0$

$H = 60·21$ m

Velocity $V = 0·95 \sqrt{2gH}$

$= 0·95 \sqrt{2 \times 9·81 \times 60·21}$

$= 32·65$ m/s

Depth of flow d =

$$\frac{\text{intensity of discharge}}{\text{velocity}} = \frac{q}{V} = \frac{135·0}{32·65}$$

$= 4·13$ m

$$\frac{V^2}{2g} = \frac{(32·65)^2}{2 \times 9·81} = 54·33$$

Downstream slope of ogee is 0·6 H; 1 V

$$\therefore \theta = \text{Tan}^{-1} \frac{(1)}{(0·6)} = 59·036°$$

$\cos\theta = 0·51$

$d \cos\theta = 4·13 \times 0·51 = 2·106$

$\frac{P_b}{y} = 10·356$ m of water

$$K = \frac{d \cos\theta + \frac{P_b}{r} - \frac{P_v}{r}}{v^2/2g}$$

$$= \frac{2·106 + 10·3 - 0·223}{54·33} = 0·224$$

[Assuming vapour pressure $\frac{(P_v)}{\gamma} = 0·223$ m at 20°C]

However, so long as the flow cavitation index is less than 1·7, structure is not free from cavitation. In fact, at discharge of 1/3rd the design discharge cavitation index will be even less and protection to cavitation damages is essential.

A-1.2 Design of Aeration Groove

The calculations involve:

a) Angle of ramp and impact point,
b) Length and height of ramp,
c) Quantity of air required,
d) Size and shape of aeration groove, and
e) Spacing of air grooves.

A-1.2.1 *Angle of Ramp and Impact Point*

Consider a point at R.L. 80·0 m

Relationship for determining the impact point is given by:

$$\cos^2\phi\,(S_o - \text{Tan}\,\phi) = \frac{gx}{2v^2} \quad ......(A)$$

where, ϕ = vertical angle between ramp and the horizontal

S_o = Downstream slope of spillway,

g = acceleration due to gravity,

x = distance to impact point in m, and

v = reference velocity in m/sec.

Assume: $\phi = 55°$

$S_o = 1·666$ (since slope 0·6 : 1)

$v = 0·95 \sqrt{2gH}$

$= 0·95 \sqrt{2 \times 9·81 \times (140·21 - 80·0)}$

$= 32·65$ m/s

Rearranging the above equation (A);

$$X = 2v^2 \frac{\cos^2\phi\,(S_o - \text{Tan}\,\phi)}{g} \quad ......(B)$$

$$= 2 \times \frac{(32·65)^2 \times \cos^2 55° (1·666 - \text{Tan}\,55°)}{9·81}$$

$= 17·01$ m

A-1.2.2 *Length and Height of Ramp* (*as per para* **3.4.4.4** *equation 4*):

$$\frac{(S_o - \text{Tan}\,\phi) L}{\sqrt{1 + S_o^2}} + \frac{gL^2}{2v^2 \cos^2\phi\,(1 + S_o^2)^{1/2}}$$

$S_0 = 1.666$ Assume : $L=4.0$ m (ramp length)
$V=32.65$ m/s

$\phi = 55°$

$$H = \frac{(1.666 - \text{Tan } 55°) \times 4}{\sqrt{(1+1.666)^2}} + \frac{9.81 \times 4^2}{2 \times (32.65)^2 \text{Cos}^2 55° \times (1+1.666^2)^{\frac{1}{2}}}$$

$= 0.605$ m.

A-1.2.3 *Quantity of Air Required*

(as per **3.4.4.5** equation 5)

$$Q_a = \frac{B_v^3 \text{Cos}^3 \phi \, (S_0 - \text{Tan } \phi)^2}{4 g}$$

$B = 18.3$ (c/c distance of piers in m)

$V = 32.65$ m/s

$\phi = 55°$

$g = 9.81$

$$Q_a = \frac{18.3 \times (32.65)^3 \text{Cos}^3 55° \, (1.666 - \text{Tan } 55°)^2}{4 \times 9.81}$$

$$= \frac{18.3 \times 34\,805.64 \times 0.188\,7 \, (0.056\,57)}{4 \times 9.81}$$

$= 173.28$ m³/s

A 1.2.4 *Size and Shape of Aeration Groove*

Area of groove $= \dfrac{173.27}{30} = 5.77$ m²

that is 2.4 m × 2.4 m

(limiting the value of air velocity 30 m/s)

Finding out details of components as per Fig. 1 (L' and R)

$$L' = \frac{D \, (\text{Cos } \theta + 1)}{\text{Sin } \theta}$$

where, $D = 2.4$ m $\theta = \text{Tan}^{-1} \dfrac{(1)}{0.6} = 59.036°$

$$L = \frac{2.4 \, (\cos 59.036° + 1)}{\text{Sin } 59.036}$$

$$= \frac{2.4 \, (0.514\,5 + 1)}{0.857\,49}$$

$= 4.239$

Say : 4.25 m

$$R = \frac{D \times \text{Cot} \, (\theta/2)}{\text{Sin } \theta}$$

$$R = \frac{2.4 \times \cot \left(\frac{59.036°}{2}\right)}{\text{Sin } 59.036°}$$

$$= \frac{2.4 \times 1.766\,2}{0.857\,49}$$

$= 4.943$ m

Say $= 4.95$ m

A-1.2.5 *Spacing of Air Groove*

(As per **3.4.4.9** equation No. 6)

$$S = 3.5 \, d \, \frac{(d V\text{m})^{1/4}}{\nu}$$

Depth of flow: $d - \dfrac{g}{v} = \dfrac{135}{32.65} = 4.13$ m

Mean Velocity of flow : $V_m = 32.65$ m/s

ν = Kinematic viscosity $= 0.000\,001$ m²/sec

$$S = 3.5 \times 4.13 \, \frac{(4.13 \times 32.65)^{1/4}}{0.000\,001}$$

$= 1\,557.67$ m

NOTE — Thus, second aeration groove may not be required. However, the above aeration arrangement shall be tested by carrying out model studies and if required, suitable modification may be considered. Necessity of additional aeration groove at suitable location also shall be decided from the model studies.

ANNEX B

(*Clause* 4.4.2)

DETERMINATION OF AIR REQUIREMENT AND SIZE OF AIR VENT FOR OUTLET

Size of gate : 1.52 m × 2.74 m

Conduit size : 2.74 m dia

Head of water : 60.98 m

Maximum air demand occurs at 80 percent gate opening

Air requirement $Qa = \beta \, Q\text{w}$, in m³/s

(as per equation No. 11)

Discharge of conduit : $Q\text{w} = C \, G_0 \, B \sqrt{2 g H^1}$

(as per equation No. 10)

Value of C is 0.805 for 80 percent gate opening obtained from graph of Fig. 4.

(G_0 = gate opening) G_0 = 80 percent of gate height

$= 0.80 \times 2.74 = 2.192$ m

y = depth of vena contracta = $C\,G_o$

$= 0{\cdot}805 \times 2{\cdot}192 = 1{\cdot}765$ m

$B = 1{\cdot}52$ m width of gate

H^1 = Head on vena contracta =

(Head of water — y)

$= 60{\cdot}98$ m—$1{\cdot}765$ m

$= 59{\cdot}215$ m

$Q_w = 0{\cdot}805 \times 0{\cdot}80 \times 2{\cdot}74 \times 1{\cdot}52 \times \sqrt{2 \times 9\,81 \times 59{\cdot}215}$

$= 91{\cdot}42$ m³/s

Velocity at vena contracta $V_r = \sqrt{2gH^1}$

$= \sqrt{2 \times 9{\cdot}81 \times 59{\cdot}215}$

$= 34{\cdot}085$ m/s

Froude number $F_r = \dfrac{Vr}{\sqrt{gy}}$

$= \dfrac{34{\cdot}985}{(9{\cdot}81 \times 1{\cdot}765)^{\frac{1}{2}}} = 8{\cdot}20$

$F_r - 1 = 8{\cdot}20 - 1 = 7{\cdot}20$

β is obtained from graph of Fig. 3 that is 0·25

$Q_a = \beta \times Q_w$

$= 0{\cdot}25 \times 91{\cdot}42$ m³/s

$= 22{\cdot}855$ m³/s

Area of air vent $A_r = \dfrac{Q_a}{V_w}$

where, V_w is air vent velocity, and considered as 40 m/s maximum

Area of air vent $A_r = \dfrac{22{\cdot}855}{40} = 0{\cdot}571\,4$ m²

Diameter of air vent $d_r = \sqrt{\dfrac{4 \times A_r}{\pi}}$

$= \sqrt{\dfrac{4 \times 0{\cdot}571\,4}{3{\cdot}14}}$

$= 0\,85$ m

Use 0·90 m pipe

Standard Mark

The use of the Standard Mark is governed by the provisions of the *Bureau of Indian Standards Act, 1986* and the Rules and Regulations made thereunder. The Standard Mark on products covered by an Indian Standard conveys the assurance that they have been produced to comply with the requirements of that standard under a well defined system of inspection, testing and quality control which is devised and supervised by BIS and operated by the producer. Standard marked products are also continuously checked by BIS for conformity to that standard as a further safeguard. Details of conditions under which a licence for the use of the Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

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