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Air Demand for High Head Gates

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ABSTRACT
Artificial air entrainment has been widely used to avoid cavitation damage in spillways where high-velocity flow occurs, and its performance is very important for spillway safety. Due to high head gate, dams are susceptible to cavitation damage, surface deformities, and high velocity. To minimize these effects, air vents (vented to the atmosphere) are installed on the upstream and the downstream side of the gate to limit downstream pressure to something above vapor pressure (i.e., near atmospheric pressure). In the large-dam air demand, analysis has been based on the Froude number of the supercritical flow at the vena contract (located between the gate and the hydraulic jump) and the water flow rate. The primary functions of an air vent are: Reduce or eliminate sub-atmospheric pressure in the conduit during emergency closure or partial-gate operation; Permit drainage of the conduit; and Allow air to escape when the conduit is being filled.

Keywords – (High head gate, Air vent, Cavitation, A)

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I. INTRODUCTION

In recent years, there has been a great increase in the number and height of high dams. Ever increasing height of these structures has posed serious problems for the design of their control elements for regulating the releases through the outlets. The most common of these control elements are fixed wheeled vertical lift gates, slide gates or radial gates. When the gate of a high head outlet is partly open, a high velocity flow occurs downstream of the gate resulting in sub atmospheric pressures which can be as low as vapour pressure leading to cavitation damage. Such a highly turbulent flow gives rise to fluctuating pressures. Which may cause vibration of the gate and its suspension system also. Besides the flow has a capacity to drag with it and entrain considerable air resulting in air demand. It has been found that if the air demand is notsatisfied (by providing a continuous supply of air through an air vent of suitablesize), cavitation and vibration are intensified. Thus, all the three phenomenaviz. cavitation, vibration, and air demand are interrelated and get intensifiedwith an increase in the head.

AERATION

The necessity of providing adequate supply of air immediately downstream of the gate need not be over-emphasized. Cavitation and attendant vibration are minimized with proper air supply arrangement. As an example of how inadequate supply of air could cause vibration problems even if hydraulic conditions everywhere are favorable

II. AIR DEMAND

When the gate of a high head conduit is partly open, a high velocity flow occurs downstream of the gate resulting in sub atmospheric pressures. Theoretically, these pressures can be as low as the vapour pressure of water and may lead to cavitation and attendant vibration. To avoid this situation, the conduit is connected to the atmosphere through an air vent located downstream of the gate. The purpose of the air vent is to draw in air and thereby keep the pressures downstream of the gate at a safe level. The required quantity of air depends on the entraining and carrying capacity of the flow whereas the drop in pressure behind the gate is a function of the size, shape and length of the air vent. Therefore, if the entraining and carrying capacity of the flow (i.e. air demand) is determined accurately the air vent can be designed in such a way that the pressure downstream of the gate is within desirable limits. Besides preventing the pressure to drop, the air vent also functions to (i) permit escapage of air displaced by gushing flow when the gate is being raised and (ii) admit air into the conduit when the gate is being closed.

III. CAVITATION

Cavitation occurs when the local pressure on a boundary falls down to the vapour pressure. Bellow Figure shows some of the locations where danger of cavitation erosion exists. The desirable lip shapes and gate slot configurations are also shown which eliminate cavitation potential.

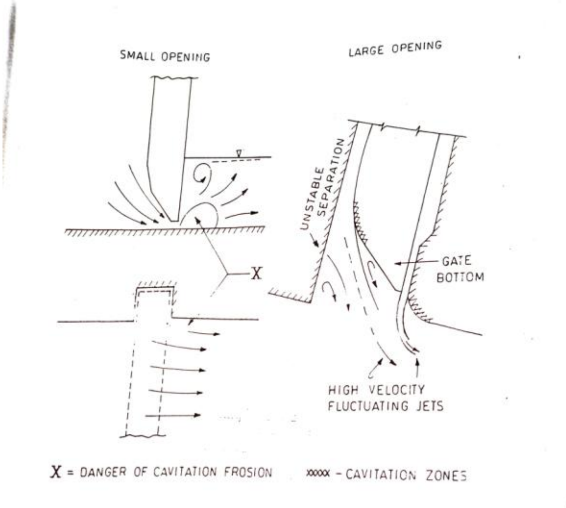


Figure of cavitation no 1

A. Cavitation may be defined as the formation of vapour filled cavities in a liquid at substantially constant temperature by a dynamic action which reduces the pressure in localized regions to the vapour pressure of the liquid. These cavities travel along with the flow and collapse (implode) when they enteregions of higher pressure. The implosion forces are so great as to cause damage to the flow surface by pitting action.

B. The cavities are formed in the regions of very low pressures consequent to separation of the high velocity flow. The flow in a high head gated conduit separates usually at the bottom of the gate and/or at the gate slot. Figure 1 shows the regions in a gate and gate slot system where cavitation is most likely to occur. Thus, the design of bottom lip of the gate and the shape of the gate slots are the most important factors for a cavitation free design of gates. Cavitation investigations of a fixed wheel gate model in a cavitation tunnel indicated that for gate openings upto 30%, cavitation occurs downstream of the gate slots whereas for openings above 50% cavitation occurs in eddy, formed between upstream face of slot and gate skin-plate. The other sources are gaps in the seals and geometric configurations of sluice barrels downstream of gates.

CAVITATION IN GAP

Cavitation in gates can be observed when water leaks through clearances at seals during gate operations. Under high heads, gap cavitation may be found to the principal source of cavitation damage to the gate or the slots, particularly with leakages, which unavoidably arise through gaps formed between the sealing elements. A case of damage involved the skin plate of a radial gate in a sluice way outlet under a head of 70 m.

There are numerous instances of cavitation damage to outlets which are of Course not directly related to gate or gate slot. These include damages caused to the bed and side of the sluice barrels downstream of the gates. The causes were; surface irregularities, misalignments and inadequate transitions and curvatures of sluice bottom profiles. In the decades of fifties and sixties, a large number of cases of damage were reported in USA and USSR. Notable among them were; Inverts of Palisades dam outlet, Navajo auxiliary outlet, Pueblo dam outlet, Crystal dam outlet, Glen Canyon dam outlet, etc. in USA and Votkinksk hydro power project, Pavlova dam and Charka dam, USSR and Sere Poncon dam, France. In all these cases, construction and modifications where carried out by providing offsets and grooves to aerate the boundaries of the structures adjacent to the high velocity flow. In fact, design of aerators owe its development to the experience gained from these damages and subsequent remedies.

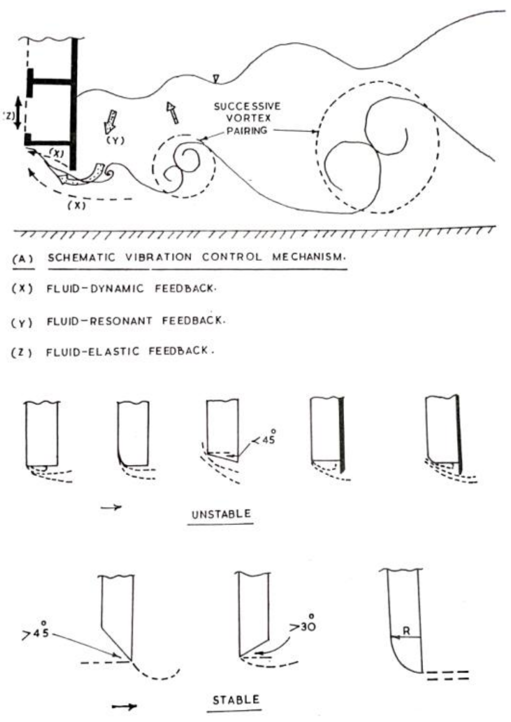
Besides taking care in the design of gate lip shape and gate slots, cavitation damage can be minimized by providing adequate aeration by way of air vents located on the roof immediately downstream of the gates. Provision of sufficient quantity of air also reduces the risk of vibration.

GATE VIBERATION

The physical situations leading to gate vibrations are usually very diverse and complex in nature. One of the most frequent sources of gate vibrations is due to a condition of unstable flow separation and reattachment at the gate bottom. In general, whenever flow is detached from an upstream edge and wavers near the remaining part of the gate profile under submerged flow conditions, significant vibrations may develop.

Schematic of the vibration control mechanism is depicted in Figure 2 the parameters involved are –

- Fluid-dynamic feedback associated with the instability of shear layer
- Fluid-resonant feedback associated with free surface oscillations, and
- Fluid-elastic feedback associated with the movements of the edge from which the flow separates.



Gate-Edge Configuration and Typical Flow Condition

Figure no 2

As far as hydraulic gates are concerned, there are three modes of vibration; vibration of the entire gate body is the first mode, vibration of individual gate members like girders, beam etc. come under the second mode while in the third mode ancillary features like seals etc. vibrate individually. The first mode is of prime importance since the second mode is restricted to very wide and small height gates like radial gates on tidal barriers etc.

The most efficient way to avoid gate vibration of this type is to ensure that the flow remains attached to the gate underside or to remove the latter sufficiently far from the separated flow. From this consideration, the gate edge configurations, which were found to be unstable and stable, are shown in Figure 2

Vibrations are more severe in the case of fixed wheel gates owing largely due to relatively large dimensions of gate slots. Flow circulation in the gate slots for partial opening of the gates is the principal cause. These can be eliminated by designing proper shape of the gate bottom profile and gate slots. High head slide gates are considered to be more suitable with low vibration potential mainly because of smaller dimensions of the gate slots and relatively higher damping offered by the sliding friction.

Radial gates have practically no problems of vibration due to the absence of gate slots and fouling of the bottom girder etc. provided the top seal is secure properly and there are no gaps causing leakages. Free surface radial gates on spillway crests however exhibit vibrations at very small openings. Vibrations may also be caused due to vortices occurring in corners for small openings and due to obliquity of the approach flow. The intensity of vibrations is generally insignificant to cause any concern. However, sustained operation of the radial gates for very small openings should not be permitted since damages to wire ropes and hoisting devices may be caused due to fatigue.

Radial gates, which are to operate under simultaneous underflow and overflow as those, which are to withstand submergence by the downstream water level have maximum vibration potential. This can be overcome in the former by providing aeration to the underside of the overflowing nappe by spoilers. In the latter, hydraulic model, studies are often helpful in evolving suitable pattern of operation with respect of upstream and downstream water levels as well as gate openings.

IV. OBJECTIVES OF THIS STUDY

To study the factors affecting air demand are gate opening, type of flow, velocity, conduit profile, head loss in the air vents
Study the designing aspects for the aeration system {the important aspects necessary to consider are}

1. Velocity of air
2. Correct volume of air
3. Size and shape of air vent

V. DETERMINATION OF AIR DEMAND

Kelinske & Robertson, which yielded the relationship, conducted the first systematic study of air demand
$\beta=0.0066\ (Fr - 1)^{1.4}$

Where β= Ratio of air flow to water flow (by volume)

Fr= Froude number at location of gate.

Later, several investigators as modified this relationship

Campbell and Guyton $\beta= 0.04\ (Fr - 1)^{0.85}$

Haindl and sotornik $\beta= 0.012\ (Fr -1)^{1.4}$

Us-WES $\beta= 0.03\ (Fr -1)^{1.06}$

Where Fr = froud number at vena contracta.

Determine, from field observations on a dam with outlets in three tiers operating under heads of about 30, 60 and 90 m concluded that depended on the form of gate, was independent of head and had a maximum value of unity i.e. .max =1.

While no investigators above included in their analyses, the parameter of gate opening Wunderlich, for the first time considered the factor relative gate opening thus

$$\mathbf{1 + \beta= 1 / (Ac/At)}$$

Where Ac denotes flow area at vena contracta and at is the cross sectional area of the conduit.

Lysne and subsequently Wisner modified Wunderlich's relationship to cover different types of flow conditions. Finally, Sharma defined seven distinct categories of flow i.e.

1. Flow of air alone (gate closed)
2. Spray flow B =0.2 F 1c
3. Free flow 1+ B = 0.09 F 1c
4. Foamy flow 1 +B= 1/ (Ac/At)

5) Hydraulic jump with free surface flow

($\beta = 0.006\ (Fr -1)^{1.4}$)

6).Hydraulic jump with drowned flow

7. Flow of water alone

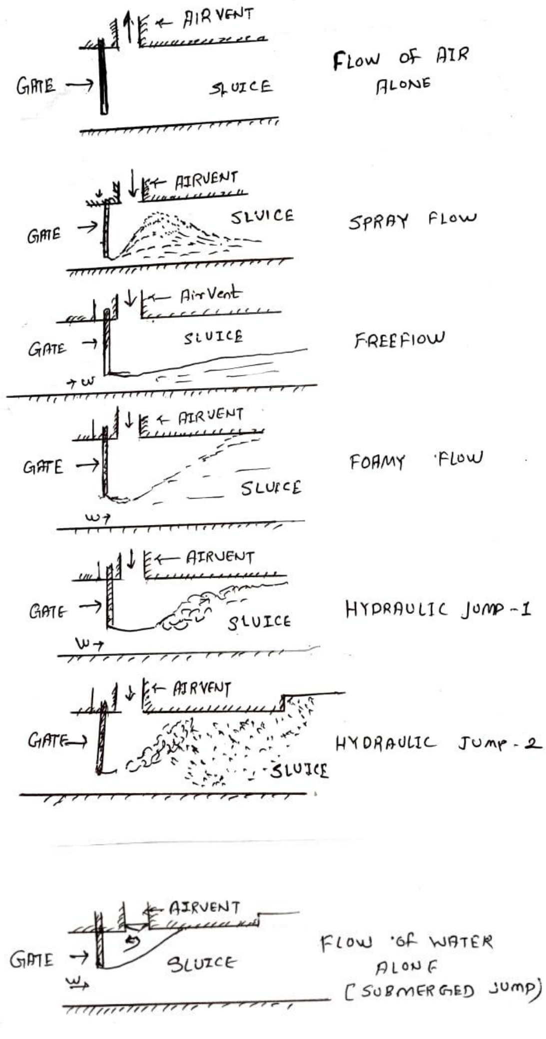
These conditions were represented by the magnitudes of F.

Nature of variation of air demand downstream of regulating gate observed in model is shown in bellow Figure. Air demand gradually increases, reaches maximum at gate opening around 50%. Thereafter even though discharge increases air, demand decreases due to flow conditions downstream of regulating gate.

Point to be consider during Airvent Design:

Air velocity through Airvent should not exceed 50 m/s

Total pressure drop in the Airvent should not exceed 2.0 meters.



CLASSIFICATION OF FLOW TYPES IN GATED SLUICE

VI. METHOD WE USED FOR CALCULATION OF AIR DEMAND

Determination of Air requirement and size of air vent for outlet

 Qa=β x Qw m3/s

The great interest in determining the air demand induced various authors to conduct systematic research and prototype measurements. The results brought about a great dispersion of values and various formulas were developed for calculating the air-demand ratio, which is given by

- **β = Qa/ Q**

Where- Qa=the quantity of air in m3/s

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β= the ratio between quantity of air requirement Vs quantity of water discharge through conduit

Qw=the quantity of water discharge through outlet in m3/s

The β ratio is a function of various parameters such as the conduit and gate geometry, the velocity and depth of the vena contracta and the water head. Most published papers suggests the following formula for determination of the air-demand ratio:

- **β = K (Fc-1)**

Where

Fc = Froude number at vena contracta

K and n = empirical coefficients.

Qw= C x Go x B x $\sqrt{2gH'}$ **m3**/s

Where: -

C is discharge coefficient or contraction coefficient …. (As per graph no 1 shown below)

Go is the gate opening above invert in (m)

B is the width of the gate opening in m.

H is the height between energy head elevation – (m)

(Invert elevation – C Go)

Note-

- **Fr = Vr /** $\sqrt{gy}$ **(Froude number)**

Where: -

Vr = Water Velocity at Vena Contracta

- **Vr=**$\sqrt{2gH'}$ m/s

y = Depth at Vena Contracta = (C x Go)

Qa = Air Demand m3/s

Qw = Water Discharge m3/s

Also, Fr will be determined by graph of β

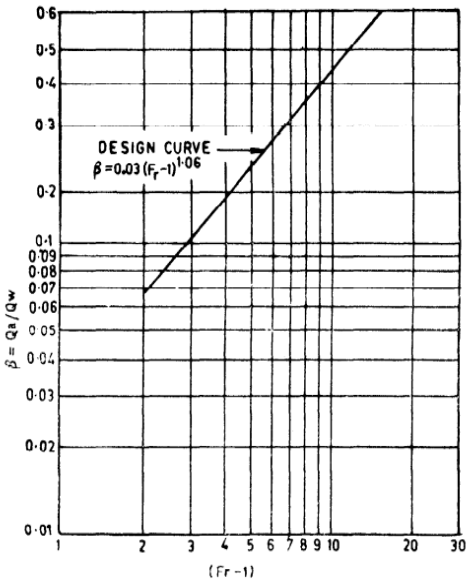
The size of air vent can be worked out by knowing the quantity of air, to be supplied and considering the maximum air vent velocity at 40 m/s.

Therefore, area of air vent

- **(Ar= Qa/40). in m2**

Diameter of air vent in m

- dr = √(**4** $X\ Ar/\Pi$



Graph no (1)

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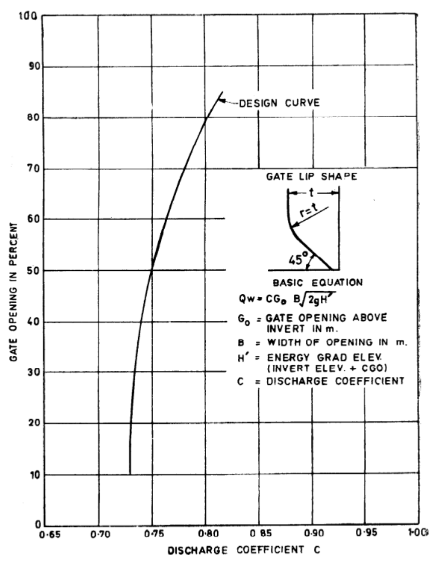

Fig. 4 Graph for Determination of Discharge Coefficient

Graph no (2)

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VII. CONCLUSION

1. In this study we saw that shape and size of conduit and due to high head gate, air passes from the conducted in large quantity with in a fraction of time only.
2. Due to this to pass this air we need air vent as a factor of safety.
3. Velocity of air increases with decreasing a gate level
In addition, velocity of air increases with increasing a gate level.
4. Means at the 40% to 60 and 80% gate opening the velocity of air remains stable, which does not form a cavitation and vibration and it, may form some time but in the micro level in the tunnel.
5. Correct volume of air directly proportional to the velocity of air. It means air vent shape and size is necessary for it.
6. The size of the Airvent is vary with the change in gate opening percentages.
7. As the gate opening increases the air vent size will also increase and as gate opening decreases the air vent size also decreases,
8. It means gate opening directly proportional to the size of air vent.
9. We also found that in the tunnel spillway there is no need of air vent as per our calculation and because of the size of tunnel is aal ready big with the open end
BUT,
When vertical bulkhead gate will open and radial gate is closed then we need the air demand due to lack of air demand in the tunnel bellow the radial gate.
10. As per our calculation on the service gate in the extreme case of 80% and 100% of the gate opening our air requirement is 282.07 m3/s and 308.96 m3/s respectively, area of the air vent is 7.05 m and 7.72 m respectively Diameter as per the calculation is 3.00 m and 3.14 m respectively in which is more enough sufficient that we provided in the prototype which has the size of 5.5m hence all calculation done for service gate is ok for the prototype.

Acknowledgements

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