EVALUATION OF AIR VENTS AND RAMP ANGLES ON THE PERFORMANCE OF ORIFICE SPILLWAY AERATORS

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ABSTRACT

The performance of steep slope ($\theta > 30^o$) orifice spillway aerators by varying air vent size and ramp angles were experimentally studied. Three air vents of different sizes and five ramps with different angles were tested on a physical model of Bunji dam spillway, which was constructed at Irrigation Research Station Nandipur, Gujranwala. In each case, the cavity length, cavity pressure, flow velocity and water depth at the aerator were measured by changing operating conditions. Non-dimensional jet length (λ), air entrainment co-efficient (β) and non-dimensional cavity pressure (P_n) were computed to evaluate the performance of the aerator against ramp angle and air vent size. Results noted an improvement in the performance of aerator with the increase of air vent size. However, the ramp initially improved the performance of the aerator but at higher reservoir level with large gate opening, no significant improvement in the performance of the aerator was noted, rather negative impact was observed due to reduction in cavity pressure.

Key Words: Orifice Spillway, Aerator, Ramp Angle, Air Vent

INTRODUCTION

Large-capacity gated outlets usually called orifice spillways are used to release flood water from the reservoirs (Novak et.al.[1]). Bhosekar et.al.[2] noted that deep-seated orifice spillways are subjected to cavitational damages when the cavitations index drops below 0.2. The cavitational damage near the concrete surface can be controlled by the presence of about 8% air (Paterka[3] & Zhang[4]). The Bhosekar et.al.[2]) also noted that the most effective method for the entrainment of air at the spillway surface is aeration through aerators.

The major types of aerators are offsets, air galleries/ slots, ramps and their combinations (Falvey[5]). Offsets and aeration ramps separate the flow form spillway surface and form a cavity for the induction of air at lower nappe. Air galleries or slots are connected to a vertical air intake shaft while air vents supply air to the cavity (Khatsuria[6]). Variation in ramp angle and air vent size affects the cavity length, air entrainment and cavity pressures which ultimately affects the performance of aerators. Recent work of Bhosekar et.al.[2] on flat slope orifice spillway ($\theta < 30^o$) aerators shows significant improvement in the performance of aerator with the increase in ramp angle and air vent size, particularly at large gate openings. Keeping in view this background, present study intends to analyze the performance of steep slope spillway aerators with and without ramp by changing the ramp angle and air vent size.

Bunji Hydropower Project

Bunji hydropower project is to be constructed on Indus River, in Gilgit-Bultistan province of Pakistan. Spillway with five bays is proposed to drawdown the reservoir for flushing operation. The spillway is provided with vertical sliding gates with radial gates and stoplogs. Against maximum head, the discharge capacity of each is 1850 m^3/s. Downstream of the gate the spillway has a short horizontal stretch, leading to a convex curvature with radius of 120 m ending up in curvilinear flip bucket. Calculations show that potential for cavitations exists on the downstream part of the chute for discharges higher than 1300 m^3/s, which leads to the provision of aerator on chute close to the downstream face of the spillway, to introduce air and to avoid cavitational damages over exposed part of the chute. An aerator structure comprising an offset and two air intake shafts (on left and right side) connected to an air vent and air gallery / slot, are proposed on spillway profile (WAPDA[7]). Table 1 shows the salient features of spillway.

PHYSICAL MODEL OF BUNJI SPILLWAY

The partial physical model of Bunji dam spillway shown in Fig.2 was constructed by WAPDA on a scale of 1:30 at Irrigation Research Institute (IRI) Nandipur,

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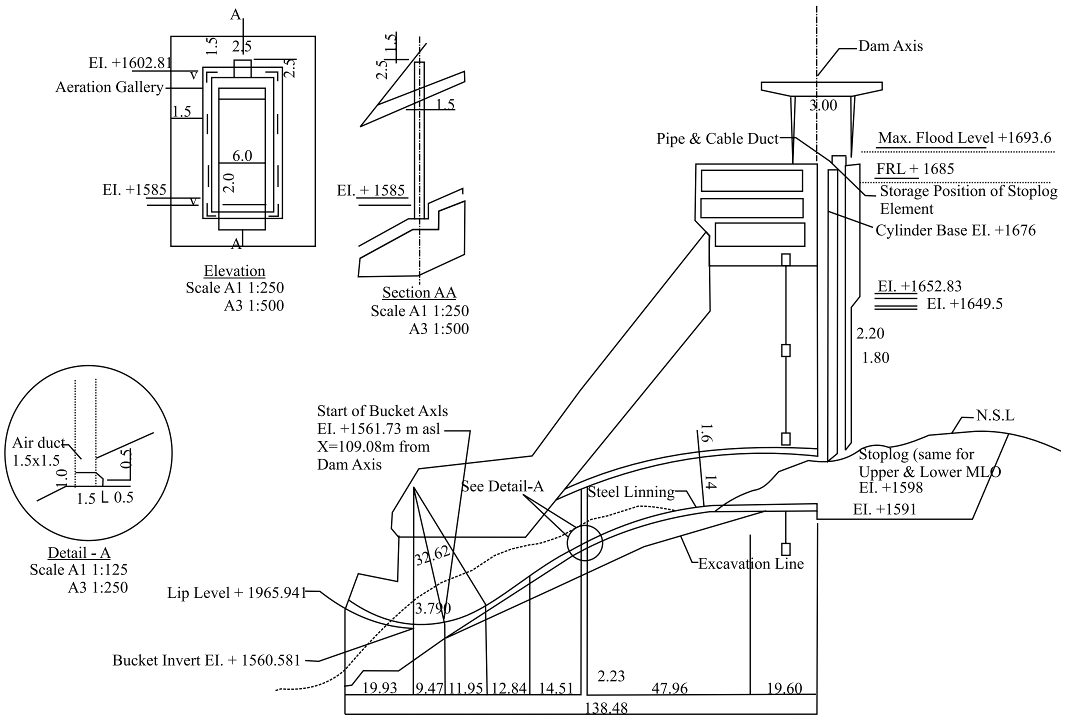

Figure 1. Sketch of Spillway and proposed Aerator

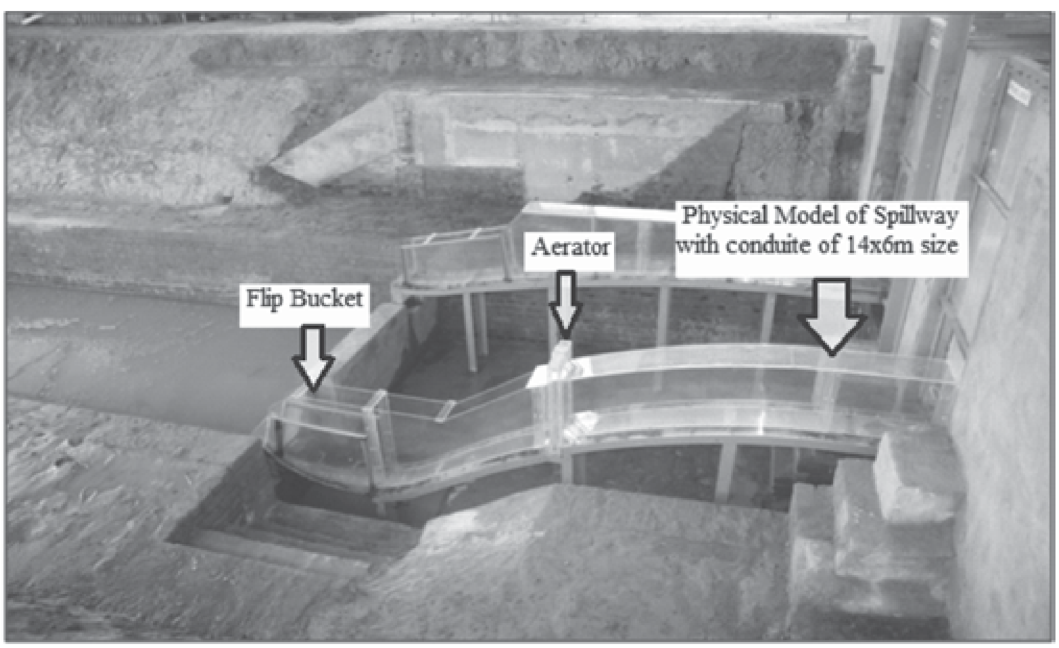

Figure 2. Physical Model of Spillway

Gujranwala, Pakistan. The invert level of spillway inlet was at 1595 masl, whereas ten (10) observation points were adjusted along the spillway profile. The model was fabricated in Plexiglass for visual observation and mounted on a steel frame to avoid deformations / vibrations. The water was supplied form a canal located upstream of the model. The discharge passed through the model was measured by a sharp crested rectangular weir, which was installed at the downstream side of the model. Over the spillway at selected points the water depth, pressure head and velocity were measured with level, U-tube manometer and the current meter, respectively. Jet length was visually observed using scale plotted on side wall of the spillway.

Spillway flows were modeled using equations of hydraulic similitude based on Froudian relation as it represents the gravity and inertia effects which are important for free surface flow modeling (Henderson[8], Novak et.al.[1]).

On geometrically similar models the true dynamic similarity cannot be achieved as it is not possible to satisfy simultaneously Froude and Reynolds similarities (Rafi et. al.[9]). Keeping $L_{ref.} = d_o$, the scale effects regarding air entrainment coefficient of aerators and general two-phase flow characteristics became negligible if We >110 and Re $>1\times10^5$. Moreover, Pfister and Hager[10] noted that the scale effects also became insignificant if We > 500 and Re > 3.5×10^6. During this study, these limits were observed to reduce the scale effects.

MODEL OPERATION

The Model was operated by varying reservoir level and gate opening, to assess the impact of ramp angle and air-vent size on the performance of the aerator. Table 3 shows the detail of experiments conducted on the physical model. Three air vents and five ramps were tested; consequently 48 experiments were performed for various geometric alternatives of aerator against operating conditions as shown in the table 3.

PERFORMANCE ASSESSING PARAMETERS

The experimental observations were used to determine non-dimensional jet length (λ), air entrainment co-efficient (β) and non-dimensional cavity pressure (P_n). The parameters given as under are important for hydraulic performance assessment of the aerators as noted by Chanson[2]; Pinto[10]; Rutschmann and Hager[12] .

Jet Length

Where, L = jet length; d_o= water depth; and λ = non-dimensional jet length

$$\lambda = \frac{L}{do}$$

Air entrainment co-efficient

$$\beta = \frac{Qa}{Qw}$$

Where, Q_a = air flow rate m³/s ; Q_w = discharge through spillway in m³/s ; and β = air entrainment co-efficient

Cavity Pressure

$$Pn = \frac{\Delta p}{pgdo}$$

Where, = average cavity pressure (N/m²); = density of water (kg/m²); d_o= flow depth; and P_n = non-dimensional cavity pressure

MODEL STUDY RESULTS AND DISCUSSION

Impact Assessment of Air Vent Size

The plot between non-dimensional jet length, air entrainment co-efficient, non-dimensional cavity pressure and Froude No. are shown in Figs.3, 4 and 5, respectively. The Fig.3 shows non-dimensional jet length (λ) at varying air vent size keeping reservoir level at 1620 masl and1650 masl and changing gate opening from 25% to 75%. The results indicate that the jet length was increased with the increase in Froude number. The highest value of λ was noted against the largest air vent size (1.50m x 2.55m), whereas for other air vent sizes, almost identical values of λ were obtained at all operating conditions.

Fig.4 shows the impact of air vent size on air entraining capacity of the aerator. Results indicate that air entraining capacity of the aerator is increased by the increase of air vent size. However, it increased marginally in case of large gate opening against both reservoir levels.

The air entrainment co-efficient remained constant, for small air vents (1.15x2.20 m & 1.25x2.30 m) at high head (1650 masl) with at all gate opening. This indicates that there was no improvement in air entraining capacity of

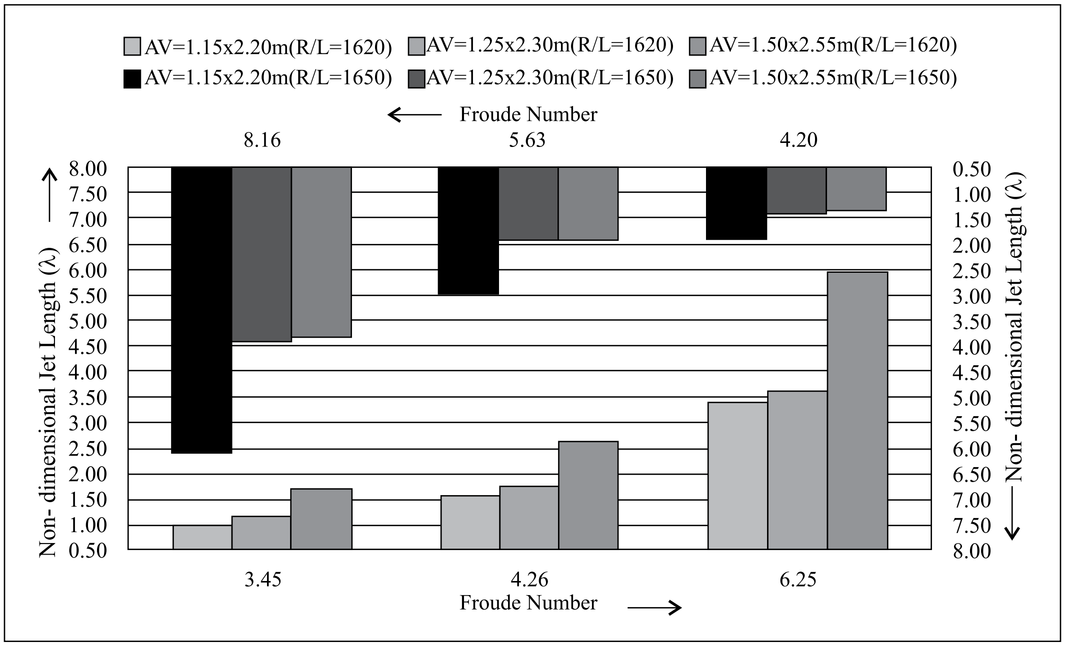

Figure 3. Impact of Air Vent Size on Non-dimensional Jet Length

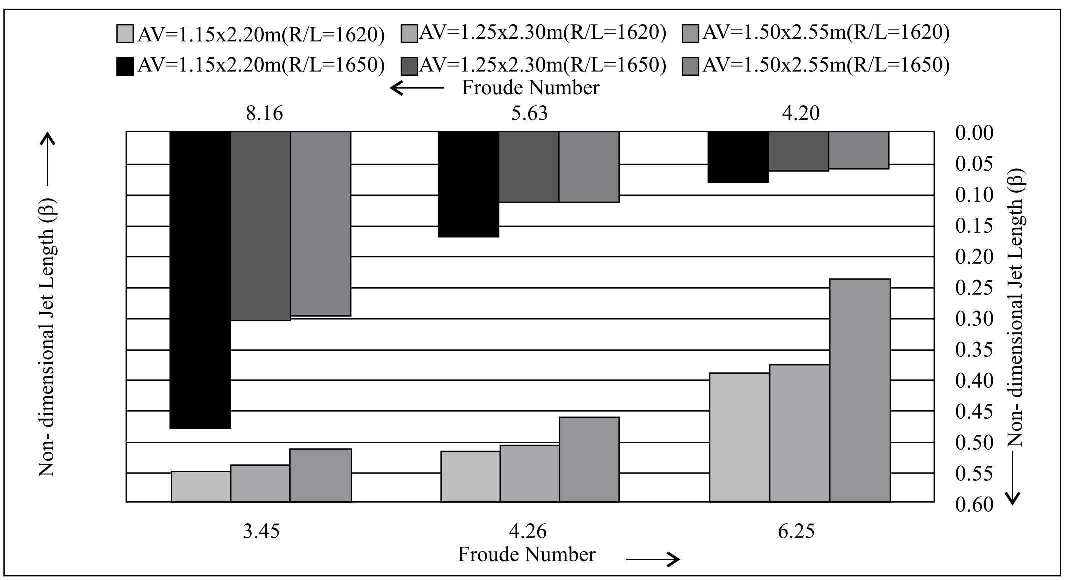

Figure 4. Impact of Air Vent Size on Air Entrainment Co-efficient

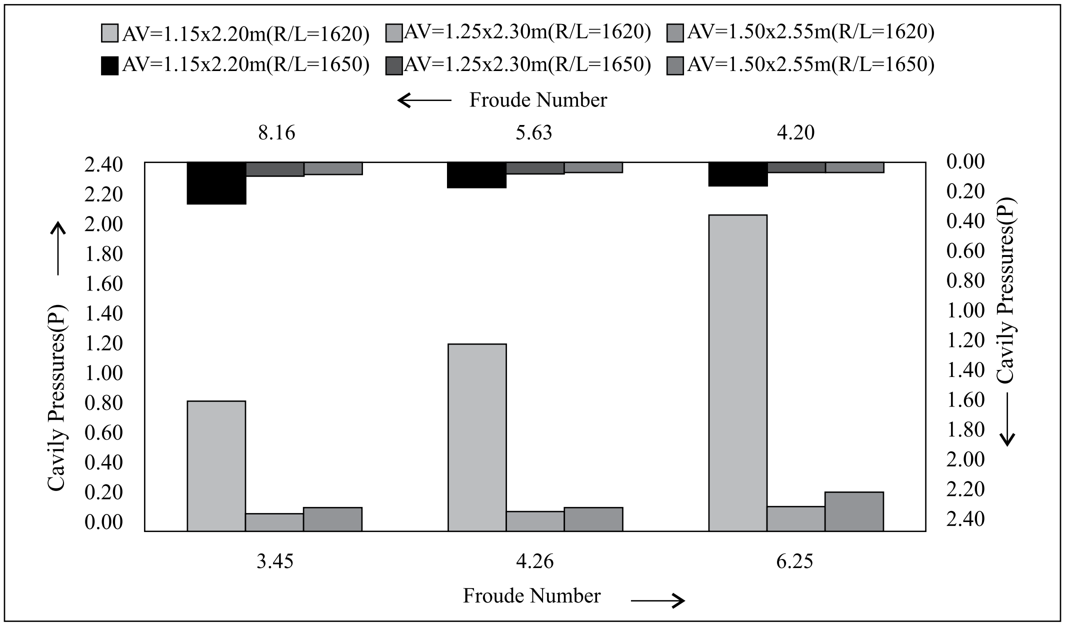

Figure 5. Impact of Air Vent Size on Non-dimensional Cavity Pressures

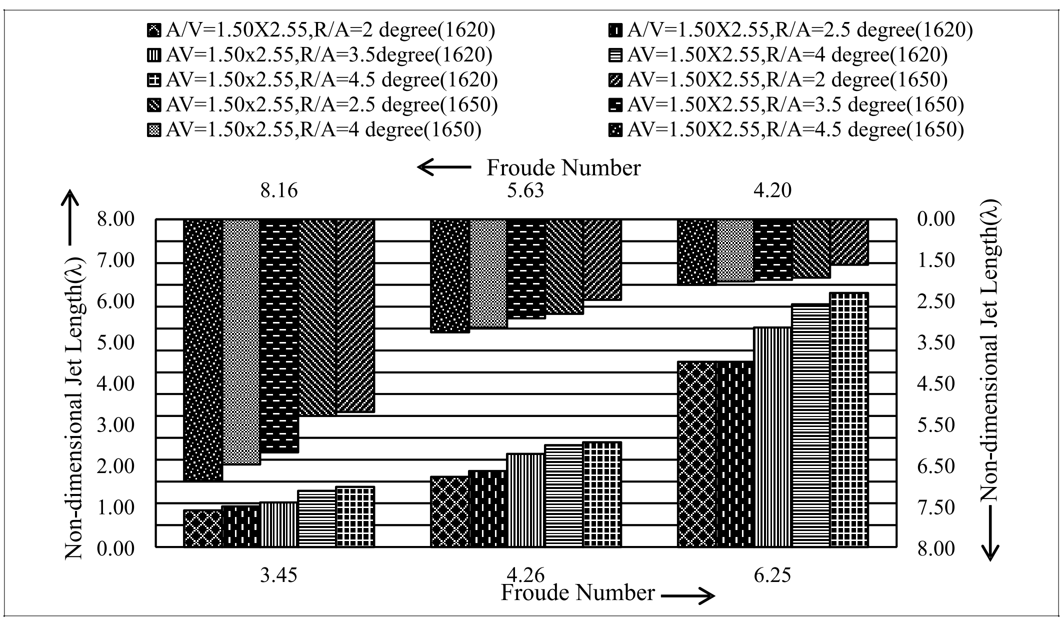

Figure 6. Impact of Ramp Angle on Non-dimensional Jet Length

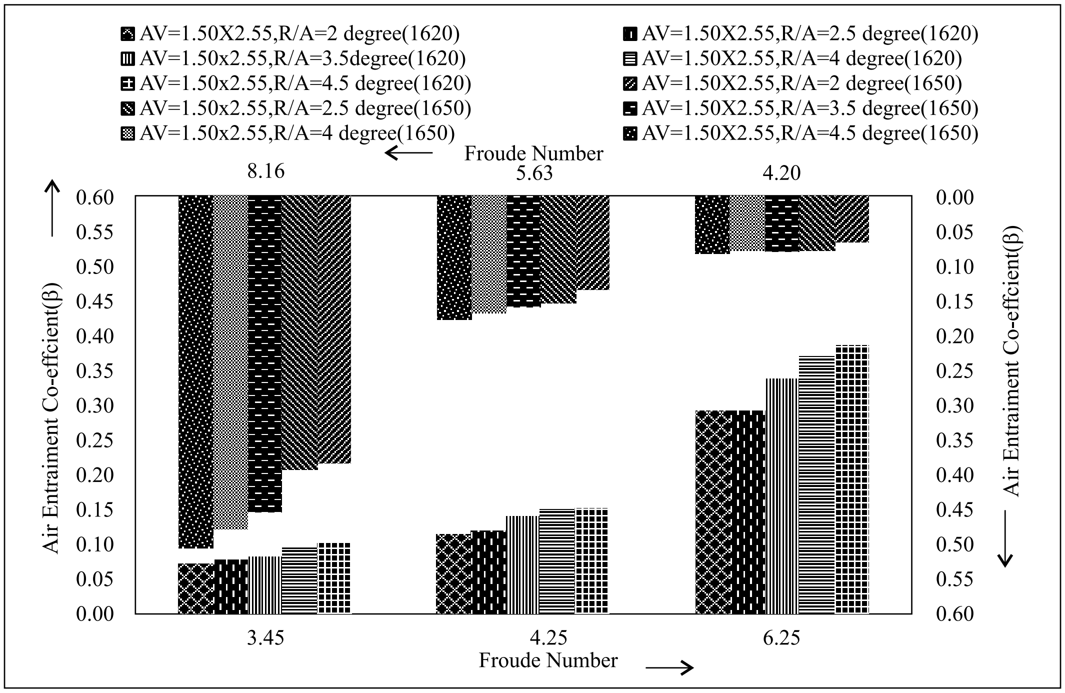

Figure 7. Impact of Ramp Angle on Air Entrainment Co-efficient

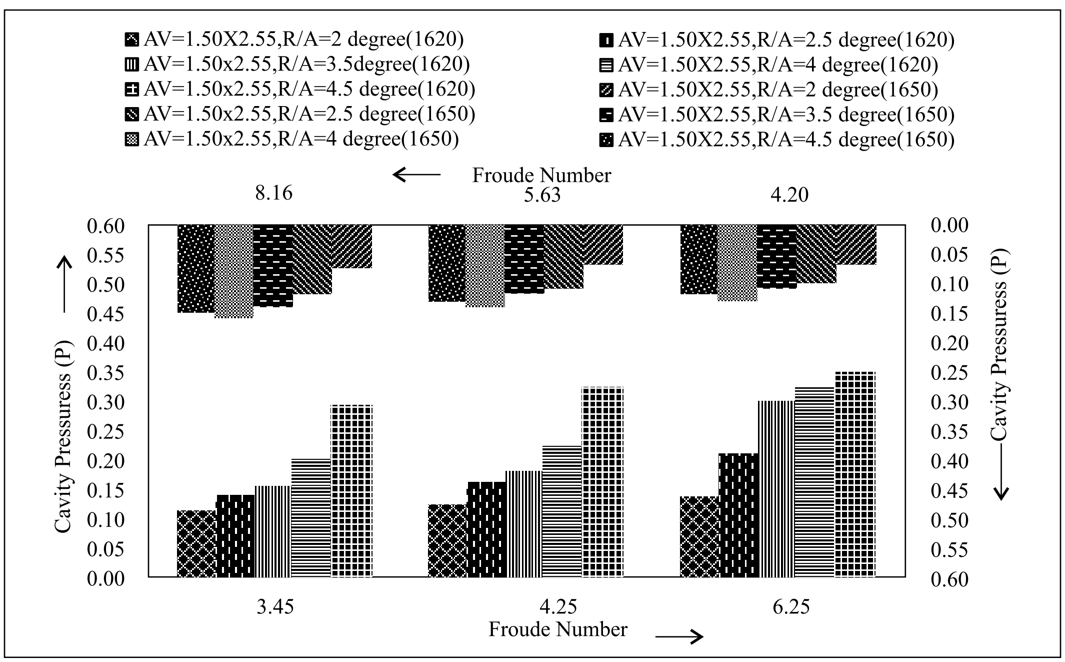

Figure 8. Impact of Ramp Angle on Non-dimensional Cavity Pressures

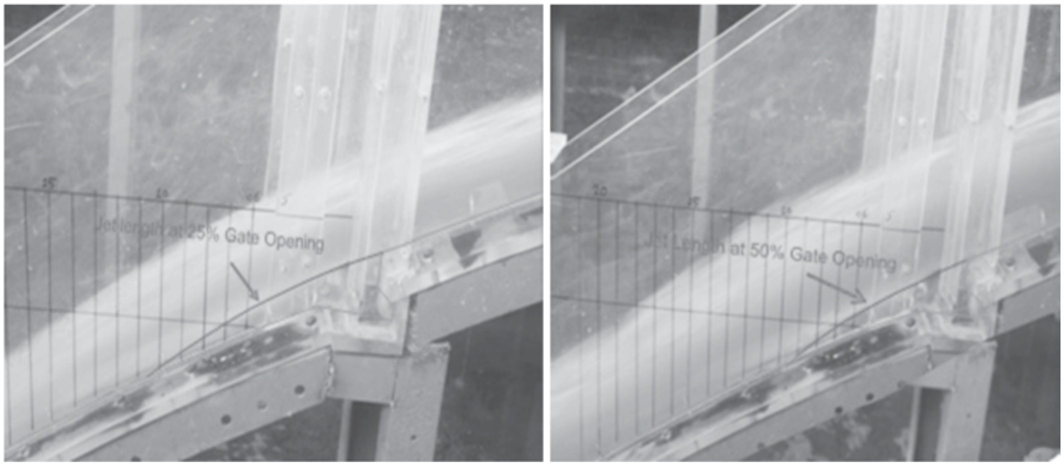

Figure 9. Measurement of Jet length at reservoir level of 1620 masl and at gate opening of 25% & 50%

the aerator. The results further showed that air entrainment co-efficient became maximum, with maximum air vent size for high head and small gate opening. The air entrainment co-efficient remained small for large gate opening (75%) at both the reservoir levels because of small cavity length[11,12].

The impact of air vent size on non-dimensional cavity pressure is given in Fig.5. Generally the P_n values are improving with the increase in air vent size because of increase in cavity length and air entrainment. The abnormal values of non-dimensional cavity pressures at small reservoir level indicate the location of some observation points in impact region. Beside abnormal values, figure shows that cavity pressures are more positive in case of maximum air vent size for all gate openings. At high head and large gate opening, non-dimensional cavity pressures are comparatively low than other gate openings which indicates the reduction in air entraining capacity of aerator and jet length.

It was revealed that the impact of air vent size (1.50m×2.55m) on jet length, air-entrainment and cavity pressure is considerable, so it was further tested with varying ramp angle to assess the performance of the aerator.

Impact Assessment of Ramp Angle

The impact of ramp angle on performance of aerator is shown in Figures. 6, 7 & 8. It is noted that the jet length (λ) increased with the increase in ramp angle at both reservoir levels and at all gate openings (Figure 6).

It is also noted that the jet length (λ) remaind same for high head and large gate opening (75%) which indicate that impact of ramp angles on cavity length is insignificant. The jet length (λ) increased with the increase in Froude number at both the reservoir levels because of decreasing flow depths and increasing flow velocity. The value of jet length (λ) remains in the range of 1.34 to 6.48.

Maximum cavity length is noted against high head and small gate opening and with maximum ramp angle. Fig.3 and Fig.6 indicate that non-dimensional jet lengths are in the range from 1.50 to 2.0 with and without ramp for maximum air vent size (1.50m×2.55m) at high head (1650masl) and at large gate opening (75%), which indicate that the impact of ramp is insignificant.

Fig.7 shows, variation in air entrainment co-efficient for different ramp angles and gate openings. Air entraining capacity of the aerator became better with the increase in ramp angle, whereas the improvement was diminished for large gate opening (75%) especially at high head where identical values of β are noted for the ramp of 2.5^o and onward. The maximum value of β for all ramp angles is achieved against small gate openings (25%) because of large cavity length. Value of β varied between 0.06 and 0.51; highest value corresponds to maximum cavity length. The addition of ramp with maximum air vent size (1.50×2.55m) seems to be ineffective at high head and large gate opening as indicated in Fig.4 and Fig.7.

The variation in cavity pressure against Froude number is plotted (Fig.8). At low head (1620 masl), cavity pressure vary considerably. Increasing trend in P_n value with the increase in ramp angle was observed. Furthermore, with the increase in ramp angle, the jet angle also increases which causes the high pressures in impact zone and more circulation of air in the cavity[13,14].

Figure shows comparatively low P_n values against high head due to large cavity length and consequently increasing total shear force at air water interface. At high head, drop in cavity pressure with the increase in ramp angle (from 4 to 4.5^o) is noted. Due to negative effect of cavity length, the increase in jet length has increased shear force at air-water interface instead of increasing the air circulation in cavity. The results also indicate that at high head, addition of ramp has reduced P_n as compared with the values shown in Fig. 5 for maximum air vent size (1.50m×2.55m).

CONCLUSIONS

With air vent size = 1.50 m x 2.55 m, high values of cavity length were achieved which ultimately enhanced the air entraining capacity of the aerator. Moreover, improved values of cavity pressure were also achieved for this air vent size at high head. No significant improvement in cavity length was observed with the addition of ramp for highest reservoir level and large gate opening (R/L=1650, G/O=75%). Same values of air entrainment co-efficient (**β**) were noted after addition of ramp against high head and 75% gate opening. The cavity pressures were reduced after installation of ramp at high head and at all gate openings. Hence, ramp doesn't improve the performance of the aerator at extreme operating conditions and also shows negative impact by reducing the cavity pressure.

NOTATION

The following symbols are used in this paper:

We = Weber number;

Re = Reynolds number;

d_o = Flow depth at aerator;

L = Observed jet length;

λ = non-dimensional jet length;

L_{ref} = reference length;

Q_a = air discharge through air vent in m^3/s ;

Q_w = Water discharge through spillway in m^3/s ;

β = air entrainment co-efficient

ΔP= average cavity pressures in N/m^2;

P=density of water in kg/m^2;

P_n = non-dimensional cavity pressures

θ = spillway angle;

β = air entrainment coefficient;

ABBREVATIONS

WAPDA = Water and Power Development Authority

IRI = Irrigation Research Institute

masl = meter above sea level

R/L = Reservoir Level

G/O = Gate Opening

AV = Air Vent

R/A = Ramp Angle

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