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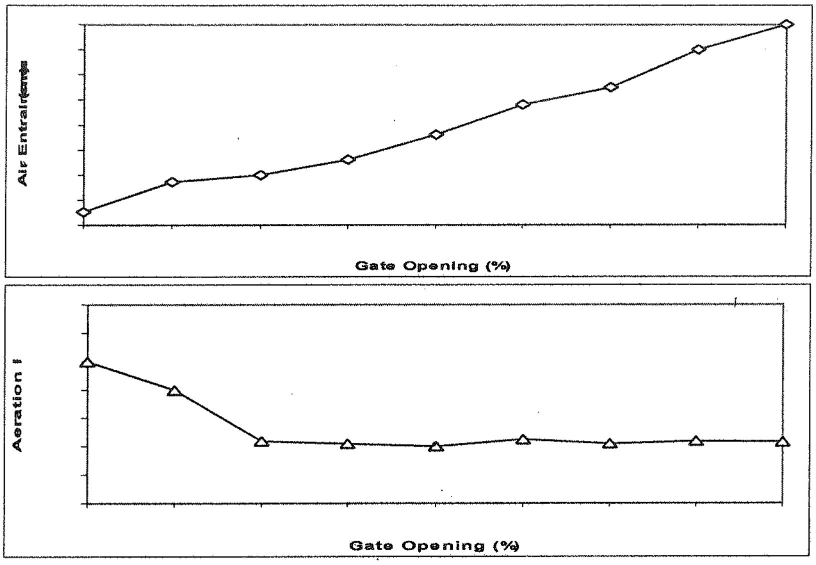

Figure (6) Variation of air demand and aeration ratio for service gate of Kosar dam.

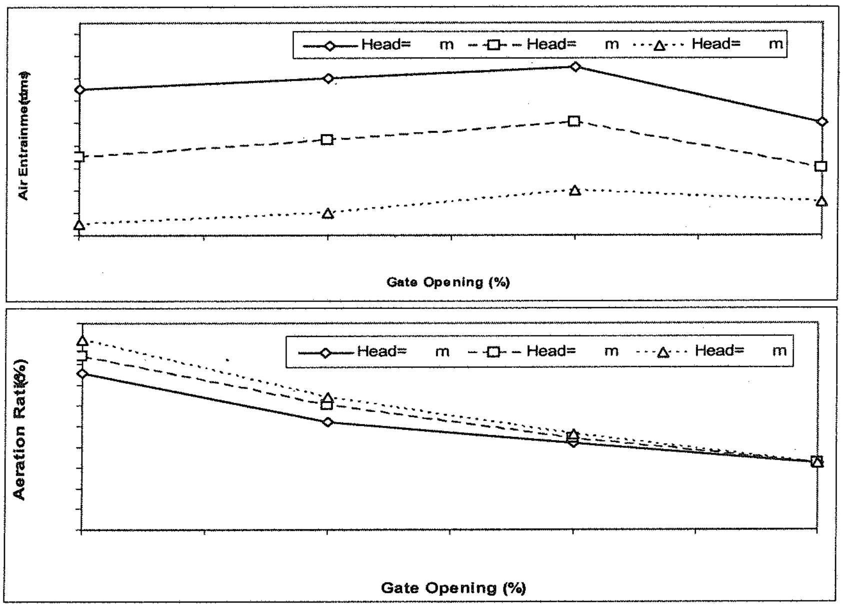

Figure (7) Variation of air demand and aeration ratio for service gate of Karkheh dam.

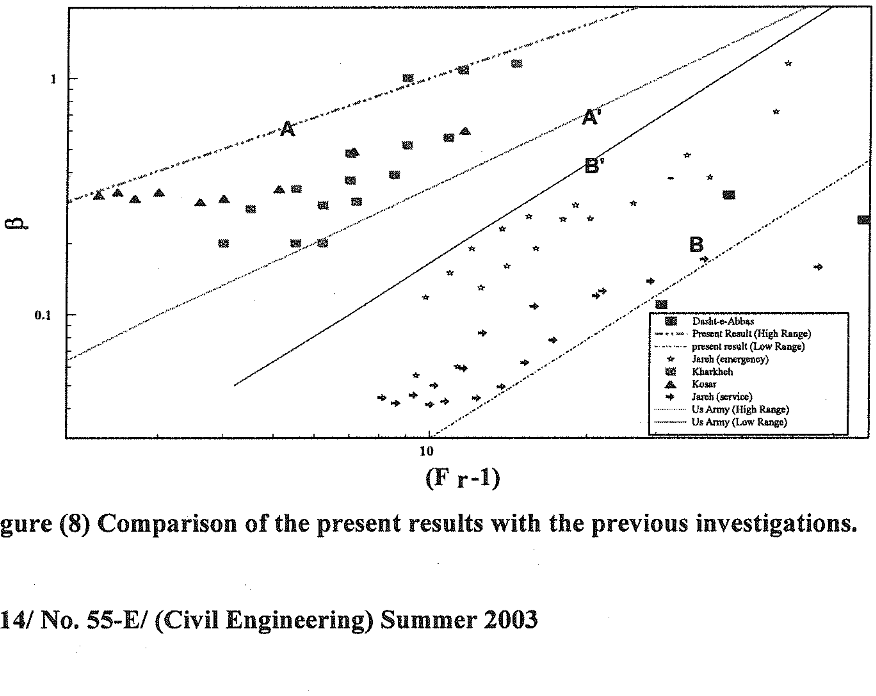

Figure (8) Comparison of the present results with the previous investigations.

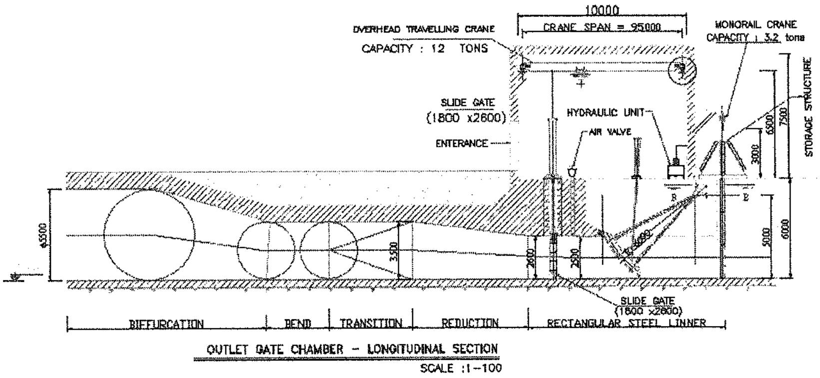

Figure (3) Schematic view of Dasht-e-Abbas bottom outlet.

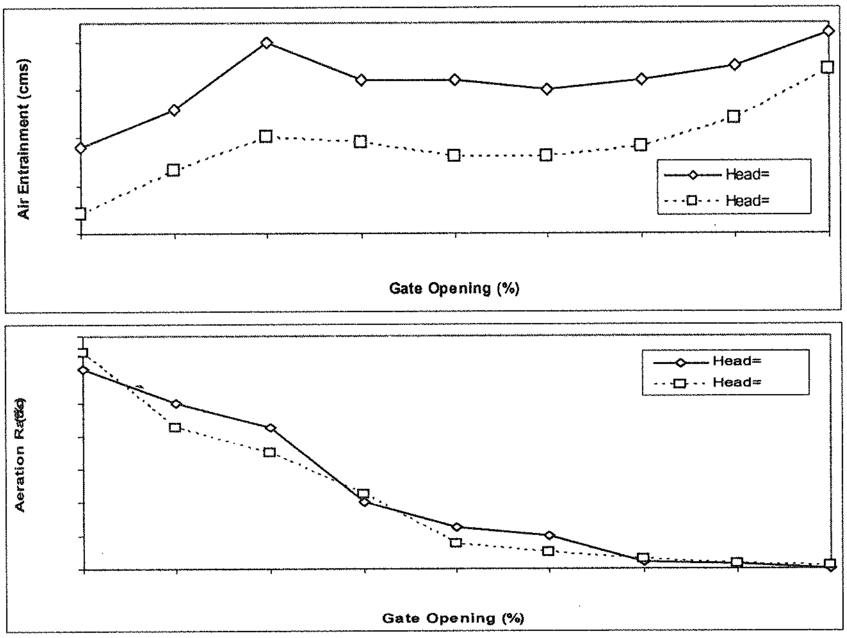

Figure (4) Variation of air demand and aeration ratio for service gate of Jareh dam.

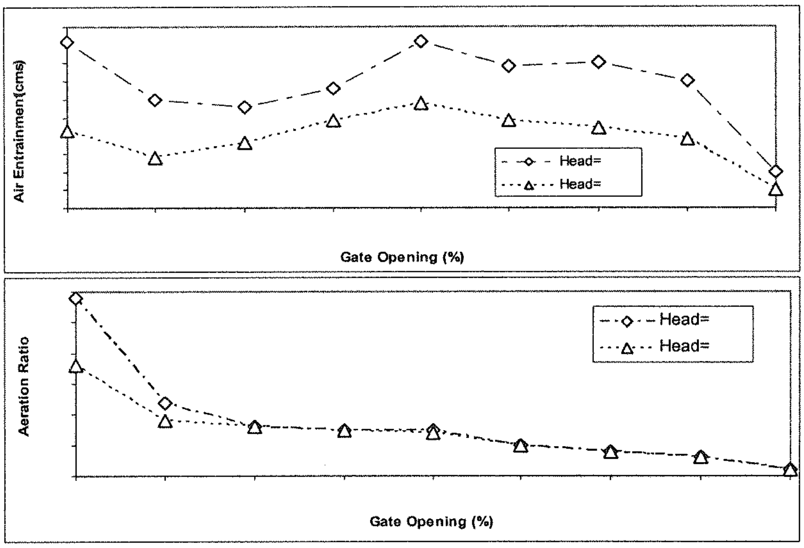

Figure (5) Variation of air demand and aeration ratio for emergency gate of Jareh dam.

Equation 5 is suggested for determining the air demand and thus, the geometry of the aerator.

Conclusion Remarks

Experimental studies were carried out on model scales of three bottom outlet gates to check the quantity of air demand downstream of the gates. It is believed that the information provided here, would be valuable for the designers of aerators downstream of bottom outlet gates. The results showed that considering maximum air demand at 80% gate opening in the design of aerator geometry will not satisfy the required air demand. Based on the present information, it is recommended that if the process of aeration is only from the top of the surface water, maximum flow aeration occurs within the range of up to 50% gate openings, which is in reasonable agreement with the previous investigations. However, if the jet downstream of the gate is aerated from all sides (i.e. cross sectional area is expanded), maximum aeration occurs within the range of 80% to 100% gate openings. In this condition, it is recommended to determine the geometry of aerator based on the gate opening of 100%. The results also showed that the quantity of air required for this condition is significantly high, comparing to the previous condition. Therefore, in such cases it is recommended to consider equation 5 in determining the geometry of aerator downstream of normal gates.

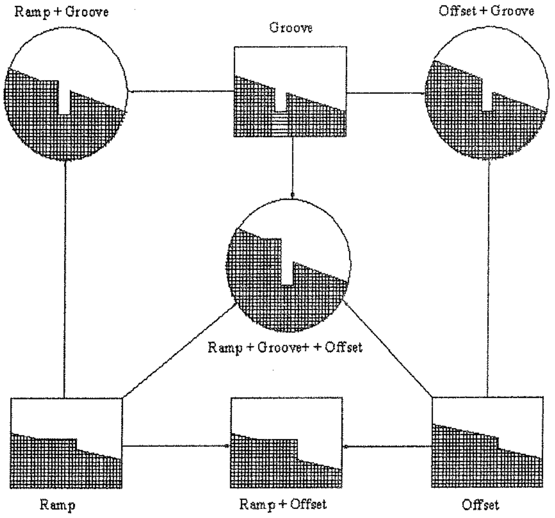

Figure (1) Different types of aerators used in hydraulic structures.

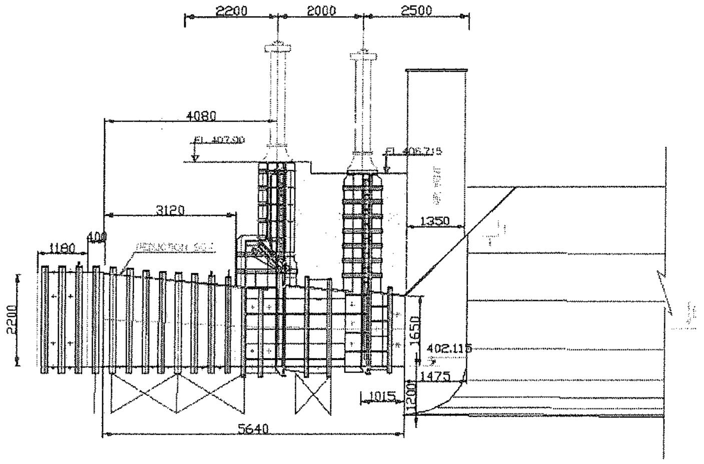

Figure (2) Schematic view of Jareh bottom outlet.

was very old and we had no access to the model. However, the reports showed that maximum air demand for the service gate has been measured at 100% gate opening (WRC, 1998).

Results

A wide range of experiments were conducted in this study, but only typical results are presented in our conclusion. Figure 4 shows the variation of air injection downstream of the service gate of Jareh for two heads of water. The upper graph represents the variation of the quantity of air injection with gate opening and the lower graph shows the variation of aeration coefficient with gate opening. It is observed that the maximum air demand occurs at 90% to 100% gate opening. The figure also shows that aeration coefficient reduces with increasing gate opening, but the variation of water head has no significant effects on the aeration coefficient. Figure 5 shows the results of the quantity of air and aeration coefficient for emergency gate of Jareh dam. The reduction of aeration coefficient with respect to the gate opening can be observed from the figure. However, the variation of the quantity of air with gate opening is quite different. Maximum air demand occurs at about 10% and 50% gate openings and minimum demand occurs at 90% to 100% gate openings. A comparison of the figures 4 and 5 demonstrates two distinguished behaviors for the aerators of service and emergency gates.

Figure 6 shows the results of flow aeration downstream of the service gate of Kosar dam. The figure shows that the maximum air demand occurs at about 90% to 100% gate openings, which is in reasonable agreement with the results of Jareh bottom outlet service gate. Figure 7 shows the variation of air demand with gate opening for the service gate of Karkheh dam. Maximum air demand occurs at 80% gate opening. The figure also presents the variation of aeration coefficient, which is comparable with the other results. The last results are due to the bottom outlet gates of Eilam dam.

A review of the results demonstrates that the two distinguished behaviour, depend on the geometry conditions. The first appears when the cross sectional area of the conduits remains constant and thus, the wall jet is only aerated from the top surface. In this condition, maximum air demand takes place at gate opening of less than 50%, which is comparable to the previous investigations (air demand for emergency gate of Kosar and Jareh). In the second, maximum air demand takes place at gate opening of 80% to 100% (air demand for service gate of Kosar, Karkheh and Jareh). In this case, the cross sectional area of the conduit increases just downstream of the gate and thus, the jet is aerated from the sides, and upper and lower surfaces. Therefore, higher air demand is expected in this situation.

Measurements of air demand downstream of the gates were also compared with the results of previous investigations (Equations 2 to 4). It was concluded that these relationships underestimate the quantity of air demand. Figure 8 shows the comparison of present results with the previous investigations. It is observed that if the cross sectional area downstream of the gate increases, so that air injection occurs from all around the jet, the quantity of air demand increases significantly (≈3-4 times). This behaviour should be very important for the designers of such structures. Therefore, based on the present results new relationships were derived for air injection downstream of the leaf gates. The figure consists of the new relations for the upper and lower limits of aeration as shown by lines A and B. These lines can be expressed by the following equations:

$$\beta = 0.18\left(F_r - 1\right)^{0.75} \quad \text{Upper Limit} \tag{5}$$

$$\beta = 0.0012\left(F_r - 1\right)^{1.39} \quad \text{Lower Limit} \tag{6}$$

$$\beta = 0.03(F_r - 1)^{1.06} \tag{3}$$

A similar equation was also suggested in 1953 by Campbell and Guyton as:

$$\beta = 0.04(F_r - 1)^{0.85} \tag{4}$$

To establish and check the air demand design criteria for air vents in bottom outlet gates, the present paper studied several physical models of outlet gates, which have been constructed at Water Research Centre of Iran. In this research, the quantity of air was determined to check the variation of air demand with the flow condition and the geometry of aeration system. Depending upon the aerator geometry, two different mechanisms are distinguished in this study.

Model Studies

In this research, the physical models of bottom outlet gates belong to Kosar, Karkheh, Eilam, and Jareh dams, and also Dasht-e-Abbas bottom outlet were studied in details. The models were made of plexy glass to visualize the flow and to reduce the roughness effects. The velocity of air was determined using hot-wire anemometer and/or inclined manometer. The quantity of air was determined, using the velocity of air and the cross sectional area of the air vent. Then, the aeration coefficient β was calculated to check its variation with respect to gate opening.

Jareh bottom outlet consists of service (1.85m×1.5m) and emergency (1.75m×1.5m) gates. The scale of the model was 1:13. Measurements were made with two heads of 65m and 101.4m (WRC, 2000). Downstream of the service gate, offsets were provided on the sides, top and bottom walls of the conduit to increase its cross sectional area (Figure 2). In this zone, a 3cm diameter aerator is fixed to the top wall to inject air into the flow. Also for flow aeration during the operation of the emergency gate, a 5cm diameter aerator was fixed to the top wall between the service and emergency gates. Downstream of the service gate, from where the high velocity jet separates from the offset and reattaches to the boundary, the flow aeration from all around the jet takes place. However, downstream of the emergency gate, the flow is aerated only from the upper side of the jet.

Dasht-e-Abbas bottom outlet consists of a service radial gate (2.5m×2.1m) and an emergency leaf gate (2.6m×1.7m). The scale of the model was 1:12 and the maximum head was 175m (WRC, 2001). Downstream of the service gate, the flow enters an open channel (Figure 3). Therefore, flow downstream of service and emergency gates is aerated from only the top of water.

Kosar bottom outlet consists of service and emergency gates of 3m×3m to pass 160m^3/sec at 61.5m head of water. The scale of the model was 1:20 (SCWMRC, 1999). Downstream of the service gate, offsets are provided on four sidewalls of the conduit to increase the cross sectional area of the conduit and to locate the aerator on the top wall. Thus, the jet is aerated from all sides.

Karkheh is an earth dam with three bottom outlets, having dimensions of 1.8m×2m to discharge 300m^3/sec at the maximum head of 122m. The scale of the model was 1:11.63. Each of the outlets has a service and an emergency gate. Measurements showed that maximum air demand for the emergency gate occurs at about 20% gate opening (WRC, 1999).

Finally, Eilam bottom outlet consists of a service and an emergency gate (1.6m×1.3m) to discharge 48m^3/sec at the maximum head of 57m. The scale of the model was 1:10. The work the vapour pressure of fluid. Accordingly, cavitation will occur, if the index σ is lower than a critical value σ_{cr}, which is a function of gate opening. The critical value for conduits and spillways is suggested as 0.2-0.25.

Aeration

It is known that the injection of air into the flow will reduce cavitation damage. Peterka (1953) showed using venturi-type cavitation apparatus that for 2% air concentration, adjacent to the boundary, cavitation damage was greatly reduced and that for 6% to 8%, it was virtually eliminated. It was after publishing his results that the use of deflectors in spillway of high dams for flow aeration was rapidly increased. Aerators may be in the form of a ramp (deflector), offsets or grooves as shown in Figure 1. They can also be arranged singly or in combination. Among the various devices used, the inclusion of the ramp or deflector is reported to be most effective. Ramps tend to provide strong aeration and operate at small discharges. Grooves provide space for the air supply, and offsets enlarge the trajectory of the jet at higher discharges.

In practice, aeration coefficient, which is the ratio of the quantity of air injection to the quantity of flow of water $\beta = Q_a/Q_w$, of 5% to 8% is usually recommended (Rutschmann and Volkart 1988). In addition, both Rutschmann and Volkart (1988) recommend higher aeration coefficient for flow velocities exceeding 30m/s on the surface of structure. Russell and Sheehan (1974) reported that 5% entrained air, adjacent to the surface, was adequate to prevent cavitation damage. However, they recommended maximum air concentration, if the structure subjects to cavitation damage.

Aeration of flow will reduce the fluid density and increase its compressibility. Injection of air also increases the mean pressure and reduces the intensity of pressure fluctuations, resulting in reduction of cavitation risks (Kavianpour 1997, 2000, Nakhaei & Kavianpour 1999). In the near field of the aerators, cavitation risk reduces due to the increase in the mean pressure and reduction of the intensity of pressure fluctuations. Therefore, aeration of flow in outlet works such as, spillways of high dams and bottom outlet conduits is recommended as an effective and relatively cheap way to eliminate cavitation damages.

Literature Review

The U.S. Army Corps of Engineers suggests the use of various design assumptions to arrive at the size of air vents. The method of computing air demand for regulating gates is based on the observation that maximum air demand for free surface discharges occurs at about 80% gate openings (Pine Flat Dam=50% opening, Tygart Dam=83.3% opening) (USACE, 1988a). Assuming a contracted coefficient of 0.8 for a 45° leaf bottom and the maximum air velocity of 45m/sec to 90m/sec within the air vent, the cross sectional area of the vent is calculated (Davis & Sorensen, 1984).

In 1943, Kalinske and Robertson reported their results of air demand when a hydraulic jump forms in the downstream conduit (USACE, 1988b). Based on their results, the aeration coefficient β where a hydraulic jump forms, was suggested a function of froude number Fr, in the form of:

$$\beta = 0.0066(F_r - 1)^{1.4} \tag{2}$$

moreover, for a free surface flow, in a partially full conduit with no hydraulic jump, the following relationship was suggested:

Aerators in Bottom Outlet Conduits

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Abstract

Flow aeration downstream of normal gates in bottom outlet conduits has been found to be an effective and cheap way to eliminate cavitation damages. Studies on aerators have been focused on the question of how much air is entrained into the flow for different geometry of aerators and flow conditions. Designers of the aerators use empirical equations to calculate the quantity of air required by the aerators. The area of the aerator is determined using empirical relationships, assuming the air velocity not exceeded a certain values. This paper is based on the results of hydraulic model studies of new bottom outlets, recently constructed and examined at Water Research Center of Iran. The results consist of Jareh, Karkheh, Kosar, Dasht-e-Abbas, and Eilam bottom outlet dams in Iran. The model studies showed two different mechanism of flow aeration. These mechanisms depend on the geometry of conduits downstream of the gates with respect to the upstream geometry. It is hopped that this information provides a better understanding of the process of aeration for the designers of such structures.

Keywords

Aerator, Bottom Outlet, Gate, Aeration, Cavitation

Introduction

With the construction of high dams in the past decade, the flow rates discharging over the spillways and through bottom outlets have been very large. High-pressure bottom outlet gates, which are used to control the discharging flow through the outlet conduits, are one of the main important parts of high dams. These gates operate under high-pressure and flow velocity conditions. As the velocity on the surface of outlet works increases, the threat of damage to the structure by cavitation erosion also increases. Once damage is initiated on the surface, catastrophic damage is accelerated by the combined action of cavitation and impingement attack. Therefore, the design of outlet works and their related structures such as gates have attracted the attention of many investigators. Cavitation tendency, vibration of gates, hydrodynamic force and aeration of flow are the main aspects of these studies.

In the presence of a leaf gate in a conduit, the flow separates from the lip of the gate, forming a recirculation zone downstream. In this region, depending upon the gate opening, the pressure reduction takes place. Also high intensity pressure fluctuations may cause the local pressure to drop significantly and thus, the situation will be suitable for cavitation to occur (Kavianpour 1997, Narayanan & Kavianpour 2000). Quantifying the level of cavitation requires a dimensionless similarity index called index of cavitation or cavitation number. The index of cavitation is usually used to ascertain whether cavitation will occur or not. For cavitation caused by surface roughness or an offset in the boundary, the cavitation number (σ) is defined by:

$$\sigma = \frac{P - P_V}{0.5\rho U^2} \qquad (1)$$

where P, ρ and U are the pressure, fluid density and flow velocity respectively, and P_V is