PAP-567

AERATION OF A SUBMERGED JET-FLOW GATE

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Abstract

Submerged operation of a jet-flow gate requires special treatment of the area downstream from the gate to avoid cavitation damage. The Bureau of Reclamation studied operation of a submerged jet-flow gate in a 1:21 scale hydraulic model of the Seminoe Dam outlet works. A 60-inch (1524-mm) jet-flow gate discharges into an 84-inch (2134-mm) diameter discharge tube (1.4D expansion). Due to the inability to provide a larger diameter expansion, aeration of the discharge tube by an air vent downstream from the gate was studied. Four different locations for the air vent were tested. Discharge characteristics, pressures in the discharge tube, and air demands were measured for each of the locations. A design curve relating air demand, gate opening, and a submergence parameter was developed.

Introduction

The jet-flow gate was originally developed by the Bureau of Reclamation in 1945 for use in the intermediate and upper tiers of outlets in Shasta Dam (Lowe, 1946). Since then, jet-flow gates have been installed at numerous sites as regulating gates. Their wide acceptance is largely due to low cost, low maintenance, and a high discharge coefficient. Traditionally, the jet-flow gate has been used for discharging into atmospheric conditions. The use of this gate in submerged conditions exposes the area downstream of the gate to shear layer cavitation. Shear layer cavitation has been shown to have a high damage potential, especially at small gate openings (Oba et.al., 1985). Normally, an expanded conduit section downstream from the gate is used to ensure that the cavitation cloud generated in the shear layer does not collapse on the discharge tube walls. The size of the recommended expansion is 3D, where D is the diameter of the jet-flow gate (Isbester, 1975). This size expansion allows good circulation around the jet, protecting the downstream surfaces from cavitation damage (Isbester, 1974; and Burgi and Fujimoto, 1973). The diameter of the expansion can be reduced somewhat if the length of the discharge tube is kept very short (Mefford, 1987). Alternative measures, such as a stainless steel lining or aeration, can also offer levels of protection to the discharge tube.

In the past, a major design feature of jet-flow gate installations has been a vent system to aerate the jet at partial gate openings. When discharging

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into atmospheric conditions, this allows the jet to spring free from the control surfaces of the gate. However, under submerged conditions, the back pressure is too large to allow complete aeration of the jet. In the early 1950's, it was shown that when air was entrained into the flow in amounts of 5-10 percent (air to water volume ratio), cavitation damage on surfaces adjacent to the flow was greatly reduced (Peterka, 1953). Since then, aeration has been used successfully many times to mitigate cavitation damage in hydraulic structures (Falvey, 1990) and equipment (Arndt, 1981).

The Study

The studies were made using a 1:21 scale hydraulic model (Frizell, 1990). The model included one jet-flow gate with existing piping upstream and downstream of the gate (fig. 1). Model scaling was based on equal Froude numbers in the model and prototype. Tests were conducted to compare four different air vent locations. Measurements of upstream head, discharge, gate opening, air velocity and flow into the vent piping, and piezometric pressures at four locations on the invert of the discharge tube were taken. All tests were run with a submergence of 2.5 ft (0.76 m) above the gate centerline.

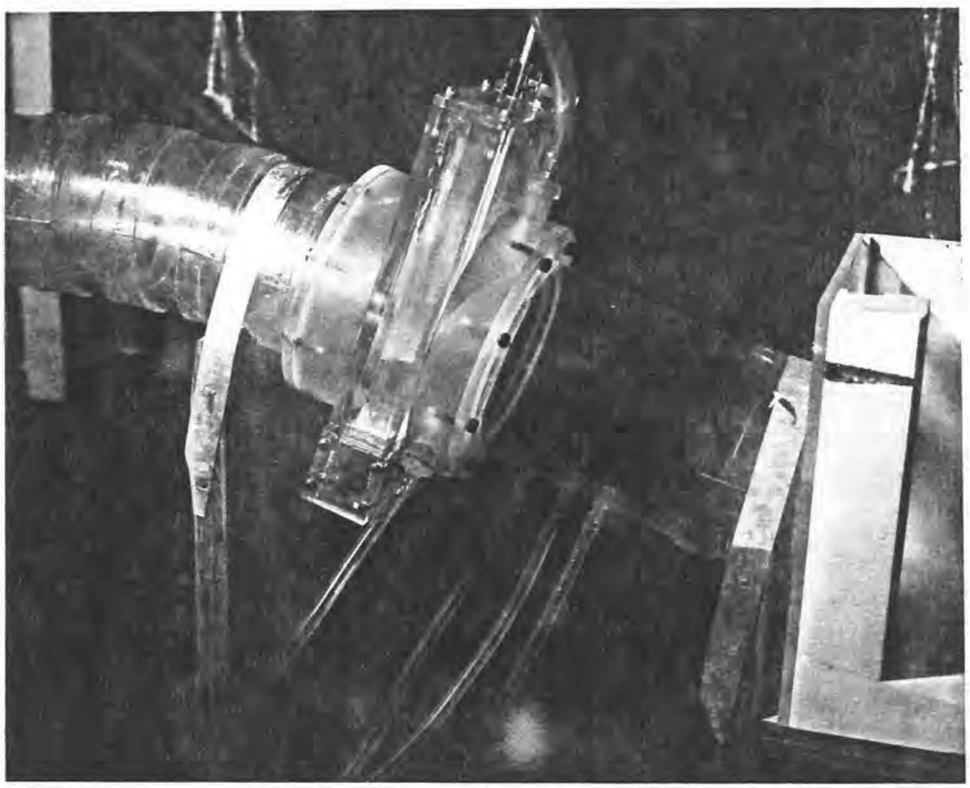

Figure 1: 1:21 scale hydraulic model of the Seminoe 60-inch jet-flow gate.

In addition to the tests mentioned above, a more general design curve relating aeration, gate opening, and a nondimensional submergence parameter was developed. In these tests, gate position, upstream head, and downstream head were varied widely for a single air vent location.

Results and Discussion

The tests specific to the Seminoe gate yielded some interesting results. In particular, the coefficient of discharge varied widely depending on air vent location. The discharge coefficient C_d is defined as:

$$C_d = \frac{Q}{A_{up}(2g(H_{up}-H_{dn}))^{\frac{1}{2}}} \tag{1}$$

where: Q - discharge
A_{up} - area of the upstream pipe
g - gravitational constant
H_{up} - pressure head upstream from the gate
H_{dn} - pressure head downstream from the gate

Without aeration, the discharge coefficient reaches a value of 0.88 when the gate is fully open. This value drops to 0.62 when the discharge tube is aerated with the top or 45° vent configurations and to only 0.41 for the bottom vent configuration (fig. 2).

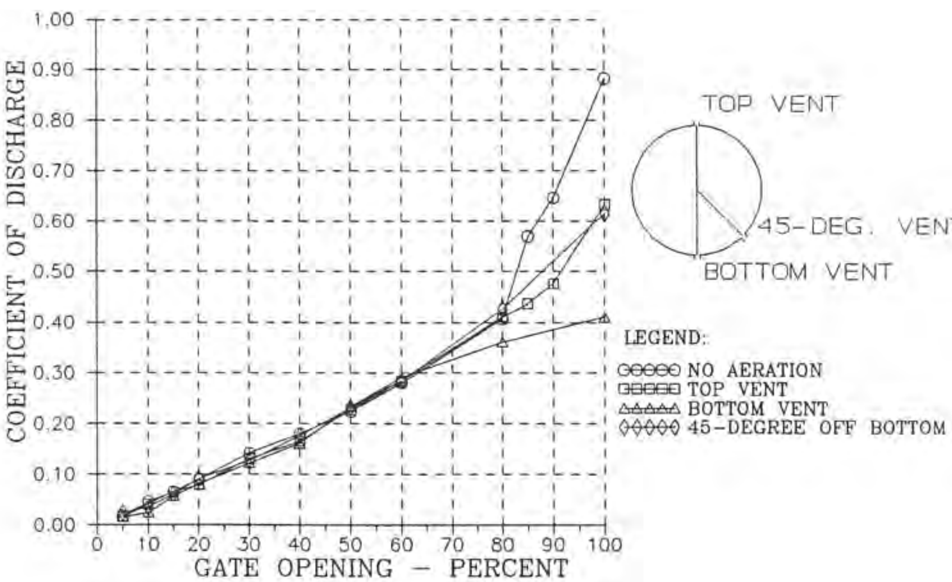

Figure 2: Discharge coefficient for different vent configurations.

Aeration was best accomplished through the vent on the crown of the discharge tube (top vent). Air was pulled into the discharge tube for all gate openings tested (fig. 3). The quantities ranged from 13 to 22 percent (air to water volume ratio). The air was pulled down the gate slots and distributed evenly across the bottom of the orifice seal ring (fig. 4). The other vent locations tested were less effective, pulling in only 2 to 6 percent air to water, and only with gate openings above 20 percent. Due

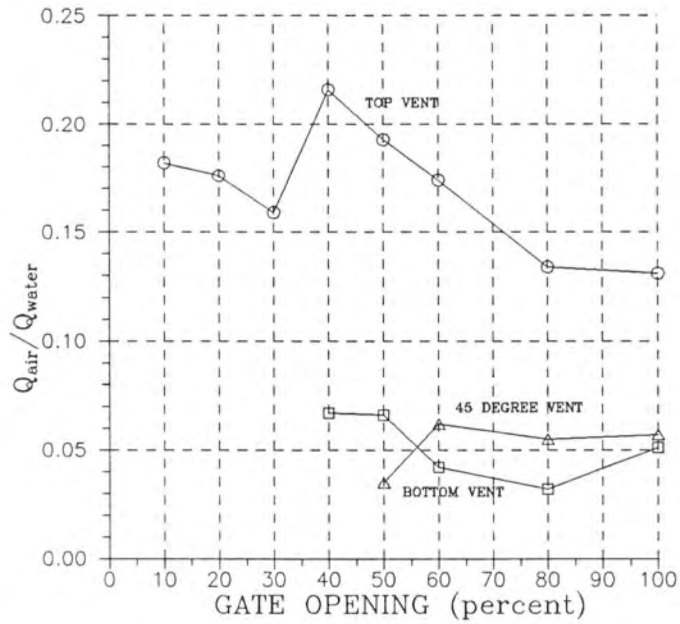

Figure 3: Air demand curves for the three vent configurations tested.

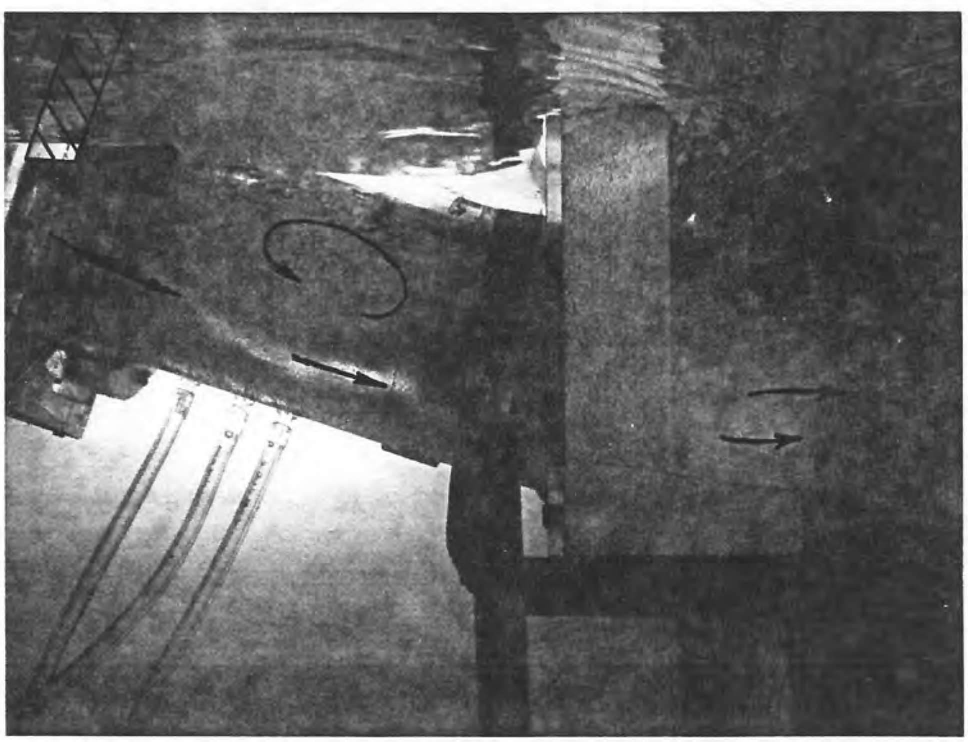

Figure 4: Aeration from top vent, air-water mixture flowing along bottom of discharge tube.

to the limited data on aeration of submerged jet-flow gates, additional tests were run to investigate the effect of the amount of submergence on aeration and to define the inception point for aeration as a function of gate opening. A systematic group of tests were run where the upstream head and level of submergence were varied. Air volume flowrate was measured with an orifice meter. These data were correlated using a nondimensional submergence parameter (fig. 5). The critical point for inception of aeration is where the curves intersect the horizontal axis (β=0).

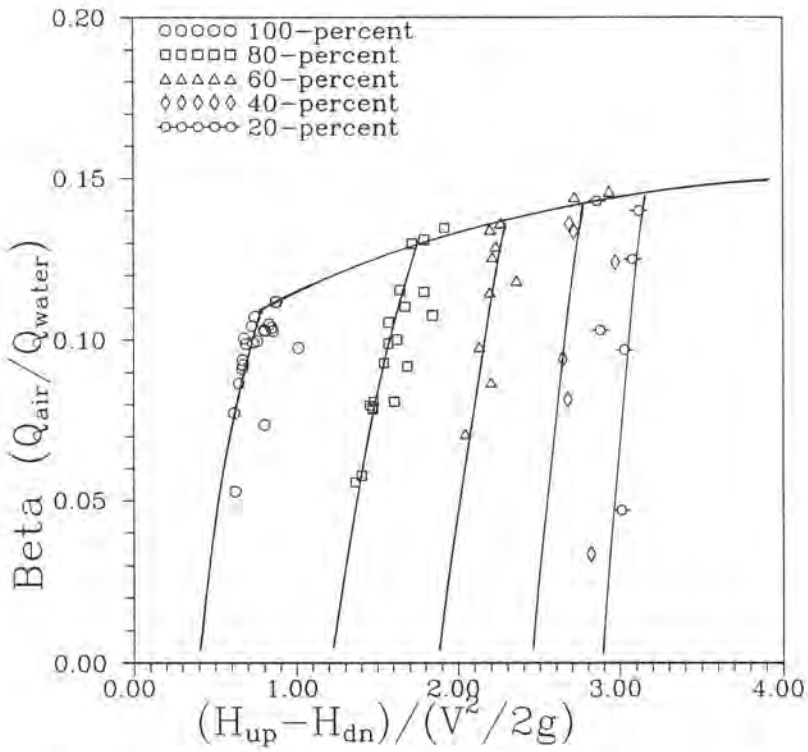

Figure 5: Air demand data from a 1:21 scale hydraulic model. Vent is on top centerline, just downstream from gate.

However, from a closer look at these data, ΔH does not appear to be the sole parameter which influences aeration as the actual submergence head is also quite important.

While the research presented in this paper does not fully address all the factors which influence the scaling of aeration, it does provide additional understanding into the operation of submerged jet-flow gates. In particular, it addresses the effects of aeration on typical design parameters, such as the coefficient of discharge. Because the majority of these data were taken with a single vent configuration (or head loss), care should be exercised when using model data to size prototype structures.

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