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Modeling Aeration Devices for Glen Canyon Dam

Clifford A. Pugh*, M., ASCE

Abstract. - The 41-ft (12.5-m) diameter tunnel spillways at Glen Canyon Dam experienced major damage during the 1983 spring runoff. This damage was initiated by cavitation. Hydraulic model studies were conducted in the Bureau of Reclamation hydraulic laboratory at a 1:42.8 scale to determine the location and configuration of an aeration device to prevent damage from reoccurring.

Introduction. - A hydraulic model study does not necessarily indicate that cavitation will or will not be a problem, or that aeration is needed to prevent damage. In order to produce cavitation, atmospheric pressure must be simulated in the model. Most models are not capable of scaling the correct atmospheric pressure. A model may indicate that pressures are positive throughout; however, cavitation damage can still occur. The potential for cavitation damage is dependent on the cavitation index

$$K = (p_o - p_v)/(\rho V^2/2) \quad (1)$$

Experience at Bureau of Reclamation structures has shown that major damage does not occur in flows for which $K > 0.20$. As K decreases, the potential for damage magnifies. For $K < 0.15$, potential for major damage exists. The need for protection against cavitation damage is determined by analyzing the cavitation potential with a computer program. Falvey [2] has developed a computer program for determining the potential for cavitation damage.

Earlier studies of Yellowtail Dam [1] were used to help develop a configuration for an aeration device in a tunnel spillway.

Aerator Design for Glen Canyon Dam. - A ramp is needed to lift the water over the air supply slot and prevent the slot from filling with water. This also provides a free surface under the jet to entrain air with the flow.

In circular conduits, a fin forms where the jet strikes the conduit walls (figure 1). If the ramp is continued completely around the tunnel, the fin can fold over and choke off the tunnel at high flow rates. In a configuration with the ramp gradually feathering out to zero at the springline, the fin actually decreases in size for flow depths above the springline.

One disadvantage of this design is that the flow will impact close to the air slot above the springline. To alleviate this situation and ensure

*Hydraulic Engineer, Bureau of Reclamation, PO Box 25007, Denver, Colorado 80225.

that the slot will not fill with water, an offset away from the original tunnel profile is provided downstream of the slot. This offset continues all the way around the downstream edge of the slot to ensure that water does not enter the air slot for any flow condition. This offset should be about one-fourth of the slot depth. A straight line transition back to the original tunnel surface at a 1:15 to 1:20 chamfer is adequate.

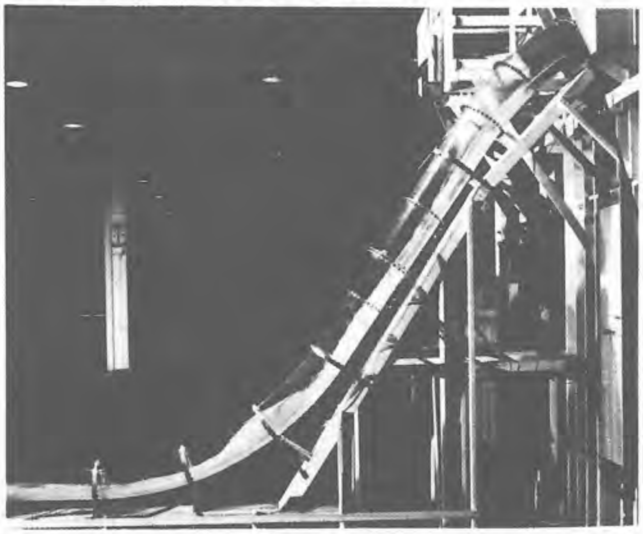


Figure 1 The jet strikes the conduit walls downstream from the aeration device and causes side fins. Q = 20 000 ft^3/s (566 m^3/s).

The aeration device should be located above the point where the cavitation index drops below 0.20 to prevent the ramp from being damaged. The trajectory length of the water jet can be estimated from the equations of motion for the path of a moving particle.

The ramp angle can be chosen to cause the jet to impact at any desired location. It would be desirable to have the jet impact past the point where the cavitation index is the lowest. However, the jet should not impact the flow surface within the vertical bend because this will cause extremely poor flow conditions in the downstream tunnel. Therefore, the jet is designed to impact upstream from the start of the vertical bend.

The aeration device was located 108.6 ft (33.1 m) above the start of the vertical bend, to be upstream of the point where K drops below 0.20. Ramp heights of 4 and 7 in (102 and 178 mm) were tried in the model. The ramp angle was set at 7.8°. Figure 2 shows the final design of the aeration device. The location of the damage sustained in the left spillway tunnel during the 1983 flood is also shown on figure 2.

The aeration slot size was set at 4 by 4 ft (1.22 by 1.22 m) and extends around the lower three-fourths of the tunnel. Air is drawn into both sides of the slot from above the free water surface in the upper part of the tunnel.

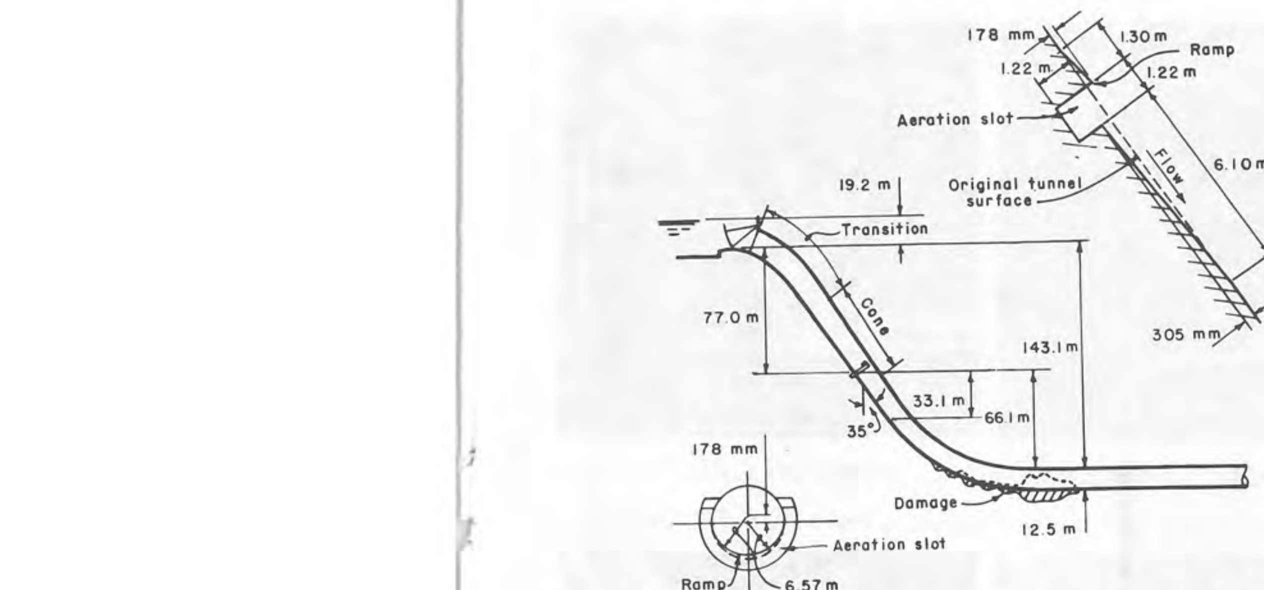


Figure 2 Final design of the aeration device (1 m = 3.28 ft).

Air demand was determined in the model by measuring the maximum air velocity in the slot (at the water surface) and multiplying by the area of the slot. Figure 3 shows the air demand in the slot.

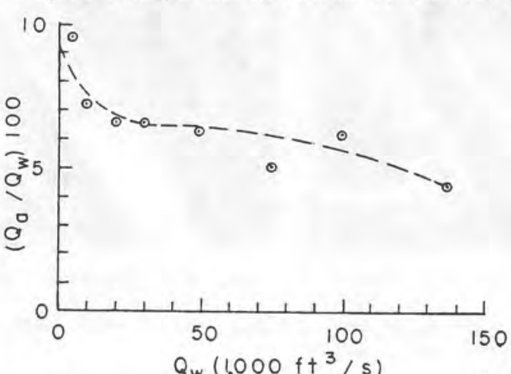
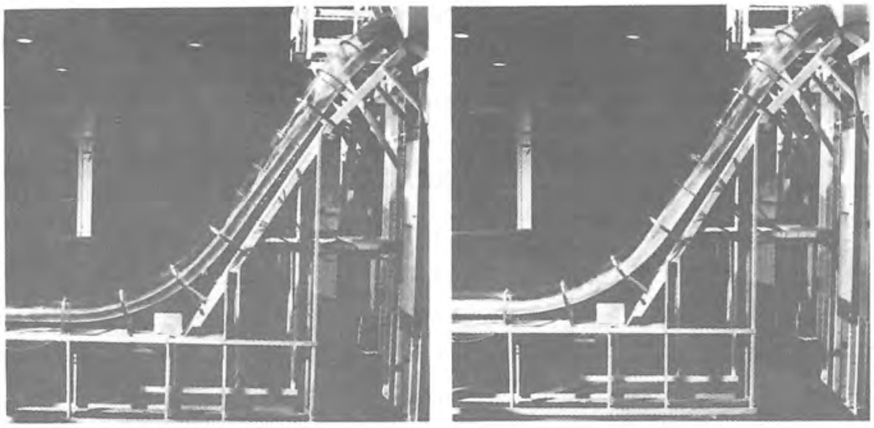


Figure 3 Model air demand vs. water discharge (1 ft^3/s = 0.02832 m^3/s).

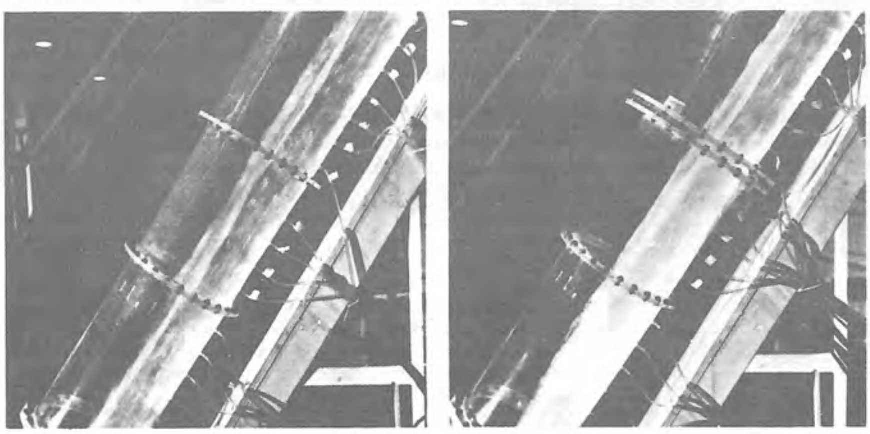
At the lower flows, the total air drawn into the water does not pass through the slot. Air is also drawn in around the free jet downstream from the slot.

The air drawn into the free jet is concentrated along the surface of the nappe and stays near the surface through the vertical bend. Figures 4 and 5 show the spillway model with and without the aeration device.



a. Without aeration slot b. With aeration slot

Figure 4 Glen Canyon left spillway tunnel, Q = 100 000 ft^3/s (2830 m^3/s).



a. Without aeration slot b. With aeration slot

Figure 5 Sloping portion of left spillway tunnel (55° angle). Q = 75 000 ft^3/s (2120 m^3/s).

Pressures were measured along the tunnel invert with and without the aeration device installed. The pressures measured without the aeration device are very close to pressures predicted by the computer program (figure 6).

At low flows the jet flips to the start of the vertical bend. At the maximum flow, Q_w = 138 000 ft^3/s (3900 m^3/s), the jet strikes the tunnel surface about halfway to the vertical bend.

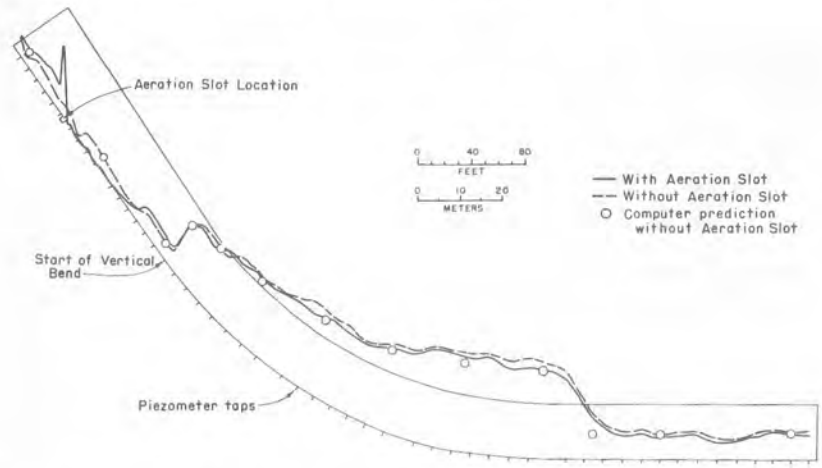


Figure 6 Pressure profiles on the invert. Q = 100 000 ft^3/s (2830 m^3/s).

The pressure profiles measured with the ramp and air slot installed show that under the free jet the pressure drops slightly below atmospheric. After the jet strikes the conduit, the pressure is not significantly different than it was without an aeration device.

Conclusions. - (1) The aeration device as designed will supply air to the underside of the water jet downstream from the device for all flow conditions. (2) Flow conditions in the tunnel downstream from the aeration device are acceptable. (3) Bulking in the downstream tunnel due to the additional air is not a problem. (4) In the preliminary aeration device configuration, the slot filled with water at high flows. The model study, therefore, was very useful in designing a configuration which works for all flow conditions.

Appendix 1 - References

1. Borden, R. C., Colgate, D., Legas, J., and Selander, C. E., "Documentation of Operation, Damage, Repair, and Testing of Yellowtail Dam Spillway," REC-ERC-71-23, Bureau of Reclamation, May 1971.

2. Falvey, H. T., "Air-Water Flow in Hydraulic Structures," Bureau of Reclamation, Engineering Monograph 41, 1980, 143 pp.

Appendix 2 - Notations

K - cavitation index
p_o - pressure
p_v - vapor pressure
V - velocity
g - gravitational constant
Q_a - air discharge
Q_w - water discharge
ρ - water density