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Outlet Works Emergency Gate Closure Air Vent Analysis Deadwood Dam, Boise Project

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WATER RESOURCES MANAGEMENT.....FOR THE FUTURE

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Introduction

Deadwood Dam is part of Reclamation's Boise Project and is located on the Deadwood River in Idaho. The dam was constructed in the early 1930's and is a 165-ft-high concrete-arch structure with a crest length of 749 ft and total storage capacity of 162,000 acre-ft. Releases from the dam are made via a service spillway with a total capacity of 11,300 ft^3/s at reservoir elevation 5343.5 ft and two 66-in-diameter outlets regulated by two 60-in jet flow gates with a total capacity of 2,600 ft^3/s at reservoir elevation 5334 ft. Two 54-in balanced needle valves were originally installed to regulate the outlet works; however, these valves were replaced in 1990 with jet flow gates. Two parallel 4.5 ft by 4.5 ft emergency gates are located a short distance (approximately 15 ft) upstream of the jet flow gates. The centerline elevations for the outlets are at 5205 ft at the upstream face of the dam and 5204.83 at the downstream face. A 2-in combination air vacuum/air release valve is located just upstream of each jet flow gate. These valves were installed at the same time as installation of the jet flow gates.

The Water Resources Research Laboratory was asked to perform an air demand and vent pressure drop analysis at the request of the Snake River Area Office, PN Region in Boise Idaho. The request pertains to an RO&M recommendation to determine whether the existing 2-in air vacuum/air release valves are adequate for venting during an unbalanced closure of the emergency gates and hence whether the originally installed 8-in air vents may be removed from service.

Methods

To satisfy the objectives of this request, a computational transient analysis code was developed to determine pressure drop across the 2-in air vacuum/air release valve during an emergency gate closure for four different jet-flow gate openings including 100-, 75-, 50-, and 25-percent at the maximum reservoir elevation of 5334 ft. The pertinent drawings used to determine geometric and operating details include USBR drawings 3-D-2758, 3-D-2737, and 3-D-403. The emergency gate closure rate was taken to be 1-ft/min giving a total closure time of 4 minutes and 30 seconds and losses between the outlet conduit entrance and the emergency gate were neglected. The computational code applies the method of characteristics to determine the change in static pressure downstream of the emergency gate to the point at which an air cavity develops (i.e. when the static head downstream of the emergency gate falls below the top elevation of the pipe and hence the pipe is no longer pressurized). Following the start of air entrainment the code then uses a quasi steady state method for determining the air demand and vent pressure drop for the given air vacuum/air release valve characteristics (assuming a discharge coefficient of 0.4) during the remainder of the emergency gate closure.

Results

Air Vacuum/Air Release Valve Pressure Drop

The results of the transient analyses are given as Table 1. The emergency gate position at which the head in the pipe section downstream of the emergency gate falls below the top elevation of the pipe (i.e. the pipe is no longer pressurized) decreases with decreasing jet flow gate openings. The physical explanation for this is that for decreased jet flow gate openings the initial discharge at start of emergency gate closure is decreased and hence the pressure drop across the emergency gate is decreased resulting in smaller emergency gate openings at the point when the pipe is no longer pressurized. For the 100-percent jet flow gate opening the air demand is expected to be very small since very soon after the pipe depressurizes, the flow sweeps out and venting is possible from downstream of the jet flow gate. For the 75- and 50-percent jet flow gate openings, the pressure drop across the vent is expected to be a full vacuum (i.e. 1.0 atm pressure drop across the vent) since venting from downstream of the jet flow gate is not possible for a significant duration of time after the pipe depressurizes. The mechanisms for air demand include air entrainment in the high velocity flow and pipe evacuation due to a falling water surface elevation. For the remaining jet flow gate opening of 25-percent, the maximum pressure drop due to the air demand is estimated to be 5.4 lb/in^2 below atmospheric pressure. In this case, the pressure drop is reduced due to reduced flow rates and a relatively slow pipe evacuation time. For all cases, venting from downstream of the jet flow gate is expected after the point at which the jet sweeps out of the pipe since submerged operation of the outlets is not expected. Normally a pressure drop of 1.0 atm would be of concern, however it was recognized that the pipe section downstream of the emergency gate is effectively reinforced due to the relatively short section between the emergency gate and the jet flow gate. An analysis of the pipe collapse pressure reveals that it is not physically possible to collapse the pipe section, even under a full vacuum pressure drop across the vent.

Table 1. – Transient Analysis for emergency gate closures with 100%, 75%, 50%, and 25% Jet Flow Gate opening.

Jet Flow Gate Opening (percent)	Initial Discharge (ft^3/s)	Emergency Gate Opening at Start of Venting (percent)	Discharge at Start of Venting (ft^3/s)	Pipe Pressure at Start of Venting
100	1300	19.8	196.4	1.0 atm
75	1208.8	17.5	166.3	Vacuum
50	671.6	11.7	92.8	Vacuum
25	268.6	6.3	37.1	-5.4 psig

Pipe Collapse Pressure

Following the air demand analysis the pipe collapse pressure was initially estimated for infinite length given as,

$$P_c = 5.02\times10^7 (t/D)^3 = 5.02\times10^7 (0.375/60)^3 = 12.25 \text{ lb/in}^2 \qquad (1)$$

However, it was recognized that given the relatively short distance between the concrete encased pipe just downstream of the emergency gate and the jet flow gate, the section of pipe in question is better represented by the equation for a pipe with stiffening rings located on 7-ft centers. This equation gives a collapse pressure of

$$P_c = \frac{7.29\times10^7 (t/D)^{2.5}}{(L/D)} = \frac{7.29\times10^7 (0.375/60)^{2.5}}{(84/60)} = 160 \text{ lb/in}^2 \qquad (2)$$

Thus, for unbalanced emergency gate operating conditions the pipe section between the emergency gate and the jet flow gate will not collapse since the greatest pressure differential physically possible is approximately 12 lb/in^2 or 1-atm.

Conclusions

- The estimated pipe collapse pressure for the Deadwood Dam outlets conduit between the emergency gates and the jet flow gates is an order of magnitude greater than is physically possible and hence collapse is not predicted under any unbalanced emergency gate operating conditions.

- Based on the findings of this analysis the existing 2-in air vacuum/air release valves on the outlets at Deadwood Dam are considered sufficient since venting is only necessary during filling or draining of the pipe sections between the upstream emergency gates and downstream jet flow gates.

Recommendation

- Since pipe collapse pressure cannot be reached during unbalanced operation of the emergency gates, venting is only required during filling or draining operations. Thus, there is no need for the existing 8-in air vents and they may be taken out of service.

References

Colgate, D., (1969), Calibration of a 10-in Jet Flow Gate, U.S. Department of the Interior, Bureau of Reclamation Report No. HYD-569.

Falvey, H.T., (1968), Air Vent Computations - Morrow Point Dam, Colorado River Storage Project, U.S. Department of the Interior, Bureau of Reclamation Report No. HYD-584.

Falvey, H.T., (1980), Air-Water Flow in Hydraulic Structures, Engineering Monograph No. 41, U.S. Department of the Interior, Bureau of Reclamation.

Frizell, K.W., (1988), Emergency Gate Closures – Summary Memorandum Report 1985-1987, U.S. Bureau of Reclamation, Water Resources Research Laboratory, PAP-539.

Wylie, E.B. and V.L. Streeter, Fluid Transients, McGraw-Hill, Inc., 1978.