TECHNICAL MEMORANDUM Bureau of Reclamation

Alcova Power Plant – Evaluation of a full-flow closure of the ring follower gates

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The power plant at Alcova Dam was designed and built in the 1950's, using portions of the existing outlet works that had been constructed in the 1930's. Two 84-inch needle valves were removed and replaced with an upstream wye section that connected into the two existing 96-inch-diameter conduits. This wye transitioned into an 18-ft-diameter penstock which was placed within the existing outlet tunnel. The thin-walled steel pipe was embedded in a reinforced concrete shell and grouted back to the original tunnel surface. A downstream wye section transitioned the 18-ft-diameter penstock into two 11 ft 9 in penstocks that lead to two Francis-type turbines. The turbines are configured with individual butterfly valves used as guard gates, and the shut-off or emergency gates remain the two 96-inch-diameter ring follower gates in the central gate chamber (part of the original construction). The ring follower gates do feature air valves but were sized based on the original purpose as a shutoff for the needle valves. They were short coupled to the needle valves with a 1D length of conduit. The automatic air valves provided air to escape during filling and could also relieve low pressures during unbalanced gate closure.

In order to perform a full-flow closure of the emergency gates, the critical mode of failure to prevent is the full or localized buckling of the steel pipe (liner). The majority of the Alcova penstock has a D/t (Diameter to thickness) ratio of 864. This is off the charts of most design criteria with concern of buckling. The reinforced concrete and grout layer that surrounds the penstock is designed for the positive internal pressure. However, the buckling failure due to low internal pressures is not protected. Generally air venting is provided to allow internal pressure to remain safely above the collapse pressure of the penstock. Using the standard Stewart

formula for a free standing pipe, the critical pressure is given by: $P_c = 50200000\left[\frac{t}{D}\right]^3$ results in a collapse pressure of only 0.08 lb/in^2 below atmospheric pressure. This treatment is not entirely correct as there is additional resistance to buckling due to the embedment. However, it does point out a very small factor of safety against buckling that most likely exists. In order to do a more appropriate analysis for buckling we can follow either Amstutz or Jorgensen's analytical techniques concerning buckling of steel liners without stiffeners subject to high external pressure (or in our case low internal pressure). In this treatment, the liner is flattened and separates from contact with the surrounding concrete resulting in the most common form of buckling, a single lobe that is parallel to the axis of the liner. While complete collapse may not occur, localized buckling failure such as this essentially render the penstock inoperable.

Amstutz's critical buckling pressure is given by $P_c = \frac{F}{r}\sigma_n\left[1 - 0.175\left[\frac{r}{e}\right]\frac{\sigma_F - \sigma_N}{E}\right]$. Using the dimensions for Alcova, the critical external buckling pressure is 23 lb/in^2. So this corresponds to a pressure below atmospheric of about 8.5 lb/in^2. The conservative air venting approach is to provide air flow equal to the water flow. So the maximum capacity would need to be of the order of 4000 ft^3/s for the tunnel. This is not reasonable.

Considering the original design intent for the ring follower gates and their function in the present arrangement, I would not recommend performing a full flow unbalanced closure test. Should an emergency arise, for example a penstock rupture or inability to shut unit wicket gates, the ring follower gates should close without issue to this operation. If some type of testing is needed to verify hoist capacity, a standard 10-percent opening test with evacuated conduit downstream from the gate structure would perform this function.