Hydraulic Laboratory Technical Memorandum, PAP-1214

Numerical Model of Single-Gate Releases at Canyon Ferry Dam

Canyon Ferry Dam, Montana
Missouri Basin Region 5

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services
Denver, Colorado

April 2022

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Introduction

In February 2022, facility personnel at Canyon Ferry Dam contacted the Waterways and Concrete Dams Group of Reclamation's Technical Service Center (TSC) regarding plans to perform full travel gate tests at Canyon Ferry Dam. Several years ago, the bulkhead slots were removed from the pier noses at the facility which prevents dewatering individual gates for full travel testing on a regular basis. Since 2001, the gates have not been full-travel tested. Reservoir levels are currently low and performing the full travel gate tests during a low water year may be required to prevent exceeding the no-consequence safe discharge capacity for the downstream river during watered-up gate tests.

Standard Operating Procedures for this facility state that for releases greater than 2,000 cfs, the spillway gates are to be operated "with equal discharges through all four radial gates." Uniform gate operation is required to prevent adverse impacts to the stilling basin including differential loading on the splitter wall in the center of the basin and horizontal eddy formation that could pull streambed materials into the basin through the action of recirculating flow. In 2016 a small 1:232 scale physical model was constructed and tested to look at spillway operations outside of the SOP guidance when Gate #3 was inoperable (Toothman, 2016). Several gate operation scenarios were identified that could be used to make reservoir releases without utilizing Gate #3, all of which involved multiple gates and outlet works in operation. It is unknown whether the spillway was ever operated in this manner after that analysis was performed. One issue mentioned in the associated memo was the need to be mindful of the center training wall and excessive erosion and scour downstream of the basin which could pull material into the basin and cause ball-milling of the concrete surfaces during normal spillway operation.

The Hydraulic Investigations and Laboratory Services Group of the TSC was consulted to assess the effects of single gate operation. Given the short turn-around time, it was decided that looking at single gate operations using Computation Fluid Dynamics (CFD) modeling would be the most practical approach for determining whether this operation would be acceptable.

Model Setup

A 3D stereolithography model of the dam, spillway, stilling basin and small portion of the downstream river was generated from historical drawings (Figure 1) using AutoCAD. FLOW-3D®, a commercially available CFD software package developed by Flow Science Inc. was used for all CFD simulations. FLOW-3D® solves the Reynolds-averaged Navier-Stokes (RANS) equations for fluid flow. Modifications to the standard RANS equations include algorithms to accurately track the water surface and flow around geometric objects (Hirt and Nichols, 1981; Hirt and Sicilian, 1985; Hirt, 1992). The location of the free surface and solid objects is tracked throughout a Cartesian gridded domain using the true volume-of-fluid (VOF) method presented by Hirt and Nichols (1981).

The CFD model meshing was set up using a 1-ft cubic cartesian grid around the crest structure and a 2-ft cubic cartesian outer grid for the reservoir and stilling basin downstream of the hydraulic jump entering the basin. Boundary conditions included a constant reservoir water surface elevation upstream of the spillway and constant downstream tailwater elevation. Both boundaries maintained the target water surface elevation by allowing fluid in or out of the boundary.

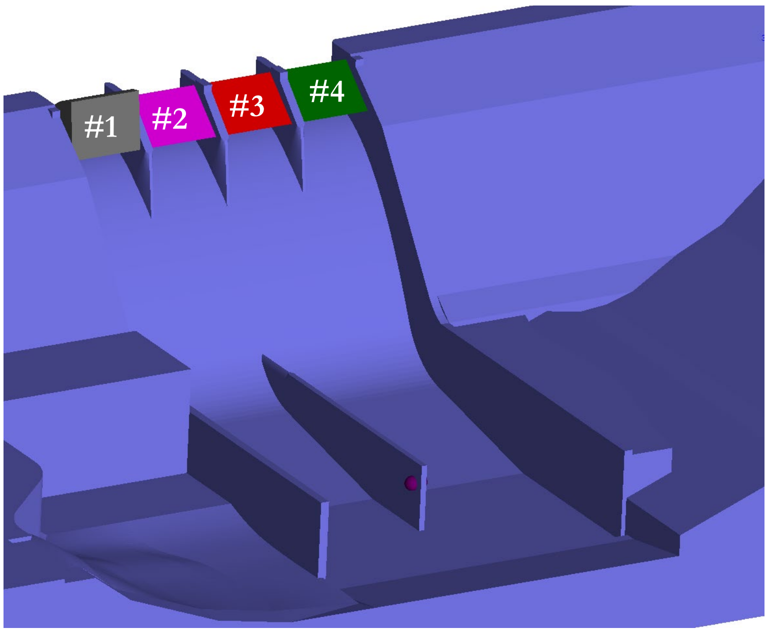

Figure 1. 3D geometry that was generated from historical drawings of Canyon Ferry Dam. The gate numbering is shown starting with gate 1 on the right of the spillway when looking downstream.

Nine simulations were run during this analysis. Two runs were made for each single gate opened under two reservoir elevations: El. 3782 and El. 3778 ft. One additional simulation was made at reservoir El. 3782 with gate 2 fully open and gate 3 set to a 2-ft opening. All simulations maintained a tailwater pool at El. 3650.

Results

Figure 2 through Figure 6 provide isometric views for each gate scenario with a reservoir elevation of 3782 ft. Flows entering the stilling basin create a hydraulic jump with large recirculating flow towards the gates that are not in operation. Water entering the operating side of the basin produces a lower water surface elevation than the side where recirculation occurs, which creates a hydraulic differential and causes flow to spill over the center splitter wall. When one of the outer two gates (gates 1 or 4) are in operation the water level differential across the wall (Figure 2 and Figure 5) is small. When one of the center two gates operate (gates 2 or 3) the differential across the wall is much larger at the upstream end (Figure 3 and Figure 4). The hydraulic jump created by the flow from the operating center gate sweeps out into the basin far enough that water spills over the splitter wall and into the hydraulic jump from the opposite side. The overtopping discharge entering from the side creates an unstable hydraulic jump that tends to surge upstream and downstream. This surging could create a scenario where, intermittently, there is little or no water depth against the splitter wall creating a full differential load across the splitter wall.

The final simulation with gate 2 fully opened and the adjacent gate 3 set to a 2 ft opening was performed to test whether this operating condition could stabilize the hydraulic jump when a center gate is operated. With the adjacent gate open 2 ft the flow entering the side of the hydraulic jump due to splitter wall overtopping is significantly reduced, creating a relatively stable jump. Table 1 provides a summary of the hydraulic differentials across the splitter wall that were obtained from the CFD model for each case.

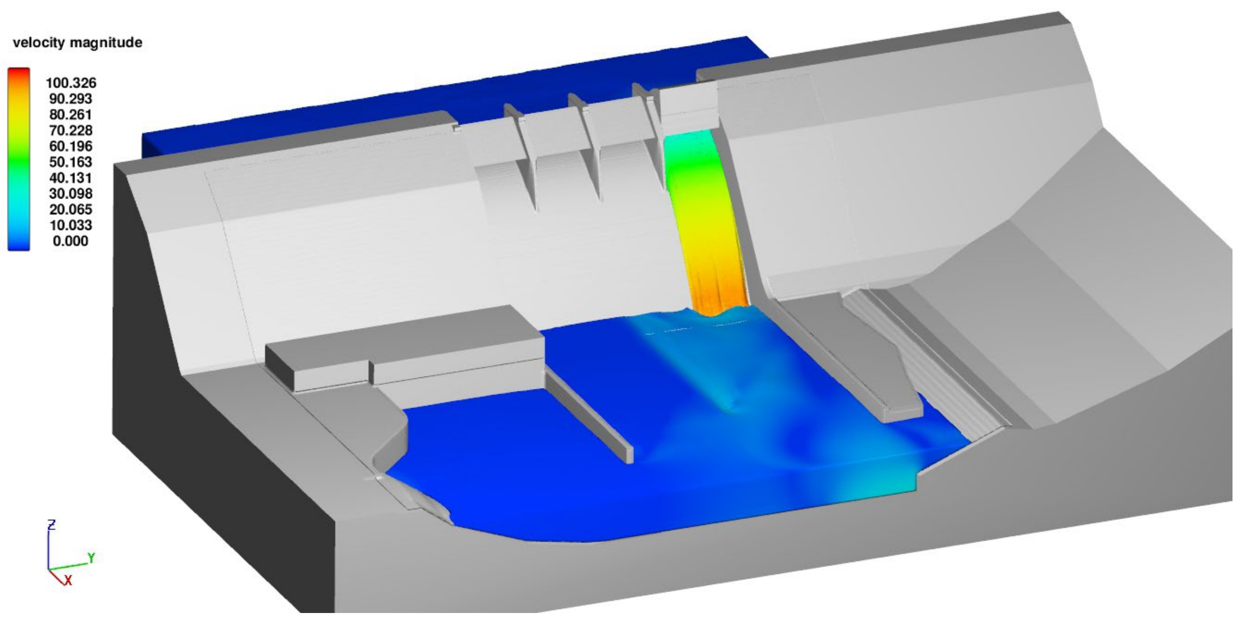

Figure 2. Gate 4 fully opened with a reservoir water surface elevation of El. 3782.

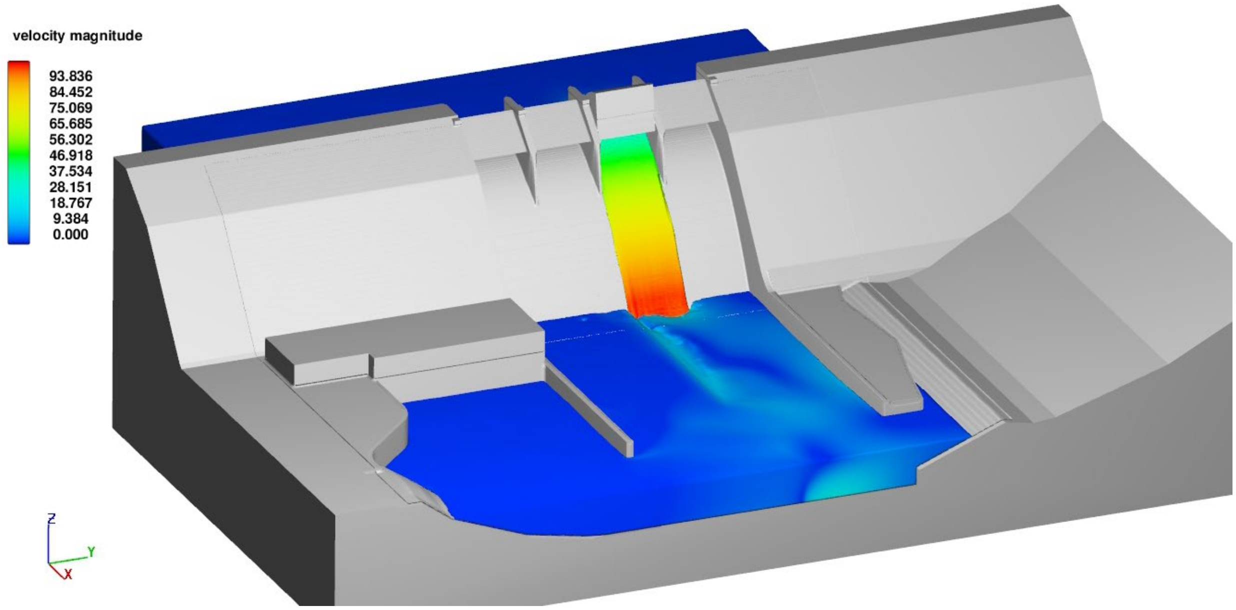

Figure 3. Gate 3 fully opened with a reservoir water surface elevation of El. 3782.

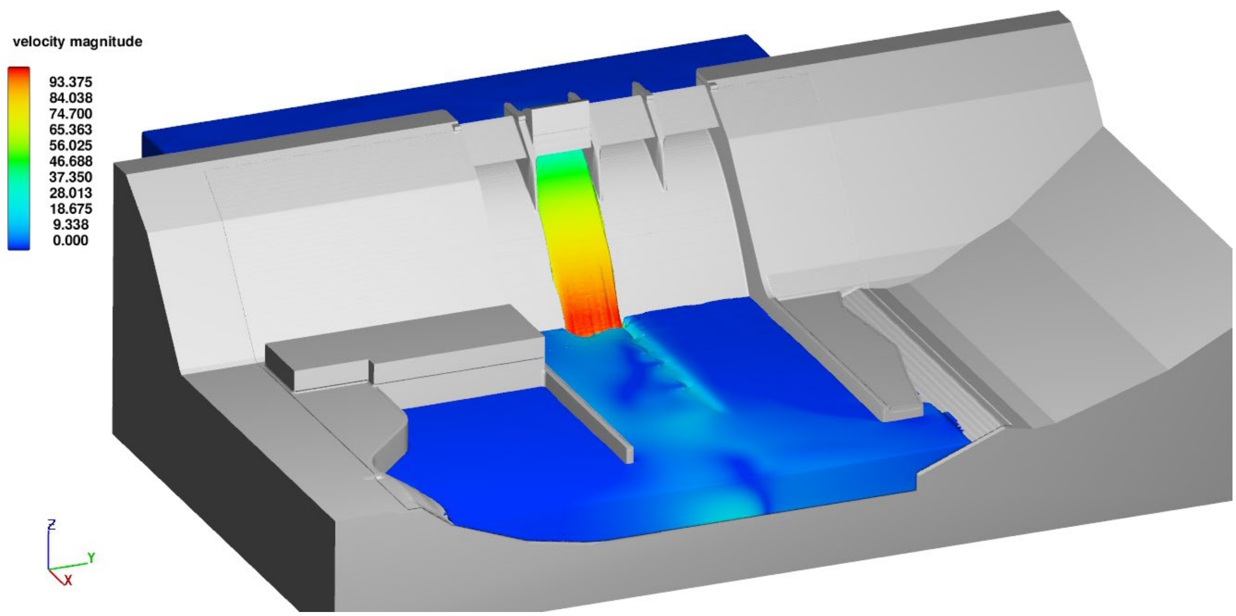

Figure 4. Gate 2 fully opened with a reservoir water surface elevation of El. 3782.

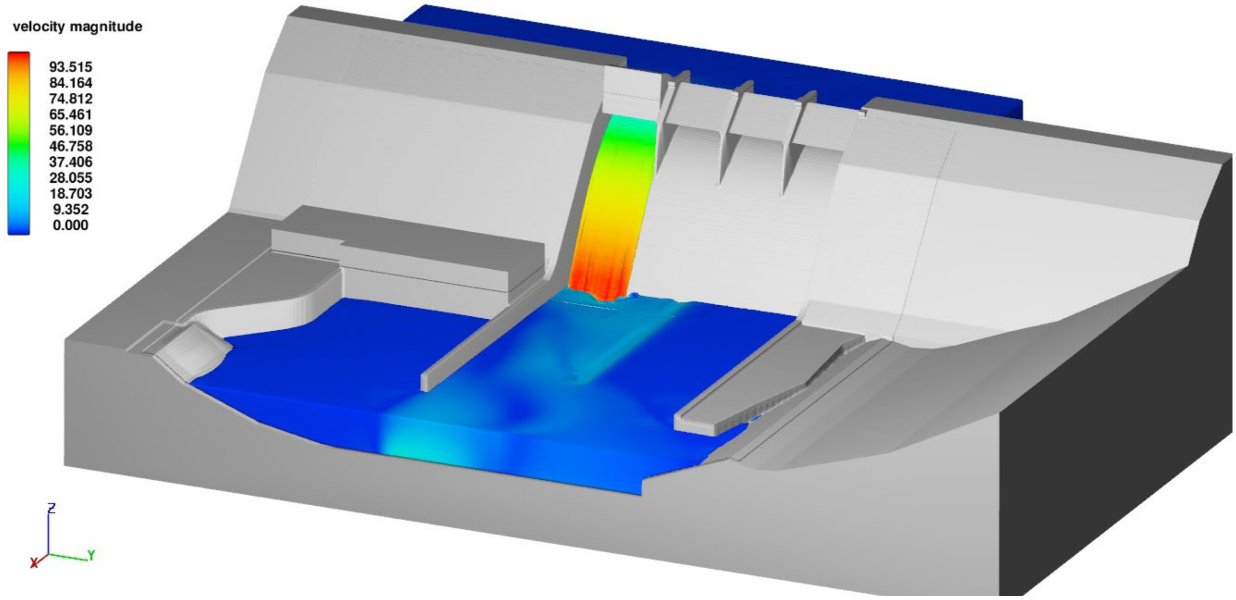

Figure 5. Gate 1 fully opened with a reservoir water surface elevation of El. 3782.

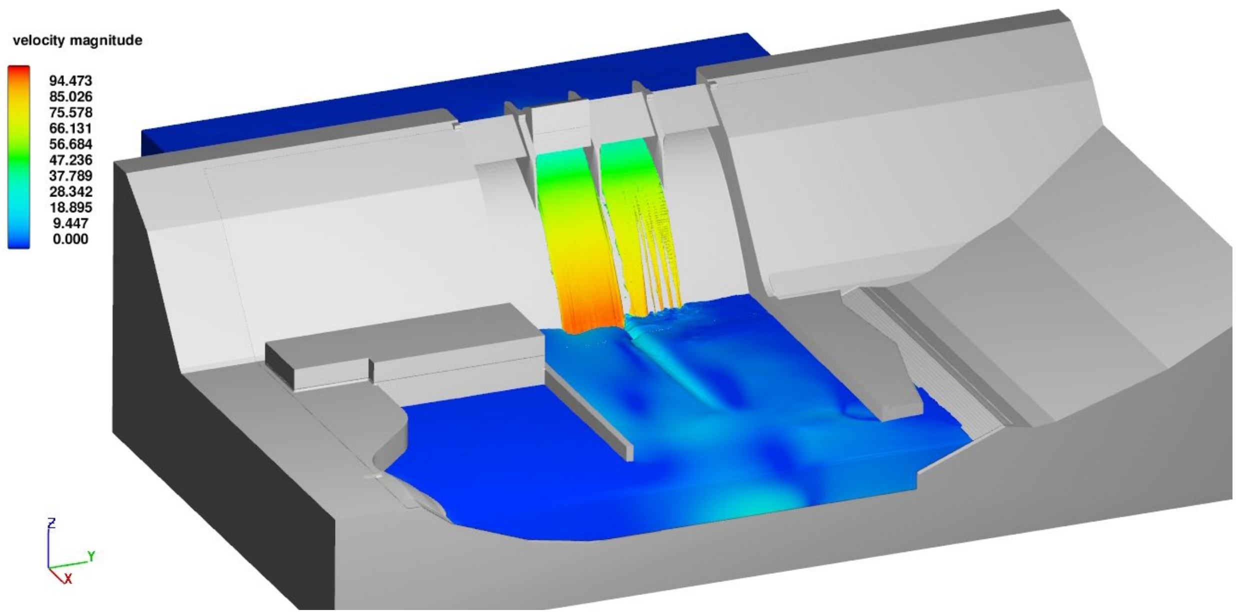

Figure 6. Gate 2 fully opened and gate 3 open 2-ft with a reservoir water surface elevation of El. 3782.

Table 1. Hydraulic differential head across the center splitter wall for each gate operation.

Gate that is Fully Open	Reservoir Water Surface Elevation, ft	Differential at Upstream End of Splitter Wall, ft	Differential at Downstream End of Splitter Wall, ft
Gate #4	3782	1.6	2.2
Gate #3	3782	6.6	2.8
Gate #2	3782	7.2	2.9
Gate #1	3782	2.9	1.7
Gate #4	3778	1.4	2.0
Gate #3	3778	6.5	2.6
Gate #2	3778	7.1	2.8
Gate #1	3778	2.6	1.6
Gate #2 Full Gate #3 2-ft	3782	3.0	0.9

Conclusions

The differential heads obtained from the CFD modeling scenarios were provided to the Waterways and Concrete Dams Group of the Technical Service Center to analyze the structural loadings on the splitter wall. A detailed summary of their results can be found in the separately prepared memorandum by Sperlazza and Maier 2022. The results indicated that the wall has sufficient strength to withstand the differential loads, provided the jump in the basin does not sweep past the chamfered section (first 40-ft) of the splitter wall. Based on the hydraulic analysis, a single-gate full-travel test is possible while keeping all other gates closed for gates 1 and 4. When testing gates 2 or 3 it is recommended to keep the adjacent center gate open at least two feet to increase the stability of the hydraulic jump directly downstream of the tested gate. Operating either center gate without the adjacent center gate opened at least two feet is not recommended and may cause damage to the splitter wall.

References

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