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USBR Experience with Multiple-Slot-Baffled Fishways

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ABSTRACT: A discussion of recent designs and construction methods for fishways using multiple-slot baffles is presented. A further enhancement of the design to convey increased fish attraction flow and flush floating debris through the fishway during periods of high river flow is also presented. This style of fishway is referred to in the paper as a skimming flow fishway. The multiple-slot baffle design was developed to provide a wide range of passage velocity and flow depth to promote passage of multiple species and life stages. The hydraulic design and fish passage attributes of the design are presented based on physical and numerical modeling and case studies. In recent years, the Bureau of Reclamation has constructed nature-like, technical and combination style fishways of this type for both salmonid and non-salmonid fish passage with excellent results.

INTRODUCTION

Reclamation has constructed many low head water diversion dams during the last 100 years. Many of these now require upstream passage for warm and cool water non-salmonid fish native to the western United States. For many native fishes, little data is available on swimming strength or behavior. Starting in the early 1990's, research on passage for native fish was initiated at Reclamation's Water Resources Research Laboratory. The research goal was to evaluate existing technologies and develop upstream passage applicable to the wide diversity of native fish species and age classes that inhabit western rivers. This multi-year effort of research and development has resulted in the construction of several non-traditional fish passage designs targeting multi-specie passage. The program started with investigations of non-salmonid passage through vertical slot fishways and roughened-channel fishways with application to run-of-river diversion dams. A maximum passage velocity of 1.2 m/s was adopted to meet the program goals based on available fish swim test data, habitat studies and experience from existing fishways, (Burdick, 2001, Broderick, 1997, Bramblett, 1996). Laboratory fish passage tests were conducted using shovelnose sturgeon (*Scaphirhynchus platorynchus*) native to the Yellowstone River, Montana, Rio Grande silvery minnow (*Hybognathus amarus),* native to the Rio Grande and razorback sucker (*Xyrauchen texanus)* native to the Colorado River system. Both wild and hatchery fish in pre- and post-spawned condition were used in the tests. During the tests, fishway hydraulic parameters were measured and recorded in conjunction with observations of fish behavior in response to flow conditions.

These studies identified several general flow conditions that resulted in reduced fish passage performance for the species tested. The studies also included testing of fishway modifications for improving passage effectiveness. The major study findings for step pool style fishways are outlined below.

1. In Reclamation studies the presence of large stationary eddy patterns within the pools between baffles was found to delay successful passage, increase fish fall-back within the fishway and concentrate predator and prey, (White and Mefford, 2002). Frequent observations were cited of fish holding for extended periods within fishway pools when encountering standing eddies larger in width than approximately their body length. Fish holding within large stationary eddies often displayed disoriented behavior and loss of positive rhetaxis to the main flow. Repeated vertical searching behavior combined with repeated nosing of the fishway pool boundaries was frequently noted. This behavior was less prevalent when fish encountered elongated eddies of relatively narrow cross section. Katopodis (1992) identified the flow circulation pattern in pools downstream of different single vertical slot baffle designs. The circulation patterns occur in two general forms. Directing the flow jet into the pool results in a large dominant eddy either side of the jet driven by shear between the high and low velocity water. If the jet passes through the pool as a wall jet, the single shear line results in a single eddy dominating the pool. The size of the dominant eddies was reduced in the Reclamation study by increasing the number of jets entering the pool. Introducing multiple passage slots symmetrically spaced about the channel centerline increases the number of shear lines, resulting in more eddies of smaller width. Flow patterns from several multiple slot baffle designs were investigated using Computational Fluid Dynamics (CFD) models. The investigation resulted in an upstream pointing baffle with one or more flow slots per side being selected for physical testing. Chevron baffles of total internal angle between 150 degrees and 120 degrees were modeled. The chevron baffle shape with symmetric slots produces higher velocities in the center of the pool where the jets merge and weaker velocity to the outside with elongated eddies occurring along each wall (Figure 1). Fish passage tests of the design showed improved upstream orientation of fish holding within pools. Increasing the number of slots also increases the fishway flow and the volume of the pool required to dissipate the flow energy of the jets. When flow must be limited the minimum acceptable slot width for passage should be used. Slot widths between 300 mm and 400 mm were used during the study.

2. The second study finding focused on providing greater variability of flow conditions to support passage of different species and age classes. Step-pool style technical fishways generally yield through baffle passage flow conditions that are nearly uniform vertically or horizontally**.** Many habitat and tracking studies of native non-salmonids report flow preference as an important signature of fish migration patterns (Bramblett 1996, Broderick, 1997).

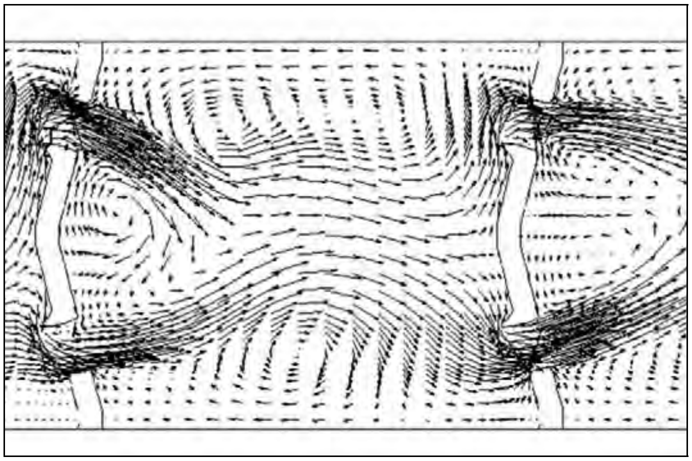


Figure 1 – CFD flow simulation of flow velocity patterns in a fishway with 150 degree chevron-shaped dual-slot baffles.

Greater variation of through-slot depth and velocity was achieved in the passage study by using channels with sloping side walls in combination with a chevron baffle with multiple slots. Slots located on the channel side slope convey flow at a lower average velocity at a shallower depth. This configuration was found to work well for roughened-channel fishways. Roughened-channel fishways are rock-lined channels that more closely emulate flow conditions in natural channels. These fishways often use large boulders to either increase the average channel flow resistance or as flow control baffles creating pools and drops (Heimeri et al. 2008, DVWK, 2002, White and Mefford, 2002, Bestgen and Mefford, 2003). Roughened-channel fishways are typically designed at channel slopes less than five percent with channel slopes of two percent commonly used for passing multiple species and life stages. Fish passage studies at Reclamation included studies of roughened-channel designs using a trapezoid channel with 2:1 side slopes containing a series of boulder weirs, Figure 2. A major goal of the study was to develop an effective roughened-channel step-pool style fishway that could be easily constructed in the field. To obtain similar flow conditions to that favored for dual-slot technical fishways, large boulders were placed in a similar chevron pattern with spaces between the boulders of 300 mm. These studies found significantly higher passage rates in the roughened fishway compared to a vertical slot fishway in rectangular channel for similar pool-to-pool drop.

3. The third significant study finding was derived from observations of non-salmonid fish attempting passage through a standard vertical slot style fishway. Observations of fish behavior during laboratory trials reported frequent failed passage attempts resulting from fish losing orientation to the passage flow while attempting to swim through zones of high fluid strain at the entrance to slot openings. Generally the loss of orientation resulted from fish swimming into a strong shear plane at angles in excess of about 45 degrees. Fish passing through roughened-channel fishways with baffles constructed of round boulders displayed little problem with shear flow. The large width of the boulders in the direction of flow provided for a milder convergence and divergence of the flow. These observations lead to guide walls being added to the

Figure 2 – View of a full scale roughened-channel test facility used to study non-salmonid passage using chevron shaped boulder weir drops.

downstream face of the dual-slot baffle design previously tested, Figure 3.
A CFD generated velocity vector plot of the fishway flow for the chevron baffle with guide walls is shown in Figure 4. Fish passage tests of the baffle with guide walls showed improved passage efficiency. Fish swimming upstream along the outer edges of the slot flow maintained a more positive rheotaxis to the main flow. Fish displayed less difficulty swimming from areas of weak flow along the outer edges of the passage jet into the main core of the jet near the slot.

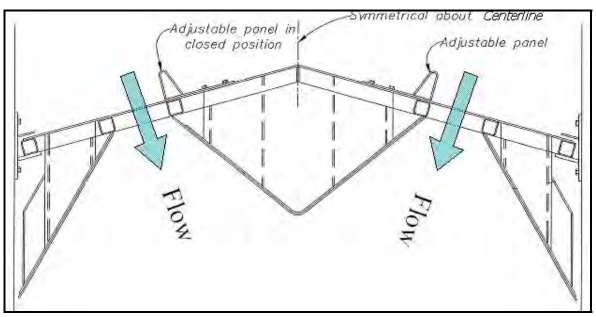


Figure 3 – Plan view of a dual-slot chevron shaped baffle with downstream guide walls.

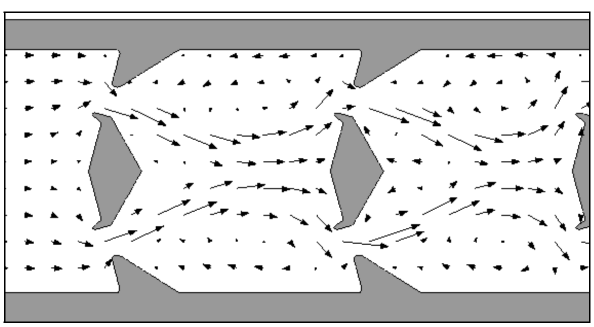


Figure 4 – CFD simulation showing the flow vector field in a fishway with dual-slot chevron baffles.

CASE STUDIES

Technical Fishways - Reclamation has constructed two technical fishways using the chevron shaped dual-vertical slot baffle design. The fishways are located on the Government Highline Diversion Dam (GHDD) located on the Colorado River near Grand Junction, Colorado (Figure 5) and Link River Dam located near Kalmath Falls, Oregon. Both fishways are designed at about 4.5 percent slope for passing native non-salmonid fish species. The GHDD fishway provides 5.2 m of elevation gain. Baffles are spaced 2.44 m apart providing a water surface drop per baffle of 110 mm. The fishway contains an adult fish trap located in the fishway exit channel that is operated to sample fish specie composition using the fishway. The trap has been operated for a few weeks to several months each year since 2005. Each year 10,000+ fish have been trapped (Burdick, personal communication 2008). The sampling to date shows 17 fish species, of which approximately 90 percent are native, pass through the fishway. At the Link River Dam a passage study focused on fishway use by native species is planned for 2009.

Roughened-channel Step Pool Fishways - Five step pool roughened-channel fishways with multiple slot baffles have been constructed. All of these fishways are designed for passage of native non-salmonids at channel slopes 2.5 percent or flatter. Four of the fishways use flow control baffles referred to as boulder weirs constructed using large boulders. Boulders are placed across the channel in an upstream pointing chevron. Chevrons with total internal angles of 120 degrees and 150 degrees have been used with good success, Figure 6. Typical designs use boulders separated by 300 mm ft to 400 mm (minimum clearance) to create flow chutes for fish passage. Spacing is dependent on design flow and water surface drop across each weir. Greater spacing of boulders can be used if fishway flows and channel geometry permit. Typically, the diameter of the center boulder, referred to as the tuning boulder, is greater than the normal hydraulic design depth of the fishway. The diameter of tuning boulders typically falls in the range of 1.0 m to 1.25 m diameter. Tuning boulders are placed on top of the riprap channel such that they can be moved

Figure 5 – View of the Government Highline Diversion Dam fishway, Colorado River, CO.

Steel baffles prior to installation in the fishway.

upstream or downstream if necessary to adjust the water surface drop across the boulder weir. Boulders placed on the channel side slope are set below the top of riprap to increase stone stability. Typically, side slope stones are buried between 20 to 30 percent of their diameter. The stability of stones set on the side slope should be assessed based on the maximum likely flow the fishway could encounter during its design life. Boulder stability is determined following a method presented by Stevens et al. (1976) for determining the stability of riprap based on evaluating the forces acting on the particle.

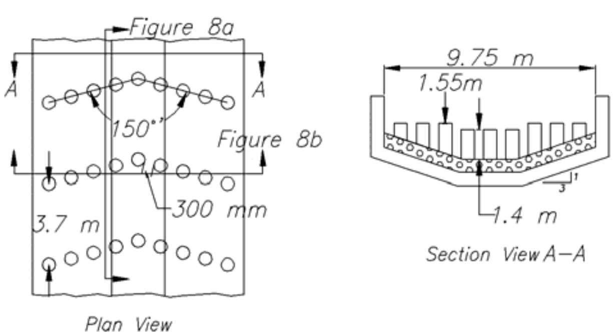
Figure 6- View of the Derby Diversion Dam roughened-channel fishway, Truckee River, NV.

A limitation of the boulder weir fishway is the size and weight of large boulders. Where flow control is needed for fishway depths greater than about 1 m to 1.5 m, boulders become impractical. In many locations large boulders are not locally available and are costly to ship to site. This problem was solved by using concrete cylinders in place of boulders at Price-Stubb fishway located on the Colorado River near Grand Junction, Colorado, Figure 7. Flow control for river stages varying two meters was needed to provide passage for native species. The fishway provides four meters of elevation gain. The fishway is a rock lined trapezoidal channel with 1.52 m wide invert and 2:1 side slopes. Multiple-slot baffles are spaced 4.57 m apart, providing a water surface drop per baffle of 116 mm. The baffles are composed of vertically mounted, 1.15 m diameter concrete cylinders spaced 300 mm apart. Evaluation of fish passage through the structure is scheduled to begin in 2009.

Skimming Flow Fishways - Traditional methods for providing auxiliary attraction flow to fishways often require construction of separate flow release facilities. These facilities can require extensive maintenance to keep debris from clogging trashracks or flow diffusers. Reclamation is studying fishway concepts using multiple-slot chevron-shaped baffles where the center portion of the baffle is designed to operate submerged during high river flows. This concept has shown success in low-gradient roughened-channel fishways with boulder weirs.

Figure 7 – Looking upstream at the cylinder baffles in the Price-Stubb Dam roughened-channel fishway, Colorado River, Co.

High flows passed through the fishway serve to carry floating debris through the fishway and increase fishway attraction as river flows increase. During skimming flow conditions, near center flow velocity increases while channel fringe velocities remain relatively constant as long as baffles near the channel banks protrude above the water surface. Studies for applying this concept to a new auxiliary fishway for Robles Diversion Dam on the Ventura River in southern California are in progress. The fishway is being designed on a 1:12 slope for passing southern California steelhead trout (*Oncorhynchus mykiss)*. The Robles auxiliary fishway is intended to supplement passage of an existing fishway during large river flows. To function as intended, the fishway must provide large attraction flows and operate during river flows conveying large amounts of floating woody debris. Figure 8 shows a baffle design with the tops of three center most cylinders set 0.15 m lower than the outer cylinders. To the right is a CFD simulation showing surface flow velocity for the preliminary design during a flow of 5.5 m^3/s. Figures 9a and 9b show velocity magnitude at sections cut along longitudinal and transverse sections shown in the plan view in Figure 8. The center cylinders are overtopped by 0.25 m for the discharge shown.



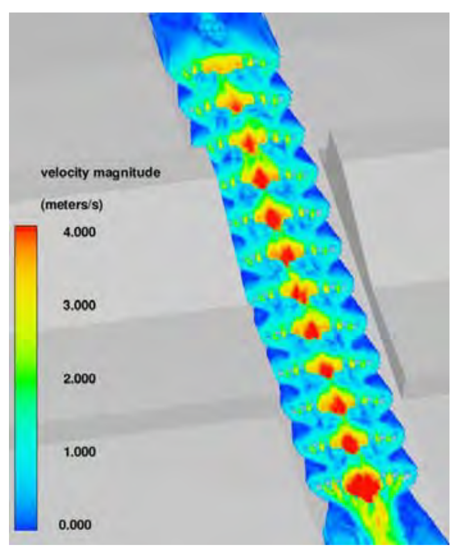


Figure 8 – Schematic of a skimming flow fishway design being studied for Robles Diversion Dam located on the Ventura River, CA. To the right is a CFD flow simulation showing the surface velocity in the fishway.

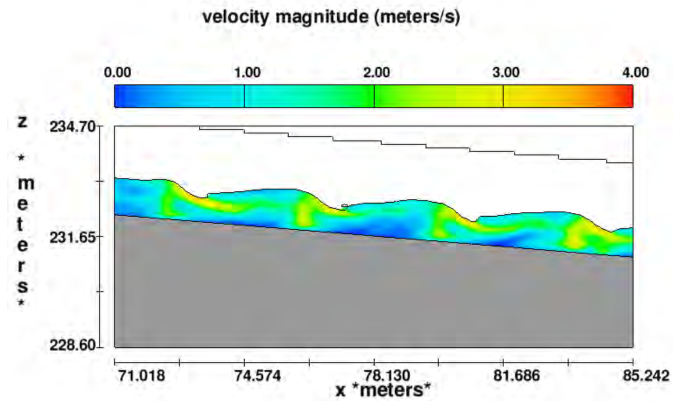


Figure 9a – CFD simulation showing flow velocity along a longitudinal section cut through the flow slot to the side of the center cylinder shown in Figure 8.

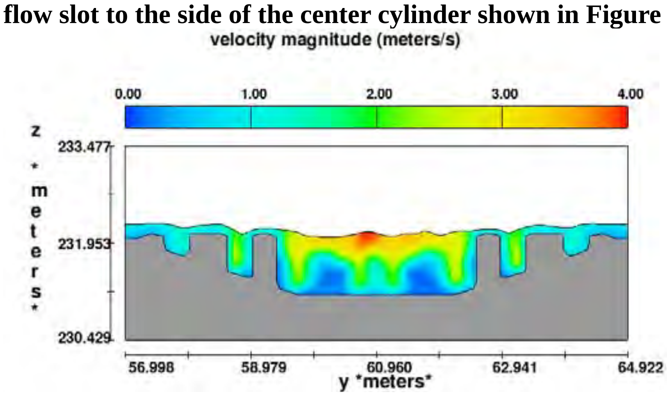


Figure 9b - CFD simulation showing flow velocity on a section cut normal to the channel at the third cylinder looking upstream shown in Figure 8. Fishway flow is 5.5 m^3/s.

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