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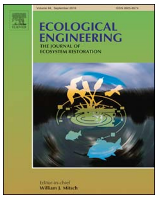

Research Paper

Sensitivity of the downward to sweeping velocity ratio to the bypass flow percentage along a guide wall for downstream fish passage

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ABSTRACT

Partial-depth impermeable guidance structures (or guide walls) are used as a method to assist in the downstream passage of fish at a hydroelectric facility. However, guide walls can result in a strong downward velocity causing the approaching fish to pass below the wall and into the direction of the turbine intakes. The objective of this study was to describe how the ratio of the vertical velocity to the sweeping velocity magnitude changes along the full length and depth of a guide wall under a wide range of bypass flow percentages within a power canal. This paper focused on two guide wall configurations, each set at an angle of 45 ° to the approaching flow field and at a depth of 10 and 20 ft (3.05 and 6.10 m). The hydraulic conditions upstream of each guide wall configuration were shown to be impacted by a change in the bypass flow percentage, not only near the bypass but also at upstream sections of the guide wall. Furthermore, the effect of changing the bypass flow percentage was similar for both guide wall depths. In both cases, the effect of increasing the bypass flow percentage was magnified closer to the bypass and deeper in the water column along the guide wall.

1. Introduction

Partial-depth impermeable guidance structures (or guide walls) are used to actively guide out-migrating and surface-oriented diadromous and potadromous fish to a safe passage route around a hydroelectric facility. Guide walls typically consist of steel panels attached to a floating boom (Scott, 2012), although earlier designs used fixed concrete walls (TransCanada Hydro Northeast Inc., 2012; RMC Environmental Services, 1991). The structures start at a location upstream of the hydroelectric facility, in either a power canal or river channel, and are angled toward the safe passage route (i.e. the bypass). The effectiveness of the guide wall varies by site, although many have been shown to be highly effective at guiding surface-oriented fish to the bypass (Scott, 2012). However, depending upon the depth and angle of the guide wall, these structures can create a high downward velocity (defined as the z-velocity component – see Fig. 1) and a low sweeping velocity (defined as the magnitude of the x and y velocity components – see Fig. 1) upstream of the wall. This can lead to fish passing below the wall by either volitionally following the flow or being entrained by it.

Mulligan et al. (2017) studied the flow field upstream of a guide wall set at multiple depths and angles under different approach velocities. The author developed a design methodology to ensure that fish approaching the wall given an expected vertical distribution would encounter sweeping dominant conditions (i.e. a greater sweeping velocity than downward velocity). The author used computational fluid dynamics (CFD) to show that a guide wall set at an angle in the range of 15–22.5° would result in a sweeping velocity magnitude equal to or greater than the absolute value of the downward velocity along the full depth of the wall and at each guide wall depth in the study (ranging from 10 to 20 ft.).

Mulligan et al. (2017) focused on only the hydraulic conditions at the longitudinal midpoint of the guide wall and for a bypass flow rate equivalent to 5% of the flow rate in the power canal. Similarly, Chapter 2 of Mulligan (2015) analyzed the hydraulic conditions upstream of the guide wall for a bypass flow percentage of only 5%. Conversely, Mulligan (2015) included an analysis of the hydraulic conditions at multiple cross-sections along the longitudinal length of the wall. The objective of this paper was to examine the sensitivity of the primary metric used both in Mulligan (2015) and Mulligan et al. (2017), the Upper Guidance Zone Depth (d^*), to changes in the bypass flow rate percentage (p) and to evaluate how this metric varies along the full length of the guide wall. The Upper Guidance Zone Depth is based on the hypothesis that, due to the tendency of a guide wall to create strong downward flows along its face, the guide wall can be split into an

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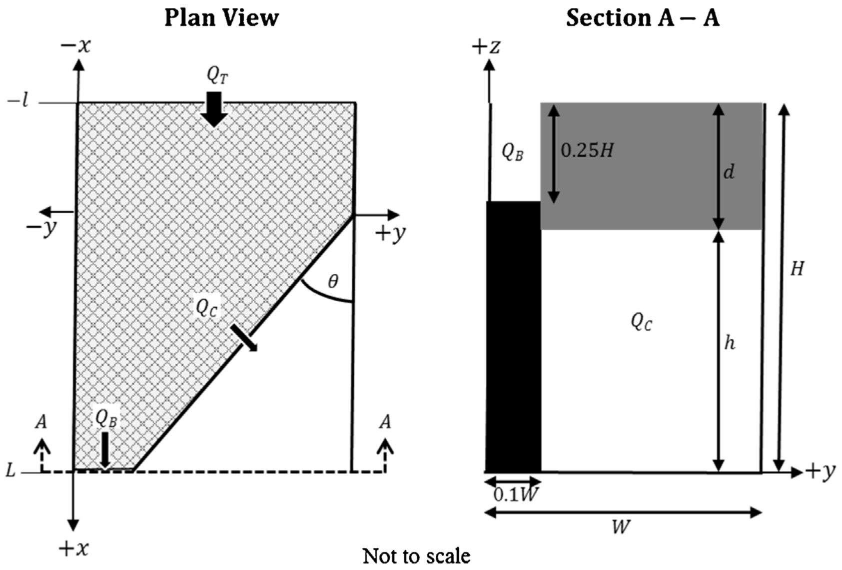

Fig. 1. The schematic on the left shows the plan view of the idealized power canal. The hatched area (upstream of the guide wall and bypass entrance) is the modeled region. The schematic on the right shows the cross-sectional view from A-A, the furthest downstream location as seen in the plan view. The gray area is the guide wall. The black area is the wall directly below the bypass entrance. Note the x-y-z axis, the intersection of the x and y axis always occurs at the most upstream section of the guide wall, as shown above. On the x-axis, the bypass outlet is located at x = L and the model inlet is located at x = −l (Mulligan et al., 2017).

"Upper Guidance Zone" and a "Lower Guidance Zone". The Upper Guidance Zone is considered to be more likely to effectively guide fish because of its relatively smaller (in absolute value terms) downward to sweeping velocity magnitude ratio. The Lower Guidance Zone is considered to be less likely to effectively guide fish because of its greater downward to sweeping flow ratio. The ratio of downward velocity to sweeping velocity magnitude was previously defined by Mulligan et al. (2017) as the *DSR* and is shown in Eq. (1).

$$DSR = \frac{V_z}{\sqrt{V_x^2 + V_y^2}} \tag{1}$$

Where V_z is the velocity in the z-direction, V_x is the velocity in the x-direction, and V_y is the velocity in the y-direction.

The Upper Guidance Zone Depth, $d^*(t^*)$, was defined as the depth at the maximum elevation where the *DSR* was less than a threshold value of t* along the guide wall. *DSR* values range from 0 to −2.3 in Mulligan et al. (2017). A *DSR* value of approximately 0 indicates no downward flow and was typical near the water surface elevation. A *DSR* value of −2.3 indicates a downward velocity 2.3 times greater than the sweeping velocity along the face of the guide wall. Minimum *DSR* values were consistently located at the bottom of the guide wall.

2. Experimental design

The CFD model of a full-scale guide wall and power canal developed in Mulligan et al. (2017) was used to perform the evaluation. The model was constructed in © ANSYS Fluent v 14.5 (ANSYS Inc., 2012). Fluent is a finite-volume code that iteratively solves the conservation of mass and momentum over a set of discretized control volumes within the model domain until convergence. The CFD model was run in steady-state, used a second order solver for both momentum and turbulence, and consisted of approximately 350,000 finite volumes. Three different types of boundary conditions (velocity inlet, pressure outlets, and a wall condition) were used in each of the model scenarios. The realizable k-Ɛ turbulence closure model with standard wall functions was used to describe the turbulent kinetic energy and turbulent dissipation rate. Convergence criteria included the equation residuals for continuity, x-velocity, y-velocity, z-velocity, turbulent kinetic energy, and turbulent dissipation rate. The generic model schematic is shown in Fig. 1, copied from Mulligan et al. (2017).

For each scenario, the inlet location is fixed and the approach distance ℓ was held constant at 25 ft (7.62 m). The guide wall angle (θ) was 45° for all model runs and thus L, the total length of the model, was 115 ft (35.1 m). The canal width, W, was 100 ft (30.5 m). and the canal depth, H, was 40 ft (12.2 m). The width of the bypass was 0.1W or 10 ft (3.05 m). The depth of the bypass opening was 0.25H or 10 ft (3.05 m). The size of the bypass opening is within the typical range for surface flow outlets (Johnson and Dauble, 2006). The total flow through the model inlet, Q_T, was equal to 8000 cfs (227 cms) and constant for all model runs. The flow through the bypass outlet, Q_B, and the flow through the main power canal outlet, Q_C, vary depending upon the bypass flow percentage, *p* (equal to $100^*Q_B/Q_T$). Eight different bypass flow percentage, *p*, values were used from 1% to 15% at an interval of 2%. Each bypass flow percentage was run with a guide wall depth, *d*, of 10 ft and 20 ft (3.05 and 6.10 m). The total number of model runs was 16.

Generally, the bypass flow percentage ranges from 1% to 17% of the mean annual discharge, depending upon the type of bypass (Johnson and Dauble, 2006). The Northeast Region U.S. Fish and Wildlife Service typically prescribes a bypass flow percent of up to 5% of the power station hydraulic capacity (the maximum amount of flow the power station turbines can pass) (Odeh and Orvis, 1998), which at most sites will fall within the range described by Johnson and Dauble (2006). The other varied design parameter, *d*, was set at the minimum and maximum value of the Mulligan et al. (2017) study. The authors chose an angle of 45° because it was expected to be the most sensitive to the changes in the bypass flow percentage due to its larger *DSR* magnitude when compared to guide walls of lesser angles (as shown in Mulligan et al. (2017)).

3. Experimental results

Fig. 2 (d = 10 ft. [3.05 m]) and Fig. 3 (d = 20 ft. [6.10 m]) illustrate the effect of the bypass flow percentage, *p*, on the Upper Guidance Zone Depth at multiple cross-sections along the x-axis of the model. The x-axis location of each cross-section was defined by $x = n$L, where n is equal to 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9 (refer to Fig. 1 for the axis orientation).

Similar patterns exist for both guide wall depths. At the most upstream cross-section, x = nL where n = 0.1, the DSR was the greatest in absolute value along the full depth of the guide wall relative to cross-sections further downstream. At this location, the sweeping velocity at the guide wall had not built up a significant amount of momentum in the direction of the bypass. In addition, the changes in *p* present an unclear and varying signal in the Upper Guidance Zone Depth at this far upstream location.

At the next downstream cross-section, n = 0.2, the effect of the