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Comment on "Experimental hydraulics on fish-friendly trash-racks: an ecological approach"

by M. SZABO-MESZAROS, C. U. NAVARATNAM, J. ABERLE, A. T. SILVA, T. FORSETH, O. CALLES, H.-P. FJELDSTAD, K. ALFREDSEN

Ecological Engineering 113. 2018, 11-20

Commenters:

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The Commenters congratulate the Authors for addressing the pressing topic of downstream fish protection and guidance technologies for run-of-river (RoR) hydropower plants (HPPs) by experimentally studying angled "fish-friendly trash-racks". Their paper focuses on head-losses and hydrodynamic performance of six geometrically different fish guidance structures (FGS), which are of prime importance for successful fish protection and guidance, and sustainable use of hydropower. Similarly, the Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, has been conducting research on FGSs with vertical bars such as louvres, angled bar racks and modified angled bar racks (MBRs) (Albayrak et al., 2017), as well as horizontal bars (HBRs) (Albayrak et al., 2018).

Introduction

Trash-racks with clear bar spacings typically ranging from 20 mm to 500 mm (Meusburger, 2002) are installed in front of hydropower intakes to avoid turbine damages caused by large wood and floating debris (Fig. 1a). They can further act as physical barriers for larger fish and as behavioural barriers for small fish by creating hydraulic and visual cues. If a surface or side bypass is adjoined to the trash rack, it may also guide the fish. However, the fish guidance efficiency (FGE) is low (Larinier and Travade, 2002). Vertical or horizontal inclination of trash racks with reduced bar spacings improve the FGE (Fig. 1). Many examples of those trash racks exist worldwide and are studied with regard to their hydraulic performance and FGE (Amaral, 2003; Courret and Larinier, 2008; Raynal et al., 2013, Albayrak et al., 2017). The authors conducted a laboratory study covering a range of the above described rack configurations and investigating the head losses and turbulent flow structures around the racks, and particularly in the bypass. The studied rack configurations included a horizontal approach flow angle to the rack α = 30°, clear bar spacing s =15 mm and three different bar setups: (i) vertical-streamwise bars, (ii) vertical bars angled β = 60° to the approach flow and (iii) horizontal bars. The commenters noticed that the authors did not distinguish between physical and behavioural barriers, although the operating principle is entirely different. In this comment we would therefore like to put special emphasis on the definition and the engineering application of different types of FGSs with regard to the rack parameters, hydraulic cues, and hydrodynamic performance. Additionally, selected statements on the performance or application of those FGSs are discussed.

Definitions

Trash-racks, which are modified for the purpose of fish protection and guidance, are often called fish guidance structures (FGS) in the literature. FGSs can be divided into horizontal and vertical bar racks and are typically installed upstream of the turbine intakes with a horizontal approach flow angle to the rack α (Fig. 1). FGSs protect fish from turbine entrainment and guide them to a bypass providing safe downstream passage. For a sustainable use of hydropower, FGSs should not only efficiently protect and guide the fish but also keep head losses and other negative hydrodynamic impacts to a minimum. In the following, different FGSs are defined. Their range of application is determined with regard to hydraulic and fish-biological criteria. Thereby, the distinction between physical and behavioural barriers is made.

Physical barriers

One approach to keep fish from turbine entrainment is to reduce the bar spacing to 10 - 30 mm based on the size of the target fish species and orient the rack with either a horizontal angle α or vertical angle γ to the intake. For such spacings, most fish are physically hindered to pass the racks. These physical barriers can consist of vertical or horizontal streamwise-oriented bars, herein termed 'vertical bar racks' (VBRs) or 'horizontal bar racks' (HBRs), respectively. Most of the fish have a proportion index larger than one, which means their height is larger than their width (Ebel, 2016). Therefore, higher FGEs of physical barriers are expected for HBRs in comparison to VBRs for similar bar spacings. HBRs are widely used and approved by authorities (Boes et al., 2016) and have been successfully applied at many HPPs in Germany and Switzerland (Ebel, 2016, Albayrak et al, 2018). Until now, HBR application has been limited to relatively small HPPs with Q_d < 90 m^3/s, complying with the velocity limitation for physical barriers to avoid fish impingement, i.e. the average velocity component normal to the rack should not exceed the sustained swimming speed of fish (Ebel, 2016). In general, HBRs are placed across an intake canal or forebay at an angle to the flow direction of typically α = 30° ÷ 45° (Fig. 1d). Since HBRs are subject to clogging by organic fine material like leaves and branches, sophisticated rack cleaning machines are needed. HBRs can be configured with either bottom, top or both bottom & top overlays to improve FGE and the diversion of driftwood and/or sediment to the bypass.

Vertically inclined bar racks, i.e. VBR (Fig. 1b), complete the variety of physical barriers. They have been investigated with regard to head losses and flow fields (Raynal et al., 2013a) and are e.g. installed at HPPs in France (e.g. Las Rives, Pébernat). The vertical inclination guides the fish to a near-surface bypass, which might reduce the FGE for bottom oriented fish.

Behavioural barriers

The operating principle of behavioural barriers intends to protect fish with distinct hydraulic cues instead of physically shielding them from the turbine intake. These FGSs include louvres (louvers in American English), angled bar racks and Modified angled Bar Racks (MBR), i.e. VBRs (Fig.1c) (Bates & Vinsonhaler, 1957; EPRI & DML, 2001; Amaral et al., 2001; Amaral, 2003; Raynal et al., 2013b; Albayrak et al., 2017). They typically consist of vertical bars oriented with an angle between β = 45° ÷ 90° to the flow direction with clear bar spacings s = 5 ÷ 100 mm (Fig. 1c). Vertical bars are oriented with a bar angle of β = 90° to the flow direction for louvres while they are β = 90° − α and $\beta \neq$ 90° − α for angled bar racks and MBRs, respectively (Fig. 2). These FGSs are typically placed in front of a power intake at an angle α = 15° ÷ 30°. The vertical bars of all three described FGSs increase turbulence, create flow separations and thus pressure changes, which are perceived and avoided by approaching fish. The rack-parallel velocity component guides the fish towards a bypass system. These FGSs induce strong hydraulic cues and allow for a wider bar spacing thus reducing the hydraulic resistance (EPRI & DML, 2001; Kriewitz, 2015; Albayrak et al., 2017). They are therefore suitable for medium and large HPPs with Q_d > 90 m^3/s (Boes et al., 2016). However, the hydraulic head losses Δh_R and asymmetric turbine admission flow caused by these FGSs (Kriewitz, 2015) are a decisive indicator for long-term production losses and are therefore of great concern for HPP operators.

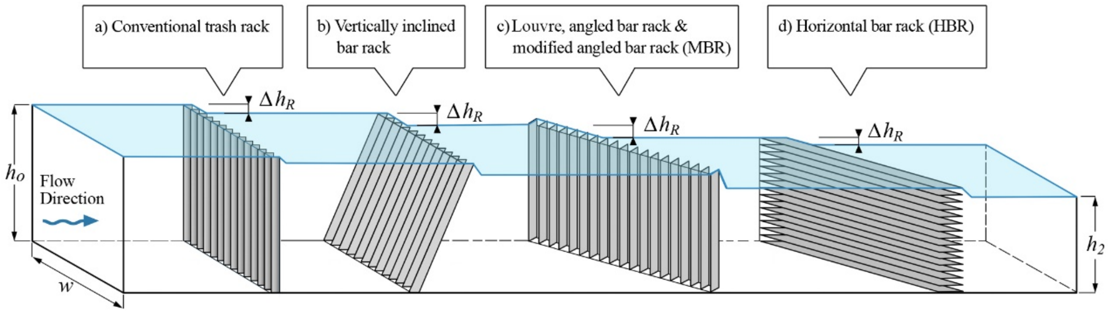

Figure 1 Detailed geometric view of (a) conventional trash rack, (b) vertically inclined bar rack, (c) louvre, angled bar rack and modified angled bar rack (MBR), and (d) angled horizontal bar rack (HBR): s = bar spacing, w = channel width, h_o = upstream water depth, h_2 = downstream water depth, β = bar angle normal to the flow direction, α = horizontal rack angle, γ = vertical rack angle, Δh_R = head loss (adapted from Albayrak et al., 2018).

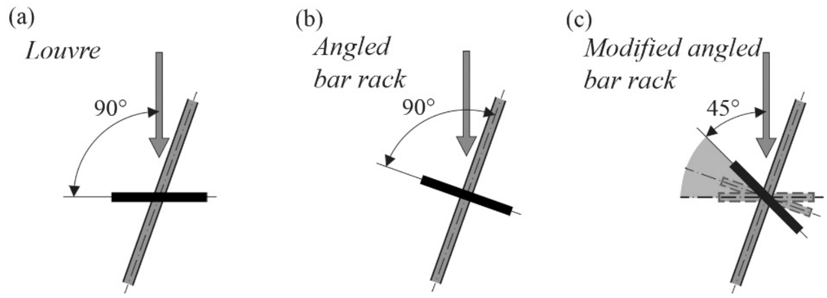

Figure 2 Top view of (a) louvre, (b) angled bar rack and (c) modified angled bar rack (MBR)

Discussion of engineering application

The authors investigated a bar rack with α = 30° and β = 60°, which corresponds to an angled bar rack setup indicating a behavioural barrier (Fig. 1c and 2b). With the narrow bar spacing of s = 15 mm this FGS is additionally considered as a physical barrier. As expected, the authors observed significantly higher head losses compared to the racks with vertical streamwise bars and horizontal bars (HBR). In their discussion, the authors pointed out that the high transverse velocities along the rack and the eddy characteristics in front of the bars might negatively affect the FGE. For this reason and due to high head losses, the authors recommended to operate this type of FGS, i.e. angled bar racks, for lower flow rates only. The commenters argue that the altered flow parameters are essential for the efficiency of behavioural FGSs and might even be beneficial not only for behavioural but also for physical barrier FGSs due to : (a) increased turbulence, flow separation and pressure changes triggering an avoidance reaction of fish and (b) rack-parallel velocity components guiding the fish towards the bypass entrance. Since exact parameter values provoking certain fish behaviour are still unknown, comparative statements of different FGSs remain speculative and need to be confirmed with live-fish experiments. Operational issues such as accumulation of large wood and organic fine material are further important factors to be considered, since narrow-spaced racks can clog easily and the head losses can multiply.

To decrease head losses and thus mitigate negative impacts on hydropower production, Albayrak et al. (2017) investigated louvres, angled bar racks and MBRs with larger bar spacings of $s = 50 \div 230$ mm (Fig. 2c). They recommended a MBR with $\alpha = 30°$, $\beta = 45°$ and $s = 50$ mm based on the results from live-fish laboratory tests (Kriewitz, 2015; Boes & Albayrak, 2017). The head loss coefficient of the recommended MBR is $\xi_R = 2.5$, which is significantly smaller compared to $\xi_R \approx 5.5$ for the angled bar rack with $\alpha = 30°$, $\beta = 60°$ and $s = 15$ mm investigated by the authors. In conclusion, with reduced head losses, high FGE, and robustness against large wood and sediment clogging, MBRs as a behavioural barrier with relatively large bar spacings represent a viable solution for medium to large HPPs.

The authors observed different discharges in the bypass for each studied rack configuration. They pointed out that the high velocity gradients through the ramp at the bypass entrance and comparatively high discharge proportion for angled bar rack configurations might have negative impacts on fish guidance and HPP production. The commenters remark that the bypass flow conditions should be regulated and optimized independent of the installed FGS to meet the requirements of the target fish species. In the published study, the effect of bypass regulation on the bypass approach flow field and thus on the fish guidance efficiency has not been considered. We therefore do not agree with the evaluated criterion of "diverted discharge" as a decisive parameter.

In the discussion section the authors present Table 5 as a guidance for FGS type selection among six different types. Table 5 lists the decisive features of FGSs in three categories: operational questions, bypass section, and upstream of the racks. The commenters already discussed the last two categories above and here focus on the following four operational questions: required material, maintenance complexity, head-losses, and retrofitted built in. The required material was related to the rack blockage ratio only. The costs for a FGS are small compared to the total installation costs including construction site equipment, secondary structures (e.g. rack cleaning machines), and labour. With the larger clear bar spacing of behavioural barriers and thus smaller blockage ratios, the cost differences between FGSs become negligible. The authors state that "maintenance of horizontal trash-racks is at present less developed, in particular in terms of available cleaning systems." We do not agree with the authors because there is a number of successfully operating cleaning systems applied in Germany and Switzerland (Albayrak et al., 2018). In particular, comb type rack cleaning systems with elements protruding into the bar gaps are proven to be effective. Therefore, there is no advantage or disadvantage between the studied FGSs regarding their cleaning systems.

The authors point at the higher head loss coefficients of angled bar racks with vertical bars. Increasing the clear bar spacing and decreasing the bar angle β for behavioural barriers as discussed above significantly reduces head loss coefficients and the disadvantages compared to other FGSs (Albayrak et al., 2017). New bar shapes applied for MBRs (e.g. curved bars) may even lead to head loss coefficients similar to those of HBRs (Beck et al., 2018). The authors further compared the investigated FGSs regarding a 'Retrofitted built in' without detailed explanations or discussion and considered HBRs as disadvantageous. We think that a retrofitted built in should be evaluated based on site-specific parameters such as the local target fish species and size, the river bathymetry, and the approach flow field to the HPP intakes.

Conclusions

The commenters clarify different operating principles of FGSs by giving a wider overview and thus complement the important contribution by Szabo-Meszaros et al. (2018).

Technical solutions for fish protection and guidance at small HPPs exist and are successfully applied. The challenge is to find applicable solutions for larger HPPs, where relatively high head losses of MBRs are still a major concern. In contrast to the authors' conclusions, angled bar racks, particularly MBRs provide a viable solution for medium to large HPPs provided that they are applied appropriately in terms of rack angle, bar angle and bar spacing.

The commenters agree with the authors' conclusion that flow conditions in front of the bypass entrance are of prime importance for a high FGE. Therefore, further research on the hydraulics and the design of bypass, and on fish behaviour is required. For HBRs, operational issues leading to high blockage and high head losses need to be mitigated.

An overall evaluation of the suitability of different FGSs is questionable because fish responses to FGSs are complex and involve a combination of various parameters such as velocity fields, pressure differences, turbulent flow structures, type of HPP and target fish behaviour, swimming capabilities and body size. For selection and adequate engineering design of FGSs, the commenters recommend to consider those parameters and follow the criteria: (I) efficient fish guidance, (II) reduced head losses, (III) robust against large wood and sediment clogging, and (IV) economy.

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