Study on fish-friendly inclined and angled trashracks

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Aim of European directives:

- **Increasing the number of hydropower plants** *(Renewable Energy Sources Directive, 2001)*

- **Preserving fish downstream migration** *(Water Framework Directive, 2000)*

- **Different solutions** (fish friendly turbine, fish protection, turbine interruptions)

- **Fish-friendly trashracks**: bar spacing, rack angulation or inclination, bypass entrance
Fish-friendly trashrack criteria proposed in the guide of ADEME (2008):

- **Bar spacing around 20 mm**

- **Ratio of tangential to normal velocity components at the trashrack** (angled racks: $V_t/V_n > 1$, inclined racks: $V_t/V_n > 2$.

- $V_n \leq 0.5 \text{ m/s}$) (inclination of $\beta = 26^\circ$ angulation of $\alpha = 45^\circ$)

- **Criteria related to bypass entrances at the end of the rack** (dimension, discharge, etc...)

- **Parameters identical to other national agencies** (OTA, 1995; NMFS, 2011; Environmental Agency, 2012)
Head loss formulation

Some historical formulation:


\[ \xi_{\text{Kirschmer-Mosonyi}} = K_F \left( \frac{b}{e} \right)^{\frac{4}{3}} \sin(\beta) \cdot K_{K-M}. \]

Meusburger [2002]

\[ \xi_{\text{Meusburger}} = K_F \left( \frac{O_g}{1 - O_g} \right)^{1.5} \cdot \frac{\alpha}{90} \cdot O_g^{-1.4 \tan(90 - \alpha)} \cdot \sin(\beta) \]

Clark et al. [2010]

\[ \xi_{\text{Clark}} = 7.43 \eta \cdot O_g^2 \cdot (1 + 2.44 \tan(90 - \alpha)) \]
Head loss formulation

Some historical formulation:

Kirschmer [1926] + Mosonyi [1966] \[ \xi_{Kirsch} \]

Meusburger [2002] \[ \xi_{Meusburger} = K_F \left( \frac{O_g}{1 - O_g} \right)^{1.1} \]

Clark et al. [2010] \[ \xi_{Clark} = 7.43 \eta * O_g^2 * (1 + 2) \]

- Channels could be different
- Large bar spacing
- Rotating bars
New Head loss formulation

Experimental set-up

- 10-metre long open channel
- 0.9 m deep and 0.6 m wide
- Inclination angle $\beta$ between 90° (i.e. vertical rack) and 15°
- Angulation angles $\alpha$ between 90° and 30°
- $e/b$ ratios between 1 and 3
- 3 bar depths $p$
- 2 bar shapes: rectangular bars (PR) and hydrodynamic bars (PH)
New Head loss formulation

Definition for a large range of parameters

- Inclined trashrack
- Angled trashrack
- Angled trashrack with streamwise bars

= More than 150 configurations tested
New Head loss formulation

Definition for a large range of parameters

- **Inclined trashrack**
  \[
  \xi = K_{b,i} \left( \frac{O_b}{1 - O_b} \right)^{1.65} \sin^2(\beta) + K_{sp} \left( \frac{O_{sp,H}}{1 - O_{sp,H}} \right)^{0.77}
  \]
  \((K_{b,PR} = 3.85, \ K_{b,PH} = 2.1) \quad (K_{sp} = 1.79).\)

- **Angled trashrack**
  \[
  \xi = K_i \left( \frac{O_g}{1 - O_g} \right)^{1.6} K_{\alpha}
  \]
  \((K_{PR} = 2.89 \ \text{and} \ K_{PH} = 1.7)\)

**Bar Blockage**
\[
O_b = \frac{(N_b b + 2b_{ext})}{B}
\]

**Spacer Blockage**
\[
O_{sp,H} = \frac{(N_{sp}D_{sp})}{H_1 / \sin \beta} (1 - O_b)
\]

\[
K_{\alpha} = 1 + k_i \left( \frac{90 - \alpha}{90} \right)^{2.35} \left( \frac{1 - O_g}{O_g} \right)^3 \quad \text{for perpendicular bars}
\]

\[
K_{\alpha} = 1 \quad \text{for streamwise bars}
\]

[Raynal et al., JHR, 2013a, 2013b, 2014]
New Head loss formulation

Comparison with the classical formula

The table compares these head loss coefficients for six fish-friendly configurations: PR and PH bars for inclined racks ($\beta = 25^\circ$) and for the two types of angled racks ($\alpha = 45^\circ$).

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Inclined rack ($\beta = 25^\circ$)</td>
<td>PR</td>
<td>0.78</td>
<td>0.67</td>
<td>0.41</td>
<td>0.62</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>PH</td>
<td>0.55</td>
<td>0.54</td>
<td>0.18</td>
<td>0.38</td>
<td>-</td>
</tr>
<tr>
<td>Angled rack with perpendicular bars ($\alpha = 45^\circ$)</td>
<td>PR</td>
<td>3.29</td>
<td>3.33</td>
<td>2.16</td>
<td>2.70</td>
<td>5.06</td>
</tr>
<tr>
<td></td>
<td>PH</td>
<td>2.39</td>
<td>2.46</td>
<td>0.92</td>
<td>1.15</td>
<td>3.39</td>
</tr>
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<td>1.39</td>
<td>0.96</td>
<td>1.59</td>
<td>1.79</td>
</tr>
<tr>
<td></td>
<td>PH</td>
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<td>0.82</td>
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<td>0.67</td>
<td>1.20</td>
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1 rounded edges instead of a PH shape
2 calculated for vertical racks
New Head loss formulation

Comparison with the classical formula

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<td>0.41</td>
<td>0.67</td>
<td>1.20</td>
</tr>
</tbody>
</table>

[Raynal et al., JHR, 2013a]

2 calculated for vertical racks
Application to an existing hydropower plant

Saverdun hydropower plant, located on the Ariège river

- hydropower plant on the right bank
- channel upstream of the plant is $B = 7.8$ m wide, and is $H_1 = 3.7$ m deep in normal conditions.
- water discharge $Q = 20.7$ m$^3$s$^{-1}$, with 0.7 m$^3$s$^{-1}$ reserved for the bypass alimentation.
- approach velocities around $V_1 = 0.72$ m$s^{-1}$.
Application to an existing hydropower plant

Saverdun hydropower plant, located on the Ariège river

- 3 solutions for enhancing the hydropower plant are studied
  + Inclined trashrack
  + angled trashrack
  + angled trashrack with streamwise bars
Application to an existing hydropower plant

Saverdun hydropower plant, located on the Ariège river

- Bars are 8 mm thick and spaced by 20 mm
- Bars may be either PR- or PH-shaped
- Circular bar spacers of 20 mm diameter separated by one meter.
- Longitudinal supporting bars are placed along the trashrack to rigidify it. They are 50 mm wide and are separated by one meter.
Application to an existing hydropower plant

Saverdun hydropower plant, located on the Ariège river

- For inclined trashrack, impingement risks are rather low and $V_1 = 0.72 \text{ m/s}$ does not require a specific trashrack angle. $\beta = 26^\circ$
- For angled trashracks with perpendicular bars, measurements at $\alpha = 30^\circ$ showed that the maximum normal velocities were approximately $0.75 \times V_1$, which corresponds here to maximum $V_n$ around 0.54 m/s.
Application to an existing hydropowerplant

Saverdun hydropower plant, located on the Ariège river

- For angled trashracks with streamwise bars, velocity measurements showed that the maximum normal velocities can be related to the trashrack angle with

\[ V_{n,max} > \frac{\sin(\alpha)}{0.8} V_1 \]

which gives \( \alpha = 35^\circ \)

[Raynal et al., JHR, 2014 in press]
Application to an existing hydropower plant

Saverdun hydropower plant

<table>
<thead>
<tr>
<th>Angle</th>
<th>Trashrack Type</th>
<th>$a$ (°)</th>
<th>$β$ (°)</th>
<th>$B_g$ (m)</th>
<th>$L_g$ (m)</th>
<th>$N_b$</th>
<th>$PR/PH$</th>
<th>$C$ (%)</th>
<th>$K_C$</th>
<th>$ξ$</th>
<th>$ΔH$ (mm)</th>
<th>$ΔH/H_1$ (%)</th>
<th>Total bar length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclined</td>
<td>Trashrack</td>
<td>90</td>
<td>26</td>
<td>7,8</td>
<td>8,4</td>
<td>260</td>
<td>$PR$</td>
<td>0</td>
<td>1</td>
<td>0,87</td>
<td>23</td>
<td>0,5%</td>
<td>2194</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$PH$</td>
<td>0</td>
<td>1</td>
<td>0,66</td>
<td>17</td>
<td>0,3%</td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$PR$</td>
<td>25</td>
<td>3,3</td>
<td>2,86</td>
<td>75</td>
<td>1,5%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$PH$</td>
<td>25</td>
<td>3,3</td>
<td>2,17</td>
<td>57</td>
<td>1,1%</td>
<td></td>
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<tr>
<td></td>
<td>Angled trashrack with perpendicular bars</td>
<td>30</td>
<td>90</td>
<td>15,6</td>
<td>3,7</td>
<td>519</td>
<td>$PR$</td>
<td>0</td>
<td>1</td>
<td>4,79</td>
<td>126</td>
<td>2,5%</td>
<td>1920</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>$PH$</td>
<td>0</td>
<td>1</td>
<td>3,10</td>
<td>81</td>
<td>1,6%</td>
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<td></td>
<td></td>
<td></td>
<td>$PR$</td>
<td>25</td>
<td>2</td>
<td>9,57</td>
<td>251</td>
<td>5,0%</td>
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</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$PH$</td>
<td>25</td>
<td>2</td>
<td>6,19</td>
<td>162</td>
<td>3,2%</td>
<td></td>
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<tr>
<td></td>
<td>Angled trashrack with streamwise bars</td>
<td>35</td>
<td>90</td>
<td>13,6</td>
<td>3,7</td>
<td>260</td>
<td>$PR$</td>
<td>0</td>
<td>1</td>
<td>0,56</td>
<td>15</td>
<td>0,3%</td>
<td>962</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>$PH$</td>
<td>0</td>
<td>1</td>
<td>0,33</td>
<td>9</td>
<td>0,2%</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$PR$</td>
<td>25</td>
<td>4</td>
<td>2,24</td>
<td>59</td>
<td>1,2%</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$PH$</td>
<td>25</td>
<td>5</td>
<td>1,64</td>
<td>43</td>
<td>0,9%</td>
<td></td>
</tr>
</tbody>
</table>

trashrack width $B_g$ and length $L_g$

multiplicative factor $K_C$ for clogged racks (Raynal et al 2012, 2nd E IAHR Congress)
Application to an existing hydropower plant

Saverdun hydropower plant
Conclusion

The effects of the bar spacing, the bar shape and the rack angle on head-losses have been investigated for different inclined and angled racks in an open channel flow.

Different equations of the head losses have been proposed for both cases and have been compared with various equations from the literature.

These new head loss equations, which take account the different parameters, showed better approximation in fish-friendly configurations.

These equations are applied to a real case of the hydropower plant and showed the differences obtained for the head losses and the number of bars in the case of inclined and angles trashracks.
Conclusion

The reliability of angled trashracks with streamwise bars for fish-friendly intakes has been showed. Head losses generated by angled racks with streamwise bars are much lower than those obtained with perpendicular bars.

Only two economical criteria have been taken into account during this comparison, and other ones, such as downstream velocity distribution or bypass design, may modify these conclusions.

Some works are still in progress to define the position of the bypass and its flow discharge.

Measurements on hydro power plants are now necessary for the final validation of all these criteria.
THANK YOU FOR YOUR ATTENTION!

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[Logos of ADEME, EDF, Compagnie Nationale du Rhône, GDF Suez, France Hydro Electricité, Region Poitou Charentes, and INSTITUT]