Jun 24th, 2:30 PM - 2:45 PM

Session C8: Development of Criteria for the Design and Dimensioning of Fish-Friendly Intakes for Small Hydropower Plant

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Courret, Dominique; Larinier, Michel; David, Laurent; and Chatellier, Ludovic, "Session C8: Development of Criteria for the Design and Dimensioning of Fish-Friendly Intakes for Small Hydropower Plant" (2015). International Conference on Engineering and Ecohydrology for Fish Passage. 16.
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Development of criteria for the design and dimensioning of fish-friendly intakes for small hydropower plant

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Several studies funded by:
Context in France

- **Downstream migration is taking into account for:**
  - *Salmon*: smolts (+ adults)
  - *Sea trout*: smolts + adults
    ➔ Can have a lot of hydropower plants on their migration route
  - *Silver eels*
    ➔ Suffered high mortality
  - *Brown trout* at medium or high head hydropower plant

- **A lot of small hydropower plants on migration route (old mills)**
  - Run-of-river operation
  - Turbine discharge mostly < 50 m³/s, some between 50 – 100 m³/s
  - A few big plants:
    » Dordogne and Garonne river: 300-500 m³/s
    » Rhine and Rhone river: 1000 – 1500 m³/s

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**Smolts**: (12) 15 - 20 (22) cm

**Silver eels**:
- Male 30-45 cm
- Female 50-90 (110) cm
Brief overview of solutions and ONEMA positions

4 main types of solutions

- **Fish friendly turbine** *(VLH, Screw)* ➔ Good solutions, but limited to low height dam and discharge, mostly for new equipment, not really cost-effective on existing plant

- **Behavioral device** *(sound, light, electricity)* ➔ No system approved until now, except light to attract smolts

- **Targeted shutdown of turbines** ➔ Foreseen for eels at biggest dams where other solutions are not feasible, difficult to define, ongoing research

- **Material barriers which can induce both behavioral or physical effects**:
  - Louver ➔ Not implemented due to maintenance constraints
  - Surface guiding wall with bypasses ➔ Reserved to biggest dams (1 case)
  - **Bypass in association with trashrack** ➔ Main solution implemented at small plants in France
Studies conducted


  - A satisfactory solution in some cases
  - But difficulties to obtain regularly good efficiencies, especially for eels

Bypass efficiency for silver eels:
- Baigts: ≈ 20% (surface), very low (bottom)
- Halsou: 56 – 64%
Studies conducted

- **2007-2008**: Synthetize the feed-back of all efficiency assessment and intake design in France and abroad (mainly USA) to define criteria for systems of racks and bypasses with high efficiency (> 90%)
  - So-called “fish friendly intakes”
  - Production of a technical guide in 2008

- **2010 – Until now**: hydraulic studies, mainly on down-scaled physical model + numerical simulation:
  - Characterize head-losses through racks in fish-friendly configurations
  - Verification of guiding conditions and adaptation of criteria
  - Precise criteria for the design of bypasses (attractivity in function of position, flow, ...)

Angled trashrack
3 fundamentals functions

1) Stop fish and avoid their passage through turbine

- **Smolts**:
  - Possible to obtain good efficiency with a behavioral effect
  
  ➔ Bar spacing : \( \leq 25 \text{ mm} \)

- **Silver eels**:
  - Necessity to install a physical barrier: bar spacing \( \leq \) head diameter
  
  ➔ Bar spacing : 15 - 20 mm to stop eels longer than 50 - 60 cm

- **Velocities upstream the rack low enough to**:
  - Allow fish swimming during the time necessary to find bypasses
  - Do not induce rapid passage through or impingement of fish against the rack
  
  ➔ Normal velocity (flow divided by the wetted rack surface) \( \leq 50 \text{ cm/s} \) for eels and smolts
  
  ➔ Give a minimal surface of the rack for a given turbine discharge : at least 2 \( \text{m}^2 \) of rack for 1 \( \text{m}^3/\text{s} \) of turbine discharge
3 fundamentals functions

2) Guide fish towards bypasses ➔ Inclined trashrack perpendicular to the flow:

- Moderate acceleration of velocities along the rack ($\approx +10\%$ at the top of the rack)

- Minimal inclination at $\beta \leq 26$° to obtain $V_t \geq 2V_n$ and guide fish to the surface

- Approach velocity acceptable up to $\approx 0.80$-$0.85$ m/s at $\beta = 26$° ➔ higher inclination in case of higher velocities

Measured velocities (side view)

Normal and tangential velocity along the rack (normalized to the approach velocity)
2) Guide fish towards bypasses ➔ Angled vertical trashrack:

- Minimal angle $\alpha \leq 45^\circ$ to obtain $V_t \geq V_n$

- Conventional rack (bar perpendicular to the rack axis)
  - Flow acceleration along the rack + head-losses increasing with angulation
  - Approach velocity acceptable limited to 0.5 m/s at $\alpha = 45^\circ$ ➔ Low gain on acceptable approach velocity with an increase of the angulation

- Rack with streamwise bars (experimental configuration)
  - Homogeneous velocities upstream the rack + reduction of head-losses
  - Approach velocity acceptable up to 0.6 m/s at $\alpha = 45^\circ$ ➔ higher angulation in case of higher velocities, but solution to find to clean the rack
3 fundamentals functions

2) Guide fish towards bypasses ➔ Angled vertical trashrack:

- Angled rack with horizontal bars are interesting:
  - no installation in France; several installations in Deutschland and Sweden
  - Looking for studies and feedback on this configuration

- Rack in bank alignment are favorable configuration for fish guidance
3 fundamentals functions

3) Downstream transfer of fish ➔ Inclined rack

- Surface bypasses at the top of the rack
- Criteria to determine bypass number and flow:
  - Velocity at the bypass entrance $V_b = 1.1 V_A$
  - Minimal dimensions recommended: 1 m wide ($B_b$) and 0.5 m deep ($H_b$)
  - Obstruction of the top of the rack, between bypasses, over the same depth ➔ to generate transversal velocities
  - Maximal distance between bypasses: 4-5 m ➔ Determination of the number of bypasses $N_b$

➔ From 5-6% of turbine discharge for small intakes, down to 2-3% for intakes > 50 m$^3$/s
3 fundamentals functions

3) Downstream transfer of fish ➔ Angled rack

- Bypass positioned at the downstream end of the rack

- Not a complete set of criteria nowadays:
  - Surface bypass: as deep as possible, ideally same depth as the intake ➔ high flow; difficulties to create such deep bypass on existing site
  - Interrogation about bottom bypass, notably for eels:
    » Sensible to clogging and difficult to clean
    » Necessity? ➔ Eels seem to prospect all the water column if they are stopped by the rack.
  - Velocity at the bypass entrance $V_b$ of about velocities at the downstream end of the rack:
    » $V_b = 1.7 \, V_A$ for a "conventional" angled rack à 45° ➔ high flow
    » $V_b = 1.0 \, V_A$ for an angled rack with streamwise bars
    » Criteria for an angled rack with horizontal bars and rach in bank alignment?
Head-losses and clogging issues

- Experimental measurement of head-losses
- Existing formulae not adapted to fish-friendly configurations

→ Production of new formulae (Raynal et al. 2013)

Decreasing head-losses with inclination

Increasing head-losses with angulation
Conclusions

- **Preference for inclined rack:**
  - Lower head-losses
  - Compatible with high approach velocity
  - Existing solutions for rack cleaning ➔ Except for deep intakes and long racks
  - Bypass design criteria well-defined
  - But not adapted to forebay with water level fluctuations

- **Angled rack reserved to deep intakes, or intake with fluctuating water levels, or in bank alignment**
  - « Conventional » rack constraining (head-losses, admissible approach velocity)
  - Rack with stream-wise bars ➔ interesting solution, trashrake design to find
  - Rack with horizontal bars ? ➔ Feed back in Deutschland and Sweden
  - Design criteria for bypass to complete

- **Absolute necessity to adapt the trashrake**

- **Feed back to acquire on operation and biological efficiency (ongoing)**
Thank you for your attention