Session D1: Classification of Flow Patterns in a Nature-Oriented Fishway Based on 3D Hydraulic Simulation Results

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Classification of flow patterns in a nature-oriented fishway based on 3D hydraulic simulation results

Rebekka Czerny, Peter Oberle, Franz Nestmann
Hydraulics in fishways

Need for research

- Hydraulic values concerning passability
  \( (v_{\text{min}}, v_{\text{max}}, h_{\text{min}}) \)
- Horizontal and vertical distribution of velocity, 3D flow pattern
- Nature-oriented fishways: lack of knowledge concerning hydraulics → special need for research

Numerical modeling

- Basis: topographical model
- Problem: complex topography and hydraulics

Technical fishway

- Simple and reproducible geometry
- Optimizeable

Nature-oriented fishway

- High structural diversity
- Irregular forms

Hydraulic model has to be 2D or 3D and of a high resolution

High level of detail of the geodata necessary

Data acquisition using terrestrial laser scanning (TLS)
Acquiring high-resolution topographical data

Terrestrial laser scanning (TLS)

- Technique of optical 3D measurement
- Advantages / Disadvantages
  + Highly detailed and exact data acquisition of the topography of the surroundings
  + High measurement speed
  - Significant effort for data post processing
  - In general, no data acquisition of submerged structures
    → If possible: data acquisition of dry stream bed, alternatively: data acquisition during low water period
    → Completion of data set using tacheometry

Cooperation

- Geodetic Institute (GIK), KIT
- Institute of Photogrammetry + Remote Sensing (IPF), KIT
From raw data set to the hydraulic model

Workflow

Data acquisition
Registration
Data cleansing
Segmentation
Filtering / categorization
Combination with additional data
Topographic modeling
Mesh generation
Def. of hydraulic boundary conditions

Source: Zippelt, Czerny, Nestmann 2011 (modified)
Project area and data acquisition

Project area
- Nature-oriented fishway at a diversion hydropower station at the High-Rhine
- Rock cascade pass

Data acquisition
- TLS of dry stream bed prior to flooding

Model parameters
- Topography: 3D polygon model
- 3D hydraulic simulation: FLOW-3D® (RANS)
- Block structured mesh: ≈ 4 million mesh elements (edge lengths: 5 cm, 10 cm)
Topographic model

Inflow boundary
Flow direction
Water level boundary

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Validation

Field measurements

- Water level measurements (leveling)
- Determination of flow rate $Q$
- Flow velocities in the gaps of the cross-bars (magnetic inductive method / MID)
- Flow velocities in pool A (Acoustic Doppler Velocimetry / ADV)

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Typification of hydraulic pattern

Procedure
here: pool A

XY-section: ≈ 30 cm below water surface

homogeneous

stratified

stratified / 3D-effects

homogeneous / stratified / 3D-effects
### Typification scheme

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DEFINITION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Flow Direction Symbol" /></td>
<td>Distinctly directed flow path</td>
<td>Guiding flow path within the pool between two or more gaps of the cross-bars with velocity values within critical values</td>
</tr>
<tr>
<td><img src="image" alt="Horizontal Eddy Symbol" /></td>
<td>Horizontal eddy</td>
<td>Distinctly identifiable horizontal rotational motion of the flow</td>
</tr>
<tr>
<td><img src="image" alt="Vertical Eddy Symbol" /></td>
<td>Vertical eddy</td>
<td>Distinctly identifiable vertical rotational motion of the flow</td>
</tr>
<tr>
<td><img src="image" alt="Flow Distribution Symbol" /></td>
<td>Area with reduced flow velocity</td>
<td>Area with velocities below the minimum velocity for rheotaxis ($v_{\text{min}} &lt; 0.30 \text{ m/s}$)</td>
</tr>
<tr>
<td><img src="image" alt="Homogeneous Flow Distribution Symbol" /></td>
<td>Homogeneous flow distribution</td>
<td>Velocities are nearly constant for the entire flow depth</td>
</tr>
<tr>
<td><img src="image" alt="Stratified Flow Distribution Symbol" /></td>
<td>Stratified flow distribution</td>
<td>Stratification of the flow and formation of zones of reduced velocity</td>
</tr>
<tr>
<td><img src="image" alt="Max Velocity Symbol" /></td>
<td>$v_{\text{max}}$ near the water surface</td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Max Velocity Symbol" /></td>
<td>$v_{\text{max}}$ near the stream bed</td>
<td></td>
</tr>
<tr>
<td><img src="image" alt="Undirected Flow Symbol" /></td>
<td>Undirected flow</td>
<td>Zones without distinctly directed velocity distribution, which are characterized by a high degree of turbulence and 3D flow patterns</td>
</tr>
<tr>
<td><img src="image" alt="Exceedance of Critical Values Symbol" /></td>
<td>Exceedance of critical values</td>
<td>Exceedance of critical values concerning flow velocity taken from standards</td>
</tr>
</tbody>
</table>

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Typification of hydraulic pattern

Result
here: pool A

Reduced flow
Homogeneous
Stratified
$S$ near surface
$b$ near bed
Undirected
/ 3D-Effects
Exceedance of crit. values
Analysis of simulation results

Simulation results and typification

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Conclusion and outlook

Potential

- Combination of TLS data acquisition and high-resolution hydraulic modeling enables investigations of hydraulics in nature-oriented fishways
- Typification scheme enables a visual representation of complex simulation results
  - Simplifies interdisciplinary discussion
  - Basis for ecohydraulic assessment

Outlook

- Further development of typification scheme is possible
- Significant effort for manual post processing
  → Use of improved scan and filtering methods