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

<table>
<thead>
<tr>
<th>Technical fishway</th>
<th>Nature-oriented fishway</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Simple and reproducible geometry</td>
<td>+ High structural diversity</td>
</tr>
<tr>
<td>+ Optimizeable</td>
<td>+ Irregular forms</td>
</tr>
</tbody>
</table>

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

v_{res} [m/s]

0.00
0.55
1.10
1.65
2.20
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)
Typification of hydraulic pattern

Procedure
here: pool A

XY-section: ≈ 30 cm below water surface

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### Typification scheme

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>DEFINITION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="流向" /></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="水平渦" /></td>
<td>Horizontal eddy</td>
<td>Distinctly identifiable horizontal rotational motion of the flow</td>
</tr>
<tr>
<td><img src="image" alt="垂直渦" /></td>
<td>Vertical eddy</td>
<td>Distinctly identifiable vertical rotational motion of the flow</td>
</tr>
<tr>
<td><img src="image" alt="流量分布" /></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="流量分布" /></td>
<td>Homogeneous flow distribution</td>
<td>Velocities are nearly constant for the entire flow depth</td>
</tr>
</tbody>
</table>
| ![流量分布](image) | Stratified flow distribution | Stratification of the flow and formation of zones of reduced velocity  
  \[ s \] \( v_{\text{max}} \) near the water surface  
  \[ b \] \( v_{\text{max}} \) near the stream bed |
| ![流向](image) | Undirected flow | Zones without distinctly directed velocity distribution, which are characterized by a high degree of turbulence and 3D flow patterns |
| ![流向](image) | Exceedance of critical values | Exceedance of critical values concerning flow velocity taken from standards |

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Typification of hydraulic pattern

Result
here: pool A
Analysis of simulation results

Simulation results and typification

Pool A

Pool B

Pool C

velocity magnitude \( v \) [m/s]

- 2.4
- 2.2
- 2.0
- 1.8
- 1.6
- 1.4
- 1.2
- 1.0
- 0.8
- 0.6
- 0.4
- 0.2
- 0.0

Reduced flow
Homogeneous
Stratified
Undirected
3D-Effects
Exceedance
of crit. values

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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