Jun 25th, 4:50 PM - 5:30 PM

Concurrent Sessions C: Multi-Dimensional Modeling and Fish Passage Restoration - Modeling Fish Passage for American Shad in a Steeppass Fishway Using a Computational Fluid Dynamics (CFD) Model

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*Montana State University*

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*Montana State University*

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Modeling Passage for American Shad in a Steeppass Fishway using a CFD Model

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Professor of Civil Engineering
Montana State University

Photo Credit: USFWS
Model “A” Steeppass

- designed by Ziemer in 1962 to pass salmonids
- baffle (Denil) type fishway
- prefabricated 27-inch high, 18-inch wide, 10 foot long sections
- highly portable and inexpensive
- suited to small streams and low head dams

Photo Credit: USFWS
CFD Results
velocity magnitude contours (ft/s)

low head

high head
CFD Results
velocity magnitude contours (ft/s)

low head

high head
3D Passage Model - Overview

1. Extract velocity data from CFD model results
2. Choose fish path algorithm (straight, random, low velocity, etc.)
3. Use Monte Carlo simulation to randomize start point, fish size, and ground speed
4. Calculate \textit{percent fatigue} for each cell as simulated fish advances
5. Calculate cumulative sum of percent fatigue
6. Fish fails to pass if sum of percent fatigue is greater than 100%
7. Repeat steps 3-6 to generate passage statistics
Inputs

• Fish length = 41.8 ± 3.49 cm²
• Ground speed = 0.93 ± 0.53 BL/s²
• Swim speed-fatigue curve coefficients¹
• Start point on inlet grid
• Velocities from CFD model
• Water surface elevations from CFD model
• Constants (i.e. distances between cells)
Which way should I go?
Percent Fatigue^2

• Assume constant “optimal” ground speed
• Each time interval consumes a portion of the time to failure (T), this is called \( \Delta T \)

\[
\Delta T = e^{-(a+bU_s)} \, dt
\]

• \( U_s \) is fish speed which varies to maintain constant ground speed in variable velocity flow field
• Percent fatigue (F%) is the cumulative value of the \( \Delta T \)'s

\[
F\% = 100 \times \int_{\Delta t}^{T^*} \Delta T
\]

• Failure occurs when F\% = 100%.
Simulated Fish Path

Random Path with Random Starting Point
Simulated Fish Path

Low Velocity Tendency Path with Random Starting Point
# Results

## 1:8 Slope, **Low Head**

<table>
<thead>
<tr>
<th></th>
<th>Pass</th>
<th>Fail</th>
<th>Success Rate (%)</th>
<th>Average Energy (ft-lbf)</th>
<th>Average Fatigue (%)</th>
<th>Average Transit Time (s)</th>
<th>Average Power (hp)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Straight</strong></td>
<td>4811</td>
<td>189</td>
<td>96.22</td>
<td>47.04</td>
<td>1.01</td>
<td>39.83</td>
<td>0.002</td>
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<tr>
<td><strong>Random</strong></td>
<td>4812</td>
<td>188</td>
<td>96.24</td>
<td>76.53</td>
<td>1.39</td>
<td>44.41</td>
<td>0.003</td>
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<td><strong>Low Velocity</strong></td>
<td>4816</td>
<td>184</td>
<td>96.32</td>
<td>21.61</td>
<td>0.28</td>
<td>45.83</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Low Velocity - Random</strong></td>
<td>4816</td>
<td>184</td>
<td>96.32</td>
<td>27.21</td>
<td>0.36</td>
<td>46.27</td>
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<tr>
<td><strong>High Velocity</strong></td>
<td>4804</td>
<td>196</td>
<td>96.08</td>
<td>140.17</td>
<td>4.08</td>
<td>38.90</td>
<td>0.007</td>
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<tr>
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<td>195</td>
<td>96.10</td>
<td>135.98</td>
<td>3.86</td>
<td>39.07</td>
<td>0.006</td>
</tr>
</tbody>
</table>
## Results

### 1:8 Slope, High Head

<table>
<thead>
<tr>
<th></th>
<th>Pass</th>
<th>Fail</th>
<th>Success Rate (%)</th>
<th>Average Energy (ft-lbf)</th>
<th>Average Fatigue (%)</th>
<th>Average Transit Time (s)</th>
<th>Average Power (hp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight</td>
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<td>213</td>
<td>95.74</td>
<td>119.64</td>
<td>5.36</td>
<td>34.83</td>
<td>0.006</td>
</tr>
<tr>
<td>Random</td>
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<td>95.82</td>
<td>191.77</td>
<td>6.74</td>
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<td>0.009</td>
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<tr>
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<td>185</td>
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<td>29.92</td>
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<td>44.59</td>
<td>0.001</td>
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<tr>
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<td>185</td>
<td>96.30</td>
<td>34.22</td>
<td>0.58</td>
<td>43.70</td>
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<tr>
<td>High Velocity</td>
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<td>94.22</td>
<td>279.23</td>
<td>18.11</td>
<td>30.62</td>
<td>0.017</td>
</tr>
<tr>
<td>High Velocity - Random</td>
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<td>289</td>
<td>94.22</td>
<td>292.27</td>
<td>17.87</td>
<td>31.16</td>
<td>0.017</td>
</tr>
</tbody>
</table>
Contrast with Field Study

<table>
<thead>
<tr>
<th></th>
<th>1:8 Low Passage (%)</th>
<th>1:8 Low Transit Time (sec)</th>
<th>1:8 High Passage (%)</th>
<th>1:8 High Transit Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passage Model</td>
<td>96</td>
<td>42</td>
<td>95</td>
<td>37</td>
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<tr>
<td>Field Data³</td>
<td>45</td>
<td>18</td>
<td>90</td>
<td>10</td>
</tr>
</tbody>
</table>
Conclusions

• The CFD model indicates a marked difference between HIGH and LOW velocity distributions

• Water velocity alone does not limit fish passage in this structure

• “Optimal” swim speed is not employed by American shad in the Steeppass
Acknowledgements

• Hydro Research Foundation
• Montana State University, College of Engineering
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References

