Session A3- culvert Design for aquatic organism passage

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Culvert Design for Aquatic Organism Passage (HEC 26)

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National Conference on Engineering & Ecohydrolgoy for Fish Passage
June 27 – 29, 2011
University of Massachusetts, Amherst
Project Advisories

- Technical Advisory Committee (7)
  - US Forest Service (3)
  - National Marine Fisheries Service
  - California Department of Fish and Game
  - Maryland State Highway Administration
  - Maine Department of Transportation

- FHWA Review Panel (10)
  - Ecologist, Biologist, Environmental Specialists (4)
Presentation Outline

- Brief Background
- 13–Step Design Procedure Summary
  - Focus on Steps 6-9
- Case History Comparisons
- Conclusions
Background

- “Kudos” to the Resource Agencies
- Innumerable Aquatic Organisms
- Diverse/Unknown AO swimming capabilities and behaviors require use of surrogate parameters to drive design
- Current methods use channel dimensional characteristics as surrogates
  - Bankfull Width most common
Difficulties with dimensional characteristics (Bankfull Width)

- Difficult to identify
- Variable in space and time
- Assumes dynamic equilibrium
- Selection subjective, necessarily conservative
- No direct relationship to AOP migration cues or passage demand
Goals for HEC 26

- Culvert designs providing successful aquatic organism passage via stream simulation approach
- Culvert designs satisfying peak hydraulic standards/criteria for protecting traveling public
- Objective procedure yielding reproducible results
- Universal applicability, use anywhere
- Efficient procedure, easy to apply
- Defensible results for justifying expenditures
- Interdisciplinary acceptance
**Premise:** Stream bed materials experience same forces as aquatic organisms. If bed behavior in a culvert is similar to the channel during passage flows, organisms that pass stream can pass culvert.

**Objective:** Create sediment mobility conditions within the culvert that *simulate* those in the natural channel in both structure and function for the range of passage flows.
HEC 26 Approach (cont.)

- Use ‘fixed, easy to identify’ surrogate parameters to drive design:
  - Low passage, high passage, and peak discharges
  - Permissible shear of bed material

- Use embedded, closed-bottom structures whenever possible
  - Preserve natural bed roughness and stream processes
  - Provide grade-control safety net
  - Eliminate custom foundations
Tools Required / Available

- Culvert hydraulics
  - HEC-RAS
  - HY8/Normal depth computations
- Channel hydraulics
  - HEC-RAS
  - Normal depth computations
- HEC 26 spreadsheet (iterative computations, gradation plotting, and data management)
Procedure Summary

- **Step 1:** Determine Discharges $Q_L$, $Q_H$, $Q_P$
- **Step 2:** Define Project Reach and Determine Channel Characteristics
  - Bed material
- **Step 3 and 4:** Evaluate Channel Stability
- **Step 5:** Identify initial trial culvert
  - Determine embedment depth
Step 6.
Is Culvert Bed Stable at $Q_H$?

- **Compute permissible** shear stress/unit discharge
  - Modified Shields equation (function of $D_{84}$ and $D_{50}$)
  - Bathurst critical unit discharge equation
  - USDA equation for cohesive materials

- **Compute maximum applied** shear stress at:
  - Inlet, outlet of culvert and normal depth
  - Upstream and downstream cross-sections

$$\tau = \gamma y S_e$$
Step 6 (cont). Is Culvert Bed Stable at $Q_H$?

- **Accuracy of applied shear computations**
  - Accurate depth and energy slope
  - Accurate Manning’s roughness

- **Manning’s roughness**
  - *Compute* Manning’s ‘$n$’ for bed $D_{84}$ *(Iterative Procedure)*
    - HEC 26 Spreadsheet
  - Select Manning’s $n$ for culvert walls
  - *Compute* composite Manning’s $n$ for culvert
Step 7. Check Channel Bed Mobility at $Q_H$

- If maximum shear stress in any channel $XS$ is less than permissible, culvert shear must be equal or less than permissible.
  - If not, redesign culvert

- If maximum shear stresses in all channel $XS$ are greater than permissible, bed is considered mobile (common for sand beds).
  - Culvert shear must be within channel range. If exceeds range, redesign culvert
Step 8. Check Culvert Bed Stability at $Q_p$

- Few sites will exhibit natural bed stability at $Q_p$ due to high shear of contracted flow.

- Compute applied shear for $Q_p$ and compare to permissible shear for natural bed material.
  - Repeat iterative procedure for Manning’s ‘$n$’.

- If bed not stable, design a stable sublayer.
Step 9. Design Stable Bed for $Q_p$

- Provide well-graded, oversized sublayer to resist shear at $Q_p$, provide grade control and a rough surface to aid replenishment of native materials.

- Minimum Thickness Criteria for sublayer
  - Identify maximum oversize gradation that will fit thickness criteria for culvert
Step 9 (cont.).
Design Stable Bed for Qp

- Repeat permissible shear computations for sublayer.
- Compute applied shear for Qp and compare to permissible shear for oversize sublayer.
  - Repeat iterative procedure for Manning’s ‘n’.
- If oversize layer not stable, redesign culvert.
Procedure Summary (cont.)

- **Step 10 Check: Compare Culvert and Channel Velocities for $Q_H$**
  - If culvert $\leq$ channel, Ok. If not, redesign.

- **Step 11 Check: Compare Culvert and Channel Depths for $Q_L$**
  - If culvert $\geq$ channel, Ok. If not, go to Step 12.

- **Step 12: Design a low-flow channel.**
Step 13. Review Design (HEC Example)

- Original 36” CMP
- 8.5 ft CMP
- 2.6 ft Embedment
  - 1.0’ Natural layer
  - 1.6’ Oversize layer
- Constructability
- Service life
- Other shapes or materials?
Case History Comparisons

<table>
<thead>
<tr>
<th></th>
<th>North Thompson Creek, Colorado</th>
<th>Tributary to Bear Creek, Alaska</th>
<th>Sickle Creek, Michigan</th>
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</thead>
<tbody>
<tr>
<td>AOP barrier/Existing</td>
<td>3-ft CMP</td>
<td>5-ft CMP</td>
<td>Twin 3-ft CMPs</td>
</tr>
<tr>
<td>As-built</td>
<td>12’x ? squash pipe</td>
<td>9.75’x 6.6’ pipe arch</td>
<td>16’x 6’ concrete arch bridge</td>
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<td>HEC-26 procedure</td>
<td>8.5’ CMP</td>
<td>12’ CMP</td>
<td>10’ CMP</td>
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<tr>
<td>Difference in span</td>
<td>-3.5 ft</td>
<td>+2.25 ft</td>
<td>-6 ft</td>
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<tr>
<td>Bankfull Width Estimate (ft)</td>
<td>8 - 17</td>
<td>7 - 11</td>
<td>not available</td>
</tr>
</tbody>
</table>

FLH project photo: HEC 26 yields 26’ span vs. USFS 30’ span
Conclusions

- HEC 26 stream simulation procedure results in larger openings than “hydraulic” design procedures
- Some culverts larger, some smaller, compared to alternative AOP design procedures, e.g. USFS Stream Simulation
- Monitoring needed to determine ultimate success of any AOP culvert design