Bridge Scour Prediction

• Summary of HEC 18, “Evaluating Scour at Bridges” FHA, Publ # FHWA HI-96-031
• Should really follow HEC 18, but this summary will get you the main points.

7 Steps for Total Bridge Scour

• 1: Determine scour analysis variables
• 2: Analyze long-term bed elevation change
• 3: Evaluate scour analysis method
• 4: Compute contraction scour magnitude
• 5: Compute local pier scour magnitude
• 6: Compute local abutment scour magnitude
• 7: Plot and evaluate total scour
Step 1: Determine Variables

- Find design Q (worst-case scenario) 500-yr Q or special angle, etc.
- Any future changes to river?
- Calculate water surface profiles (step method, HEC-2, WSPRO, etc.)
- Get geology, sediment size, cross-sections, planform, watershed data, similar bridge scour, energy gradeline slope, flooding history, location wrt other bridges or tributaries, meander history, erosion history, sand mining, etc.

Step 1: 2-D Computer Modeling to Get Velocities

Step 2: Analyze Long-Term Bed Elevation Change

- Find trend of aggradation/degradation using either
  - past data,
  - Site evidence,
  - worst-case, or
  - software.
Step 3: Evaluate Scour Analysis Method

- Get fixed-bed hydraulic data
- Assess profile and planform changes
- Adjust fixed-bed hydraulics for profile and planform changes
- Compute contraction (discussed later)
- Compute local scour (discussed later)
- Get total scour by adding long-term degradation + contraction scour + local scour

Step 4: Compute Contraction Scour Magnitude

- Determine if clear water or live bed by incipient motion equation:
  - \( V_c = 6.19 \frac{y^{1/6}}{D_{50}^{1/3}} \)
  - \( V_c \) = min. vel. for size \( D_{50} \) sediment movement
  - \( y \) = flow depth (m)
  - \( D_{50} \) = sed. size of which 50% are smaller (m)

Step 4 Live-Bed Contraction Scour

\[
\frac{y_s}{y_o} = \left[ \frac{Q_2}{Q_1} \right]^{-k} \left[ \frac{W_2}{W_1} \right]^{n}; y_s = y_2 - y_s
\]

- \( y_s \) = contracted section flow depth (m)
- \( y_o \) = upstream main channel depth (m)
- \( y_s \) = contracted section flow depth (m) before scour
- \( y_s \) = scour depth (m)
- \( Q_1 \) = flow in upstream channel transporting sediment (m³/s)
- \( Q_2 \) = contracted channel flow (m³/s)
- \( W_1 \) = upstream main channel bottom width (m)
- \( W_2 \) = main channel contracted section bottom width without pier widths (m)
- \( k \) = exponent determined below
Step 4: $k_1$ Determination

<table>
<thead>
<tr>
<th>$V^*/\omega$</th>
<th>$k_1$</th>
<th>Bed Transport Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;0.5$</td>
<td>0.59</td>
<td>bed contact</td>
</tr>
<tr>
<td>0.5-2</td>
<td>0.64</td>
<td>some suspended load</td>
</tr>
<tr>
<td>$&gt;2$</td>
<td>0.69</td>
<td>suspended load</td>
</tr>
</tbody>
</table>

- $V^*$ = upstream shear velocity (m/s) $= (g y_1 S_1)^{1/2}$
- $\omega = D_{50}$ fall velocity (following figure)
- $S_1$ = main channel energy grade line slope
- $g$ = acceleration of gravity (9.81 m/s$^2$)

Step 4: Fall Velocity, $\omega$

Step 4: Clear-Water Contraction Scour

$$y_s = \left[ \frac{n^2 Q^2}{K_r (S_r - 1) D_{00} W^2} \right]^{1/7}$$

- $y_s$ = contracted section depth after contraction scour (m)
- $Q$ = discharge through bridge (m$^3$/s)
- $D_{00} = 1.25 D_{50}$ (m) = min. non-movable part.
- $W$ = bottom width in contracted section without pier widths
Step 5: Local Pier-Scour Magnitudes

\[ \frac{y_s}{a} = 2K_1K_2K_3K_4 \left( \frac{y_f}{a} \right)^{0.35} \left( \frac{V_f}{(g y_f)^{1/2}} \right) \]

- \( y_s \): scour depth (m)
- \( y_f \): flow depth directly upstream of pier (m)
- \( K_1 \): pier nose shape correction
- \( K_2 \): angle of attack correction
- \( K_3 \): bed condition correction
- \( K_4 \): armoring correction
- \( a \): pier width (m)
- \( V_f \): velocity upstream of pier (m/s)

### Pier Nose Shape Correction, \( K_1 \)

<table>
<thead>
<tr>
<th>Pier Nose Shape</th>
<th>( K_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square nose</td>
<td>1.1</td>
</tr>
<tr>
<td>Round nose</td>
<td>1.0</td>
</tr>
<tr>
<td>Circular cylinder</td>
<td>1.0</td>
</tr>
<tr>
<td>Group of cylinders</td>
<td>1.0</td>
</tr>
<tr>
<td>Sharp nose</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### Angle of Attack Correction, \( K_2 \)

<table>
<thead>
<tr>
<th>Angle</th>
<th>( L/a=4 )</th>
<th>( L/a=8 )</th>
<th>( L/a=12 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>15</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>30</td>
<td>2.0</td>
<td>2.75</td>
<td>3.5</td>
</tr>
<tr>
<td>45</td>
<td>2.3</td>
<td>3.3</td>
<td>4.3</td>
</tr>
<tr>
<td>90</td>
<td>2.5</td>
<td>3.9</td>
<td>5.0</td>
</tr>
</tbody>
</table>

\( L \)= pier length (m), \( a \)= pier width (m)
Bed Correction Factor, $K_3$

<table>
<thead>
<tr>
<th>Bed Condition</th>
<th>Dune Height (m)</th>
<th>$K_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear-Water Scour</td>
<td>N/A</td>
<td>1.1</td>
</tr>
<tr>
<td>Plane Bed and Antidune</td>
<td>N/A</td>
<td>1.1</td>
</tr>
<tr>
<td>Small Dunes</td>
<td>0.6&lt;H&lt;0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Medium Dunes</td>
<td>3&lt;H&lt;9</td>
<td>1.2</td>
</tr>
<tr>
<td>Large Dunes</td>
<td>9&lt;H</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Armoring Correction, $K_4$

- $K_4=[1-0.89(1-V_R^2)]^{0.5}$
- $V_R=(V_1-V_i)/(V_{c90}-V_i)$
- $V_i=0.645(D_{50}/a)^{0.053}V_c^{0.8}$
- $V_c=6.19y^{1/6}D_c^{1/3}$
- Where
  - $V_1=$ approach velocity (m/s)
  - $V_{c90}=$ critical velocity to move $D_{90}$
  - $D_c=$ critical part. size (m) for critical vel., $V_c$
  - $a=$ pier width (m)

Limiting Values of $K_4$

<table>
<thead>
<tr>
<th>Factor</th>
<th>Min. Bed Material Size</th>
<th>$K_4$ min.</th>
<th>$V_R&gt;1.0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_4$</td>
<td>$D_{50}&gt;0.06$ m</td>
<td>0.7</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Special Cases

- Very wide piers
- Exposed footings and/or piles
- Pile caps in flow
- Multiple columns skewed to flow
- Pressure flow scour deck over-topping
- Debris

Abutment Scour Prediction

- Many kinds exist:
  - Different setbacks (in main channel, back on floodplain)
  - Shape (spill-through, vertical face, wingwall)
  - Angle to flow

\[ \frac{y_a}{y_s} = 2.27K_1K_2 \left( \frac{L'}{y_s} \right)^{0.41} F^{0.61} + 1; F = \frac{V_s}{\sqrt{g y_s}}; V_s = \frac{Q}{A_e} \]

- \( K_1, K_2 \) = correction coefficients
- \( L' \) = abutment length normal to flow (m)
- \( y_s \) = floodplain average depth (m)
- \( y_a \) = scour depth (m)
- \( Q_e \) = flow obstructed by abut. and embank. (m³/s)
- \( A_e \) = cross-sect. flow obstr. by abut. and emb. (m²)
Abutment Shape Correction, $K_1$

<table>
<thead>
<tr>
<th>Description</th>
<th>$K_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical-wall</td>
<td>1.00</td>
</tr>
<tr>
<td>Vertical-wall/wing wall</td>
<td>0.82</td>
</tr>
<tr>
<td>Spill-through</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Embankment Angle Correction, $K_2$

- $K_2 = (\theta/90)^{0.13}$
- $\theta < 90^\circ$ if embankment points downstream
- $\theta > 90^\circ$ if embankment points upstream

Alternate Equation if $L'/y_1 < 25$

$$\frac{y_s}{y_1} = 4F_r^{0.33} \frac{K_1}{0.55}$$

- $y_s =$ scour depth (m)
- $y_1 =$ flow depth at abutment (m)
- $F_r =$ Froude Number at abutment
- $K_1 =$ abutment shape correction
Step 7: Total Scour and Bridge Design

- Plot bed degradation elevation
- Subtract contraction scour and local scour (include local scour width as well=2depth)
- Is scour depth reasonable?
- Avoid overlapping scour holes
- Consider scour protection rather than a foundation deeper than the scour (can you count on it?)
- Evaluate cost, safety, environmental effects, ice, and debris.

Step 7: Re-Evaluation of Design

- Waterway width OK? (Leave as is?)
- Are scour holes overlapping?
- Relief bridges on floodplain needed?
- Abutments properly aligned?
- Can crossing location be changed?
- Can you train the flow at bridge?
- Is 2-D numerical model or physical model study needed?
**SPREAD FOOTINGS**

**DESIGN**
- Est. Avg. Pressure causing 1" Settlement
- Est. Allowable Bearing Capacity
- If greater than about 2,500 psf OK for Spreads
- Spreads OK ONLY IF BELOW SCOUR

**CONSTRUCTION**
- Footing Check at Design Bearing.
- Are Undercuts Required?
- Is Design Allowable Bearing Pressure Available?
- Adjust/Change as needed.

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**FOOTINGS ON PILES**

**DESIGN**
- Est. Length of Each Pile for Design Capacity
- Select Pile Type for Soil Profile
- PIERS - Design Piles for Scour Hole
- Check PIERS for “Extreme Events” like combined ship impact and scour, during an earthquake?

**CONSTRUCTION**
- Pile Driving Records (Spec Book method, PDA…)
- Re-Strike and Set-up.
- Is Design Allowable Bearing Load Available?
- Adjust/Change as needed.

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**CIP Concrete Pipe Piles**

1. Displaces Large Volume of Soil.
2. Deep deposits of loose sand, with firm bottom.
3. Weaker Lakebed Clays over stiff to hard clays.
4. SPT generally has to be less than 30 bpf.
5. Steel Shell Crushing ➔ Wall Thickness.
6. Has high Flexural Rigidity after CIP Concrete.
7. Avoid Soil Profiles having lots of Boulders and Cobbles.
1. Can be “Low Vibration” and “non-displacement”.
2. Suitable in Many Soil and Rock Types but Costly.
3. To Case or Not to Case?
4. Wet or Dry Concrete Placement?.
5. Big Equipment and Giant Reinforcing Steel Cage
6. “Cracked Section” Analyses.
7. Avoid Soil Profiles with Boulders and Cobbles.
1. Ground Improvement Can Increase Bearing Capacity.
2. MSE Wall Straps can Improve Global Stability.
3. MSE Abutments Becoming More Common.
4. Easy to Cast Aesthetic Textures into Panels.

F.S. for Standard Wall was Inadequate!
What do We Do?

Inter-bedded Silts and Clays
Medium to Stiff in Upper Layers
MSE Wall with Stone Column Ground Improvement

Reinf. Pulls Failure Back and Deeper

Stone adds Shear Strength
And Compresses Subsoil

Inter-bedded Silts and Clays
Medium to Stiff in Upper Layers
1. Improves loose Channel Sands creating soil-cement.
2. Can seal a Cofferdam.
3. Specialty Contractor Stuff.
Jet grouting equipment and platform (crane mats on I-beams) resting on the Pier 2 Cofferdam
Jet-Grouting Cross Section

Settlement Reduction and Cofferdam Seal “All-In-One”

By Hayward Baker, Inc.

Pier 1- Jet Grout Soil-Cement Testing Summary

Pier 1 Grout Strengths

Median Soil Cement and Grout Strength Values

Design Minimum Strength = 300 psi
Stiff-Hard Clay and Jet Grouting Don’t Mix Well

1. Minimize Wetland Impact.
2. Geogrid Strips Improve Global Stability.
3. Special Facing Fabrics/Grids allow Steeper than 1:2.
4. Special Turf Required.
1. Low Vibrations.
2. Urban Environments.
3. Special Contractors.