Summary of HEC 18, “Evaluating Scour at Bridges” FHWA NHI 01-001

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

Photo courtesy of Art Parola
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
Determine if clear water or live bed by incipient motion equation:

\[ V_c = 6.19 \, y^{1/6} \, D_{50}^{1/3} \]

- \( V_c \) = 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

\[
\frac{y_2}{y_1} = \left[ \frac{Q_2}{Q_1} \right]^{6/7} \left[ \frac{W_1}{W_2} \right]^{k_1};\ y_s = y_2 - y_o
\]

- \(y_2\) = contracted section flow depth (m)
- \(y_1\) = upstream main channel depth (m)
- \(y_o\) = 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)
- \(k_1\) = 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

\[ y_2 = \left[ \frac{n^2 Q^2}{K_s (S_s - 1) D_m W^2} \right]^{3/7} \]

- \( y_2 \) = contracted section depth after contraction scour (m)
- \( Q \) = discharge through bridge (m\(^3\)/s)
- \( D_m = 1.25 D_{50} \) (m) = min. non-movable part.
- \( W \) = bottom width in contracted section wo pier widths
Step 5: Local Pier-Scour Magnitudes

\[
\frac{y_s}{a} = 2K_1K_2K_3K_4 \left( \frac{y_1}{a} \right)^{0.35} Fr_1^{0.43} ; Fr_1 = \frac{V_1}{\sqrt{g} y_1^{1/2}}
\]

- \( y_s \) = scour depth (m)
- \( y_1 \) = 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)
- \( V_1 \) = 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, $K_4$

- $K_4 = [1 - 0.89(1 - V_R)^2]^{0.5}$
- $V_R = (V_1 - V_i) / (V_{c90} - V_i)$
- $V_i = 0.645(D_{50}/a)^{0.053} V_{c50}$
- $V_c = 6.19y^{1/6} D_c^{1/3}$

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
Abutment Scour Prediction

\[
\frac{y_s}{y_a} = 2.27 K_1 K_2 \left( \frac{L'}{y_a} \right)^{0.43} F_r^{0.61} + 1; F_r = \frac{V_e}{\sqrt{gy_a}}; V_e = \frac{Q_e}{A_e}
\]

- \(K_1, K_2\) = correction coefficients
- \(L'\) = abutment length normal to flow (m)
- \(y_a\) = floodplain average depth (m)
- \(y_s\) = scour depth (m)
- \(Q_e\) = flow obstructed by abut. and embank. (m³/s)
- \(A_e\) = cross-sect. flow obstr. by abut. and emb. (m²)
<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?
Item 113-Scour Critical Bridges

- Code 5: “Bridge foundations determined to be stable for calculated scour conditions; scour within limits of footing or piles.”
- Must complete scour calculations to know this. If a large section of piling is exposed, you may also need to do a structural / geotechnical analysis to see if the piles are stable.
Code 7: “Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical.” Instructions in a plan of action have been implemented.

Depending on what your plan of action is, you must calculate the scour first to know what event would trigger monitoring, or at least have done a HEC-RAS to get your parameters for designing countermeasures.
The End

- Any questions or discussion?