Presentation Topics
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• Project objective for NCHRP 24-20(2)
• Overview of field data
• Overview of equations
• Preliminary findings
• Upper bound of scour in laboratory and field data
Objective:

Use laboratory and field data to evaluate the performance of 2 abutment-scour prediction equations recently developed under the direction of the NCHRP.

- NCHRP Project 24-15(2)
  Abutment Scour in Cohesive Materials (Briaud and others, 2009)

- NCHRP Project 24-20
  Estimation of Scour Depth at Bridge Abutments (Ettema and others, 2010)
Abutment Scour Field Data:
Abutment Scour Field Data:

• Four primary sources:

  South Carolina

  Maine

  Alabama

  National Data
## Abutment Scour Field Data:

<table>
<thead>
<tr>
<th>Range value</th>
<th>Drainage area (miles$^2$)</th>
<th>Channel slope (ft/ft)</th>
<th>Average approach velocity (ft/s)</th>
<th>Average approach depth (ft)</th>
<th>Embankment length blocking flow (ft)</th>
<th>Median grain size (mm)</th>
<th>Observed abutment-scar depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>11</td>
<td>0.00015</td>
<td>0.1</td>
<td>1.0</td>
<td>18</td>
<td>&lt; 0.062</td>
<td>0.0</td>
</tr>
<tr>
<td>Median</td>
<td>75</td>
<td>0.0012</td>
<td>0.9</td>
<td>5.4</td>
<td>276</td>
<td>0.073</td>
<td>1.3</td>
</tr>
<tr>
<td>Maximum</td>
<td>1,620</td>
<td>0.0029</td>
<td>3.2</td>
<td>14.6</td>
<td>953</td>
<td>0.99</td>
<td>18.0</td>
</tr>
</tbody>
</table>

### South Carolina Piedmont (92 observations)

- Minimum: 6
- Median: 120
- Maximum: 8,830

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<th>Median grain size (mm)</th>
<th>Observed abutment-scar depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>6</td>
<td>0.00007</td>
<td>0.1</td>
<td>1.5</td>
<td>87</td>
<td>&lt; 0.062</td>
<td>0.0</td>
</tr>
<tr>
<td>Median</td>
<td>120</td>
<td>0.0005</td>
<td>0.5</td>
<td>4.7</td>
<td>557</td>
<td>0.18</td>
<td>7.0</td>
</tr>
<tr>
<td>Maximum</td>
<td>8,830</td>
<td>0.0024</td>
<td>1.5</td>
<td>17.4</td>
<td>7,440</td>
<td>0.78</td>
<td>23.6</td>
</tr>
</tbody>
</table>

### South Carolina Coastal Plain (106 observations)

- Minimum: 6
- Median: 20
- Maximum: 95

### Maine (93 observations)

- Minimum: 4
- Median: 20
- Maximum: 95

<table>
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<tr>
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<th>Average approach depth (ft)</th>
<th>Embankment length blocking flow (ft)</th>
<th>Median grain size (mm)</th>
<th>Observed abutment-scar depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>10</td>
<td>0.0004</td>
<td>0.1</td>
<td>3.3</td>
<td>43</td>
<td>0.001</td>
<td>1.4</td>
</tr>
<tr>
<td>Median</td>
<td>80</td>
<td>0.0008</td>
<td>0.6</td>
<td>5.3</td>
<td>400</td>
<td>0.0091</td>
<td>4.7</td>
</tr>
<tr>
<td>Maximum</td>
<td>607</td>
<td>0.0016</td>
<td>1.2</td>
<td>8.8</td>
<td>1141</td>
<td>0.17</td>
<td>10.4</td>
</tr>
</tbody>
</table>

### Alabama (23 observations)

- Minimum: 10
- Median: 80
- Maximum: 607

### National Bridge Scour Database (15 observations)

- Minimum: 836
- Median: 1,330
- Maximum: 16,000

### Large database:

- 329 measurements
- Smaller drainage areas
- Wide range in slope and grain size
- 93% of data are clear-water scour
- Data are limited and not always ideal

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[USGS logo]
Limitations of USGS Field Data:

1. Historic abutment scour – Post-flood measurements

2. Hydraulics estimated with 1-D model with index flows
   - 1-D models will underestimate velocity at abutment
   - SBR method was used to compensate for this limitation

3. Limitations will introduce error into the analysis and must be kept in mind when reviewing results
   - Currently best available data
   - Large number of measurements will provide a good indicator of equation trends
Focus:
Abutment-scour in cohesive sediments

- Extended for non-cohesive sediments
- Includes two prediction methods:
  - time dependent method
  - the maximum scour-depth equation
- Evaluation was limited to use of the maximum scour-depth equation, because of insufficient data for the time-dependent method
Maximum Scour-Depth Equation

\[ \frac{y_s}{y_1} = K_1K_2K_LK_GK_p \frac{243Re_{f2}^{-0.28}}{1.65Fr_{f2} - Fr_{fc}} \]

- \( y_s \) is the abutment scour depth
- \( y_1 \) is the approach flow depth
- \( K_1 \) is the correction factor for \textit{abutment shape}
- \( K_2 \) is the correction factor for \textit{abutment skew}
- \( K_G \) is the correction factor for \textit{channel geometry}
- \( K_L \) is the correction factor for \textit{abutment location}
- \( K_p \) is the correction factor for \textit{pressure flow}
- \( Fr_{f2} \) is the Froude number around the toe of the abutment
- \( Fr_{fc} \) is the sediment critical Froude number
- \( Re_{f2} \) is the Reynolds number around the toe of the abutment
NCHRP 24-15(2)
(Briaud and others, 2009)

Predicted vs. Observed for Field Data

- Performs better with cohesive sediments
- More frequent underprediction for rectangular channels ($K_G = 0.42$)
- Recommending that $K_G$ be set to 1.0 for rectangular channels (Melville and Coleman, 2000)
- Largest overpredictions at protruding abutments ($K_L = 1.35$)
- Recommending that $K_L$ be set to 1.0 for protruding abutments
Residuals vs. Relative Abutment Length

- Larger magnitude and frequency of underprediction for long abutments
- Recommending that Melville (1992) correction for long abutments be included for non-cohesive sediments
NCHRP 24-15(2) (Briaud and others, 2009) with Recommended Modifications

- $K_G = 1.0$ for rectangular channels
- $K_L = 1.0$ for protruding abutments
- Include Melville’s correction for long abutments for non-cohesive sediments
- Remaining underprediction is likely caused by underestimates of flow velocity from 1-D models
Focus:

Abutment-scour in non-cohesive sediments

- Conceptually, abutment scour is a function of contraction scour
- Includes scour at erodible embankments
  - tends to produce smaller scour depths than fixed embankment
NCHRP 24-20
(Ettema and others, 2010)

Scour Equation

\[ Y_{MAX} = \alpha Y_C \]

- \( Y_{MAX} \) is the maximum flow depth in the abutment-scour area
- \( Y_C \) is the mean flow depth in contraction scour
  - Use Laursen (1960, 1963) live-bed or clearwater contraction scour equation
- \( \alpha \) amplification factor accounting for additional scour at the abutment
  - laboratory derived relations for selected abutment conditions

\[ y_s = Y_{MAX} - y_1 \]

- \( y_s \) is the abutment-scour depth
- \( Y_1 \) is the approach-flow depth
Predicted vs. Observed for Field Data

- Underprediction is associated with relatively long abutments that may contribute to underprediction.
- Underprediction is likely caused, in part, by under estimates of flow velocity at abutments.
Predicted vs. Observed for Field Data
Cohesive and Non-Cohesive

- Non-cohesive sediments have an approximate symmetric scatter around the line of agreement
- However, trend of more frequent underprediction as the scour depth increases
- Cohesive sediments have infrequent underprediction but at times excessive overprediction
Predicted vs. Observed for Field Data
Cohesive and Non-Cohesive

- Performs better with non-cohesive sediments
- Recommend considering an adjustment for long abutments
- Important to obtain good estimate of increased velocity at abutment
- Conclusions -

NCHRP 24-15(2)

- Performs better with cohesive sediments
- Recommend:
  - $K_G = 1.0$ for rectangular channels
  - $K_L = 1.0$ for protruding abutments
  - Include Melville’s correction factor for long abutments with non-cohesive sediments
  - Obtain good estimate of velocity at abutment (2-D model)

NCHRP 24-20

- Performs better with non-cohesive sediments
- Recommend:
  - Include a correction factor for long abutments with non-cohesive sediments
  - Obtain good estimate of velocity at abutment (2-D model)
Investigation of Long Abutments

The USGS outdoor flume can be used to investigate long abutments

- 4,400 feet in length
- 300 feet wide
- 10-feet wide, 1-foot deep channel
- Can study scour at near field scales
Upper Bound of Scour

2014 USGS Pier-Scour Database

- 569 laboratory measurements
- 1,858 field measurements
  - 23 states
  - 6 countries
- Online spreadsheet: http://pubs.usgs.gov/ds/0845/

Data Series 845

Prepared in cooperation with the South Carolina Department of Transportation

A Pier-Scour Database: 2,427 Field and Laboratory Measurements of Pier Scour
Scour depth ($y_s$), in feet

Pier width ($b$), in feet

$y_s = 2.1b^{0.895}$

- Upper Bound of Scour -

Screened laboratory data (Sheppard and others, 2011)
Screened field data (Sheppard and others, 2011)
South Carolina clearwater data (Benedict and Caldwell, 2006)
Envelope of screened data

Screened data:
441 laboratory
791 field
Scour at I-70 bridge over Missouri River from 1993 flood, looking upstream (Photo by U.S. Army Corps of Engineers as cited in Headrick and Galat, 2007).
Upper Bound of Scour

- Upper Bound of Abutment Scour -

Data mostly long abutments

$D_{adj}/y$ - adjusted scour depth
$L$ - abutment length
$y$ - flow depth

Field data mostly long abutments

Lab Envelope curve (Melville, 1992)

331 field measurements

Envelope (Melville, 1992)
Field Envelope (non-cohesive)
Field envelope (cohesive)

Melville (1992)
Missouri River at levee breach (1993 Flood)
Missouri River at bridge (1993 Flood)
South Carolina Piedmont
South Carolina Coastal Plain
Maine
NBSD
Alabama

Lab Envelope

Field Envelope (Non-cohesive)

4.25y

Missouri Data

Long Abutment
Intermediate Abutment
Short Abutment

$D_{adj}$ - adjusted scour depth
$L$ - abutment length
$y$ - flow depth
Upper-bound envelope curves are useful supplementary tools to assist in evaluating scour potential.

**Upper Bound of Pier Scour**
- Strong envelope curve based on very large dataset

**Upper Bound of Abutment Scour**
- Good envelope curve, but additional data would be helpful to verify
Questions?