Strategies to Mitigate Scour Critical Structures

Dan Ghere
Hydraulics Engineer
(708) 283-3557
dan.ghere@dot.gov
Support Material

HEC 23, Bridge Scour and Stream Instability Countermeasures, Volumes 1 & 2

NCHRP 135048, Countermeasure Design for Bridge Scour and Stream Instability

NCHRP Report 568, Riprap Design Criteria, Recommended Specifications, and Quality Control

NCHRP Report 593, Countermeasures to Protect Bridge Piers from Scour

HEC 18, Evaluating Scour at Bridges
## Design Frequency

### Risk Based Design

HEC 18 Tables 2.1 & 2.3 combined

<table>
<thead>
<tr>
<th>Design Flood Frequencies</th>
<th>Hydraulic Design Flood Frequency, $Q_D$</th>
<th>Scour Design Flood Frequency, $Q_S$</th>
<th>Scour Design Check Flood Frequency, $Q_C$</th>
<th>Countermeasure Design Flood Frequency, $Q_{CM}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{10}$</td>
<td>$Q_{25}$</td>
<td>$Q_{50}$</td>
<td>$Q_{50}$</td>
<td>$Q_{50}$</td>
</tr>
<tr>
<td>$Q_{25}$</td>
<td>$Q_{50}$</td>
<td>$Q_{100}$</td>
<td></td>
<td>$Q_{100}$</td>
</tr>
<tr>
<td>$Q_{50}$</td>
<td>$Q_{100}$</td>
<td>$Q_{200}$</td>
<td></td>
<td>$Q_{200}$</td>
</tr>
<tr>
<td>$Q_{100}$</td>
<td>$Q_{200}$</td>
<td></td>
<td></td>
<td>$Q_{500}$</td>
</tr>
</tbody>
</table>
Bridge Design Life – 75 Years

- Hydraulic Design Flood Frequency – $Q_{50}$
- Probability of Exceedance – 78%
- Scour Design Flood Frequency – $Q_{100}$
- Probability of Exceedance – 59.2%
- Scour Check Flood Frequency – $Q_{200}$
- Probability of Exceedance - 31.3%
### Table B.1. Probability of Flood Exceedance of Various Flood Levels.

<table>
<thead>
<tr>
<th>Flood Frequency</th>
<th>Probability of Exceedance in N Years (or Assumed Bridge Design Life)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N = 1</td>
</tr>
<tr>
<td>10</td>
<td>10.0%</td>
</tr>
<tr>
<td>25</td>
<td>4.0%</td>
</tr>
<tr>
<td>50</td>
<td>2.0%</td>
</tr>
<tr>
<td>100</td>
<td>1.0%</td>
</tr>
<tr>
<td>200</td>
<td>0.5%</td>
</tr>
<tr>
<td>500</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
Hydraulic Countermeasure Types

- Riprap
- Partially Grouted Riprap
- Articulated Concrete Blocks
- Gabions & Gabion Mattresses
- Concrete Armor Units (Toskanes, A-Jacks, etc.)
- Spurs
- Bendway Weirs
- Guide Banks
- Longitudinal Peaked Stone Toe Protection
Riprap Countermeasures

- Riprap Revetment – channel bank
- Riprap Embankment Overtopping
- Riprap at Bridge Piers
- Riprap at Abutments
- Riprap for Bottomless Culverts
Similarities

- Stone quality specification
- Gradation specifications
- Filter requirements
Differences

- Equations for sizing
- Layer thickness
- Toe detail
- Lateral extent
- Filter extent
Revetment (DG 4)

\[ D_{30} = y \left( SfCsCvCT \right) \left[ \frac{V}{(K(Sg - 1)gy)^{1/2}} \right]^{2.5} \]

Bridge Piers (DG 11)

\[ D_{50} = \frac{0.692 V^2}{(Sg - 1)2g} \]

Abutments (DG 14)

\[ D_{50} = \frac{ky}{(Sg - 1)} \times \frac{V^2}{gy} \quad \text{for } F_R \leq 0.8 \]

\[ D_{50} = \frac{ky}{(Sg - 1)} \times \left[ \frac{V^2}{gy} \right]^{0.14} \quad \text{for } F_R > 0.8 \]
Riprap Calculator

- Revetment
- Pier
- Abutment/Guide Bank
- Spur
- Embankment Overtopping
- Culvert Outlet
- Open Bottom Culvert
- Wave Attack
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure type:</strong></td>
<td>Pier</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Channel Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select Channel</td>
<td>&lt;Create New&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Input Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity Input Type</td>
<td>average velocity at the bridge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channel Average Velocity (at the bridge)</td>
<td>6.600</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>Velocity Adjustment Factor for location in the channel</td>
<td>1.300</td>
<td></td>
<td>Ranges from 0.9 for a pier near the bank in a straight reach to 1.7 for a pier in a curve.</td>
</tr>
<tr>
<td>Pier Shape Factor</td>
<td>round-nose pier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pier Width (normal to flow)</td>
<td>2.500</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>Contraction Scour Depth</td>
<td>3.000</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>Bed Form Depth</td>
<td>0.000</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity of Riprap</td>
<td>2.650</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Velocity</td>
<td>12.870</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>D50</td>
<td>12.955</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>D10</td>
<td>1.080</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td><strong>Riprap Shape</strong></td>
<td>Riprap shape should be angular</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Riprap Class</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riprap Class Name</td>
<td>CLASS IV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riprap Class Order</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D15</td>
<td>10.50</td>
<td>in</td>
<td>This value is an 'average' of the size fraction range for the selected riprap.</td>
</tr>
<tr>
<td>D50</td>
<td>15.50</td>
<td>in</td>
<td>This value is an 'average' of the size fraction range for the selected riprap.</td>
</tr>
<tr>
<td>D85</td>
<td>21.00</td>
<td>in</td>
<td>This value is an 'average' of the size fraction range for the selected riprap.</td>
</tr>
<tr>
<td>D100</td>
<td>30.00</td>
<td>in</td>
<td>This value is an 'average' of the size fraction range for the selected riprap.</td>
</tr>
<tr>
<td><strong>Layout</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth of Riprap below Streambed</td>
<td>46.500</td>
<td>in</td>
<td>Design thickness of riprap below streambed is greatest of Contraction Scour Depth, Minimum Riprap Extent, Filter Placement Extent.</td>
</tr>
<tr>
<td>Minimum Riprap Extent</td>
<td>5.000</td>
<td>ft</td>
<td>See HEC 23, Figure 11.15</td>
</tr>
<tr>
<td>Filter Placement Extent</td>
<td>3.333</td>
<td>ft</td>
<td>See HEC 23, Figure 11.15</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
<td>Units</td>
<td>Notes</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>--------</td>
<td>-------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td><strong>Channel Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select Channel</td>
<td>&lt;Create New&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Input Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure Type</td>
<td>abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abutment Type</td>
<td>spill-through abutment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set-back Length</td>
<td>50.000</td>
<td>ft</td>
<td>The set-back length is the distance from the</td>
</tr>
<tr>
<td>Main Channel Average Flow Depth</td>
<td>15.000</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>Flow Depth at Toe of Abutment</td>
<td>6.000</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td>Total Discharge</td>
<td>12000.00</td>
<td>cfs</td>
<td>Calculations will use either total or overbank</td>
</tr>
<tr>
<td>Overbank Discharge</td>
<td>4000.00</td>
<td>cfs</td>
<td></td>
</tr>
<tr>
<td>Total Bridge Area</td>
<td>2000.00</td>
<td>ft^2</td>
<td></td>
</tr>
<tr>
<td>Setback Area</td>
<td>300.000</td>
<td>ft^2</td>
<td></td>
</tr>
<tr>
<td>Maximum Channel Velocity</td>
<td>6.600</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>Specific Gravity of Riprap</td>
<td>2.650</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set-back ratio</td>
<td>3.333</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Characteristic Velocity</td>
<td>6.000</td>
<td>ft/s</td>
<td></td>
</tr>
<tr>
<td>Froude Number at the Abutment Toe</td>
<td>0.432</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abutment Coefficient</td>
<td>0.890</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D50</td>
<td>7.242</td>
<td>in</td>
<td>This value is an 'average' of the size fraction</td>
</tr>
<tr>
<td>D50</td>
<td>0.604</td>
<td>ft</td>
<td></td>
</tr>
<tr>
<td><strong>Riprap Shape</strong></td>
<td></td>
<td></td>
<td>Riprap shape should be angular</td>
</tr>
<tr>
<td><strong>Riprap Class</strong></td>
<td>CLASS II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riprap Class Name</td>
<td>CLASS II</td>
<td></td>
<td>This value is an 'average' of the size fraction</td>
</tr>
<tr>
<td>Riprap Class Order</td>
<td>2</td>
<td></td>
<td>This value is an 'average' of the size fraction</td>
</tr>
<tr>
<td>D15</td>
<td>7.00</td>
<td>in</td>
<td>This value is an 'average' of the size fraction</td>
</tr>
<tr>
<td>D50</td>
<td>9.50</td>
<td>in</td>
<td>This value is an 'average' of the size fraction</td>
</tr>
<tr>
<td>D85</td>
<td>13.00</td>
<td>in</td>
<td>This value is an 'average' of the size fraction</td>
</tr>
<tr>
<td>D100</td>
<td>18.00</td>
<td>in</td>
<td>This value is an 'average' of the size fraction</td>
</tr>
<tr>
<td><strong>Layout</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riprap Thickness</td>
<td>18.000</td>
<td>in</td>
<td></td>
</tr>
<tr>
<td>Minimum Horizontal Extent of the Toe Apron from the Abutment Toe</td>
<td>12.000</td>
<td>ft</td>
<td>See HEC 23, Figure 14.7</td>
</tr>
<tr>
<td>Minimum Extent of &quot;Wrap Around&quot; beyond the Abutment Radius, along the Approach Embankment</td>
<td>25.000</td>
<td>ft</td>
<td>See HEC 23, Figure 14.7</td>
</tr>
</tbody>
</table>
Layer Thickness

- **Abutments:** Not less than 1.5 $D_{50}$ or $D_{100}$
- **Channel Lining:** Not less than 1.5 $D_{50}$ or $D_{100}$
- **Piers:** $3D_{50}$ or depth of contraction scour. When placed under water increase thickness by 50%.
Lateral Extent

HEC 23 recommends twice pier width.

I recommend a minimum of 10 ft. to account for effects of debris or changes in skew over time.

Note: filter extends only 2/3 riprap extent at piers.
Lateral Extent at Abutment (minimum)

- **Upstream** - cover abutment spill thru cone.
- **Downstream** – 2 times flow depth or 25 ft. past cone.
- **Toe (apron)** – 2 times flow depth or 25 ft.
Figure 14.8. Typical cross section for abutment riprap (Lagasse et al. 2006).
Keys to Successful Riprap Installations

• Stone Quality
  Need strong quality spec and material inspection procedures.

• Excavation for placement
  Excavate to plan depth and finish surface for uniform placement depth.

• No mounding at piers or for toe protection.

• Install and anchor filters underwater
  Filter controls the movement of soil particles. Riprap holds filter in place.
Filter Systems

- Granular
- Geotextile
- Combined – Geotextile with granular cover

Granular cover provides a layer of protection from puncturing by riprap placement.
DOTs report that few riprap installations in water have filters placed during construction. Why? Contractors say it’s too difficult and they don’t know how.
Environmental Concerns

- Increased water surface caused by obstructions
- Maintaining natural river bed
- Obstruction to fish passage
- Length of loss of native stream bed and banks
What's wrong with this installation?
Construction Supervision

Verify

- Excavation and surface preparation
- Placement of filter
- Stone size gradation & quality (check before installation)
- Thickness of layer
- Lateral Extent
- Elevation of finished surface (Not to create mounding on streambed)
Maintenance Inspection

Changed appearance

- Lose of stones
- Reduced stone size (freeze thaw or abrasion)
- Filter is visible through voids
- Lateral extent
- Sloughing or sliding down bank

Document findings (text description and photos)
Poor Quality Stone
Essentials for a Durable lasting Riprap Countermeasure

• “A” Quality Stone
• Proper size and gradation of stone
• Filter under countermeasure
• Layer thickness
• Maintenance inspection and repair
Alternatives to Riprap

Articulated Concrete Blocks (Allows some flexibility)

- Interlocking geometries
- Cable tied blocks
- Interlocking or cabled and vegetated
Applications for Articulated Blocks

- Insufficient vertical clearance for equipment for riprap installation.
- Necessary riprap stone size not available.
- Necessary stone quality not available.

Requires well prepared uniform surface for installation.
Articulating Block Systems

Interlocking

Cable Tied
Alternatives to Riprap

• Gabions and Gabion Mattresses
Applications for Gabions and Mattresses

- Required riprap size not available.
- High velocity and limited space for placing large size stone.
- Can serve as retaining wall as well as scour countermeasure.
Partially Grouted Riprap
Avoid Fully Grouted Riprap
Alternatives to Riprap

• Concrete Armor Units (Toskanes, A-Jacks, etc.)
Figure 5.23. Laboratory study of Toskanes for pier scour protection.
A-Jacks Installed as a Unit
Concrete Armor Units: A-Jacks
Hard Points – Similar to Bend Way Weirs
• NCHRP 24-42, Techniques for Installation of Filters Underwater. (2-yr. project just getting started)

• FHWA - USGS Interagency Project. Performance Evaluation of Existing Countermeasures. (Feb. 2016)
  
  Objective: Inspect and evaluate the effectiveness of existing policies, design procedures, and installation of scour countermeasures.
Interest in Countermeasure Webinar

Provide comments on evaluation sheet if interested in webinar.

Identify specific coverage areas of interest.
Questions

FHWA Hydraulics Website:

www.fhwa.dot.gov/engineering/hydraulics

Dan Ghere
FHWA Hydraulics Engineer
Matteson, Illinois
dan.ghere@dot.gov
(708) 283-3557