Scour Analysis of Proposed Atchison Bridge over the Missouri River

University of Kansas
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Proposed Bridge

RR Bridge

Existing US HW 59

Navigation Channel

Pier No. 7

Flow

Bridge Location and Pier of Interest
RR Piers and Existing Bridge Pier No. 10

44’x16’  60’x20’
In-line Position for the 4-Lane Proposed Bridge Pier

37.5' x 8'

44' x 16'

60' x 20'

Existing US HW 59

Proposed 4-lane

Flow

Railroad

15'

37.3'

78'

212'

37.5' x 8'

44' x 16'

60' x 20'

15°
Site Issues that Create Scour Concern

Existing scour hole

Alternative Locations for Pier No. 7

Flow

15° skew angle

Pier No. 7

Alternative Locations for Pier No. 7

Site Issues that Create Scour Concern
Effect of Skew Angle

Scour depth increases 50% for 15° Skew Angle

CSU Pier Scour Eq.

\[
\frac{y_s}{a} = 2.0 \, K_2 \, K_3 \, K_4 \left(\frac{y_1}{a}\right)^{0.35} \, Fr_1^{0.43}
\]

Table 6.2. Correction Factor, K_2, for Angle of Attack, θ, of the Flow.

<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></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>2.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Angle = skew angle
L = length of pier, m
Existing Scour Hole (12/08/00)

RR Piers

18-ft Scour Depth

Existing Scour Hole (12/08/00)
Scour Issues

- Scour effect of lateral spacing of Proposed Pier No. 7 relative to Existing Pier No. 10.

- Scour effect created by cofferdam placed downstream from Existing Pier No. 10 during construction phase.

- Scour effect of degree of demolition (pier height remaining) of Existing Pier No. 10.
Objectives

1. Study the scour effects of the lateral spacing between Proposed Pier No. 7 and Existing Pier No. 10 for the 500-year flood. (2-lane and 4-lane proposed piers considered.)
Objectives (Cont.)

2. Study the scour effects of the lateral spacing between the cofferdam and Existing Pier No. 10 for the 5-year flood.
Objectives (Cont.)

3. Develop a method for estimating pier scour due to a partial height pier. This would occur if the Existing Pier No. 10 were partially demolished to a height of $y_f$ above the bed.

![Diagram showing pier scour](image)
Procedures

Objectives 1 and 2 were achieved using flow visualization and observation of scour in laboratory flumes.

- **Sediment flume** — observation of scour.
  
  1.33-ft wide sediment flume (38-ft long)
  
  \((D_{50} = 0.3\text{mm})\)

- **Water only flumes** — dye injection and observation of flow patterns.
  
  2.5-ft rectangular flume (55-ft long)
  
  6.3-ft channel-shaped flume (24-ft long)
Flumes

Sediment Flume

6.3-ft Flume

2.5-ft Flume

Flumes
\[ Fr_m = \frac{V_m}{\sqrt{g y_m}} = Fr_p = \frac{V_p}{\sqrt{g y_p}} \rightarrow Fr_r = 1 \]

**Undistorted Model**

\[ x_r = y_r = L_r \rightarrow V_r = L_r^{1/2}; Q_r = L_r^{5/2} \]

**Distorted Model**

\[ x_r \neq y_r \rightarrow V_r = y_r^{1/2}; Q_r = x_r y_r^{3/2} \]

<table>
<thead>
<tr>
<th>Model</th>
<th>Horizontal $x_r$</th>
<th>Vertical $y_r$</th>
<th>Velocity $V_r$</th>
<th>Discharge $Q_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand Flume</td>
<td>1/300</td>
<td>1/96</td>
<td>0.102</td>
<td>3.54 E-6</td>
</tr>
<tr>
<td>6.3-ft Wide Flume</td>
<td>1/150</td>
<td>1/96</td>
<td>0.102</td>
<td>7.09 E-6</td>
</tr>
<tr>
<td>2.5-ft Wide Flume</td>
<td>1/75</td>
<td>1/75</td>
<td>0.115</td>
<td>2.05 E-6</td>
</tr>
</tbody>
</table>

\[ (\ )_r = (\ )_{model}/(\ )_{prototype} = (\ )_m/(\ )_p \]
Scour studies in the sediment flume were very valuable. The effect of lateral pier spacing was evident and measurable. Objectives 1 and 2 were met using the sediment flume.

Dye studies were interesting but did not provide as much in the way of meeting Objectives 1 and 2 as did the sediment flume experiments.
RESULTS
Sediment Flume
Model Piers for Sediment Flume
(1/300 hor. scale; 1/96 vert. scale)
Sediment Flume

- Only used existing and proposed piers. No RR pier modeled. A cofferdam was also tested.

- Piers were set up to slide along bridge centerlines. (Skewed 15° to flume cl)

- Observed effects relative to the lateral position of piers.
Sediment Flume

4-Lane Overhead View

(500-year Flood)
Proposed Pier Only
Existing Pier No. 10 Only
0 Lateral Spacings, 4-Lane Proposed
1 Lateral Spacing 4-Lane Proposed

(1 spacing = 37.5 \text{\textquotesingle} in prototype)
3 Lateral Spacings, 4-Lane Proposed
4 Lateral Spacings, 4-Lane Proposed
5 Lateral Spacings, 4-Lane Proposed
Sediment Flume

4-Lane Side View

(500-year Flood)
Note the 2” marker

0 Lateral Spacings, 4-Lane Proposed
5 Lateral Spacings, 4-Lane Proposed
6.3-ft Flume
(500-year Flood)
Largest Eddies, No Lateral Spacing

Smallest Eddies, Widest Lateral Spacing

Dye Between Piers
2.5-ft Flume
(500-year Flood)
Smaller Eddies
Wider Lateral Spacing

Largest Eddies
No Lateral Spacing
50’ x 100’ Cofferdam
(5-year Flood)
Cofferdam and Existing Pier No. 10

(a) Existing Pier Only
(b) Cofferdam Only
(c) Glass Bottom
(d) Pier and Cofferdam Aligned

5 Lateral Spacings (187.5')
Pier Scour for Partial-Height Piers
Eq. 6.14

\[
\frac{V_f}{V_2} = \frac{\ln\left(10.93 \frac{y_f}{k_s} \right)}{\ln\left(10.93 \frac{y_2}{k_s} \right)}
\]

Eq. 6.15

\[
\frac{y_{spc}}{y_f} = 2.0 K_1 K_2 K_3 K_4 K_W \left( \frac{a_{pc}}{y_f} \right)^{0.65} \left( \frac{V_f}{\sqrt{g y_f}} \right)^{0.43}
\]

where \( y_{spc} = \) scour depth
Pier Scour Depth for Partial Pier

### Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y_2$</td>
<td>46.3</td>
</tr>
<tr>
<td>$v_2$</td>
<td>13.3</td>
</tr>
<tr>
<td>$a_{pc}$</td>
<td>12</td>
</tr>
<tr>
<td>$K_1$</td>
<td>1</td>
</tr>
<tr>
<td>$K_2$</td>
<td>1.5</td>
</tr>
<tr>
<td>$K_3$</td>
<td>1.1</td>
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<tr>
<td>$K_4$</td>
<td>1</td>
</tr>
<tr>
<td>$K_w$</td>
<td>1</td>
</tr>
<tr>
<td>$g$</td>
<td>32.2</td>
</tr>
<tr>
<td>$k_s = D_{84}$</td>
<td>1.5 (mm) 0.00492 (ft)</td>
</tr>
</tbody>
</table>

### Table

<table>
<thead>
<tr>
<th>Pier Height (ft)</th>
<th>$y_f$ (ft)</th>
<th>$y_{spc}$ (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>20.1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>27.1</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>30.7</td>
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</tr>
<tr>
<td>20</td>
<td>34.7</td>
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<td>30</td>
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<tr>
<td>40</td>
<td>39.2</td>
<td></td>
</tr>
<tr>
<td>46.3</td>
<td>40.2</td>
<td></td>
</tr>
</tbody>
</table>
Pier Scour Depth for Partial Pier

\[ y_f = 1' \rightarrow y_{spc} = 20.1' \]

\[ y_f = 46.3' \rightarrow y_{spc} = 40.2' \]
Summary and Conclusions

- Prototype lateral spacings of Proposed Pier No. 7 for negligible scour interaction at the 500-year flow are:
  - 4 spacings (150’) for 2-lane proposed pier
  - 5 spacings (187.5’) for 4-lane proposed pier

  The worse scour conditions for the proposed 4-lane pier were observed for spacings of 0 and 1. Spacings of 2 or greater significantly reduced the observed pier scour.

- A lateral prototype spacing of 187.5’ for the cofferdam relative to Existing Pier No. 10 still showed pier scour interaction for the 5-year flow.
The partial demolition of existing Pier No. 10 will not eliminate detrimental pier scour. In fact, shortening the existing pier from 46.3 feet to 1 foot would only halve the pier scour depth of the existing pier.

The existence of the scour hole between the railroad pier and Existing Pier No. 10 represents a clear warning that this region is highly susceptible to scour. This existing scour hole is probably due to the large size of the railroad pier (20’x60’) and the 15 degree skew angle of the pier relative to the flow.
Final Design

Remove all portions of existing bridge pier above Elev. 725.00

Spacing

72'
Final Design

- Demolish Existing Pier No. 10 to an elevation of 825’. This is 7’ below the bottom of the December 2000 scour hole.

- Offset Proposed Pier No. 7 about 72’ east of the original centerline of Existing Pier No. 10. This gets it “out of the way” of the scour hole created by the 20’x40’ railroad pier. The railroad pier will not be demolished.
Questions?