HECRAS Bridges

by G. Parodi
WRS - ITC - The Netherlands

How does a bridge affect the hydraulics?

- Contraction
- Through the bridge
- Piers
- Abutments
- Bridge deck
- Expansion

2 Types of Flow at Bridges

- **Low Flow** - Flow where the water surface does not reach the low beam
- **High Flow** - Flow where the water surface reaches the deck or higher

Q: Is this low flow or high flow?

Low Flow
Low Flow Bridge Modeling: 3 Types of Flow

- **Class A Low Flow - Subcritical Flow**
  - Energy, Momentum, Yarnell, and WSPRO

- **Class B Low Flow - Flow passes through critical depth**
  - Energy and Momentum

- **Class C Low Flow - Supercritical Flow**
  - Energy and Momentum

Low Flow Bridge Hydraulics: 4 methods of modeling

- **Energy** - physically based, accounts for friction losses and geometry changes through bridge, as well as losses due to flow transition & turbulence.
- **Momentum** - physically based, accounts for friction losses and geometry changes through bridge.
- **FHWA WSPRO** - energy based as well as some empirical attributes. Developed for bridges that constrict wide floodplains with heavily vegetated overbank areas.
- **Yarnell** - empirical formula developed to model effects of bridge piers.

Low Flow Bridge Modeling
Class A Low Flow - Energy Method

- Friction losses are computed as length times average friction slope.
- Energy losses are empirical coefficient times change in velocity head (expansion and contraction losses).
- Does not account for pier drag forces.

Low Flow Bridge Modeling
Class A Low Flow - Momentum Method

- Friction losses are external skin friction = wetted perimeter times length times shear stress.
- Requires entering coefficient of drag for piers, $C_D$.
### Low Flow Bridge Modeling

#### Cₚ Coefficients for Piers

<table>
<thead>
<tr>
<th>Pier Shape</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular Pier</td>
<td>1.20</td>
</tr>
<tr>
<td>Elongated piers with semi circular ends</td>
<td>1.33</td>
</tr>
<tr>
<td>Elliptical piers with 2:1 length to width</td>
<td>0.60</td>
</tr>
<tr>
<td>Elliptical piers with 4:1 length to width</td>
<td>0.32</td>
</tr>
<tr>
<td>Elliptical piers with 8:1 length to width</td>
<td>0.29</td>
</tr>
<tr>
<td>Square nose piers</td>
<td>2.00</td>
</tr>
<tr>
<td>Triangular nose with 30 degree angle</td>
<td>1.00</td>
</tr>
<tr>
<td>Triangular nose with 60 degree angle</td>
<td>1.39</td>
</tr>
<tr>
<td>Triangular nose with 90 degree angle</td>
<td>1.60</td>
</tr>
<tr>
<td>Triangular nose with 120 degree angle</td>
<td>1.72</td>
</tr>
</tbody>
</table>

### Low Flow Bridge Modeling

#### Yarnell’s Pier Coefficient, K

<table>
<thead>
<tr>
<th>Pier Shape</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-circular nose and tail</td>
<td>0.90</td>
</tr>
<tr>
<td>Twin-cylinder piers with connecting diaphragm</td>
<td>0.95</td>
</tr>
<tr>
<td>Twin-cylinder piers without diaphragm</td>
<td>1.05</td>
</tr>
<tr>
<td>90 degree triangular nose and tail</td>
<td>1.05</td>
</tr>
<tr>
<td>Square nose and tail</td>
<td>1.25</td>
</tr>
<tr>
<td>Ten pile trestle bent</td>
<td>2.50</td>
</tr>
</tbody>
</table>

### Low Flow Bridge Modeling

#### Class A Low Flow - Yarnell Equation

- Based on 2,600 lab experiments on different pier shapes
- Requires entering pier shape coefficient, K
- Should only be used where majority of losses are due to piers.

### Low Flow Bridge Modeling

#### Class A Low Flow - WSPRO

- Federal Highway Administrations method of analyzing bridges
- Uses energy equation in an iterative procedure
Class B and C Low-flow Methods

- Two methods available:
  1. Momentum - With irregular cross-section data and rapidly changing water surface elevation, the estimate of bed slope can be erratic. Therefore, the weight component is automatically turned off for Class B flow.
  2. Energy - During Class B flow, a dramatic change in depth can occur with resulting large changes in velocity head. Contraction and Expansion energy losses may be overestimated with “traditional” contraction and expansion coefficients.

Low Flow Bridge Hydraulics: Summary

- Bridge piers are small obstruction to flow, friction losses predominate - Energy, Momentum, or WSPRO
- Pier and friction losses predominate - Momentum
- Flow passes through critical depth in vicinity of bridge - Energy or Momentum
- Pier losses are dominant - Yarnell
- Supercritical flow without piers - Energy or Momentum
- Supercritical flow with piers - Momentum

High Flow Bridge Methods

(1) Energy Method - The area of the deck is subtracted and additional wetted perimeter is added. The water surface elevation represents the hydraulic grade line.
- This method does not account for the shape of the entrance or piers.
- Conveyance is calculated treating the bridge as a cross section, including flow over the roadway.

(2) Pressure and Weir Method - Treats the flow as two separate components.
- Flow through the opening is pressure flow.
  - Gate equation
  - Full pressure (Orifice) equation
- Weir equation for flow over the roadway, with submergence correction.

Note: HECRAS will automatically select the appropriate pressure flow equation.
High Flow - Pressure

\[ Q = C_d \cdot A_{bu} \left[ Y_3 \cdot \frac{Z}{2} + \frac{\alpha_3 V_3^2}{2g} \right]^{\frac{1}{2}} \]

- \( Q \) = Total discharge through the bridge opening
- \( C_d \) = Coefficient of discharge for pressure flow
- \( A_{bu} \) = Net area of the bridge opening at section BU
- \( Y_3 \) = Hydraulic depth at section 3
- \( Z \) = Vertical distance from maximum bridge low chord to the mean river bed elevation at section BU

Figure 1.1: Coefficient of discharge for sluice gate type flow
**High Flow - Pressure (Orifice) Flow**

Used when both the upstream and downstream sides of the bridge is fully submerged

\[ Q = C \frac{A}{\sqrt{2gH}} \]

- **Q** = Total discharge from full flowing orifice
- **C** = Coeff. of discharge for fully submerged pressure flow
- **H** = The difference between the energy gradient elevation upstream & the water surface elevation downstream
- **A** = Net area of the bridge opening

**High Flow - Weir Flow**

\[ Q = CLH^{3/2} \]

- **Q** = Total flow over the weir
- **C** = Coefficient of discharge for weir flow (~2.5 to 3.1 for free flow)
- **L** = Effective length of the weir
- **H** = Difference between energy elev. upstream and road crest

**High Flow - Pressure & Weir**

**High Flow - Submergence**

\[ Q_{\text{submerged}} = Q_{\text{free}} \cdot \text{Reduction Factor} \]

Submergence = \( \frac{H_2}{H_1} \)
High Flow - Submergence

- When bridge deck is a small obstruction to the flow and not acting like a pressurized orifice, use **energy method**.
- When overtopped and tailwater is not submerging flow, use **pressure/weir method**.
- When overtopped and highly submerged, use **energy method**.

Adding the Bridge

Locating Cross-Sections Near Bridges
Locating Cross-Sections Near Bridges

- Equipotential lines: Lc is a distance from the bridge where the flowlines remain parallel to the main flow direction and there is no contraction.

Lc and Le can be determined by field investigation during high flow or can be computed.

The contraction and expansions are normally taken as linear in HECRAS.
**Expansion**

\[ ER = 0.421 + 0.485 \left( \frac{F_{c2}}{F_{c1}} \right) + 1.8 \times 10^{-5} (Q) \]

- \( F_{c2} \): Froude number at section 2
- \( F_{c1} \): same at section 1

**Contraction/Expansion Ratio**

**Rule of Thumb:**

- \( ER = 2:1 \)
- \( CR = 1:1 \)

**Contraction**

\[ CR = 1.4 - 0.333 \left( \frac{F_{c2}}{F_{c1}} \right) + 1.86 \left( \frac{Q_{ob}}{Q} \right)^2 - 0.19 \left( \frac{n_{ob}}{n_c} \right)^{0.5} \]

- \( Q_{ob} \): discharge conveyed at the two overbank sections (cfs).
- \( Q \): total discharge in the section (cfs)
- \( n_{ob} \): Manning for the overbank sections
- \( n_c \): Manning for the channel.

**Contraction/expansion ratios - How do we use them?**

- ER: Expansion Ratio
- CR: Contraction Ratio

**Diagram:**

- Expansion Reach
- Contraction Reach
- Rule of Thumb: \( ER = 2 \)
- \( CR = 1 \)
**Example Computation of Le and Lc**

- **Given:**
  - Fully expanded flow top width at Cross Section 1 = 300 feet
  - Fully expanded flow top width at Cross Section 4 = 250 feet
  - Distance from Point B to Point C (bridge opening width) = 40 feet
- **Find:**
  - Recommended locations of Cross Sections 1 and 4
  - \( \text{Le} = 2 \times \frac{(300 - 40)}{2} = 260 \) feet downstream of bridge
  - \( \text{Lc} = 1 \times \frac{(250 - 40)}{2} = 105 \) feet upstream of bridge

*This assumes \( ER=2 \) and \( CR=1 \)*

---

**Expansion & Contraction Coefficients**

**Table: Expansion & Contraction Coefficients**

<table>
<thead>
<tr>
<th></th>
<th>Contraction</th>
<th>Expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Transition</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gradual Transition</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Typical Bridge Transition</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Abrupt Transition</td>
<td>0.6</td>
<td>0.8</td>
</tr>
</tbody>
</table>

---

**Expansion and Contraction**

**Example of Coefficients at Bridge XS’s**

<table>
<thead>
<tr>
<th>Cross-Section</th>
<th>Expansion</th>
<th>Contraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 (furthest US)</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>1 (furthest DS)</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Use Cc =**

- 0.3
- 0.3
- 0.3
- 0.1

**Use Ce =**

- 0.5
- 0.5
- 0.5
- 0.3
Ineffective Flow Areas

At XS’s 2 & 3

The ineffective area option is used at bridge sections 2 & 3 to keep all the active flow in the area of the bridge opening until the elevations associated with the left and/or right ineffective flow areas are exceeded by the computed water surface elevation!!!

Ineffective Flow Areas

- Enter stations that represent the active flow area at the cross section
  - (Adjust lateral distance for bounding sections distance from bridge)
- Enter elevation that allows overbank areas to become effective when exceeded
- Rule of Thumb:
  - XS-2 > Use elevation = (low chord + top of road)/2 for first estimate
    - Assume ER=2:1 if flow can freely transition in out of bridge
    - Width should normally be as wide or wider than bridge opening
  - XS-3 > Elevation should be set at top of road or slightly lower (0.1’-0.2’)
    - Assume a CR of 1:1 in the immediate vicinity of the bridge

Ineffective Flows

Define Ineffective Flow Areas if Needed
- From Bridge data page or from XS Options (Select “Ineffective Flow Areas”)
**Bridge Data**

**Ineffective Flow Worksheet**

<table>
<thead>
<tr>
<th>Project:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge or Culvert Description:</td>
<td></td>
</tr>
<tr>
<td>Station:</td>
<td></td>
</tr>
</tbody>
</table>

**Bridges:**

<table>
<thead>
<tr>
<th>U.S. High Chord Elevation:</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offset (ft)</td>
<td>Ineff. Flow Sta.</td>
<td></td>
</tr>
<tr>
<td>U.S. Abutment Station Left:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. Abutment Station Right:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.S. Abutment Station Left:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.S. Abutment Station Right:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.S. Bridge HC Elev. Left:</td>
<td>D.S. Bk HC Elev. Right:</td>
<td></td>
</tr>
<tr>
<td>D.S. Bridge LC Elev. Left:</td>
<td>D.S. Bk LC Elev. Right:</td>
<td></td>
</tr>
</tbody>
</table>

**Culverts:** (U.S.)

<table>
<thead>
<tr>
<th>C.L. Left</th>
<th>Span/2</th>
<th>Offset</th>
<th>Ineff. Flow Sta. Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.L. Right</td>
<td>Span/2</td>
<td>Offset</td>
<td>Ineff. Flow Sta. Right</td>
</tr>
</tbody>
</table>

**Culverts:** (D.S.)

<table>
<thead>
<tr>
<th>C.L. Left</th>
<th>Span/2</th>
<th>Offset</th>
<th>Ineff. Flow Sta. Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.L. Right</td>
<td>Span/2</td>
<td>Offset</td>
<td>Ineff. Flow Sta. Right</td>
</tr>
</tbody>
</table>

**D.S. Invert Elev:**

| + Rise (ft): | |
| D.S. Crown (Low Chord Elev): | |
| D.S. High Chord Elevation: | |
| Avg. HC + LC Elev (D.S. Ineff. Flow Elev): | |

**Graphic to assist in visualizing the data at bridges:**

Q: How would the flow expand below these bridges?
Adding the Bridge

- Select the Brdg/Culv button from the geometry data window:

Adding the Bridge

- This brings up the Bridge Culvert Data window:

Adding the Bridge

There are several other options in the options menu from the bridge data window as well as the view menu.

Adding the Bridge

From the options menu, select 'Add a Bridge and/or Culvert':
Adding the Bridge

- This brings up a window with the adjacent upstream and downstream cross-sections plotted:

Deck/Roadway

- Next, select the Deck/Roadway button from the Bridge data window:

Deck/Roadway

Notice the weir coefficient and max submergence window are showing the default values:

Deck/Roadway

Enter the data for the required values. Note that the U.S. and D.S. sideslopes (SS) are for cosmetic purposes only*

*unless using the WSPRO method for low flow
Use the “Copy Up to Down” button to repeat the station-high chord-low chord data from the upstream to the downstream side, if applicable:

Deck/Roadway

After selecting OK from the bridge deck window, it replots the U.S. and D.S. x-sections showing the bridge deck:

Q: What is the extent of the bridge deck on these bridges?
Piers

- Piers can be added by selecting the Pier button from the bridge data window:

  ![Pier Data Editor](image1)

  This brings up the Pier Data Editor where you can add the data for the pier(s):

  ![Pier Data Editor](image2)

  Use the “Copy Up to Down” button, if applicable:

  ![Pier Data Editor](image3)

  The pier is then shown graphically on the plot:

  ![Pier Plot](image4)

Bridge Modeling Approach

- The modeling options, including low flow and high flow modeling methods, are available by selecting the Bridge Modeling Approach button:

  ![Bridge Modeling Approach](image5)
This brings up Bridge Modeling Approach Editor window. Notice the option to compute each type of low flow method and the option to select which one you use:

Q: Is using highest energy always a good idea?

Note the:

Orifice Coef. - between 0.7 and 0.9

Click on it to get a table of values
Unique Bridge Problems

- Debris
- Parallel Bridges
- Bridges on a Skew
- Examples

Debris

- What about debris?
- Check “Floating Debris” on pier data editor
- Enter rectangular dimensions

Parallel Bridges

- If very close could be modeled as one, OR two linked with 1 Cross Section
- If flow expands between, add sections to model transition.

Two bridges do not necessarily have twice the loss
**Bridges on a Skew**

- Skew increases pier width & decreases bridge opening
- Bridge skew up to 20° show no additional flow problems
- Projected width of bridge based on cosine of skew angle

---

**Use Skew Bridge/Culvert option on bridge/culvert editor**

**Q: What are the modeling issues?**
Q: What aspects of these bridges do you need to model in HECRAS?