Innovative, Cost-Effective Options for Short Span Steel Bridge Design

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Why Short Span Bridges?

- Roughly 600,000 bridges in the United States.
  - Majority of bridges are in the short-span range (40-140 feet)
Why Steel?

- Flexibility in design –
  - infinitely variable sizes,
  - numerous strength levels,
  - painted or unpainted,
  - numerous available deck systems
  - Allows innovative, cost effective designs
  - Modular and rapid designs possible
- Can be used in challenging applications;
  - curved girders,
  - restricted clearances,
  - easier to retrofit and repair
- Lighter weight structures; to transport and erect
- Because of above lends itself to life-cycle-cost analyses -
  100% recyclable, sustainability
- Aesthetic appeal
• Bridge engineers are well trained on the use of short span concrete bridges.
  – In fact, over than 80% of the short span bridges in the United States (possibly more in Mexico and Canada) are made of concrete.

• County and Department of Transportation (DOT) engineers are simply not educated on the design, construction, and economics of short span steel bridges.
Concrete provides simple, standardized, cost-effective, “tinker toy” solutions to construct short span steel bridges.

Steel bridges are too complex, “Swiss watch”-like, and too expensive.
Case Study Bridges: Audrain County, MO

- **MO Bridge 411**
  - Built 2012
  - 4 Steel Girders
  - 47.5 ft Span
  - 24 ft Roadway Width
  - 2 ft Structural Depth + Slab

- **MO Bridge 336**
  - Built 2012
  - 6 Precast Hollowcore Slabs
  - 50.5 ft Span
  - 24 ft Roadway Width
  - 2 ft Structural Depth + Slab
Case Study Bridges: Audrain County, MO

- **Steel:**
  - Total Bridge Costs:
    - Material = $41,764
    - Labor = $24,125
    - Equipment = $21,521
    - Guardrail = $7,895
    - Rock = $8,302
    - Engineering = $8,246
    - TOTAL = $111,853

- **Concrete:**
  - Total Bridge Costs:
    - Material = $67,450
    - Labor = $26,110
    - Equipment = $24,966
    - Guardrail = $6,603
    - Rock = $7,571
    - Engineering = $21,335
    - TOTAL = $154,035
Case Study Bridges: Audrain County, MO

- **Steel:**
  - Total Cost per ft\(^2\):
    - Total Cost = $97.48/ft\(^2\)
    - Construction = $90.29/ft\(^2\)
      - No Engineering
    - Adjusted = $83.05/ft\(^2\)
      - No Engineering or Rock

- **Concrete:**
  - Total Cost per ft\(^2\):
    - Total Cost = $120.82/ft\(^2\)
    - Construction = $104.08/ft\(^2\)
      - No Engineering
    - Adjusted = $98.14/ft\(^2\)
      - No Engineering or Rock
## Case Study Bridges: Audrain County, MO

### Steel:
- **Superstructure Only:**
  - Start to finish = 10 days
  - Girders = $21,463
  - Deck Panels = $7,999
  - Reinf. Steel = $3,135
  - Concrete = $4,180
  - Labor = $5,522
  - Equipment* = $500
  - **TOTAL** = $42,799
  - **=** $37.54 / ft$^2$

### Concrete:
- **Superstructure Only:**
  - Start to finish = 13 days
  - Slab Girders = $50,765
  - Deck Panels = $0
  - Reinf. Steel = $724
  - Concrete = $965
  - Labor = $4,884
  - Equipment* = $4,000
  - **TOTAL** = $61,338
  - **=** $50.61 / ft$^2$

*County crane (30-ton) used for steel; Larger rented crane required for concrete
(equivalent county crane cost is $1,520, would result in steel cost of $38.88 / ft$^2$)
Case Study Bridges: Audrain County, MO

- **Steel:**
  - Superstructure total cost of $37.54 per ft$^2$

- **Concrete:**
  - Superstructure total cost of $50.61 per ft$^2$

**Cost increase of 25.8%**

**Same bridge conditions:**
- Structural Depth = 2 ft + Slab (No Difference in Approaches)
- Roadway Width = 24 ft
- Same Abutments for Both Can be Used (Steel Could Use Lighter)
- Same Guard Rail System
- Same Work Crew
Advantages of Steel Bridge (MO Bridge 411)

• Lighter cranes required:
  – Owner cranes can save costs.
Advantages of Steel Bridge (MO Bridge 411)

- Lighter abutments possible for steel bridges.
Advantages of Steel Bridge (MO Bridge 411)

- Cast-in-place deck on prestressed concrete deck panels
Advantages of Steel Bridge (MO Bridge 411)

- Simple and practical details:
Advantages of Steel Bridge (MO Bridge 411)

- Elastomeric bearings and integral abutments:
Advantages of Steel Bridge (MO Bridge 411)

• Use of weathering steel:
# Case Study Bridges: Other Bridges in MO

<table>
<thead>
<tr>
<th>Superstructure</th>
<th>Steel</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge Number</td>
<td>061 140 149 152 710</td>
<td>AVG 028 057 069 520 AVG</td>
</tr>
<tr>
<td>Span Length</td>
<td>50 50 40 62 64</td>
<td>53.2</td>
</tr>
<tr>
<td>Skew</td>
<td>0 0 0 30 35</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>0 15 20 30</td>
<td>16.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cost Summary</th>
<th>Steel</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Labor</td>
<td>$14,568 $21,705 $15,853 $24,765 $31,949</td>
<td>$21,768</td>
</tr>
<tr>
<td>- Material</td>
<td>$56,676 $53,593 $46,282 $92,821 $69,357</td>
<td>$63,746</td>
</tr>
<tr>
<td>- Rock</td>
<td>$6,170 $6,216 $3,694 $8,235 $6,501</td>
<td>$6,163</td>
</tr>
<tr>
<td>- Equipment</td>
<td>$7,487 $12,026 $7,017 $19,579 $15,266</td>
<td>$12,275</td>
</tr>
<tr>
<td>- Guardrail</td>
<td>$4,715 $7,146 $3,961 $7,003 $7,003</td>
<td>$5,966</td>
</tr>
</tbody>
</table>

| Construction Cost | $89,616 $100,686 $76,807 $152,403 $130,076 | $109,918 |

| CONST. COST PER FT² | $74.68 | $83.91 | $80.01 | $102.42 | $84.68 | $86.09 | $91.54 | $107.63 | $95.48 | $91.23 | $96.32 |
Standardized designs for short span steel bridges

BTC led a 3-year industry-wide effort (owners, fabricators, designers, associations, service centers, etc. involved)

- Over 3,000 designs evaluated
- Result = **simple** standardized designs for short span bridges
  - Rolled beam, plate, & buried soil steel structures
- Standards used to develop eSPAN140
  - 650 total preliminary bridges designed
  - Adding abutments, substructure, CSP enhancements, metric, and Canadian designs in next 12 months.
- BTC working with Mexico & Canada to develop MEX/CAN version
- BTC working with AASHTO for designs to become a national guideline
Standard Short Span Steel Bridge Designs

• **Goal:**
  - Economically competitive
  - Expedite and economize the design process
  - Simple repetitive details and member sizes.

• **Bridge Parameters:**
  - Span lengths: 40 ft to 140 ft (in 5 ft increments)
  - Girder spacing: 6 ft, 7.5 ft, 9 ft and 10.5 ft
  - Homogeneous and hybrid plate girders with limited plate sizes
  - Limited depth and lightest weight rolled sections
  - Selective cross-frame placement & design
Weight Comparisons

Graph showing weight comparisons across different span lengths for Homogeneous Plate, Hybrid Plate, Limited Depth, and Lightest Weight.
Free Online Design Tool for Short Span Steel Bridges

Developed by the Short Span Steel Bridge Alliance

http://www.espan140.com/
eSPAN140 provides:

- **Standard designs and details for short span steel crossings**
  - Rolled Beam and Plate Girders
  - Corrugated Steel Pipe and Structural Plate

- **Manufacturers’ Steel Solutions (SSSBA Partners)**

- **Coatings Solutions**

- **Industry Contacts**
  - Contacts can provide budget estimates and pricing information

One-stop shop for customized steel bridge and culvert solutions located at www.eSPAN140.com
eSPAN140

- eSPAN140 is an easy-to-use and free resource for bridge engineers & owners.
- In 3 easy steps, multiple steel solutions are recommended!

Step 1.
Create a User’s Account

Step 2.
Input Your Specific Project Details

Step 3.
View Your Instant Customized Solutions Books
• Start new project:

My Projects

Welcome to eSPAN140. If this is your first time here, please click on “Start New Project” to begin.

If you have already created a project, please use the table below to view past projects, complete past existing inputs you provided, please click on “Duplicate”. This will allow you to create a new project if you have multiple bridges to design and have only a few input values to change.)
- Range of available solutions:

<table>
<thead>
<tr>
<th>Solution Type*</th>
<th>Bridge Span Length</th>
<th>Skew Angle</th>
<th>Overhang Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled Beam (40' to 100')**</td>
<td>0'</td>
<td>+/- 20 degrees</td>
<td>3'3&quot; or less</td>
</tr>
<tr>
<td>Homogeneous Plate Girder (60' to 140')**</td>
<td>40'</td>
<td>+/- 20 degrees</td>
<td>3'3&quot; or less</td>
</tr>
<tr>
<td>Hybrid Plate Girder (80' to 140')**</td>
<td>80'</td>
<td>+/- 20 degrees</td>
<td>3'3&quot; or less</td>
</tr>
<tr>
<td>Corrugated Steel Pipe/Structural Shape (0' to 85')</td>
<td>0'</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td>Manufacturer's Steel Solutions (all)</td>
<td>0'</td>
<td>All</td>
<td>All</td>
</tr>
</tbody>
</table>

*Solution Type:
* **: Indicates specific length range.
• Step 1: Project Information

- **Project Name**: Sample Bridge
- **City/County**: Morgantown
- **State/Province**: West Virginia
- **Roadway Name**: Main Street
- **Bridge Span Length**: 82 \( \text{Feet} \) 4 \( \text{Inches} \)

[Next > Return to Projects]
• Step 2: Project Details (general dimensions)
- Step 2: Project Details (pedestrian access option)
Step 2: Project Details (remaining details)

- Skew Angle: 15 Degrees
- Average Daily Traffic: Over 2,000
- Design Speed: Not applicable

Diaphragm Spacing (Equal)
Span Length
• Step 3: Customized Solutions Book is Provided (pdf)

Standard Design and Details of Short Span Steel Bridges Solutions
  • Rolled Beam Recommendations
  • Plate Girder Recommendations

Standard Design and Details of Corrugated Steel Pipe and Structural Plate Solutions

Manufacturer’s Steel Solutions (SSSBA Partners)
  • Customized Solutions from Members of the SSSBA

Durability Solutions (SSSBA Partners)
  • Galvanized & Paint
  • Weathering Steel

Additional Contact Information
  • Producers
  • Service Centers
  • Fabricators
  • Fasteners
  • Coaters
  • Industry Organizations
Design Example

• Sample plate girder (homogeneous) elevation:
Design Example

- Sample plate girder (homogeneous) data:

<table>
<thead>
<tr>
<th>SPAN (L) - ft</th>
<th>TOP FLANGE - in</th>
<th>BOTTOM FLANGE (F)</th>
<th>BOTTOM FLANGE (G)</th>
<th>WEB PLATE - in</th>
<th>DIAPHRAGM SPACING (C) - ft</th>
<th>SHEAR STIFFENERS</th>
<th>SHEAR CONNECTOR MAX. SPACING</th>
<th>INDIVIDUAL GIRDER WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>14 x 3/4&quot;</td>
<td>14 x 1&quot;</td>
<td>17&quot;</td>
<td>14 x 2&quot;</td>
<td>51&quot;</td>
<td>-</td>
<td>34 @ 6&quot;</td>
<td>14,144 lbs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STEEL D.L. CAMBER - in</th>
<th>TOTAL D.L. CAMBER - in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  0.251&quot;</td>
<td>4  5.545&quot;</td>
</tr>
<tr>
<td>2  0.469&quot;</td>
<td>5  5.288&quot;</td>
</tr>
<tr>
<td>3  0.636&quot;</td>
<td>6  4.538&quot;</td>
</tr>
<tr>
<td>4  0.742&quot;</td>
<td></td>
</tr>
<tr>
<td>5  0.778&quot;</td>
<td></td>
</tr>
</tbody>
</table>
Design Example

• Sample rolled beam (lightest weight) elevation:

**COMPOSITE ROLLED BEAM WITH PARTIALLY STIFFENED WEB - 4 GIRDERS AT 8' 10" GIRDER SPACING, LIGHTEST WEIGHT**
Design Example

- Sample rolled beam (lightest weight) data:

<table>
<thead>
<tr>
<th>SPAN (L) - ft</th>
<th>SELECTED SECTIONS</th>
<th>DIAPHRAGM SPACING (C) - ft</th>
<th>SHEAR CONNECTOR MAX SPACING</th>
<th>WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>W36x247</td>
<td>21.25”</td>
<td>36 @ 6”</td>
<td>9”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20,995 lbs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STEEL D.L. CAMBER - in</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>TOTAL D.L. CAMBER - in</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.219</td>
<td>0.415</td>
<td>0.568</td>
<td>0.666</td>
<td>0.698</td>
<td>1.268</td>
<td>2.381</td>
<td>3.259</td>
<td>3.817</td>
<td>4.008</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Design Example

- Typical girder elevation:
Design Example

• **Typical stiffener details:**

- **BEARING STIFFENER**
  (N.T.S.)
  BEARING STIFFENER TO FLANGE WELDING IS REQUIRED IF A DIAPHRAGM OR CROSS FRAME IS ATTACHED TO THE STIFFENER

- **SHEAR STIFFENER**
  (N.T.S.)

- **CLIP NOT REQUIRED**
  SEE STANDARD CLIPS & WELD TERMINATION DETAIL

- **FIT TO BEAR. NOTE 2**

- **NOTE 3**

- **£ \( \frac{1}{2} \) ” x 5”**
  SEE STANDARD CLIPS & WELD TERMINATION DETAIL
  CONNECTION STIFFENER (N.T.S.)
Design Example

• Typical diaphragm details:
Design Example

• Typical section details:
Design Example

- Typical bearing details:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>INTERNAL ELASTOMER LAYERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>16“</td>
<td>18“</td>
<td>4.375“</td>
<td>12“</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.625“</td>
</tr>
</tbody>
</table>
Proposed Press-Brake-Formed Tub Girder System

- Bridge Technology Center:
  - Modules with steel press-brake tub girders
    - Galvanized or weathering
  - Modules are joined using UHPC longitudinal closure pours
  - Modules can be shipped to site pre-topped or with a variety of deck options
Experimental Testing

- Testing was conducted on composite flexural specimens:
  - 84” × 7/16” PL
  - Dimensions shown below:
Experimental Testing (cont’d)
Experimental Testing (cont’d)
Experimental Testing (cont’d)
Analytical Methods

- FEA was completed using Abaqus v.6.10-EF2
  - S4R shell elements were employed to simulate the girder and deck
  - von Mises material laws governed steel behavior
  - A smeared cracking model incorporating tension stiffening was employed for concrete behavior
AASHTO Flexural Capacity

- In order to evaluate the applicability of AASHTO Specifications, a parametric matrix of composite girders was developed (resulting in 900 girders):
  - 18 girders (previously described)
  - 50-ksi and 70-ksi steel employed
  - 25 deck options
    - 5 deck thicknesses (7” to 11” in 1” increments)
    - 5 deck widths (defined based on out-to-out width of the girder

\[
M_n = \begin{cases} 
M_p & D_p \leq 0.1D_t \\
M_p \left(1.025 - 0.25 \frac{D_p}{D_t}\right) & 0.1D_t < D_p \leq 0.42D_t
\end{cases}
\]
Feasibility Assessments

• Assessments were conducted according to AASHTO:
  – Spans ranged from 20’ – 140’ in 5’ increments
  – The following limit states were evaluated:
    • Strength I (for moment and shear):
      – 1.25 DC + 1.50 DW + 1.75 (LL+IM)
    • Service II (for moment):
      – 1.00 DC + 1.00 DW + 1.30 (LL+IM)
    • Live load deflection:
      – Limited to L/800
Feasibility Assessments (cont’d)

Strength I Moments: PL 96" × 1/2"

- **Moments, M (ft-kip)**
- **Span Length, L (ft)**

- **Strength I Moments**
- **Design Capacity (AASHTO)**
- **Design Capacity (Proposed)**
Standardization

- Standardization of the matrix of girders was also performed:
  - Based on plate availability.
- The matrix was reduced based on standard sizes:
  - 72”, 96”, and 120” plate widths are the most common.
  - Virtually all mills produce 1/2” plate.
  - (Garrell 2011)
Standardization (cont’d)

- Therefore, based on plate availability and the feasibility of the modular system, the following standardized girders are proposed:
  - PL 72” × 1/2”
    - Applicable for spans up to 40 feet
  - PL 96” × 1/2”
    - Applicable for spans up to 60 feet
  - PL 120” × 5/8”
    - Applicable for spans up to 80 feet
  - Double PL 60” × 1/2”
    - Applicable for spans up to 65 feet
Benefits of Proposed System

• WVU system advantages:
  – Utilizes standard plate widths (based on availability)
  – Optimized to achieve maximum structural capacity
    • Majority of steel in the bottom flange
    • Increased torsional stiffness
  – Equations for girder design have been provided.

• Versatile for multiple deck options.
Benefits of Proposed System (cont’d)

- Full-depth panel:
- Partial-depth panel:
Benefits of Proposed System (cont’d)

- Pre-topped:
- Sandwich plate:
Benefits of Proposed System (cont’d)

• Currently, the BTC is working with Buchanan Co. IA on an IBRD project on a press-brake-formed tub girder demonstration project.
  – WVDOH is also working on a demo project as well

• We are also looking for opportunities with other agencies interested in deploying this technical concept!
Questions?

Thank You!

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