Development of a Modular Press-Brake-Formed Steel Tub Girder for Short-Span Bridge Applications

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Outline

• Background
• Proposed System Details
• Experimental Testing
• Analytical Methods
• Assessment of Flexural Capacity
• Feasibility Studies
• Benefits of Proposed System
Background

- Concept has been in place since 1970s
  - “Prefabricated Press-Formed Steel T-Box Girder Bridge System”
    - AISC Engineering Journal
    - Taly & GangaRao, 1979

(Significant input into the original concept development was given by Dr. Larry Luttrell, a key authority on cold bending of steel.)
Background (cont’d)

• Why didn’t this take off?
  – Concrete deck option would require refinement of expensive fabrication details
  – Lack of proof of concept testing
  – Lack of industry support

• Similar systems have been proposed that include:
  – Prestressing components
  – Inefficient girder cross-sections
  – Complex fabrication details
Current Systems

- Tokai University system:
  - “Bending Behavior of Composite Girders with Cold Formed Steel U Section”
    - Journal of Structural Engineering
    - Nakamura 2002

- System contains prestressing:
  - Requires longitudinal post-tensioning in deck
  - Increases complexity/cost

- Structurally inefficient:
  - Small bottom flange
Current Systems (cont’d)

- Tricon Con-Struct:
  - Pretopped modules with galvanized steel press-brake-formed tub girders
  - System contains prestressing:
    - Increases complexity/cost
    - Limited fabricators to implement Con-Struct
    - Decreases skew options
    - Limits deck options
- Plates are 3/8” thick (susceptible to corrosion)
Proposed 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
Short-Span Steel Bridge Alliance
Design Methodology

- **Goal:** utilize standard plate widths
  - 84”, 96”, etc.
- **Maintain 1:4 web slope, “5t” radii, and 6” $b_{tf}$**
  - Consistent w/ AASHTO Spec.
- **Optimize girder dimensions to attain maximum capacity**
Design Methodology (cont’d)

Design Iterations: 96" Standard Plates

- Yield Moment, $M_y$ (ft-kip)
- Total Girder Depth, $d$ (in)
- $t = 7/16$ in
- $t = 1/2$ in
- $t = 5/8$ in
Design Methodology (cont’d)

- Resulting girder depths:
  - 60” plate: \( d = 12” \)
  - 72” plate: \( d = 17” \)
  - 84” plate: \( d = 23” \)
  - 96” plate: \( d = 26” \)
  - 108” plate: \( d = 30” \)
  - 120” plate: \( d = 34” \)
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
Analytical Methods (cont’d)

• Using strain-compatibility methods, estimates of girder capacity were obtained:
  – Steel was assumed to behave linearly until $F_y$
  – Concrete in compression was assumed to have a uniform stress of $0.85 f_c'$
  – Neutral axis depth was iterated until equilibrium was attained.
    • Moments were then summed to obtain capacity.
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
AASHTO Flexural Capacity (cont’d)

- For a composite girder to be considered compact:
  - \( F_y \leq 70 \text{ksi} \)
  - \( D/t_w \leq 150 \)
    - True for all 18 girders
  - The following limit must be satisfied:
    \[
    \frac{2D_{cp}}{t_w} \leq 3.76 \sqrt{\frac{E}{F_{yc}}}
    \]
According to AASHTO Specifications, for compact composite girders, the following model is used to compute the capacity:

\[
M_n = \begin{cases} 
M_p & D_p \leq 0.1D_t \\
M_p \left(1.07 - 0.7 \frac{D_p}{D_t}\right) & 0.1D_t < D_p \leq 0.42D_t 
\end{cases}
\]
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\[
M_n = \begin{cases} 
M_p & D_p \leq 0.1D_t \\
M_p \left(1.025 - 0.25 \frac{D_p}{D_t}\right) & 0.1D_t < D_p \leq 0.42D_t 
\end{cases}
\]
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"

![Graph showing Moments vs Span Length]

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

Where:
- Moments, M (ft-kip)
- Span Length, L (ft)
Feasibility Assessments (cont’d)

**Strength I Shears: PL 96" × 1/2"

- **Shears, V (kip)**
  - 0 to 350
- **Span Length, L (ft)**
  - 0 to 160

- **Graph Legend**
  - Blue dots: Strength I Shears
  - Red line: Design Capacity (AASHTO)
Feasibility Assessments (cont’d)

Service II Moments: PL 96" × 1/2"

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

- Blue line: Service II Moments
- Red line: 0.95 Yield Moment
Feasibility Assessments (cont’d)
Feasibility Assessments (cont’d)

- All girders were governed by flexure at the Strength Limit State except one (governed by live load deflection):
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
Economic Assessments

• The system was also compared with traditional short-span solutions to assess its economic competitiveness:

• Traditional solutions included:
  – eSPAN140: Complimentary Solutions for Short-Span Steel Bridges
    • Rolled beams
    • Homogeneous/hybrid plate girders
  – Standardized Prestressed Concrete Solutions (Idaho Transportation Department)
    • AASHTO girders
    • Bulb-tee girders
    • WF girders
Economic Assessments (cont’d)

• Assumptions (eSPAN140)
  – Slab $f'_c = 4$ ksi
  – DW = 25 psf
  – Concrete barriers used
  – Deck thickness:
    • 8.25” w/ 0.25” IWS
  – Slab = 150 pcf

• Assumptions (ITD)
  – Slab $f'_c = 4$ ksi
  – DW = 28 psf
  – Concrete barriers used
  – Deck thickness:
    • (S+10’) /30’
    • 8” min. w/ 0.25” IWS
  – Slab = 150 pcf
Economic Assessments (cont’d)

- Results of economic assessments:
Economic Assessments (cont’d)

- Results of economic assessments:

![Graph showing girdle weight vs. span length](image_url)
Economic Assessments (cont’d)

- Results of economic assessments:
Economic Assessments (cont’d)

- Results of economic assessments:
Benefits of Proposed System

• 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 two demonstration projects as well.

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

Thank You!