JOINT TRANSPORTATION RESEARCH PROGRAM

Principal Investigator: Ashley P. Thrall, University of Notre Dame, athrall@nd.edu, 574.631.2533

Program Office: jtrp@purdue.edu, 765.494.6508, www.purdue.edu/jtrp

Sponsor: Indiana Department of Transportation, 765.463.1521

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A New Approach to Accelerated Fabrication of Steel Bridges: Design, Optimization, and Demonstration

Introduction

The aim of this research was to develop and demonstrate a new approach to the accelerated fabrication of resilient steel bridges—built-up press-brake formed tub girders (PBTGs). In contrast to existing PBTGs that are cold bent from a single steel plate, this is a built-up system in which webs are cold bent and bolted to separate, flat, bottom and top flange plates. Fabrication can be fast and inexpensive since the flanges are flat plates with drilled holes and the webs are flat plates that are cold bent in two locations in opposing directions. The system offers enhanced versatility, as this is a “kit-of-parts” where different sizes of components can be utilized to achieve required capacities or span lengths (e.g., thicker bottom flanges for negative moment regions, deeper webs for longer spans). Utilizing built-up sections joined by bolts provides internal member redundancy as crack propagation between components is arrested.

Specific research objectives included: (1) designing and building a simply supported and a two-span continuous demonstration bridge; (2) measuring the behavior of the demonstration bridges as experimental evidence demonstrating performance; and (3) developing a kit-of-parts system to facilitate adoption of this technology among Departments of Transportation nationwide.

Importantly, this research culminated in the design and construction of two demonstration bridges: (1) a 29.6-m (97-ft) simple span bridge with no skew in Noblesville, IN, and (2) a 32.0-m and 26.2-m (105-ft and 86-ft) two-span continuous bridge with 15-degree skew in New Pekin, IN. HNTB Corporation designed the demonstration bridges. The contributions of Ted Zoli, Tom Bieneman, Skyler Coombs, and Angela Pearl are gratefully acknowledged.

Findings

Findings from the design of the demonstration bridges using research-level finite element (FE) numerical modeling included the following.

- Stresses under dead and live loads (without load factors) were well below the yield strength (i.e., less than 30% of the yield strength). Considering a Strength I load combination, the stress increased but remained less than 45% of the yield strength.
- Fatigue stress ranges for the steel sections were well below the nominal fatigue resistance for Category B design details for both positive and negative moments, with peak values being less than 25% of this limit.
- Stability factors during construction for both bridges exceeded 14, which demonstrated the safety and constructability of the system.
- Dynamic and static evaluations of internal redundancy indicated that built-up PBTGs were able to redistribute load effectively if either a web or bottom flange was fractured.
- If a web or bottom flange was fractured, the resulting high-velocity stress wave created strain rates in the dynamic region. As this type of event and the cold bending fabrication process both reduced the fracture toughness of the steel, it was important to evaluate the fracture toughness of steel used in built-up PBTGs.
- The long-term behavior of the faulted structure, evaluated via nonlinear static analyses, indicated a negligible loss of stiffness when either a web or bottom flange was fractured, as compared to an undamaged structure.

Findings from the demonstration bridge fabrication and erection included the following.

- Stock material for webs should be selected based on material certifications to validate bend radii.
- For skew bridges, align diaphragms orthogonal to the girders, as opposed to with the skew.
- Further development is recommended to limit the number of different pieces (e.g., partial lateral bracing).
- A complete list of lessons learned, as well as challenges to be overcome and opportunities to promote wider adoption can be found in the conclusions section of this report.

Findings from the measured behavior of the demonstration bridges included the following.

- Overall, the measured longitudinal surface strains of the webs and flanges of the girders for both demonstration bridges were very low, indicating the conservatism of the design. Assuming a modulus of elasticity of 200 GPa (29,000 ksi), the measured strains corresponded to a peak stress 9.31 MPa (1.35 ksi) in the flange for the simple span bridge when subjected to positive moment loading (i.e., 2.70% of the yield strength). Positive values indicated tension and positive moment referred to compression on the top and tension on the bottom. For the two-span continuous bridge, the measured strains corresponded to a peak stress of 16.8 MPa (2.44 ksi) in the flange when subjected to positive moment loading (i.e., 4.88% of the yield strength) and -9.72 MPa (-1.41 ksi) in the flange when subjected to negative moment loading (i.e., 2.82% of the yield strength).
- There was generally close agreement between the measured data and the FE predictions, which validated the FE modeling approach. Considering the peak positive moment regions, the peak percent difference was 19.6% for the simple span and 13.6% for the two-span continuous bridge.
- The measured neutral axis, as compared to analytical and FE predictions, indicated that the rail was participating in carrying live load.
- The live load distribution factors in current American bridge design code are conservative for built-up PBTGs.

Findings from the development of the kit-of-parts included the following.

- Both design-level FE modeling and line girder analysis methods were suitable for design, if the designer understands the limits of each approach and accounts for them appropriately. Although CSi-Bridge was used as the FE software program for the design-level models in this research, other software programs may be appropriate.
- Two differing strategies were used to develop two alternatives for the kit-of-parts.
  - *Kit-of-Parts A–Least Number of Parts*, where only five web parts were used to achieve all the span arrangements and span lengths.
  - *Kit-of-Parts B–Shallowest Superstructure Depth*, where the number of web parts increased to seven, but shallower superstructure depths were achieved for some span arrangements and lengths.

Implementation

Implementation included the design and construction of the two demonstration bridges in Indiana. The simple span bridge (SR-32 over Stony Creek in Noblesville, IN) received a National Steel Bridge Alliance Prize Bridge Award. Research findings have been disseminated in one published journal paper, one journal paper in review, additional forthcoming papers, one PhD dissertation, and eight conferences, with two additional conference presentations planned.

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