Best Practice to Evaluate, Rehab, and Replace Local Road Bridges

Lucas Bohn, Zach Carnahan, Michael Mingo, Sandip Rimal, Mostafa Tazarv, & Nadim Wehbe
Department of Civil and Environmental Engineering
South Dakota State University

Presenter: Mostafa Tazarv, PhD, PE

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Three Research Projects: $0.5 million

- What are the common bridge types on South Dakota local roads?
- How to “Load Rating” damaged bridges?
- How to rehabilitate longitudinal joints?
- Best alternatives to replace local road bridges?
Background

Common SD Local Road Bridges & their Damages
Local Load Bridges

- Double-tee is the most common type of bridge on SD local roads.
- More than 700 DT bridges are in-service in SD.
- More than 75% of DT bridges are 20 years or older.
- Structural detailing, aging, environmental conditions, and damages are affecting the performance and load-carrying capacity of DT bridges.
Current DT Long. Joint Detailing

In-Service

Laboratory

(Wehbe et al., 2016)
What is the **safe live load capacity** of distressed double-tee bridges?
Evaluation of Existing Bridges

How to Load Rate Damaged Double-Tee Bridges?
What Was Done?

- Field tested two DT bridges.
- Performed strength testing of two 45-yr DT girders.
- Carried out an extensive analytical study to relate damage to capacity.
- Proposed a methodology for load-rating DT bridges.
# Description of Field Test Bridges

<table>
<thead>
<tr>
<th>Bridge ID</th>
<th>County</th>
<th>Span, ft. (m)</th>
<th>Damage Type and Condition State</th>
<th>Age, Yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>42165153</td>
<td>Lincoln, SD</td>
<td>42 (12.8) (Seven 30-in. (762-mm) Deep Girders)</td>
<td>Non-skewed, Spalling of stem concrete cover (with a condition state of Fair), and leakage of girder-to-girder joints (with a condition state of Poor).</td>
<td>34</td>
</tr>
<tr>
<td>51090012</td>
<td>Moody, SD</td>
<td>50 (15.24) (Eight 23-in. (584-mm) Deep Girders)</td>
<td>Non-skewed, Water leakage between all deck units, stains from minor corrosion of steel plates in longitudinal joints (with a condition state of Poor), concrete spalling (with a condition state of Fair).</td>
<td>38</td>
</tr>
</tbody>
</table>
Stains from Minor Corrosion of Steel Plates

Sign of Water Leak b/w Deck Units

Concrete Spalling at Railing

23-in Deep Double-Tee Girder Bridge
Loading Protocols

**Load Types:**

- Static Tests (5 mph)
- Dynamic Tests

**For Dynamic Tests:**

**Lincoln County**

- Shear Response = 55 mph
- Flexural Response = 35 mph

**Moody County**

- Flexural Response = 35 mph

Test Truck used for Field Testing (Similar to SD Legal Truck Type 3)

Truck Axle Weight Distribution

Truck Total Weight was 49.98 kips
Salvaged Double-Tee Girders

- Inspected two bridges in Pennington County (52-313-265 & 52-319-268).
- Selected one 50-ft and 30-ft long DT girders from the Nemo Road bridge (52-313-265).
Strength Testing of 50-ft Girder
Proposed Methodology for Load Rating

Prestressed Double-Tee Bridges
Methodology for Load Rating

Based on the data collected from the field testing, recommendations were made on the live load demand parameters in the load rating equation.

Based on the data collected from the strength testing of salvaged girders and also an extensive parametric study, modification factors were recommended to estimate the capacities of damaged girders.
Proposed Damage Types and Condition States for Double-Tee Girder Stem

<table>
<thead>
<tr>
<th>Damage Type</th>
<th>Condition States</th>
<th>CS-1</th>
<th>CS-2</th>
<th>CS-3</th>
<th>CS-4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
<td>Severe</td>
</tr>
<tr>
<td>Cover Deterioration including Delamination/ Spall/ Patched Area</td>
<td>None</td>
<td>Loss of 1/3 of the cover without exposure or corrosion of reinforcement.</td>
<td>Loss of 2/3 of the cover without exposure or corrosion of reinforcement.</td>
<td>Exposure of reinforcement without any sign of corrosion.</td>
<td></td>
</tr>
<tr>
<td>Exposed Transverse Rebar</td>
<td>None</td>
<td>Minor corrosion of the reinforcement with minimal section loss.</td>
<td>Severe corrosion of only one leg of transverse reinforcement.</td>
<td>Severe corrosion of all legs of transverse reinforcement in a section.</td>
<td></td>
</tr>
<tr>
<td>Exposed Longitudinal Prestressing</td>
<td>Exposure of reinforcement without any sign of corrosion.</td>
<td>50% section loss due to corrosion in the extreme tendon.</td>
<td>100% section loss due to corrosion in the extreme tendon.</td>
<td>Section loss due to corrosion in the two or more tendons.</td>
<td></td>
</tr>
<tr>
<td>Cracking</td>
<td>Insignificant cracks or moderate-width cracks that have been sealed.</td>
<td>Unsealed moderate width cracks or unsealed moderate pattern (map) cracking. Cracks from 0.004 to 0.009 inches wide.</td>
<td>Wide cracks or heavy pattern (map) cracking. Cracks greater than 0.009 inches wide.</td>
<td>Wide cracks or heavy pattern (map) cracking that crosses multiple shear reinforcement.</td>
<td></td>
</tr>
</tbody>
</table>

\[
\varphi_{c-M} = 1.0 \\
\varphi_{c-V} = 0.75
\]

\[
\varphi_{c-M} = 1.0 \\
\varphi_{c-V} = 0.9
\]

\[
\varphi_{c-M} = 0.90 \\
\varphi_{c-V} = 0.75
\]
Rehabilitation of Existing Bridges

How to Rehabilitate Double-Tee Girder-to-Girder Joints?
What Was Done?

- 20 Rehabilitation Joint Detailing Alternatives.
- Testing of 13 Large-Scale Beams.
- Detailed Finite Element Analysis.
- Testing of 40-ft Conventional Double-Tee Bridge.
- Rehabilitation of the Conventional DT Bridge.
- Testing of Rehabilitated Bridge.
- Recommendations.
Ultra-High Performance Concrete (UHPC)

- Fiber-reinforced cementitious concrete
- Made with very fine aggregates in size of dust
- Usually with 2% volumetric steel fibers
- Better durability than concrete
Pocket Detailing: UHPC filled pockets reinforced with steel bars.

Continuous Detailing: LMC filled joint reinforced with wire-mesh.
How to Rehabilitate Long. Joints?
Strength Testing of Rehabilitated Bridge

South Dakota State University

Lohr Structures Laboratory

Rehabilitation of Longitudinal Joints of Double-Tee Bridges

Project: SD2014-20

Strength Test Date: February 24, 2017

Full-Scale 40-ft Long Double-Tee Bridge
Bridge Replacement

Best Alternatives to Replace Local Road Bridges?
What was Done?

- Literature Review on 10 Alternatives.
- Testing of one 50-ft Long Fully-Precast Bridge.
- Testing of one 50-ft Long Girder Timber Bridge.
- Testing of one 16.5-ft Long Slab Timber Bridge.
- Evaluation and compassion with Double-Tee.
- Recommendations.
Fully-Precast Bridge – Test Model

Panel-to-Panel Joint

Full-Depth Deck Panel

Precast/Pre-stressed Inverted Bulb-Tee Girder

Hidden Pocket, Headed Studs

Full-Depth Pocket, Inverted U-Shape Bars
Glulam Bridges - Prototype

50-ft long, 34.5-ft Wide Girder Bridge

30-ft long, 34.5-ft Wide Slab Bridge
- Bridge was designed based on 26F-1.9E Southern Yellow Pine Glulam.
- Bridge was made of 24F-2.0E Southern Yellow Pine Glulam – **Construction Error**.
- Deck was made up of 11 interior 48 x 5.5 x 110.75-in. panels and 2 exterior panels with a dimension of 36 x 5.5 x 110.75 in.
- Bridge consisted of 3 girders with a dimension of 8.5 in. x 30.25 in. x 50 ft.
- Bridge was designed based on 24F-2.0E Southern Yellow Pine Glulam.
- Deck consisted of 2 interior panels with a dimension of 48 in. x 10.75 in. x 16.5 ft.
- Also consisted of 3 stiffeners with a dimension of 5.5 in. x 5 in. x 7.5 ft.
- Deck panels were connected to the stiffeners by 12 in. x 3/4 in. dia. lag bolts.
Assembly of Test Specimen
Assembled Glulam Girder Bridge and Test Setup

Test Frame

22-kip Actuators

Deck Panels

50 ft

9.3 ft

50 ft

30.25 in.

Load Cells

3.5 in.

Abutment

Cross-Frames

Middle Girder

East Girder
Assembled Glulam Slab Bridge and Test Setup
Each bridge was tested under:

- At least 0.5 million cycles of AASHTO Fatigue II loads.
- Intermediate stiffness loading.
- Strength (ultimate) loading.
Ultimate Test Results – Precast Bridge

**Midspan Deflection (mm)**

<table>
<thead>
<tr>
<th>Actuator Load, P (kips)</th>
<th>Midspan Deflection (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Load</td>
<td>263 kips (1170 kN)</td>
</tr>
<tr>
<td>Equivalent Service I Load</td>
<td></td>
</tr>
<tr>
<td>Equivalent Service III Load</td>
<td></td>
</tr>
<tr>
<td>First Cracking</td>
<td></td>
</tr>
<tr>
<td>Equivalent Strength I Load</td>
<td></td>
</tr>
<tr>
<td>Equivalent Service I Load</td>
<td></td>
</tr>
<tr>
<td>Equivalent Service III Load</td>
<td></td>
</tr>
</tbody>
</table>

**Actuator Load, P (kN)**

- 0.0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0
- 1.2

**Actuator Load, P (kips)**

- 0
- 50
- 100
- 150
- 200
- 250
- 300

**Actuator Load, P (kN)**

- 0
- 200
- 400
- 600
- 800
- 1000
- 1200

**Midspan Deflection (mm)**

- 0
- 5
- 10
- 15
- 20
- 25
- 30

**Actuator Load, P (kips)**

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1.0
- 1.2

**Actuator Load, P (kN)**

- 0
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- 200
- 400
- 600
- 800
- 1000
- 1200

**Midspan Deflection (mm)**

- 0
- 5
- 10
- 15
- 20
- 25
- 30
Fatigue Test Results – Glulam Girder Bridge

No stiffness degradation. Damage of female-male panel-to-panel connections. Use flat-end panels.
Glulam girders should be designed fully non-composite.
Strength Test Results – Glulam Girder Bridge
Bridge failed since a wrong grade of wood was used in construction. Timber girders should be designed fully non-composite.
No damage at three times the AASHTO Strength I Limit State load.
Evaluation of Three Alternatives

- **Glulam Slab Bridge**
  - Recommended Span Length (ft): 20-40

- **Glulam Girder Bridge**
  - Recommended Span Length (ft): 40-60

- **Precast FDDP Bridge**
  - Recommended Span Length (ft): 60-80

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### Bridge System | Superstructure Cost
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Glulam Slab Bridge | 50% Less than Double-Tee
Glulam Girder Bridge | 15-20% Less than Double-Tee
Precast FDDP Bridge | 11% higher than Double-Tee
Summary of Three Studies

- Double-Tee (DT) Bridges are common in SD.
- Load-rating should be performed on damaged DT bridges.
- UHPC-filled pocket or continuous detailing can be used to rehabilitate DT joints.
- Three new bridge alternatives can be used in new/replacement projects.
Go to MPC website & search for “Tazarv”

https://www.mountain-plains.org/
Questions?

Mostafa Tazarv, PhD, PE,
Assistant Professor
Department of Civil and Environmental Engineering
South Dakota State University
Tel: (605) 688-6526, Fax: (605) 688-6476
Mostafa.tazarv@sdstate.edu
https://sites.google.com/people.unr.edu/mostafa-tazarv
The measured flexural GDFs for each girder were equal to or less than those from the AASHTO LRFD.
- Failure mode was the **flange compressive failure**, which was brittle with no warning.
- The ultimate deflection was 5.4 in. at a load of 41.5 kips.
Methodology for Load Rating – Live

\[
RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_{LL})(LL + IM)}
\]

**Live Load Components:**

- To calculated GDF for a SD double-tee girder bridge with longitudinal joint damage condition state 3 or less, follow the AASHTO LRFD specifications.

- For longitudinal joint damage condition state 4, GDF is the greater of (a) the factor for the exterior girders, (b) the factor for the interior girders, and (c) 0.6.

- For Dynamic Load Allowance (IM), follow the AASHTO LRFD specifications.
Methodology for Load Rating – Capacity

\[ RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_P)(P)}{(\gamma_{LL})(LL + IM)} \]

**Capacity:**

\[ C_{undamaged} = \varphi_s \cdot \varphi \cdot R_n \]

\[ C_{damaged} = \varphi_c \cdot C_{undamaged} \]

We need to determine moment and shear condition factors \((\varphi_c)\) for different damage types and condition states and for different double-tee girder sections.
Rehabilitation of Double-Tee Bridges

Sponsors:
South Dakota Department of Transportation and Mountain-Plains Consortium (MPC) – University Transportation Center (UTC)
Project Funds: $160,000 ($85,722 from SDDOT and $74,278 from MPC)
Year: 2015-2017

Personnel:
PI: Nadim Webbe, PhD, PE
Co-PI: Mostafa Tazarv, PhD, PE
Graduate Research Assistant: Lucas Bohn

https://sites.google.com/people.unr.edu/mostafa-tazarv/research/rehab-of-dt-bridges
- Pocket joint rehabilitation cost is 28% of that of replacement.
- Continuous joint rehabilitation cost is 57% of that of replacement.
Section A – Shear key Detailing

Section B - Pocket Joint Detailing
Recommendations

➤ Preparation

1. 1-in. Saw-cut around perimeters.
2. Hammer-chip at 45 degree slope, 20 degrees between pockets:
   a. 30-lb chippers for first 2.5 inches.
   b. 15-lb chippers around reinforcement.
3. Hydro-demolition shall be permitted as an alternative.
4. Joint surface shall be sand-blasted and pre-wetted for 24 hours prior to pouring.
5. Formwork shall be water tight and installed from top of bridge.
Recommendations

Pocket Detailing

1. UHPC filled square pockets with minimum side dimensions of 18 inches. Spacing shall not exceed 5 ft c/c.
2. UHPC filled continuous key with a minimum width of 5.5 inches.
3. Pockets reinforced with four Gr. 60 No. 4 bars each direction. Continuous key reinforced with two Gr. 60 No. 4 longitudinal bars.
4. Minimum lap-splice of 3 inches between pocket reinforcement and exposed wires.
Project Website

Alternative to Double-Tee Bridges for Local Roads

Sponsors:
South Dakota Department of Transportation and Mountain-Plains Consortium (MPC) - University Transportation Center (UTC)

Project Funds: $160,000 ($85,000 from SDDOT and $75,000 from MPC)
Year: 2015-2017

Personnel:
PI: Nadim Wehbe, PhD, PE
Co-PI: Mostafa Tazary, PhD, PE
Graduate Research Assistant: Michael Mingo and Zachary Carnahan


https://sites.google.com/people.unr.edu/mostafa-tazary/research/alternative-to-dt-bridges
Fully-Precast Bridge – Prototype

Bridge Cross – Section Option 1

Bridge Cross – Section Option 2

- 50-ft Long and 34.5-ft Wide.
- Seven Prestressed Inverted Bulb-Tee Girders.
- Precast Full-Depth Panels.
Recommendations Precast Bridge

- The inverted bulb-tee girders should be designed using current codes.
  - Horizontal shear studs may require a tight construction tolerance.

- The deck panels should have a minimum thickness of 7 in.
- The deck panels should be full-width.

Bridge Cross-Section (Full-Width Panels)
- The hidden pocket detail and non-shrink grout should be used.

Hidden Pockets – Transverse Section View

3/4-in. Dia. Vent Pipe

2-in. Dia. Grouting Pipe

Hidden Pockets – Longitudinal Section View
- All deck steel reinforcement should be epoxy coated.

- The leveling bolts should be bolts (not threaded rods with nut).
Each grouted haunch should have two longitudinal steel bars for shrinkage.
- Girders shall be designed fully non-composite according to AASHTO.
- The type, rating, treatment, and geometry of the wood shall be verified and approved by the designer before fabrication of the girders.
- Glulam deck panels shall be a minimum of 6 inches.
- The bridge shall be one or two grades as shown.
The bridge shall be one or two grades as shown.

(a) Girder Bridge with Single Grade

(b) Girder Bridge with Two Grades
Recommendations for Girder Bridge

- The deck panels shall use a straight connection as shown.
Recommendations for Girder Bridge

- Solid glulam diaphragms, steel cross braces, or glulam cross braces may be used.
Recommendations for Girder Bridge

- The wearing surface shall be made up of an asphalt overlay, an asphalt chip seal, an aggregate overlay, or epoxy with embedded grit.
Recommendations for Girder Bridge

- Any crash-tested railing configuration can be used.
- It is recommended that the existing abutments be reused to save time and money as shown below.
- Bridge shall be inspected every 2 years and resealed every 6 years.
Glulam Bridges in Minnesota

9967

22508

22514

22518
Cedar Rock Bridge

- Located in Buchanan County, Iowa
- Built in 2014
- 72 ft Long x 40 ft Wide
Delivery of Glulam Girder Bridge
Girder Bridge Failure

[Images of damaged girder and bridge structure]

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Overall, the cost of the proposed bridge system is estimated to cost **15-20% less** than that for the double-tee bridge system.

<table>
<thead>
<tr>
<th>Bridge System</th>
<th>Glulam Girder Bridge</th>
<th>Double-Tee Girder Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials/Fabrication ($)</td>
<td>78,000</td>
<td>111,000</td>
</tr>
<tr>
<td>Total ($/sq. ft.)</td>
<td>45</td>
<td>64</td>
</tr>
</tbody>
</table>
Conclusions for Girder Bridge

- Construction of a glulam girder bridge is fast.
- The girder bridge did not exhibit any signs of deterioration and the bridge overall stiffness essentially remained constant throughout the fatigue test.
- Damage of male-to-female deck-to-deck connections can be eliminated by connecting flat deck panels with epoxy.
- It was found that the girders did not perform as composite members thus they should be designed fully non-composite. The bridge can be designed using current AASHTO requirements.
- The epoxy connection for the deck to girder connection in the girder bridge performed adequately throughout testing.
- The superstructure cost for a 50-ft long by 34.5-ft wide glulam girder bridge is 70% of that for a double-tee bridge with the same bridge geometry.
The bridge shall be one or two grades as shown.

- The product of the adjusted modulus of elasticity $E$ and the moment of inertia of a stiffener shall be greater than 80,000 k-in$^2$.
- The minimum width is recommended to be 5 in.
Zinc-coated lag bolts shall be installed from the underside of the bridge to connect the stiffeners to the deck panels.

The lag bolts shall be a minimum of 12. long with a diameter of 0.75in.
The wearing surface shall be made up of an asphalt overlay, an asphalt chip seal, an aggregate overlay, or epoxy with embedded grit.

(a) Asphalt Overlay

(b) Asphalt Chip Seal (Greenwald 2011)

(c) Aggregate Overlay

(d) Epoxy with Embedded Grit
Recommendations for Slab Bridge

- Any crash-tested railing configuration can be used.
- It is recommended that the existing abutments be reused to save time and money as shown below.
- Bridge shall be inspected every 2 years and resealed every 6 years.
Section 1-1 (Deck Panel Strain Gauges in Longitudinal Direction of Bridge)

Section 2-2 (Stiffener Strain Gauges in Transverse Direction of Bridge)
LVDTs
Slab Bridge Fatigue Test Results

Distance From Bottom of Deck (in.)

Strain (microstrain)

Distance From Bottom of Deck (in.)

Strain (microstrain)
Overall, the cost of the proposed bridge system is estimated to cost 50% less than that for the double-tee bridge system.

<table>
<thead>
<tr>
<th>Bridge System</th>
<th>Slab Bridge</th>
<th>Double-Tee Girders</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total ($/sq. ft.)</strong></td>
<td>30</td>
<td>64</td>
</tr>
</tbody>
</table>
Conclusions for Slab Bridge

- Construction of a glulam slab bridge is fast.
- The slab bridge did not exhibit any signs of deterioration and the bridge overall stiffness essentially remained constant throughout the fatigue test.
- No damage was observed at an actuator load of 270 kips, which was more than 3 times higher than the AASHTO Strength I limit state load of 85.7 kips.
- The superstructure cost for a 16.5-ft long by 34.5-ft wide glulam slab bridge is only 50% of that for a double-tee bridge with the same bridge geometry.
Both of these types of glulam timber bridges are viable alternatives for local roads.

The AASHTO method of design for timber bridges can be utilized for the design of these bridges.