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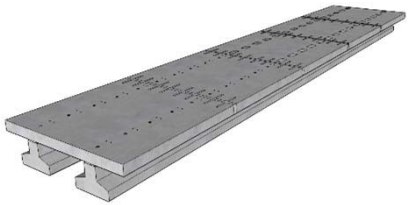

Welcome!

Development of Alternative Bridge Superstructures (MPC 19-373)

Our partners:

MOUNTAIN-PLAINS CONSORTIUM REGION 8 · MONTANA MDT DEPARTMENT OF TRANSPORTATION · NDDOT North Dakota Department of Transportation · South Dakota DOT Connecting South Dakota and the Nation · Wyoming Transportation Department · NDSU UPPER GREAT PLAINS TRANSPORTATION INSTITUTE TRANSPORTATION LEARNING NETWORK

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Development of Alternative Bridge Superstructures

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SOUTH DAKOTA STATE UNIVERSITY

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TLN Webinar

Nov. 22, 2019

Funding Agencies & Collaborators

- South Dakota Department of Transportation.
- Mountain Plains Consortium (MPC) - University Transportation Center (UTC).

Presentation Outline

- Background
- Selection of Bridge Alternatives
- Bridge Test Specimens
- Bridge Test Results
- Proposed Recommendations
- Overall Evaluation
- Conclusions

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Background

Common SD Local Road Bridges & their Damages

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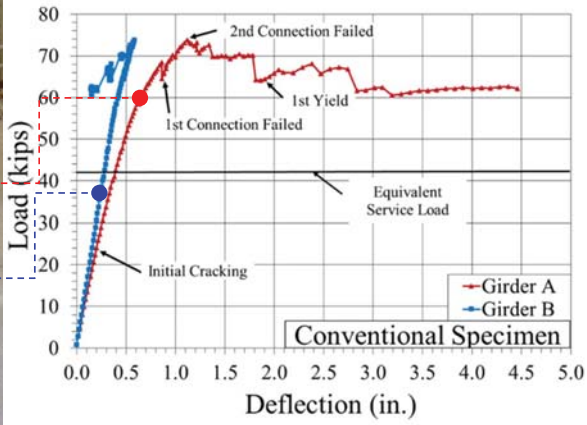
Local Road Bridges

- 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)

Other Issues to Consider

- Only one supplier for double-tee girders in South Dakota.
- Simple alternative bridge systems provide more options for local governments.

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Research Objectives

- Identify alternative single-span systems to double-tee bridges with 75-year design life and a span length of 70 ft or less.
- Perform load testing on alternative bridge systems.
- Compare cost, constructability, and performance of alternative bridge systems with those for double-tee bridges.

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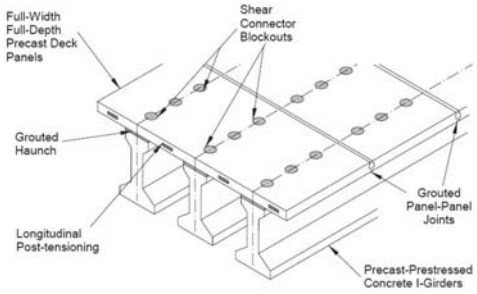
Bridge Alternatives

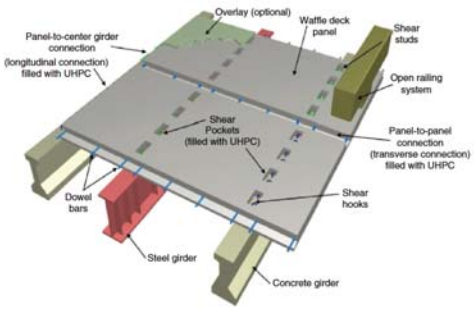
Some Options from the Literature

A few Bridge Alternatives



Deck Panel (Scholz, 2007)

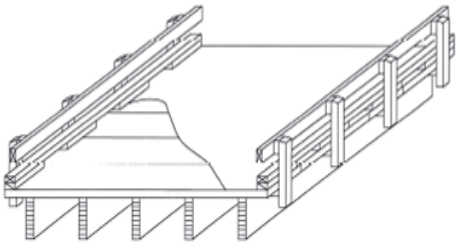
Voided Slab (Joyce, 2014)



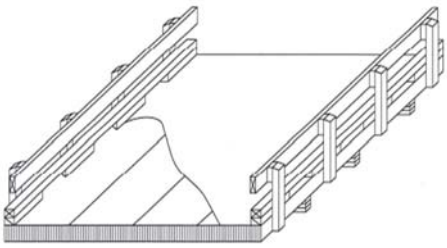
Waffle Deck (Aaleti and Sritharan, 2014)

Adv. Composite (Ji et al., 2007)

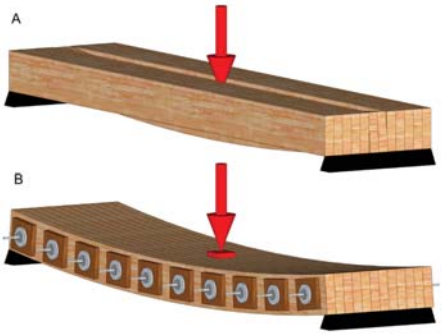
A few Bridge Alternatives



Timber Girder (Wacker and Smith, 2001)



Timber Slab (Wacker and Smith, 2001)



Stress Laminated (Ekholm, 2013)

Timber Log (Rodrigues et al., 2017)

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Bridges Selected by Project Panel

The SDDOT project panel selected the following for experimental investigation:

- Full-depth Deck Panels supported on Inverted Bulb-tee Girders.
- Two types of Glulam Bridges: Girder and Slab.

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Summary of Activities

- 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.

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Experimental Study

Bridge Test Specimens

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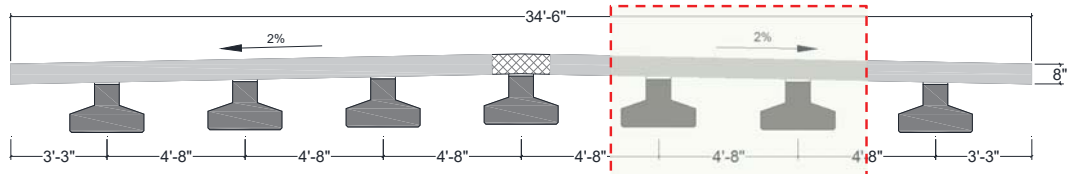
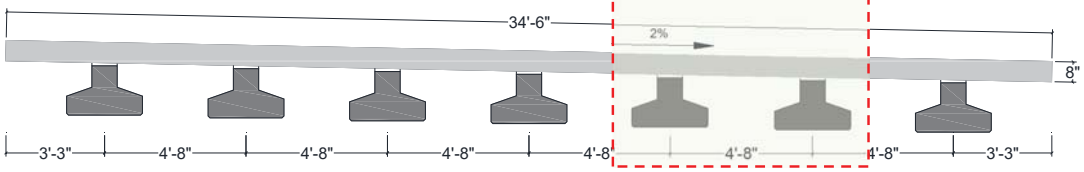
Fully-Precast Bridge – Prototype



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.

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Fully-Precast Bridge – Test Model

Panel-to-Panel Joint

Panel-to-Panel Joint

Hidden Pocket,
Headed Studs

Full-Depth Pocket,
Inverted U-Shape Bars

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Glulam Bridges - Prototype

50-ft long, 34.5-ft Wide Girder Bridge

30-ft long, 34.5-ft Wide Slab Bridge

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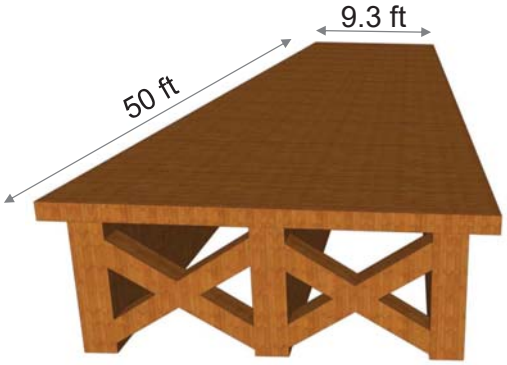
Glulam Girder Bridge – Test Model



- 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.

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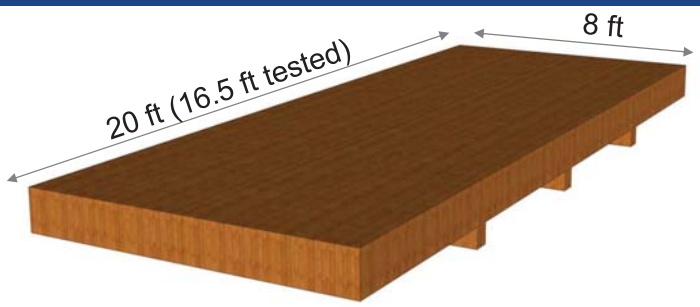
Glulam Slab Bridge – Test Model



- 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.

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Experimental Study

Construction of Precast Bridge

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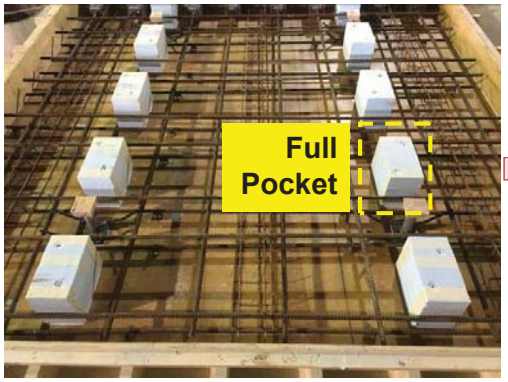
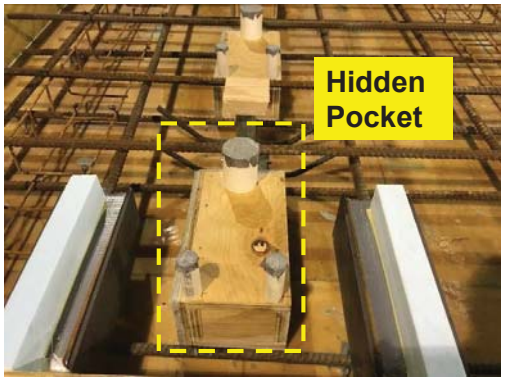
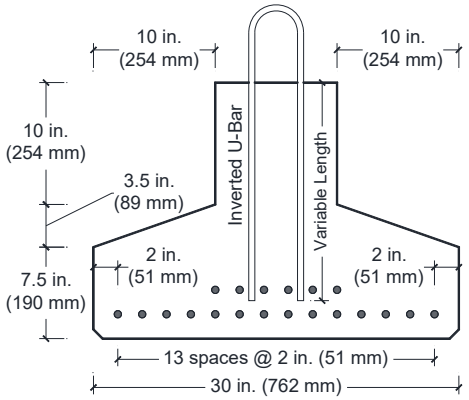
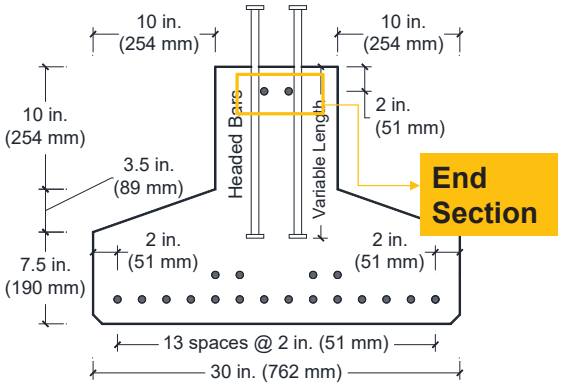
Precast Panel Fabrication



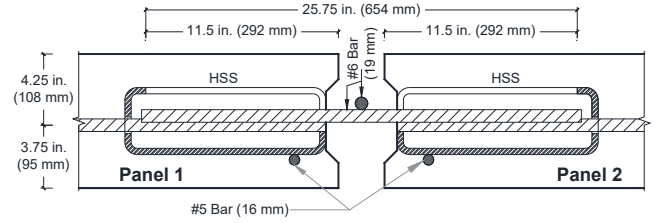


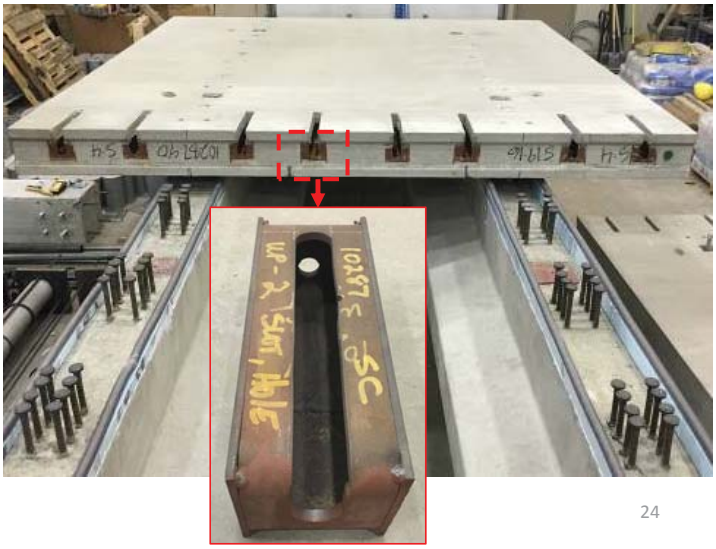
Precast Girder Fabrication





Assembly of Test Specimen





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Assembly of Test Specimen

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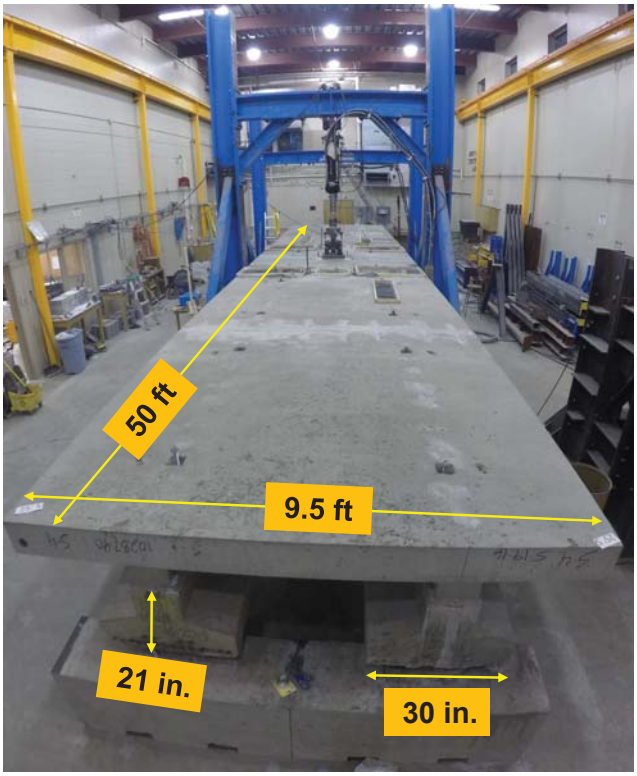
Test Setup



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Experimental Study

Construction of
Glulam Girder Bridge

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Deck Panel Fabrication for Glulam Girder Bridge

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Girder Fabrication for Glulam Girder Bridge

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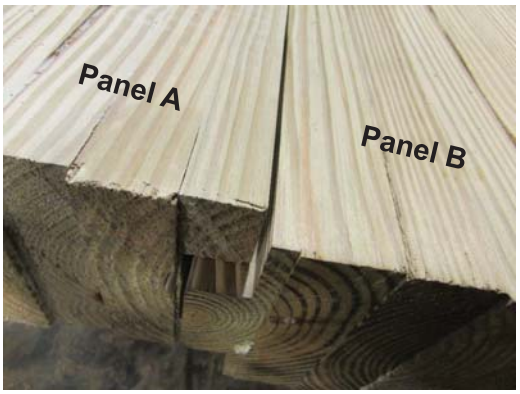
Glulam Girder Bridge Assembly



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Delivery of Glulam Girder Bridge

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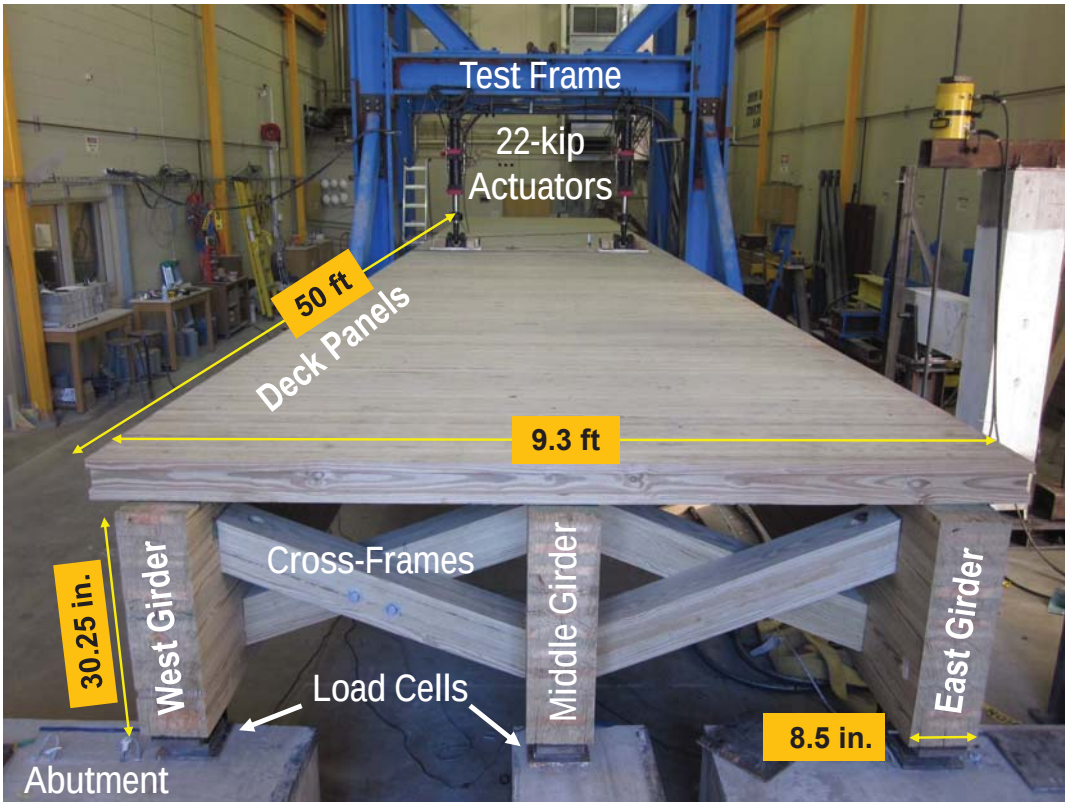
Assembled Glulam Girder Bridge and Test Setup



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Experimental Study

Construction of
Glulam Slab Bridge

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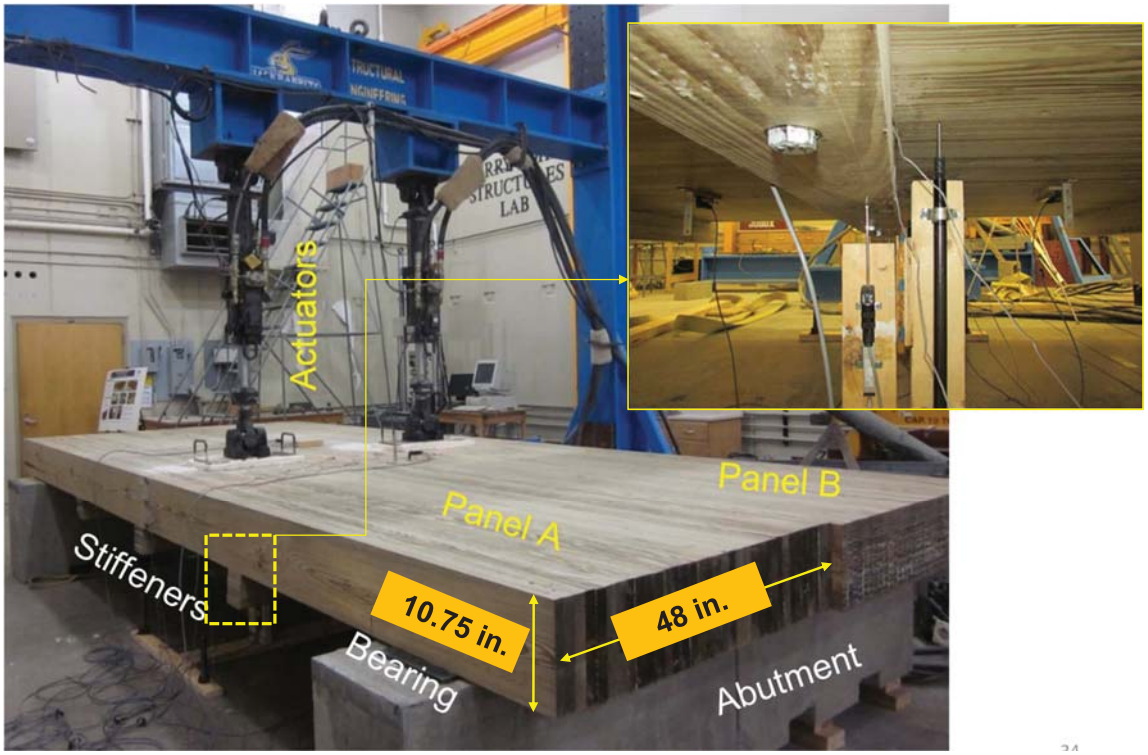
Assembled Glulam Slab Bridge and Test Setup



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Test Procedure

Each bridge was tested under:

- At least 0.5 million cycles of AASHTO Fatigue II loads.
- Intermediate stiffness loading.
- Strength (ultimate) loading.

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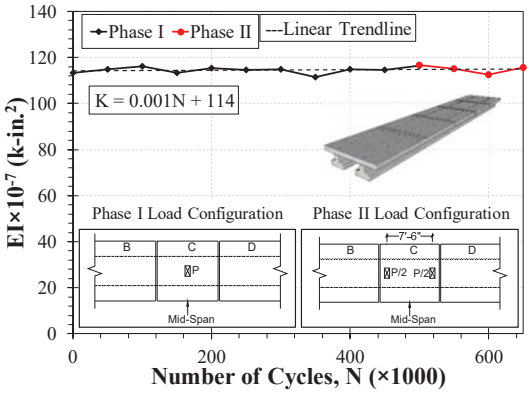
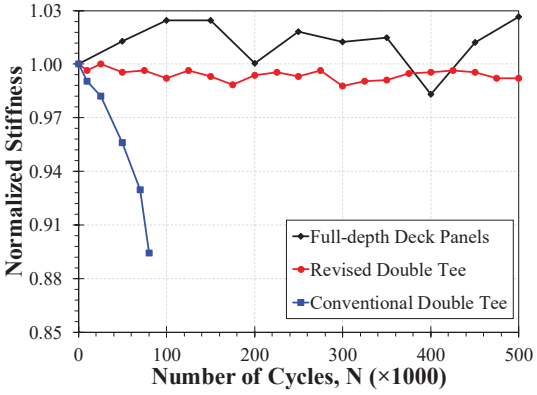
Test Results

Precast Bridge

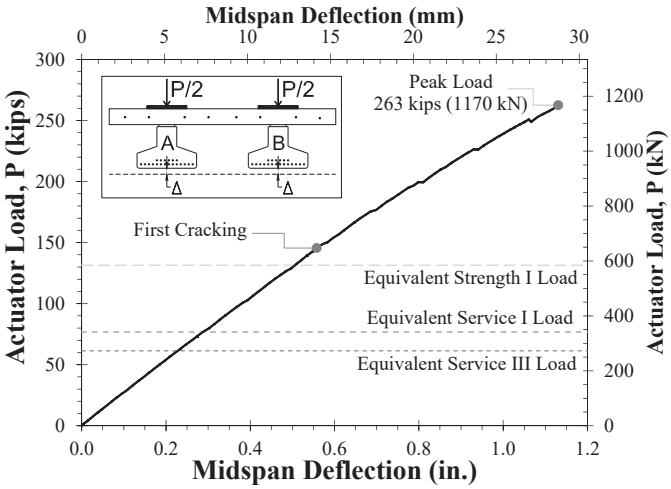
Fatigue Test Results – Precast Bridge





Shallow shrinkage cracks on panel-to-panel joints and grouted hunch region. No open-pocket and use reinforcement in the haunch area.

Ultimate Test Results – Precast Bridge



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Test Results

Glulam Girder Bridge

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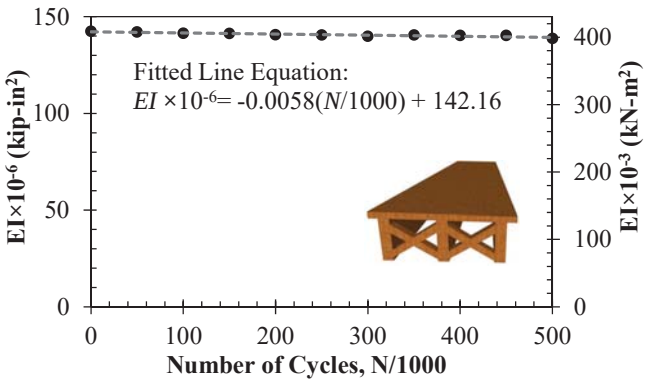
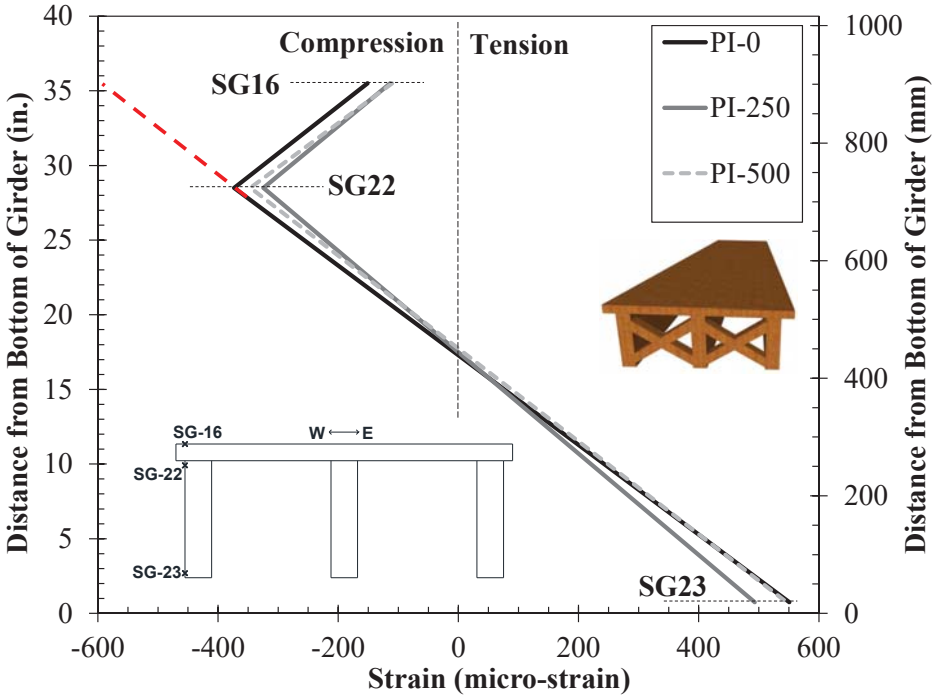
Fatigue Test Results – Glulam Girder Bridge



No stiffness degradation.
Damage of female-male panel-to-panel connections.
Use flat-end panels.

Fatigue Test Results – Glulam Girder Bridge



Glulam girders should be design fully non-composite.

Strength Test Results – Glulam Girder Bridge

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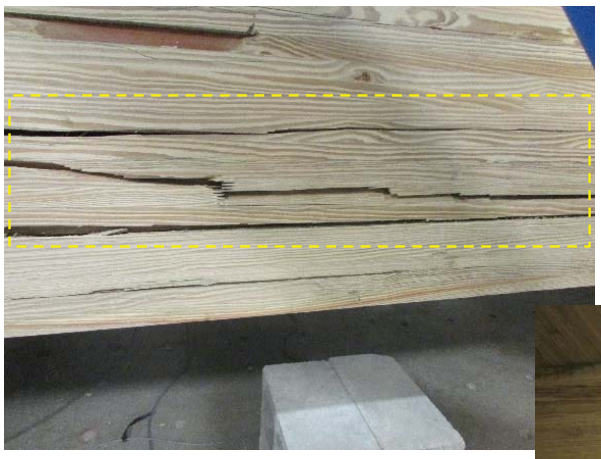
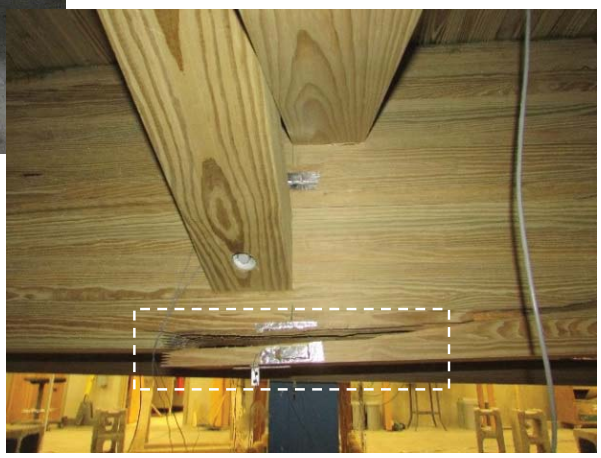
Strength Test Results – Glulam Girder Bridge



West Girder

Middle Girder



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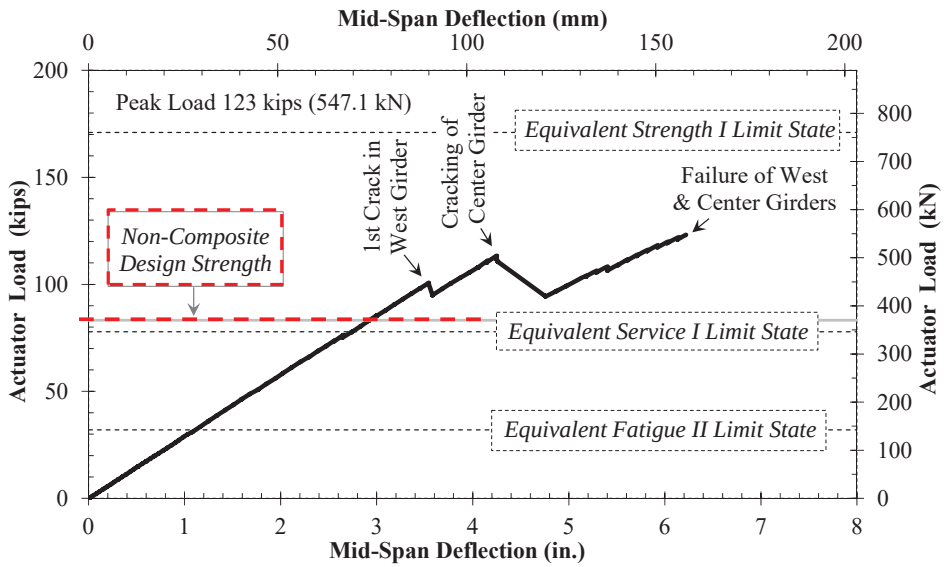
Strength Test Results – Glulam Girder Bridge

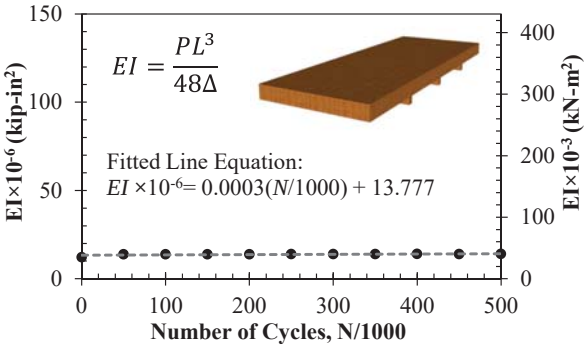


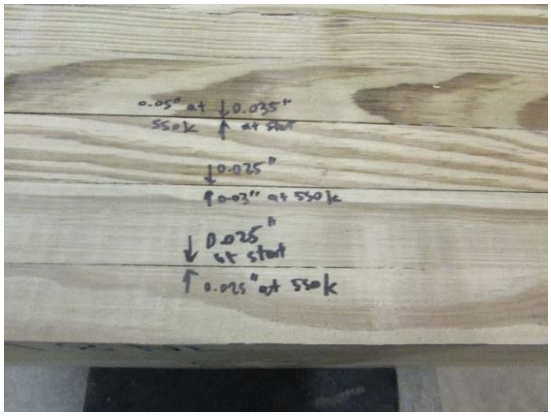
Bridge failed since a wrong grade of wood was used in construction. Timber girders should be designed fully non-composite.

Test Results

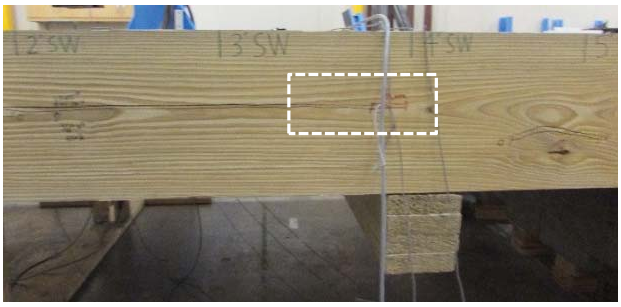
Glulam Slab Bridge

Fatigue Test Results – Glulam Slab Bridge

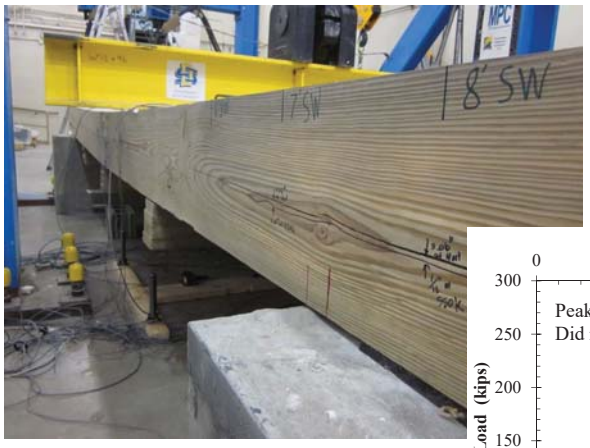


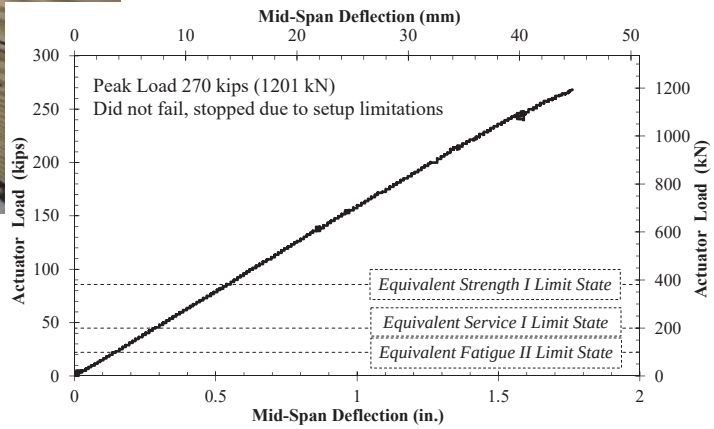


No stiffness degradation, no damage except widening of natural cracks.



Strength Test Results – Glulam Slab Bridge





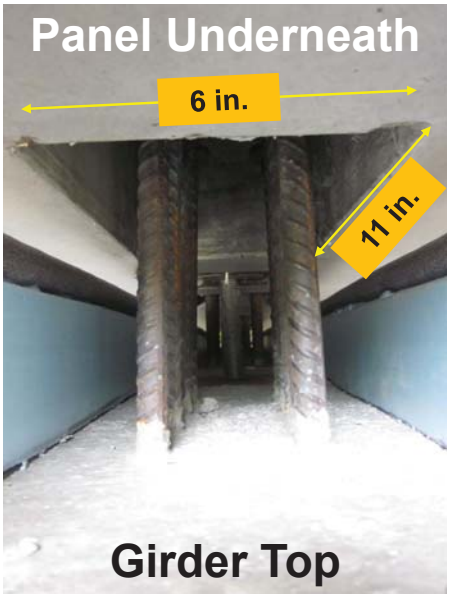
No damage at three times the AASHTO Strength I Limit State load.

Proposed Alternatives

Design and Construction Recommendations

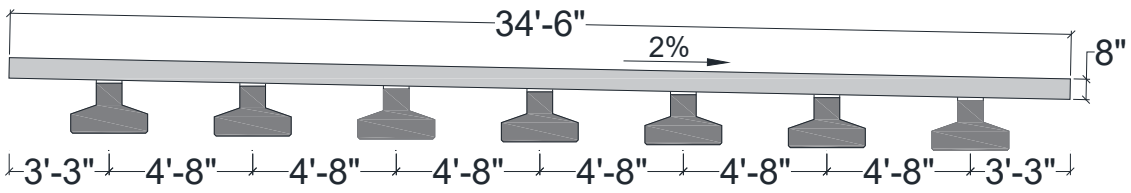
Recommendations: Precast Bridge

- The inverted tee girders should be designed using current codes (e.g. AASHTO LRFD).
- Shear studs may require a tight construction tolerance.



Recommendations: Precast Bridge

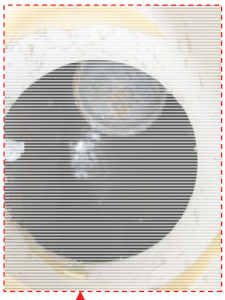
- The deck panels should have a minimum thickness of 7 in.
- The length of deck panels is recommended to cover the full-width of the bridge.
- The width of deck panels should not exceed 12 ft.

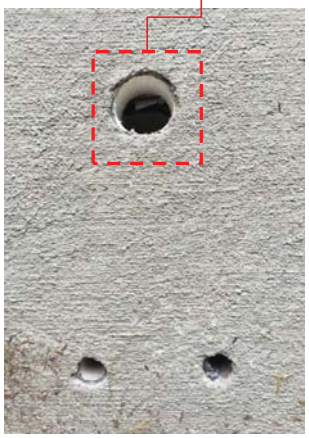


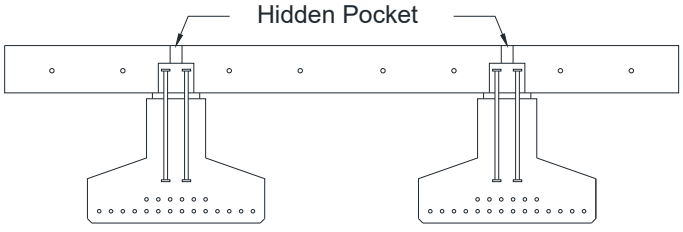
Bridge Cross-Section (Full-Width Panels)

Recommendations: Precast Bridge

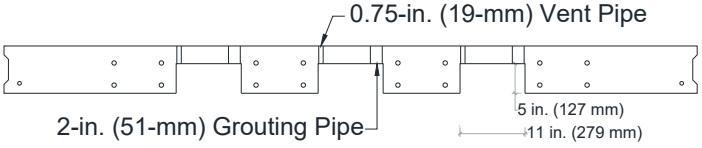
- The hidden pocket detail and non-shrink grout should be used.







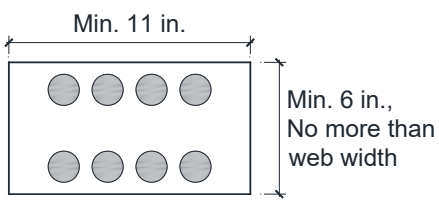
Bridge Section View

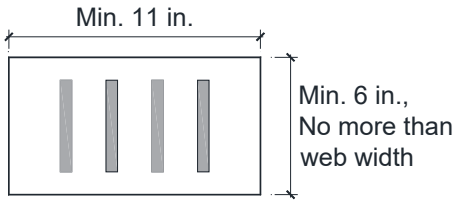


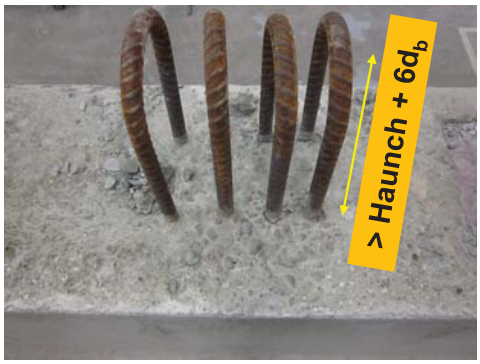
Panel Trans. Section

Recommendations: Precast Bridge

- Both types of shear studs (double-headed and inverted U-shape are viable.







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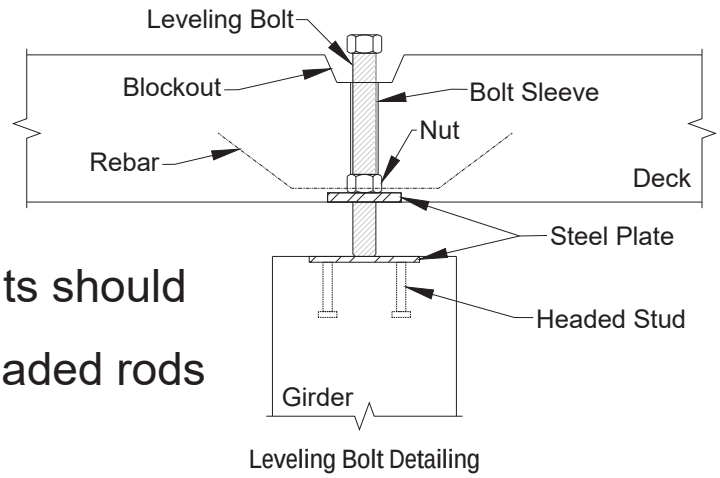
Recommendations: Precast Bridge

- All deck steel reinforcement should be epoxy coated.



Leveling Bolt Detailing

- The leveling bolts should be bolts (not threaded rods with nut).

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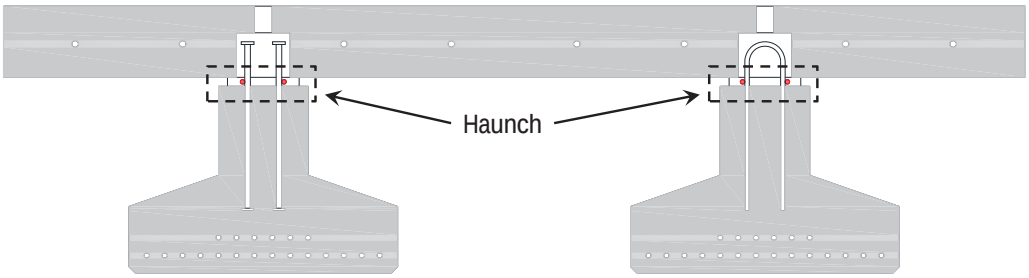
Recommendations: Precast Bridge

- The haunch depth at the bridge mid-span should not be less than 0.75 in.
- Each grouted haunch should have two longitudinal steel bars for shrinkage.



Haunch Longitudinal Reinforcing Steel Bars Detailing

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Recommendations: Glulam Girder Bridge

- Girders shall be designed fully non-composite following the AASHTO requirements.
- The type, rating, treatment, and geometry of the wood shall be verified and approved by the designer before fabrication of the girders.

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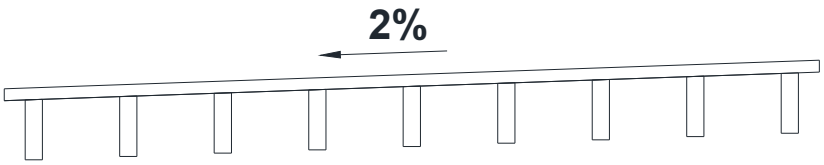
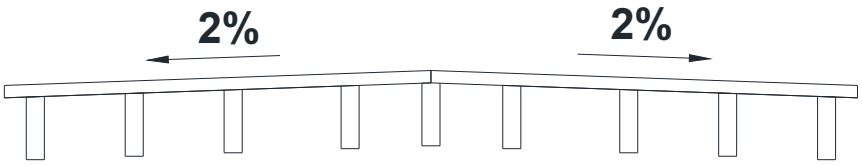
Recommendations: Glulam Girder Bridge

- The depth of glulam deck panels shall be at least 6 inches.
- The deck can have single or two grades as shown.



(a) Girder Bridge with Single Grade

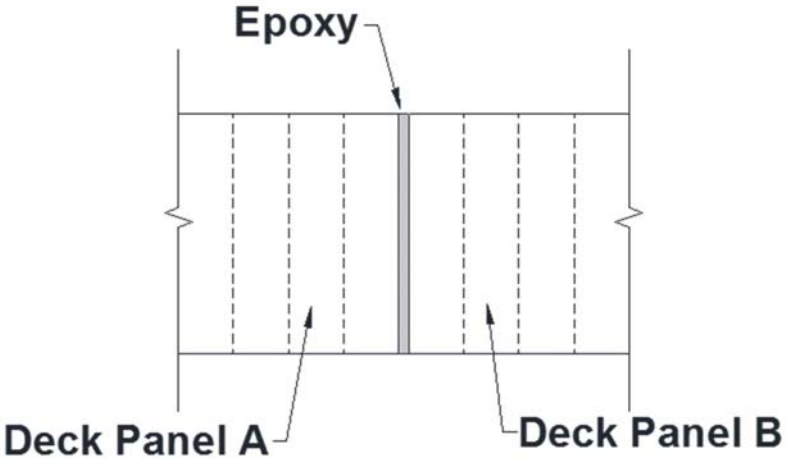


(b) Girder Bridge with Two Grades

56

Recommendations: Glulam Girder Bridge

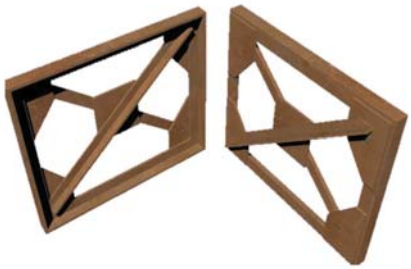
- The deck panels shall use a straight connection as shown.



57

Recommendations: Glulam Girder Bridge

- Solid glulam diaphragms, steel cross braces, or glulam cross braces may be used.



58

Recommendations: Glulam 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.

(a) Asphalt Overlay

(b) Asphalt Chip Seal (Greenwald 2011)

(c) Aggregate Overlay

(d) Epoxy with Embedded Grit

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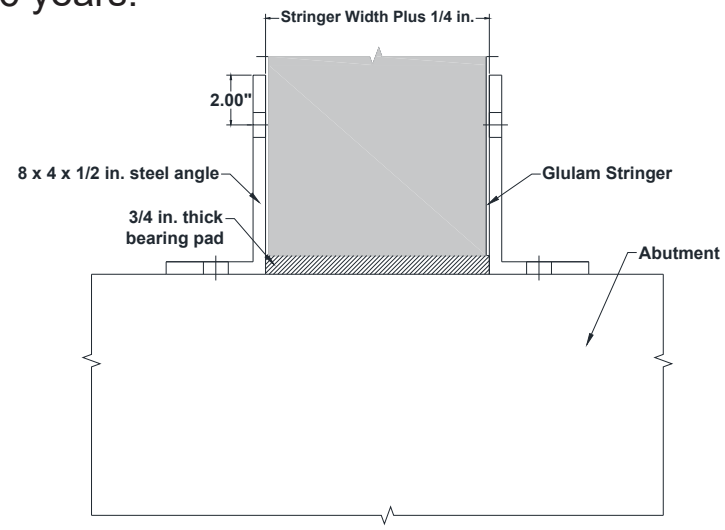
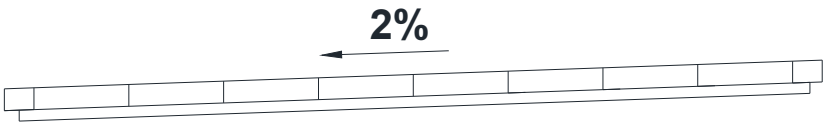
Recommendations: Glulam Girder Bridge

- 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.

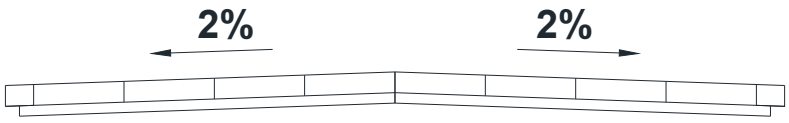


Recommendations: Glulam Slab Bridge

- The bridge can be single or two grades as shown.



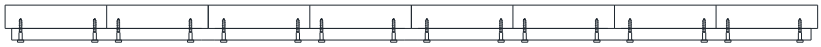
(a) Slab Bridge with Single Grade



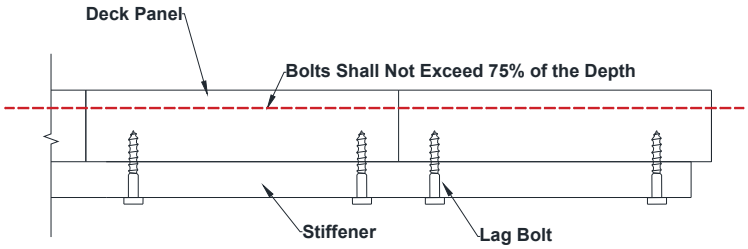
(b) Slab Bridge with Two Grades

- 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 of the stiffner is recommended to be 5 in.

Recommendations: Glulam Slab Bridge



(a) Glulam Slab Bridge Corss-Section



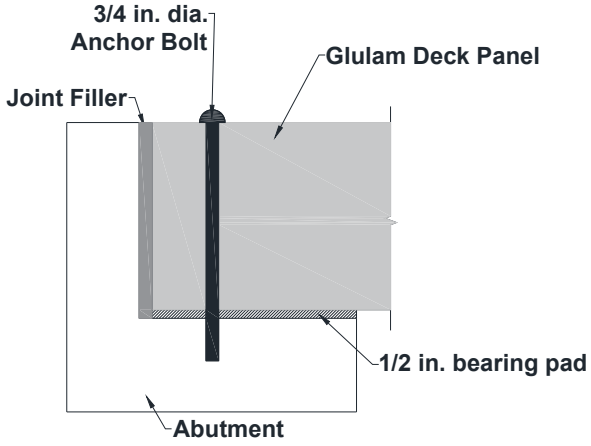
(b) Close up of Two Panels

- 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 at least of 12-in. long with a minimum diameter of 0.75 in.

62

Recommendations: Glulam Slab Bridge

- Any crash-tested railing 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.



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Proposed Alternatives

Overall Evaluation

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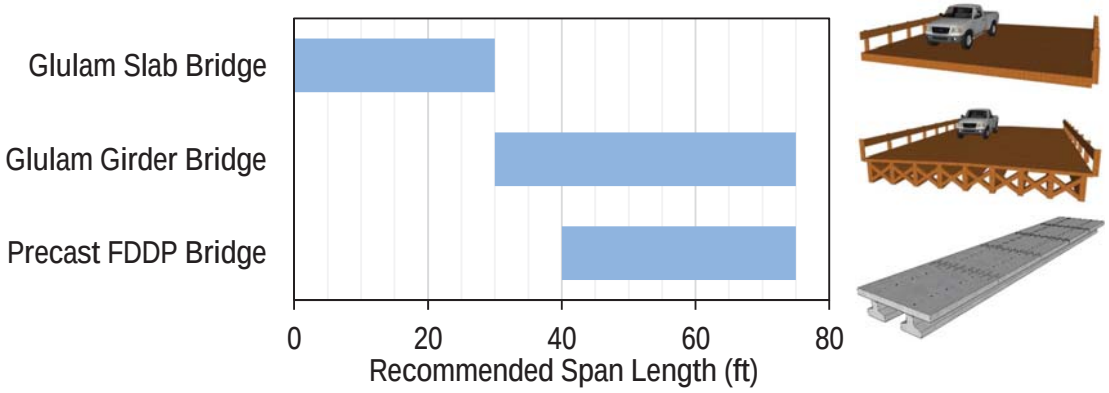
Evaluation of Three Alternatives



Bridge System	Superstructure Cost
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**

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Project Conclusions

- All three bridge systems are viable alternatives to current double-tee bridges.
- Based on the findings of the study, design and construction guidelines were developed for the three proposed bridge systems.
- Local governments will now have three additional options when designing/replacing a bridge.

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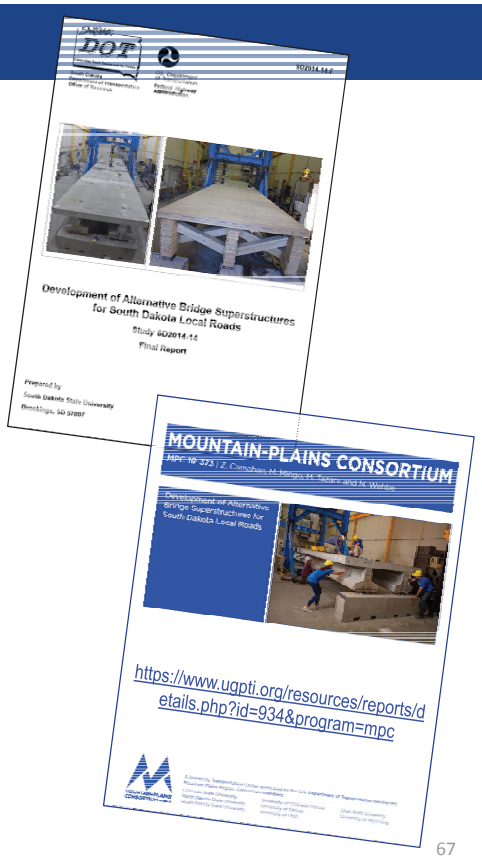
Publications

- Tazarv, M., Carnahan, Z., Wehbe, N. (2019). "Glulam Timber Bridges for Local Roads," *Engineering Structures*, DOI: 10.1016/j.engstruct.2019.03.012, Vol. 188, pp. 11-23 (Link).
- Tazarv, M., Mingo, M., Wehbe, N. (2019). "System Performance of a Precast Bridge Incorporating Full-Depth Deck Panels and Prestressed Inverted Bulb-Tee Girders," *Journal of Bridge Engineering*, ASCE, DOI: 10.1061/(ASCE)BE.1943-5592.0001426, Vol. 24, No. 6, 13 pp. (Link).
- Carnahan, Z., Mingo, M., Tazarv, M., Wehbe, N. (2019). "Development of Alternative Bridge Superstructures for South Dakota Local Roads." North Dakota State University - Upper Great Plains Transportation Institute, Fargo: Mountain-Plains Consortium (MPC), MPC Report No. 19-373, 140 pp (Link)



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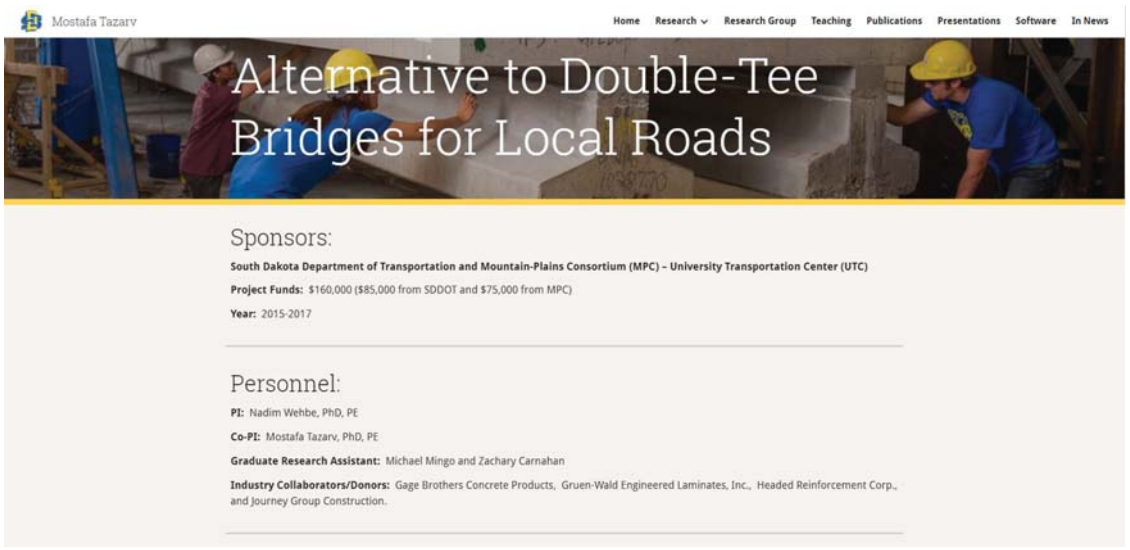
Project Website



https://sites.google.com/people.unr.edu/mostafa-tazarv/research/alternative-to-dt-bridges

Questions?

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Blank

Glulam Bridges in Minnesota

9967

22508

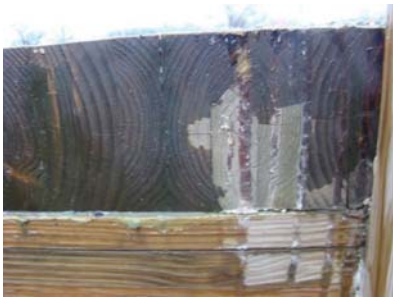
22514

22518

Cedar Rock Bridge

- Located in Buchanan County, Iowa
- Built in 2014
- 72 ft Long x 40 ft Wide



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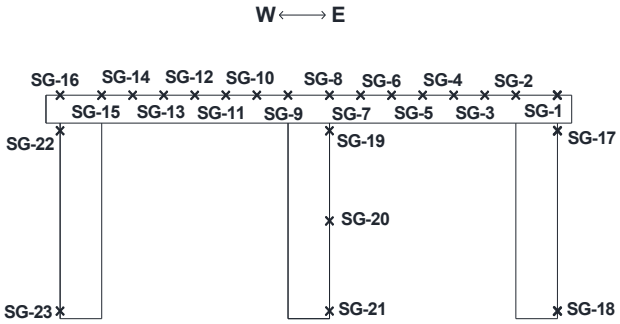
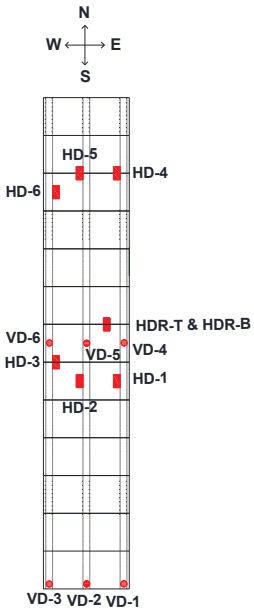
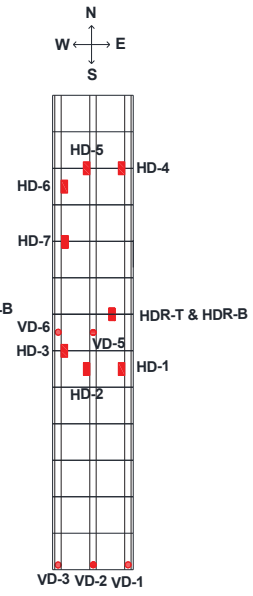
Instrumentation for Glulam Girder Bridge







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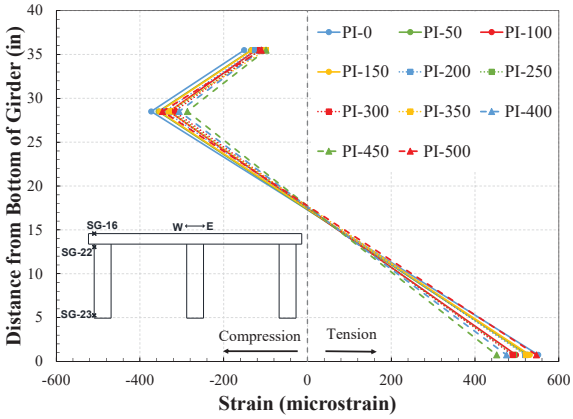
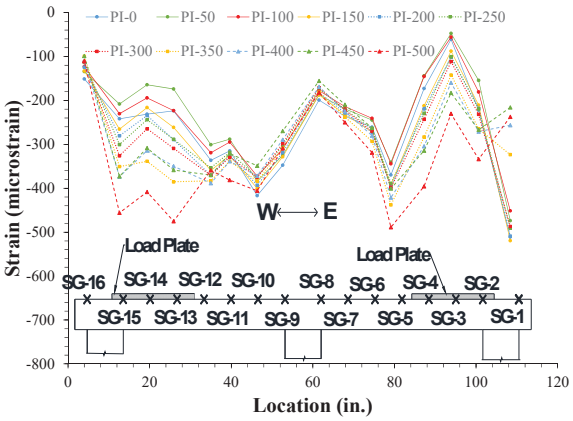
Girder Bridge Fatigue Test Results





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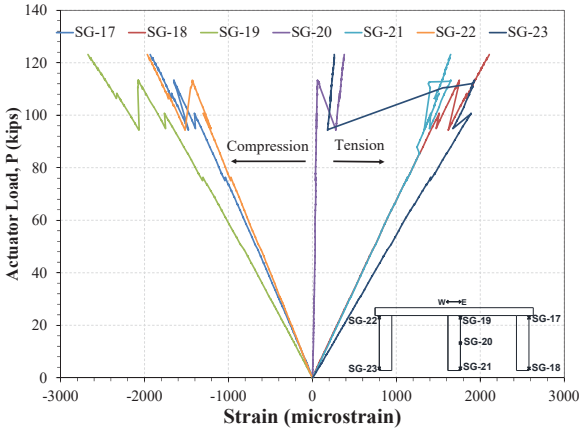
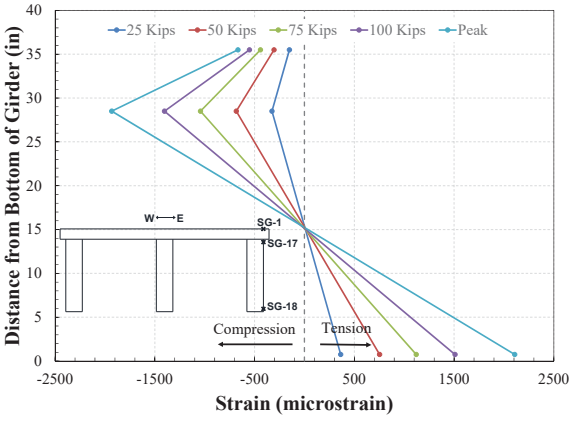
Girder Bridge Ultimate Test Results





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Conclusions for Girder Bridge

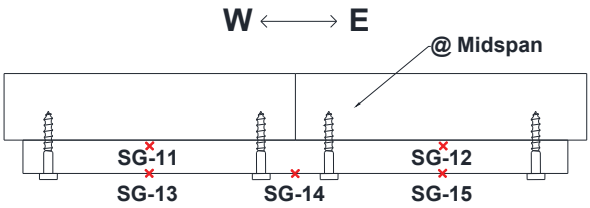
- Construction of a glulam girder bridge is fast.
- The girder bridge did not exhibit any signs of deterioration and the bridge overall stiffness essentially remained constant throughout the fatigue test.
- Damage of male-to-female deck-to-deck connections can be eliminated by connecting flat deck panels 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.

79

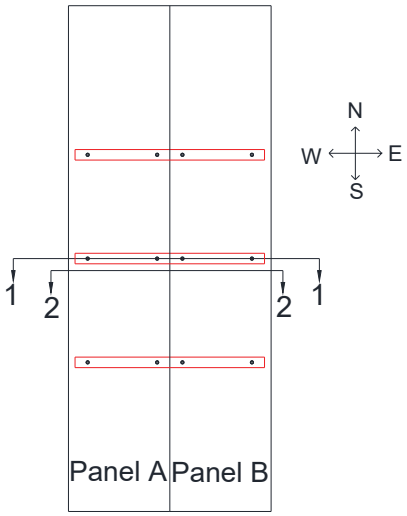
Blank

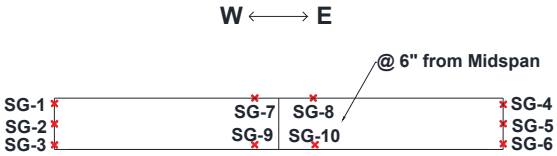
80

Slab Bridge Strain Gauges



Section 1-1 (Deck Panel Strain Gauges in Longitudinal Direction of Bridge)





Section 2-2 (Stiffener Strain Gauges in Transverse Direction of Bridge)

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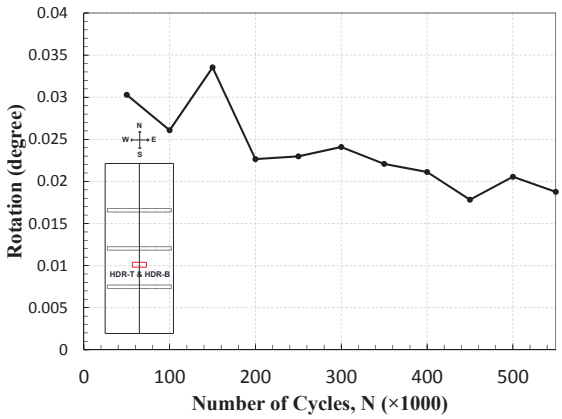
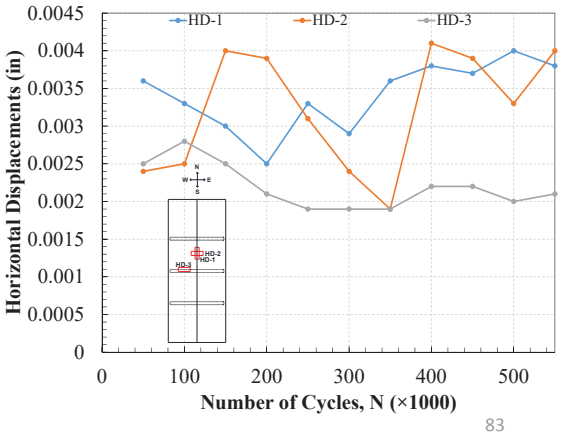
LVDTs

82

Slab Bridge Fatigue Test Results





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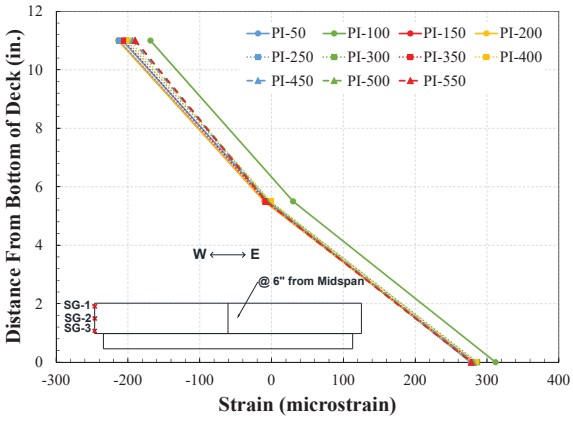
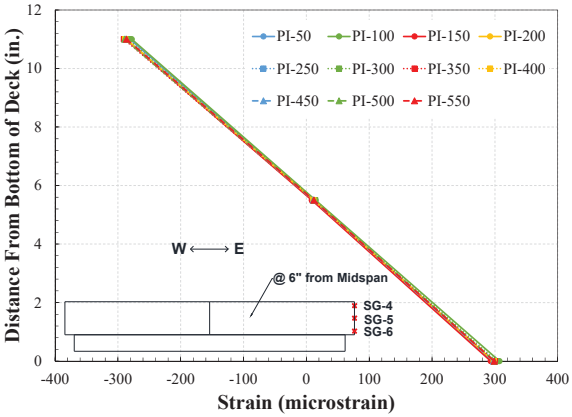
Slab Bridge Fatigue Test Results





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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.**

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