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

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Presentation Prepared for:
The 34th Annual North Central Regional Local Road Conference

Oct. 17, 2019,
Rapid City, SD

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?

Funding Agencies & Collaborators

South Dakota DOT
Connecting South Dakota and the Nation

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Background

Common SD Local Road Bridges & their Damages

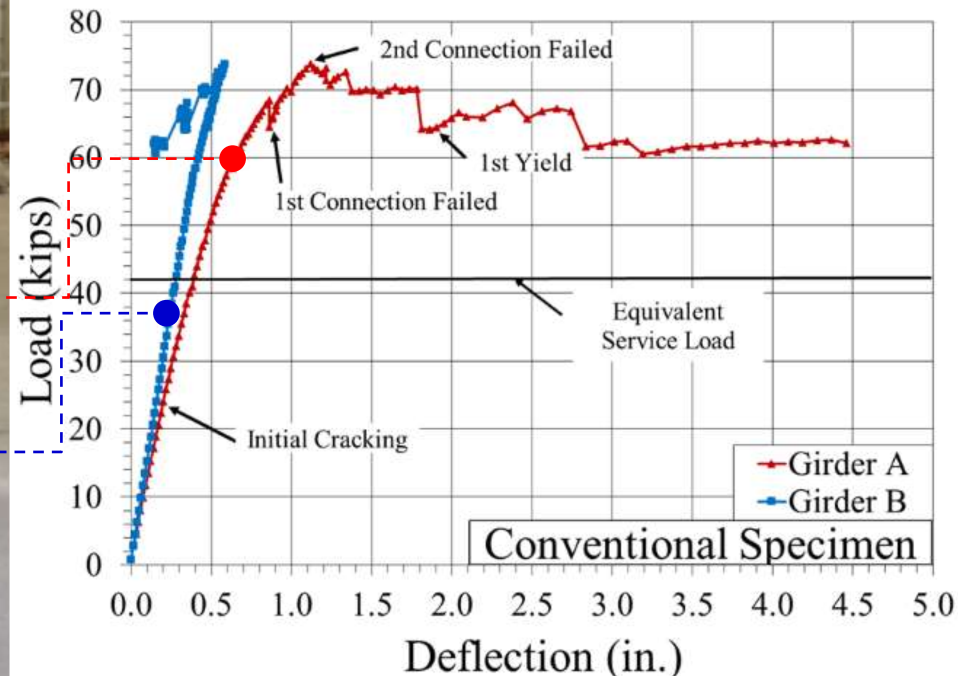
Local Load Bridges

- 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)

Damage of DT Girders

What is the safe live load capacity of distressed double-tee bridges?

Evaluation of Existing Bridges

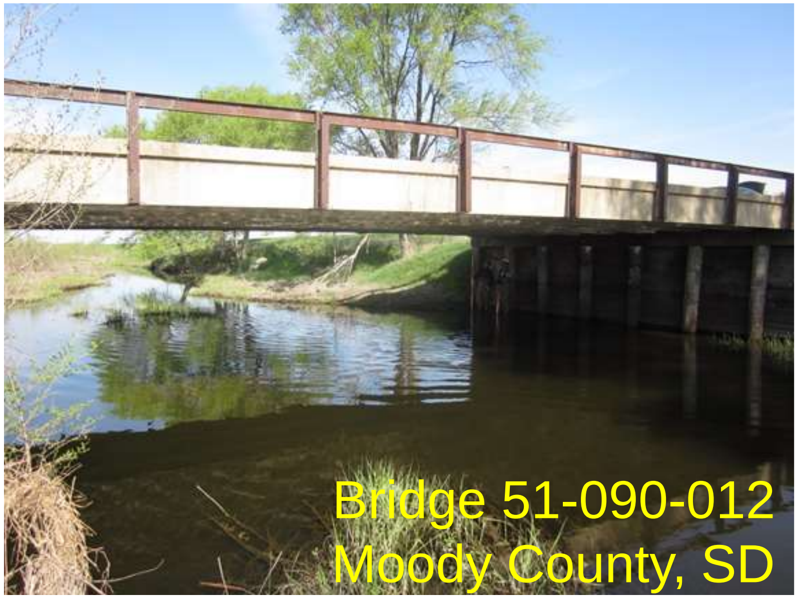
How to Load Rate Damaged Double-Tee Bridges?

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.

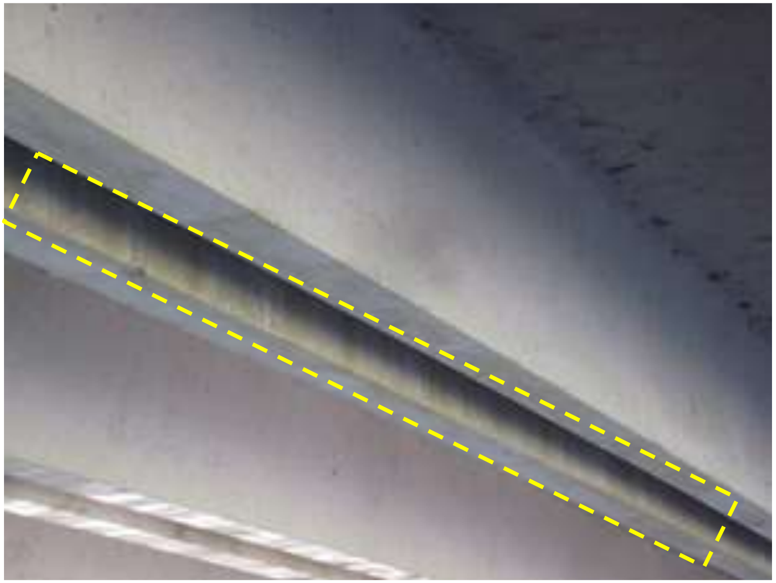
Description of Field Test Bridges

Bridge ID	County	Span, *ft. (m)*	Damage Type and Condition State	Age, *Yr.*
42165153	Lincoln, SD	42 (12.8) (Seven 30-in. (762-mm) Deep Girders)	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).	34
51090012	Moody, SD	50 (15.24) (Eight 23-in. (584-mm) Deep Girders)	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).	38



Damage of Bridge 51-090-012

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:

<u>Lincoln County</u>

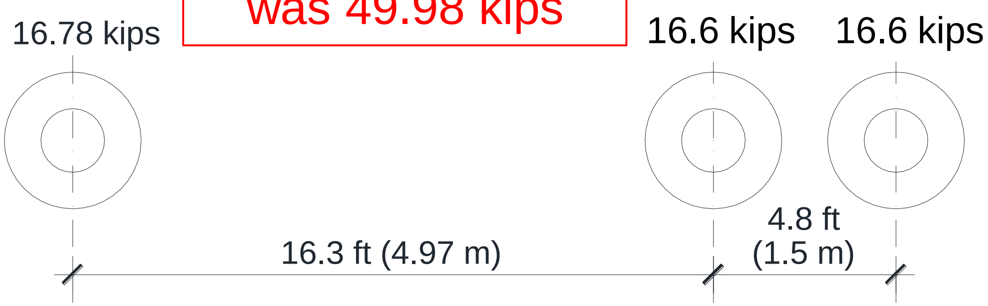
- Shear Response = 55 mph
- Flexural Response = 35 mph

<u>Moody County</u>

- Flexural Response = 35 mph

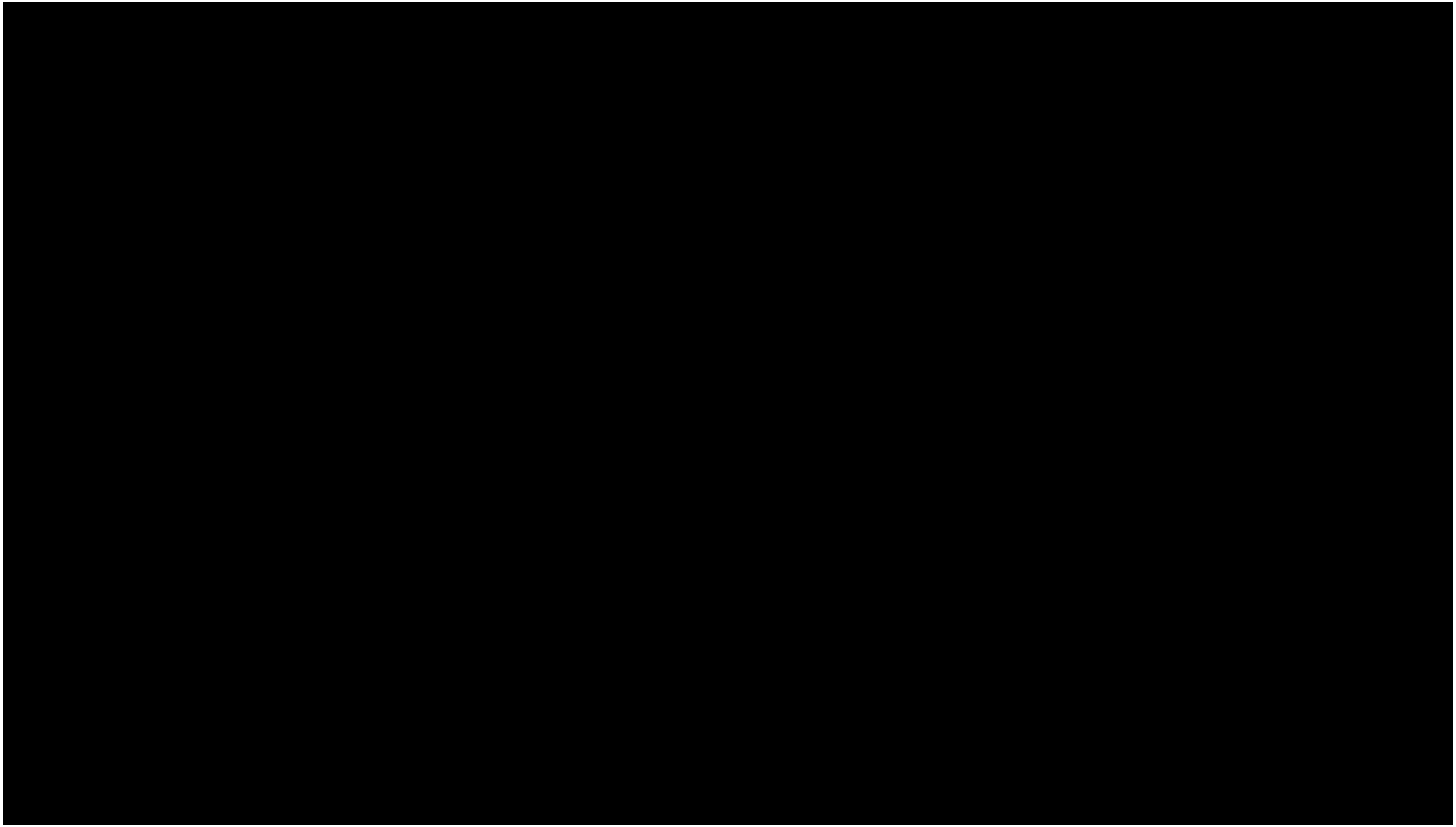
Test Truck used for Field Testing (Similar to SD Legal Truck Type 3)

Truck Total Weight was 49.98 kips



Truck Axle Weight Distribution

Sample Video of Dynamic Field Testing



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

Capacity — **Dead Load Demand** — **Live Load Demand**

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

- 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.

Example of Condition Factors (φ_c)

Proposed Damage Types and Condition States for Double-Tee Girder Stem

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

$\varphi_{c-M} = 1.0$
$\varphi_{c-V} = 0.75$

$\varphi_{c-M} = 1.0$
$\varphi_{c-V} = 0.9$

$\varphi_{c-M} = 0.90$
$\varphi_{c-V} = 0.75$

Rehabilitation of Existing Bridges

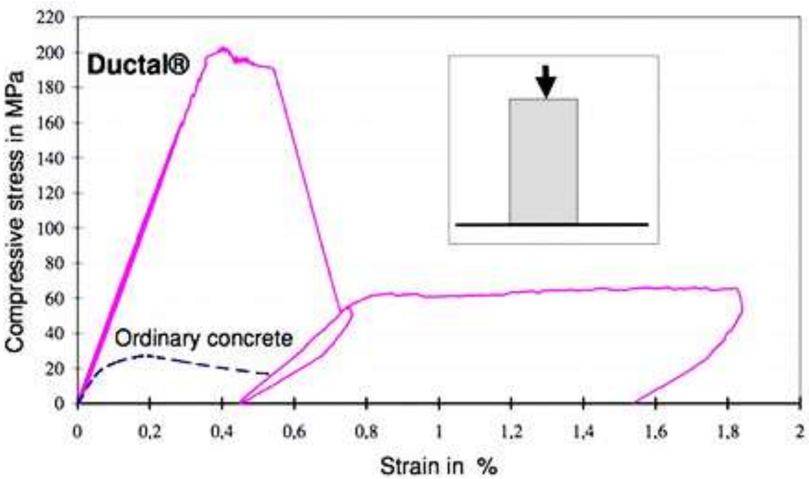
How to Rehabilitate Double-Tee Girder-to-Girder Joints?

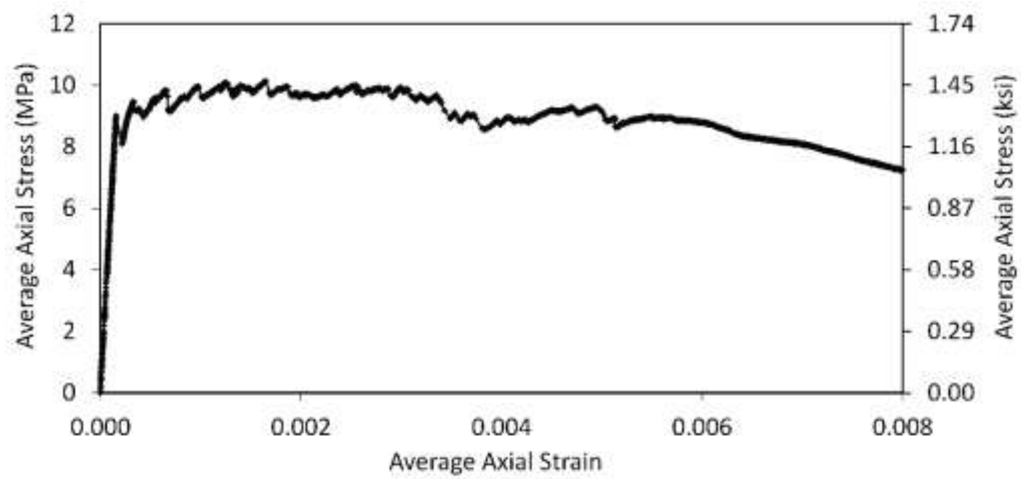
What Was Done?

- 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.

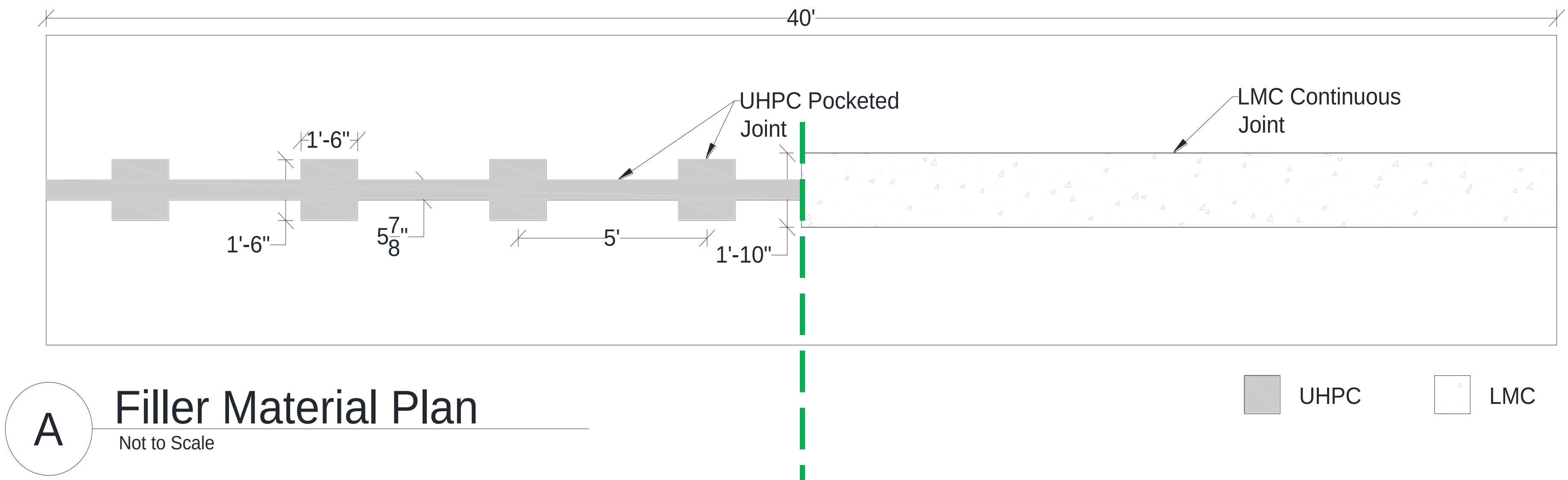
Ultra-High Performance Concrete (UHPC)

- Fiber-reinforced cementitious concrete
- Made with very fine aggregates in size of dust
- Usually with 2% volumetric steel fibers
- Better durability than concrete





How to Rehabilitate Long. Joints?

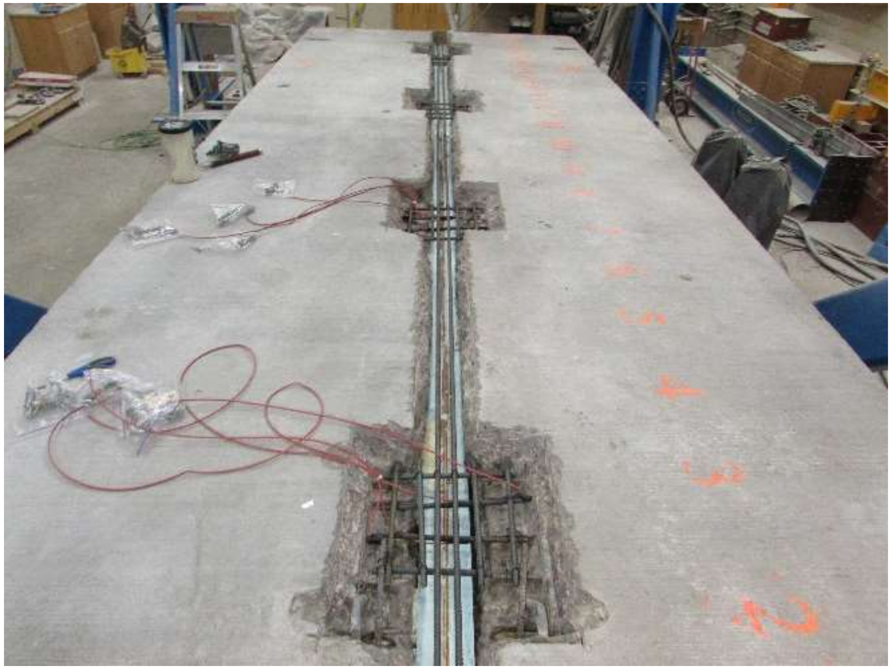
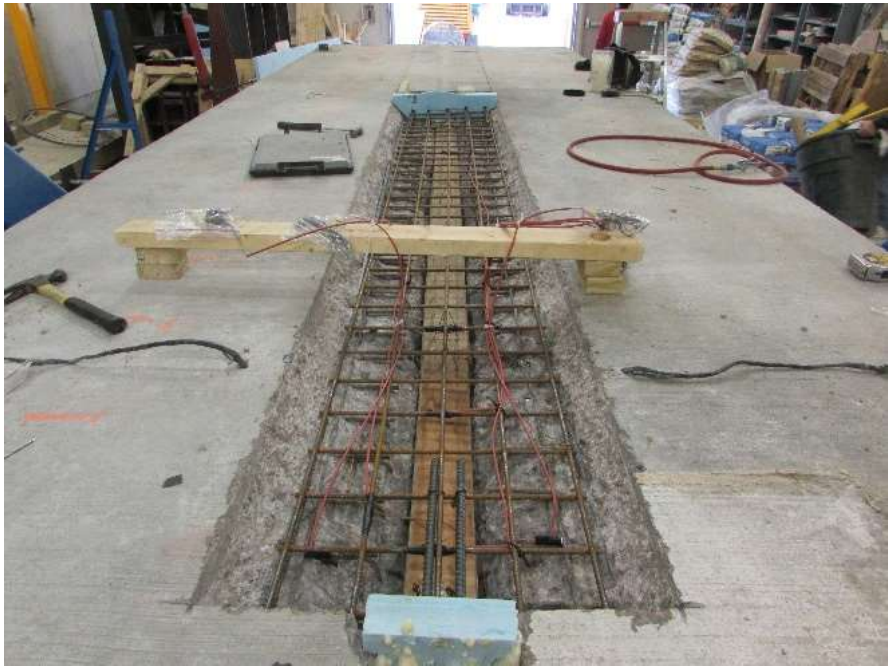


Pocket Detailing:
UHPC filled pockets reinforced with steel bars.

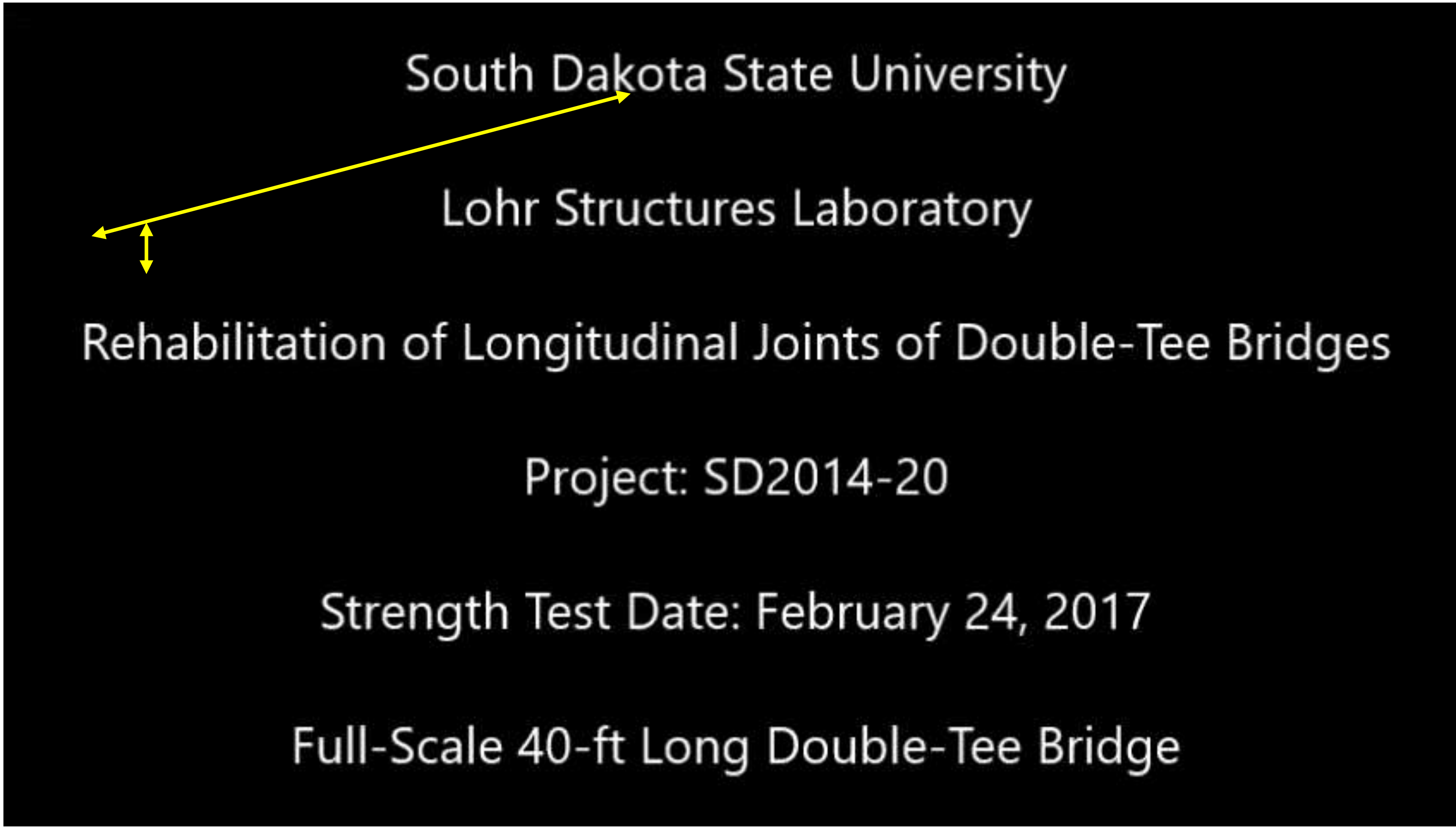
Continuous Detailing:
LMC filled joint reinforced with wire-mesh.

How to Rehabilitate Long. Joints?

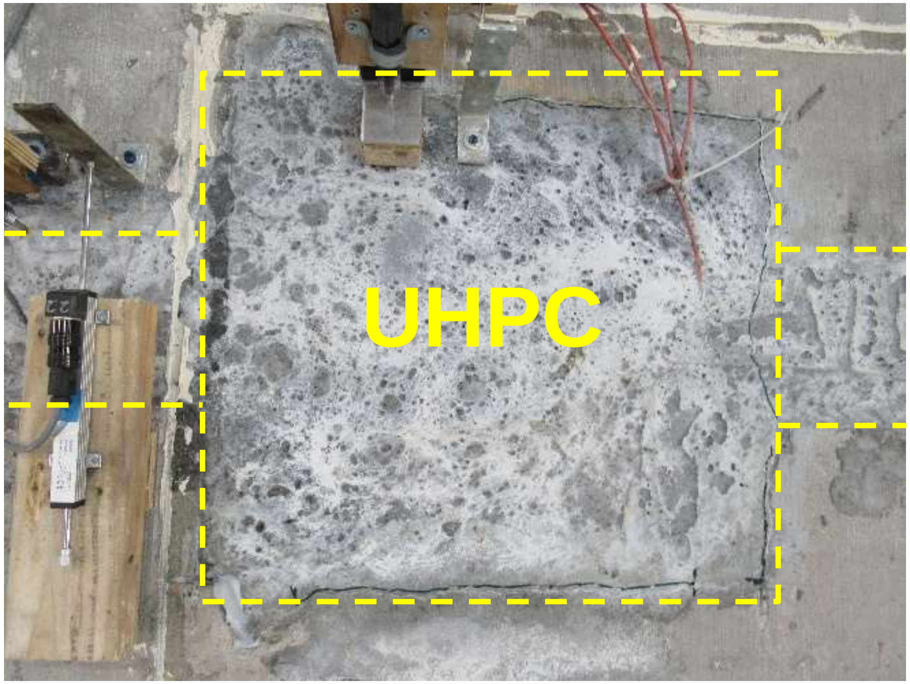


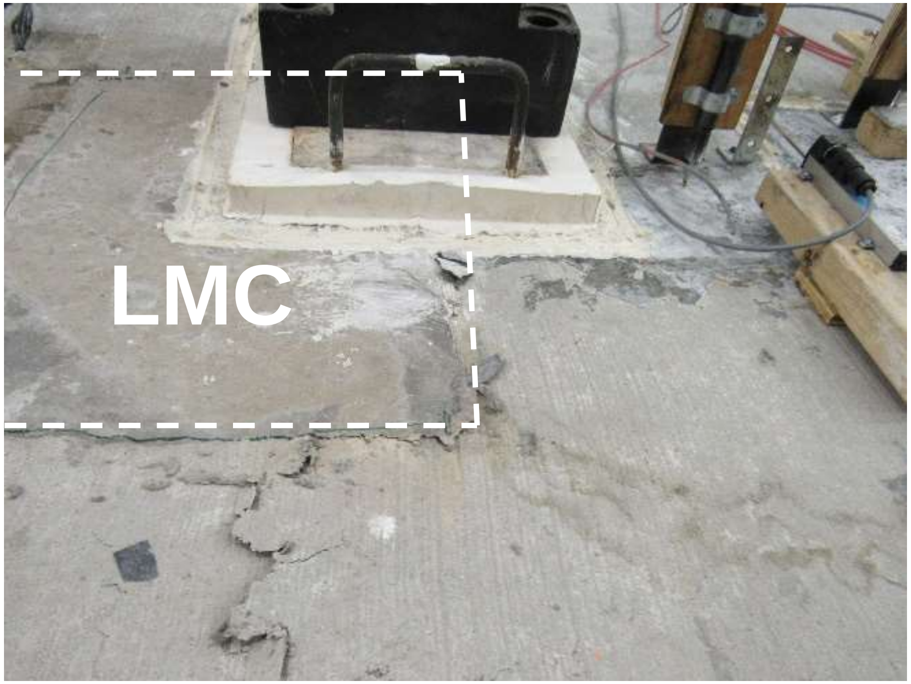




Strength Testing of Rehabilitated Bridge



Rehabilitated Bridge Failure





Bridge Replacement

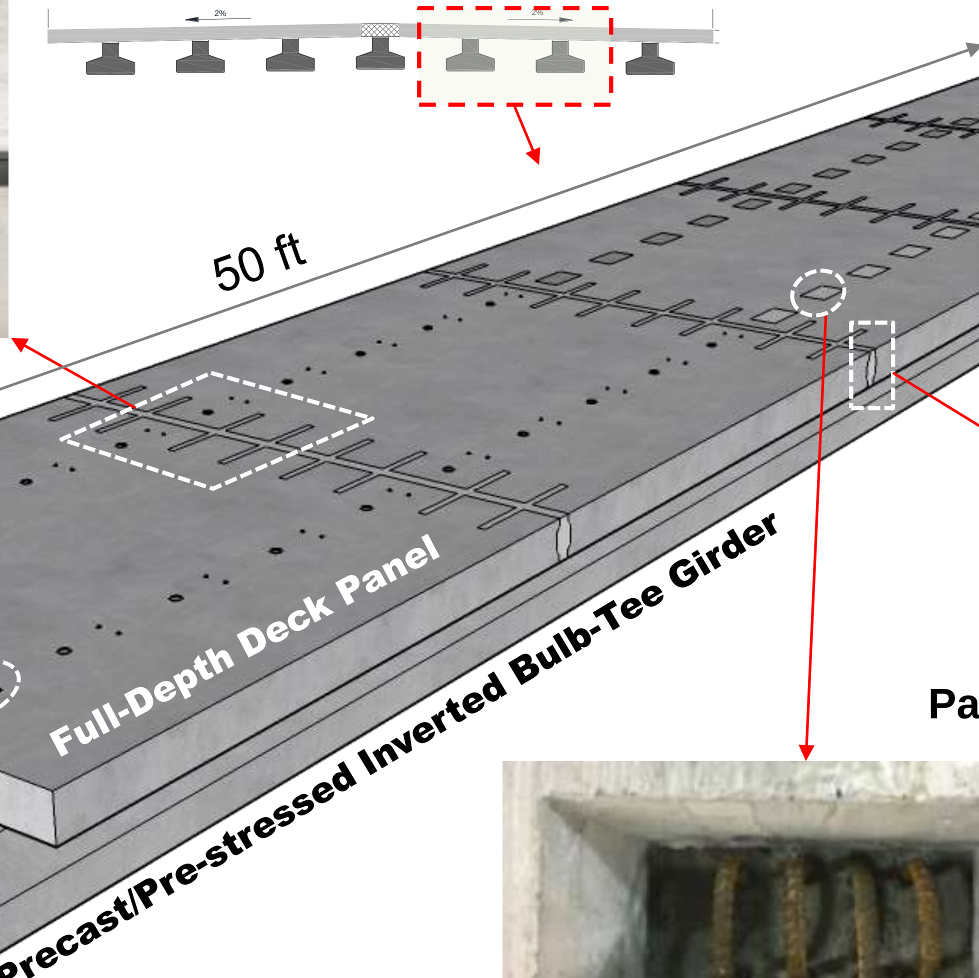
Best Alternatives to Replace Local Road Bridges?

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



Panel-to-Panel Joint

Hidden Pocket,
Headed Studs

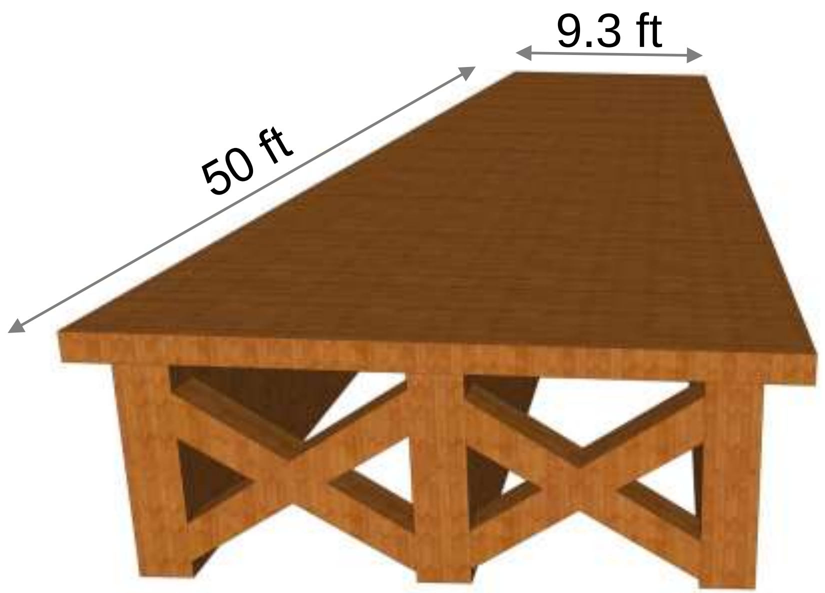
Full-Depth Pocket,
Inverted U-Shape Bars

Glulam Bridges - Prototype

50-ft long, 34.5-ft Wide Girder Bridge

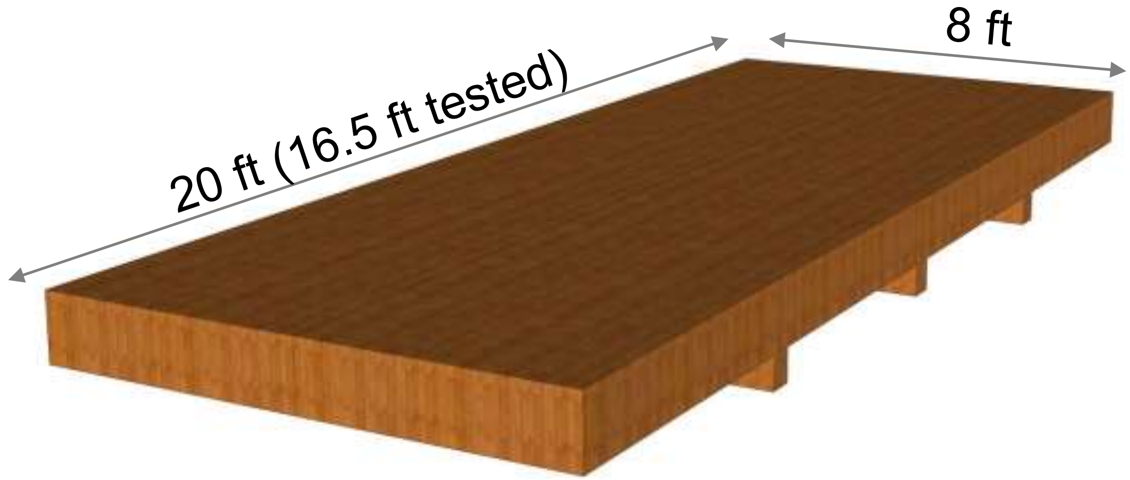
30-ft long, 34.5-ft Wide Slab Bridge

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.

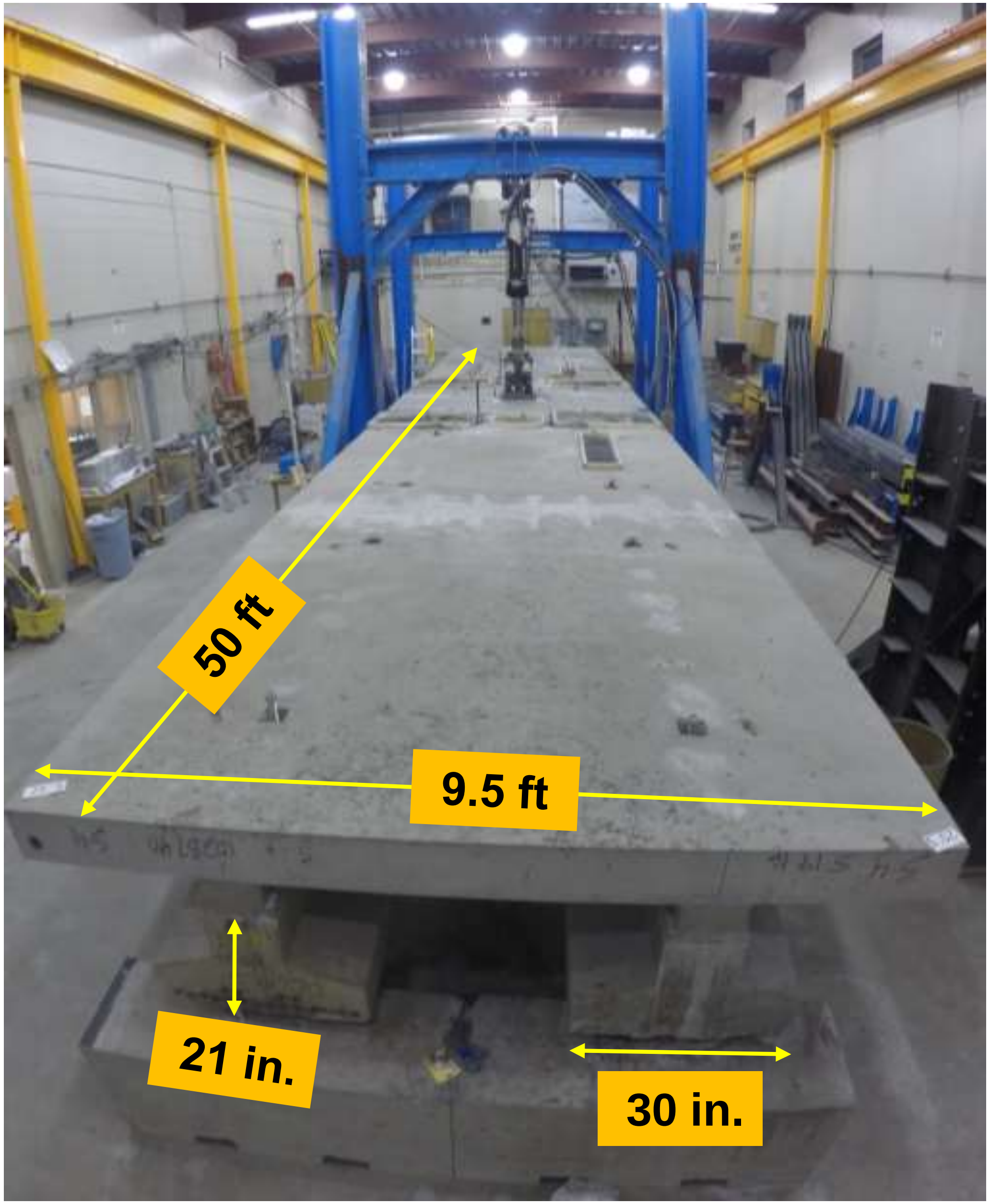
Glulam Slab Bridge – Test Model



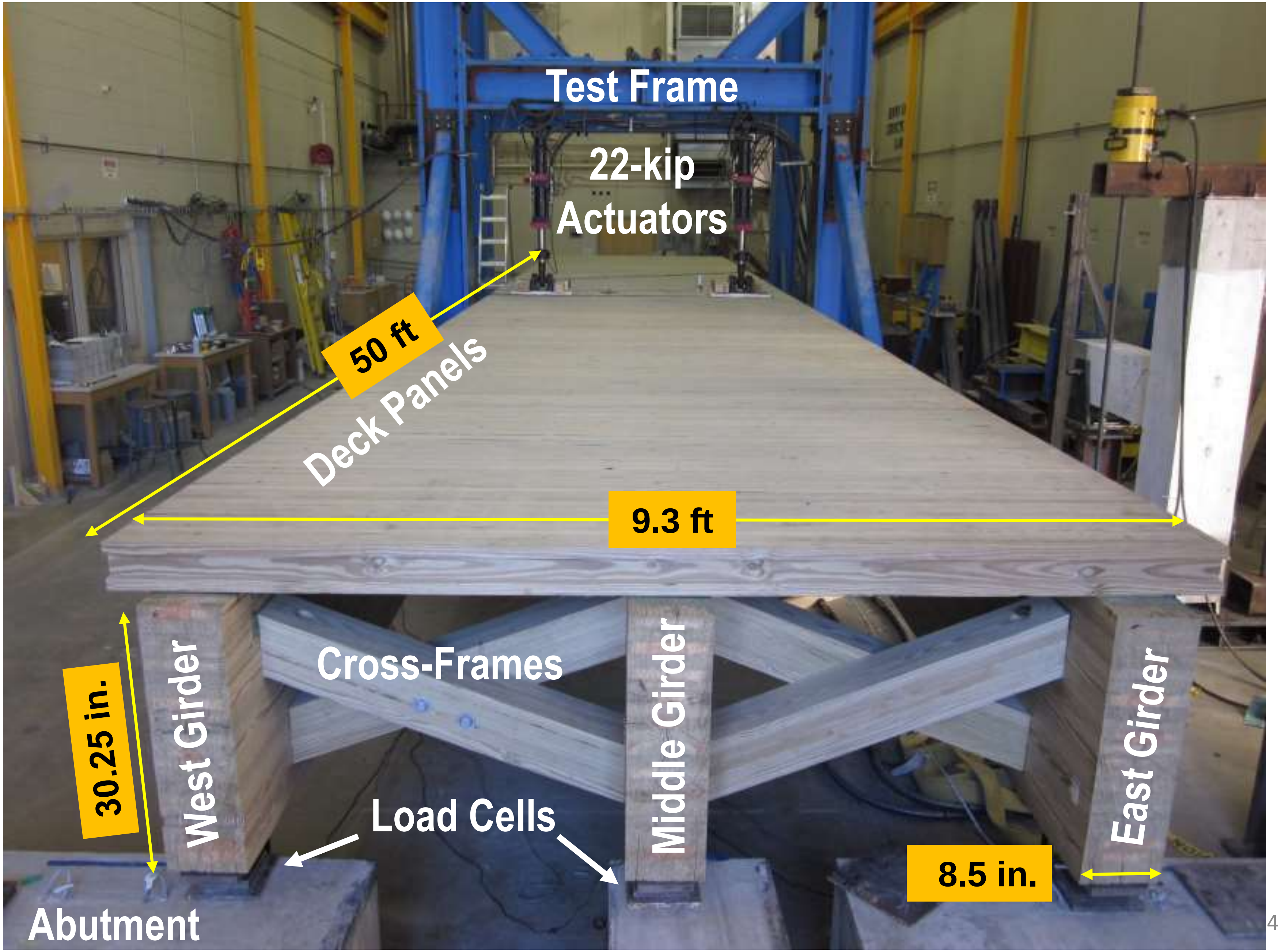
- Bridge was designed based on 24F-2.0E Southern Yellow Pine Glulam.
- Deck consisted of 2 interior panels with a dimension of 48 in. x 10.75 in. x 16.5 ft.
- Also consisted of 3 stiffeners with a dimension of 5.5 in. x 5 in. x 7.5 ft.
- Deck panels were connected to the stiffeners by 12 in. x 3/4 in. dia. lag bolts.

Assembly of Test Specimen

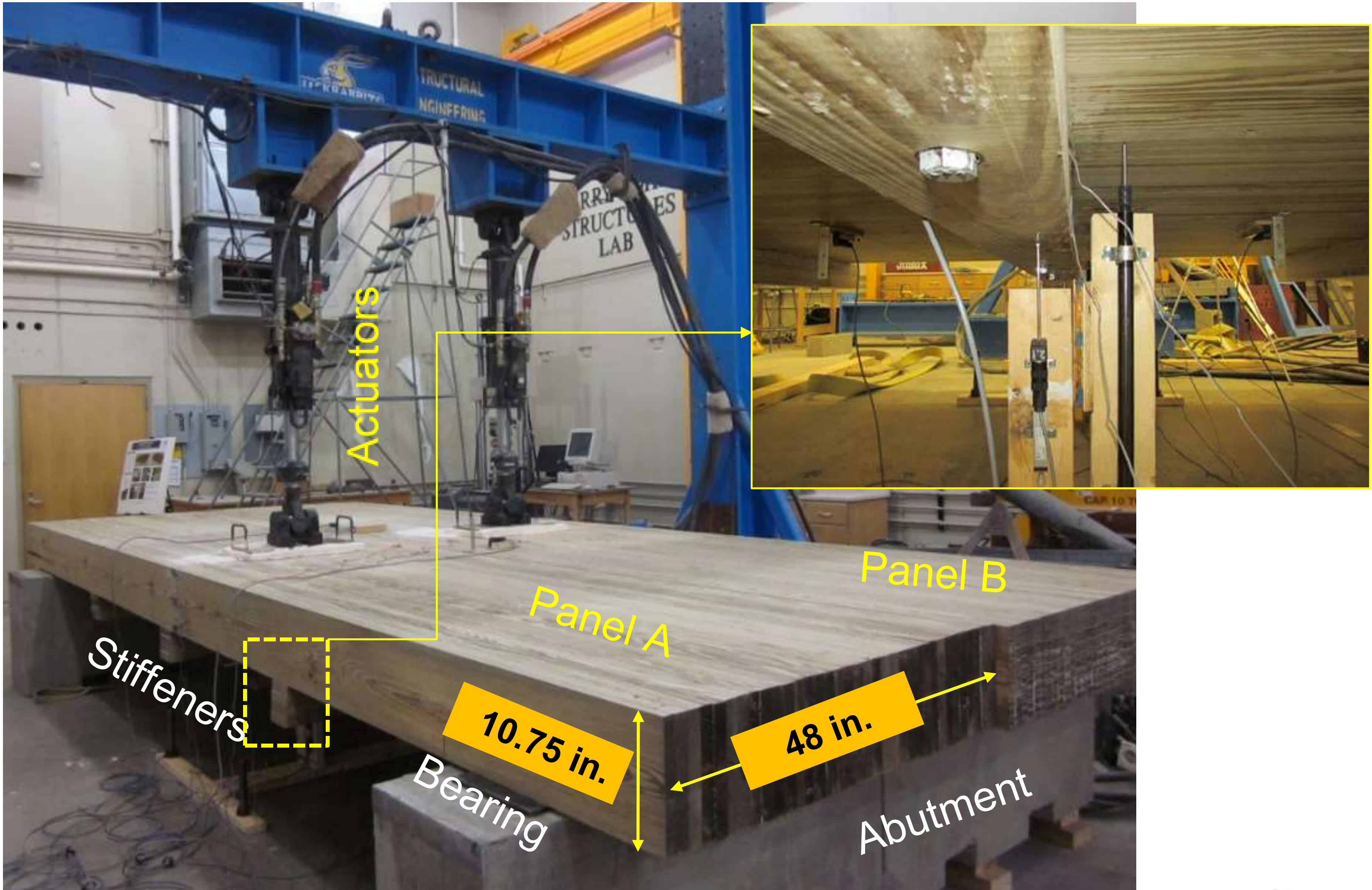
Test Setup



Assembled Glulam Girder Bridge and Test Setup



Assembled Glulam Slab Bridge and Test Setup

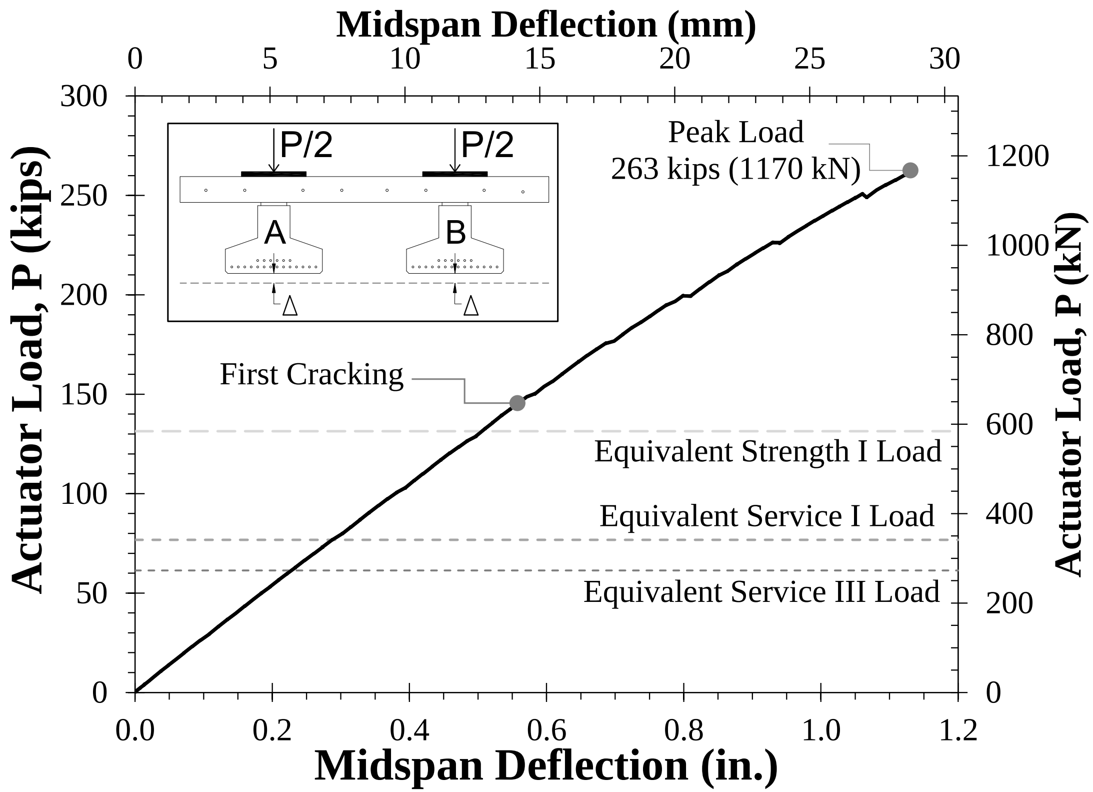


Test Procedure

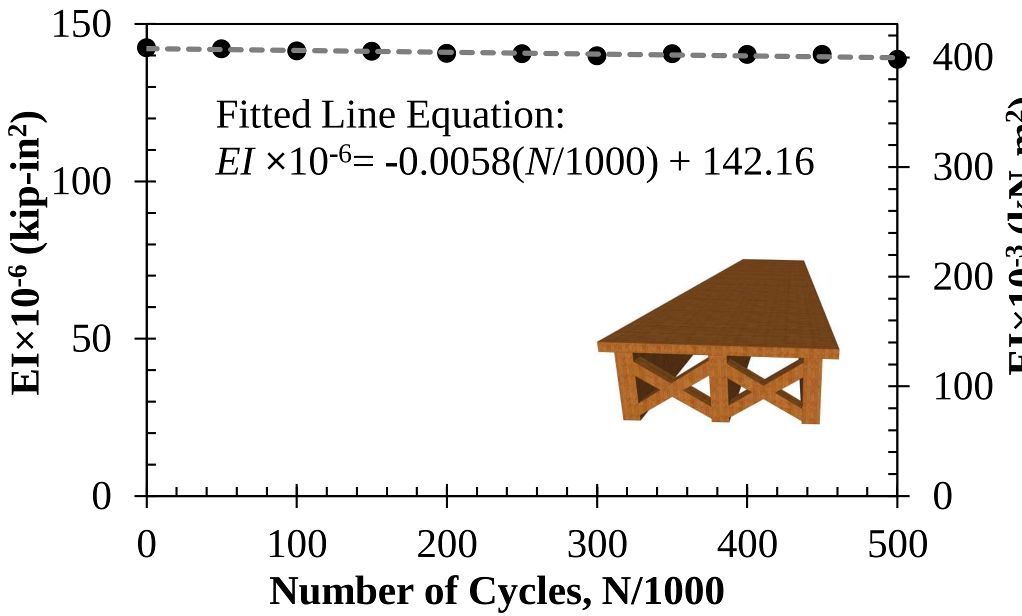
Each bridge was tested under:

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

Ultimate Test Results – Precast Bridge

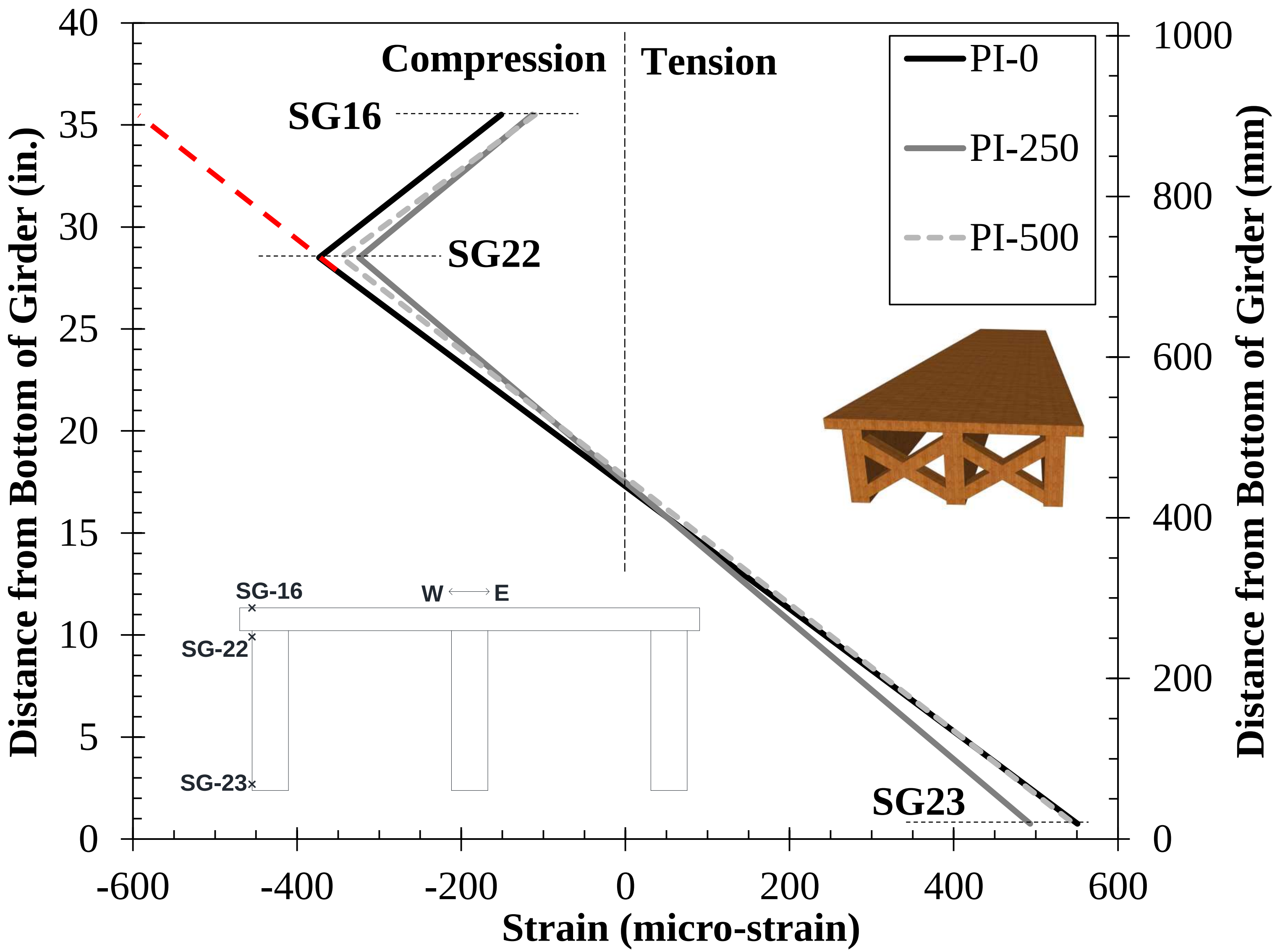


Fatigue Test Results – Glulam Girder Bridge



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

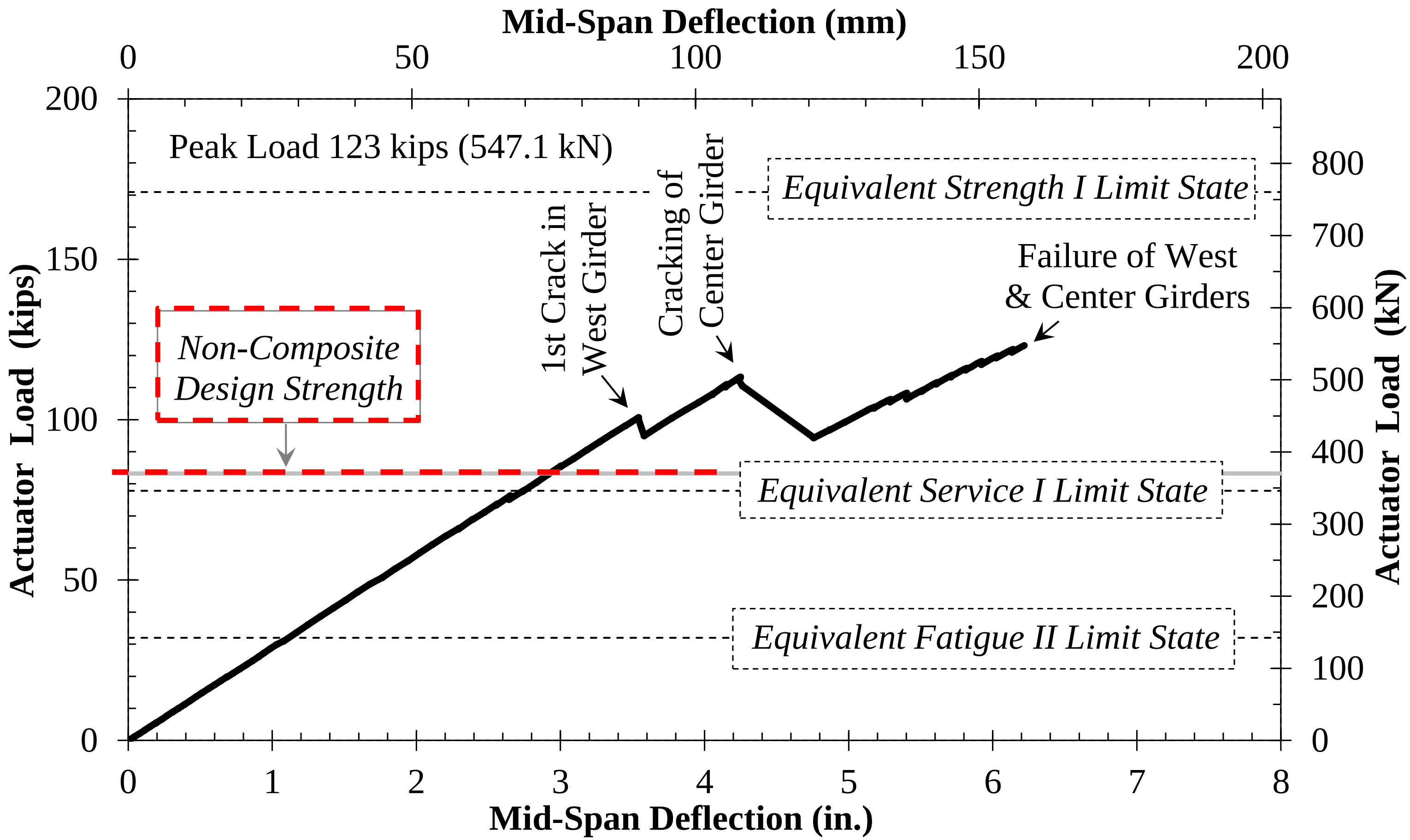
Fatigue Test Results – Glulam Girder Bridge



Glulam girders should be design fully non-composite.

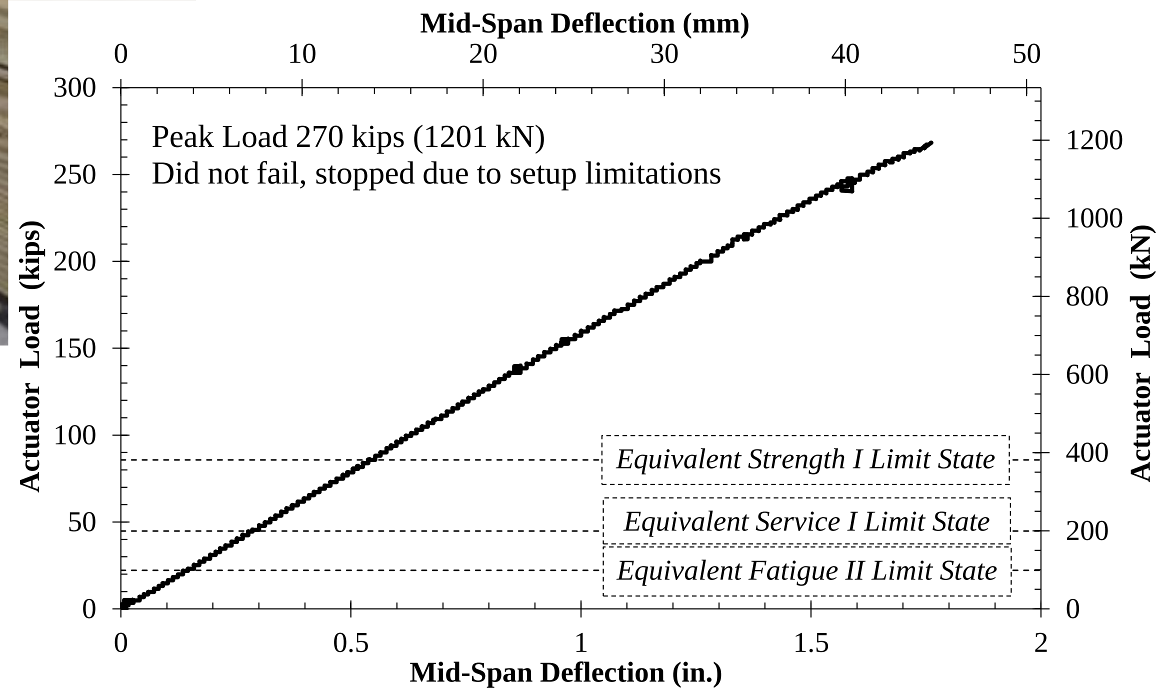
Strength Test Results – Glulam Girder Bridge

Strength Test Results – Glulam Girder Bridge



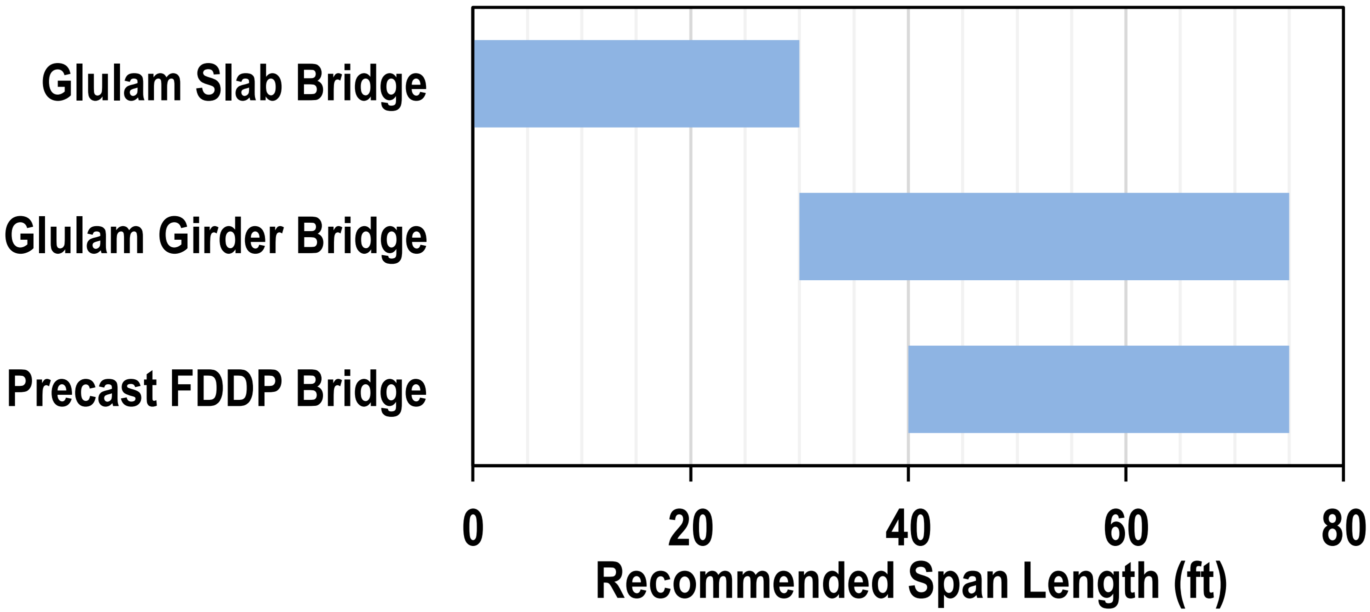
Bridge failed since a wrong grade of wood was used in construction. Timber girders should be designed fully non-composite.

Strength Test Results – Glulam Slab Bridge



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

Evaluation of Three Alternatives

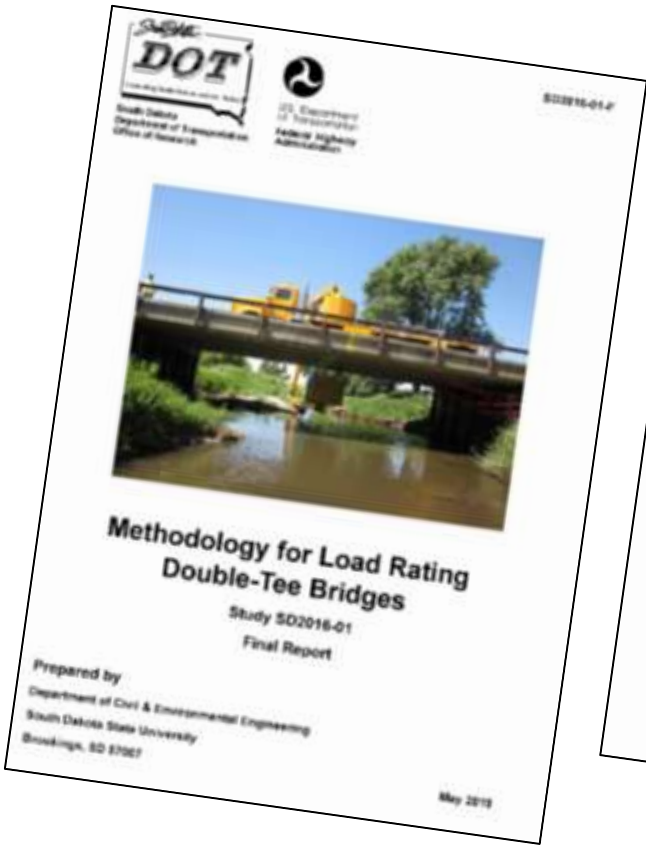


Bridge System	Superstructure Cost
Glulam Slab Bridge	50% Less than Double-Tee
Glulam Girder Bridge	15-20% Less than Double-Tee
Precast FDDP Bridge	11% higher than Double-Tee

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.

Research Reports



DOT

South Dakota Department of Transportation Office of Research

U.S. Department of Transportation Federal Highway Administration

SD2016-01-F

Methodology for Load Rating Double-Tee Bridges

Study SD2016-01

Final Report

Prepared by

Department of Civil & Environmental Engineering

South Dakota State University

Brookings, SD 57007

DOT

South Dakota Department of Transportation Office of Research

U.S. Department of Transportation Federal Highway Administration

SD2014-20-F

Rehabilitation of Longitudinal Joints in Double-Tee Girder Bridges

Study SD2014-20

Final Report

DOT

South Dakota Department of Transportation Office of Research

U.S. Department of Transportation Federal Highway Administration

SD2014-14-F

Development of Alternative Bridge Superstructures for South Dakota Local Roads

Study SD2014-14

Final Report

Prepared by

South Dakota State University

Go to MPC website & search for "Tazarv"

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

Questions?

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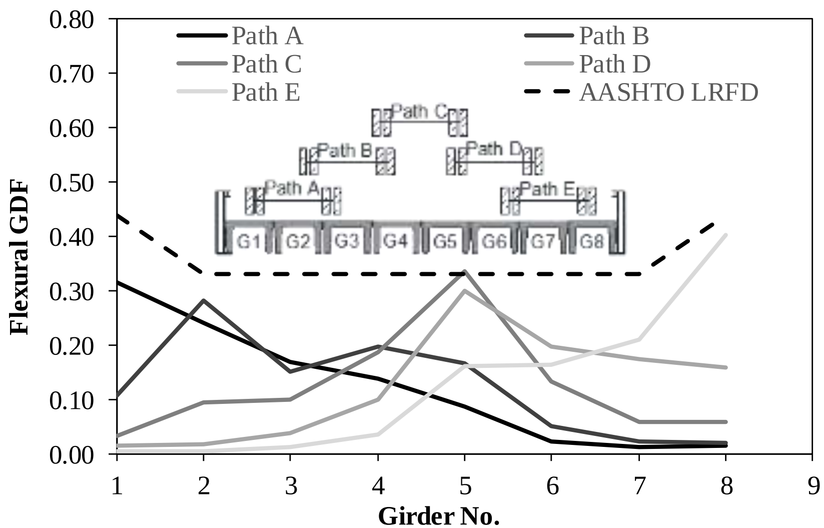
Flexural GDF

Flexural GDF of 23-in. Deep Double-Tee Girder Bridge

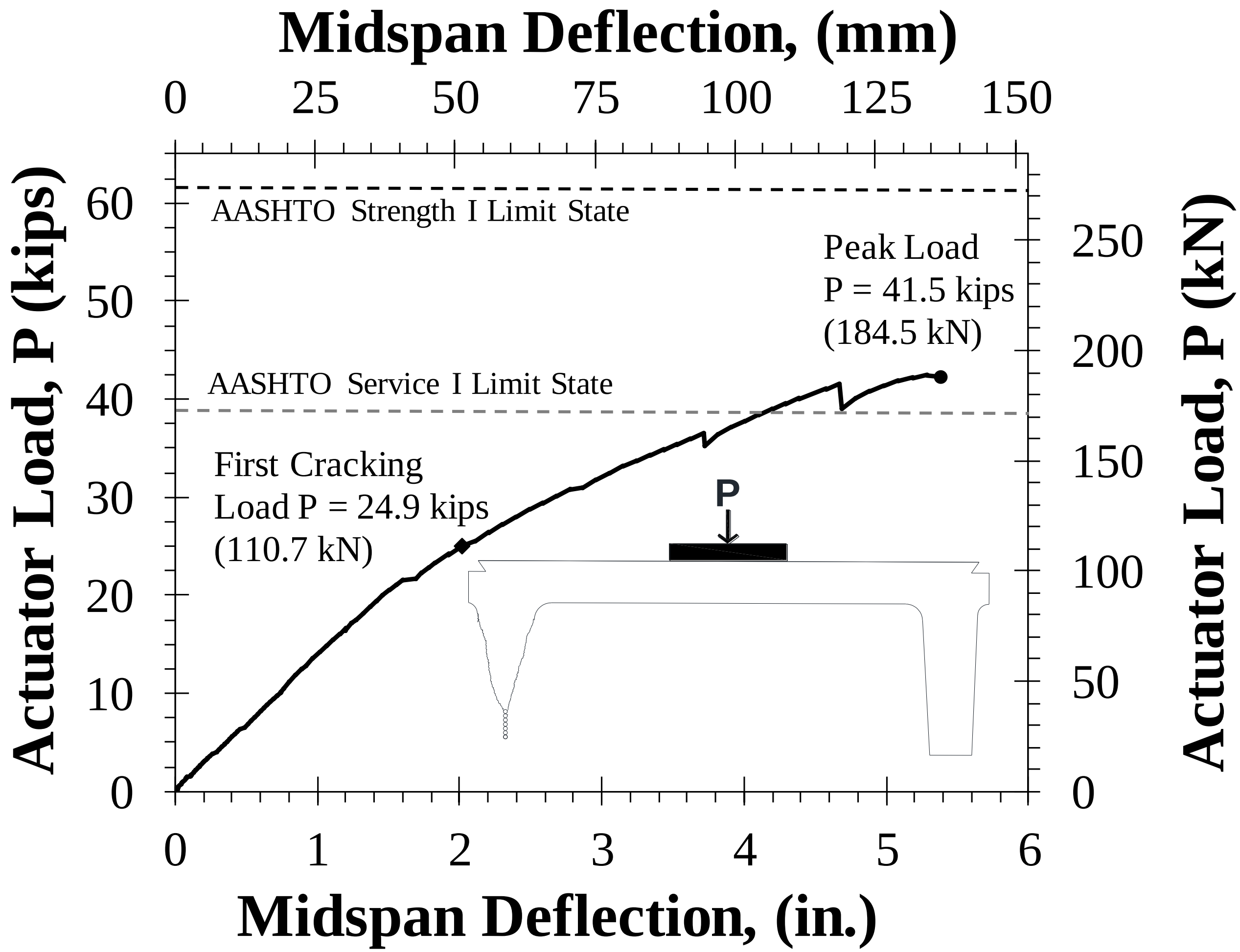
	G1	G2	G3	G4	G5	G6	G7	G8
Path A	0.32	0.24	0.17	0.14	0.09	0.02	0.01	0.01
Path B	0.11	0.28	0.15	0.20	0.17	0.05	0.02	0.02
Path C	0.03	0.09	0.10	0.19	0.34	0.13	0.06	0.06
Path D	0.01	0.02	0.04	0.10	0.30	0.20	0.17	0.16
Path E	0.01	0.01	0.01	0.04	0.16	0.16	0.21	0.40
Maximum GDF of each Girder	0.32	0.28	0.17	0.20	0.34	0.20	0.21	0.40
AASHTO GDF of each Girder	0.438	0.33	0.33	0.33	0.33	0.33	0.33	0.438



Flexural GDF of each girder in each path of 23-in. Deep Double-Tee Girder Bridge

The measured flexural GDFs for each girder were equal to or less than those from the AASHTO LRFD .

Force-Deflection Relationship: 50-ft Girder



- 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

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

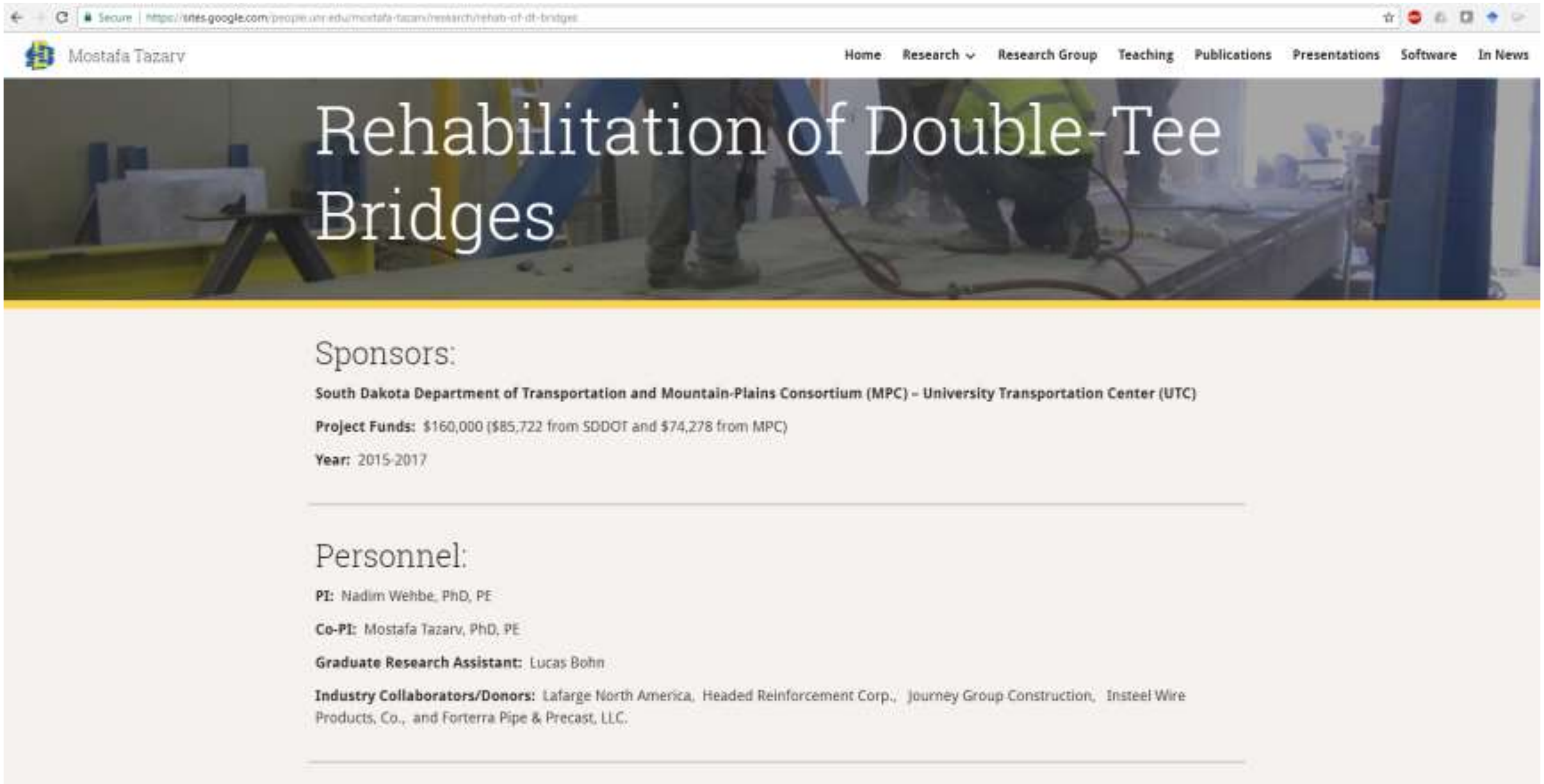
Capacity:

$$\boldsymbol{C_{undamaged} = \varphi_s \,.\, \varphi \,.\, R_n}$$

$$\boldsymbol{C_{damaged} = \varphi_c \,.\, C_{undamaged}}$$

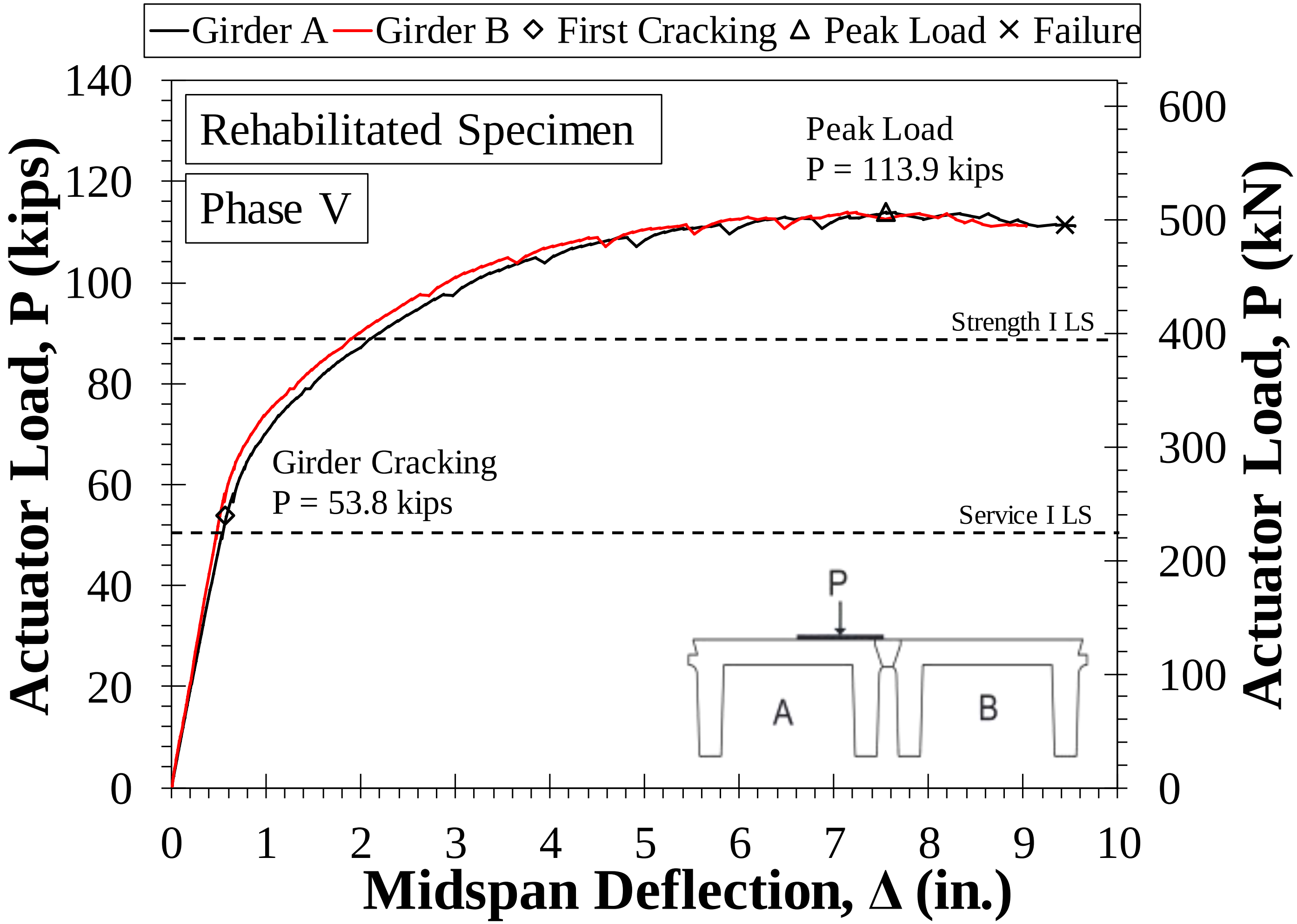
We need to determine moment and shear condition factors (φ_c) for different damage types and condition states and for different double-tee girder sections.

Project Website



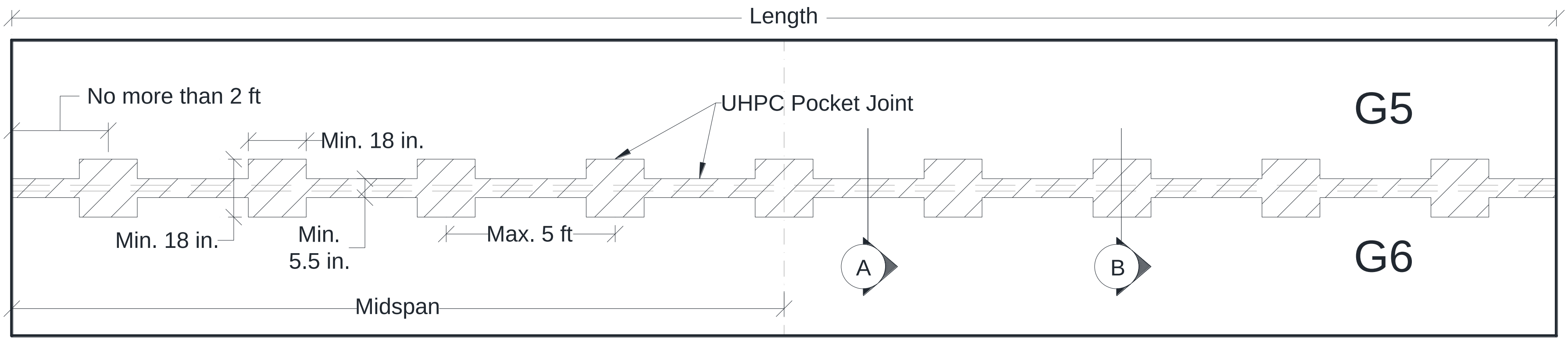
https://sites.google.com/people.unr.edu/mostafa-tazarv/research/rehab-of-dt-bridges

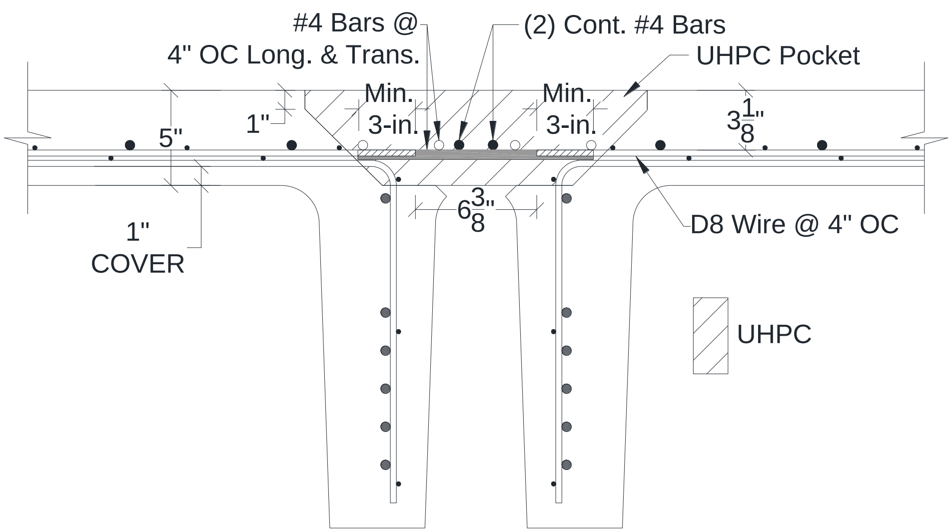
Strength Test Results and Costs



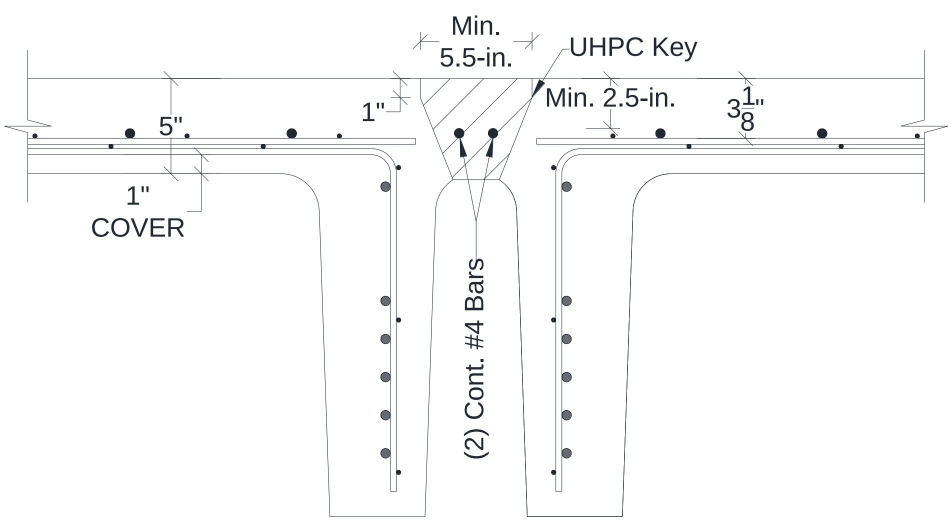
- Pocket joint rehabilitation cost is **28%** of that of replacement.
- Continuous joint rehabilitation cost is **57%** of that of

Recommendations





Section B - Pocket Joint Detailing



Section A – Shear key Detailing

Recommendations

- **Preparation**

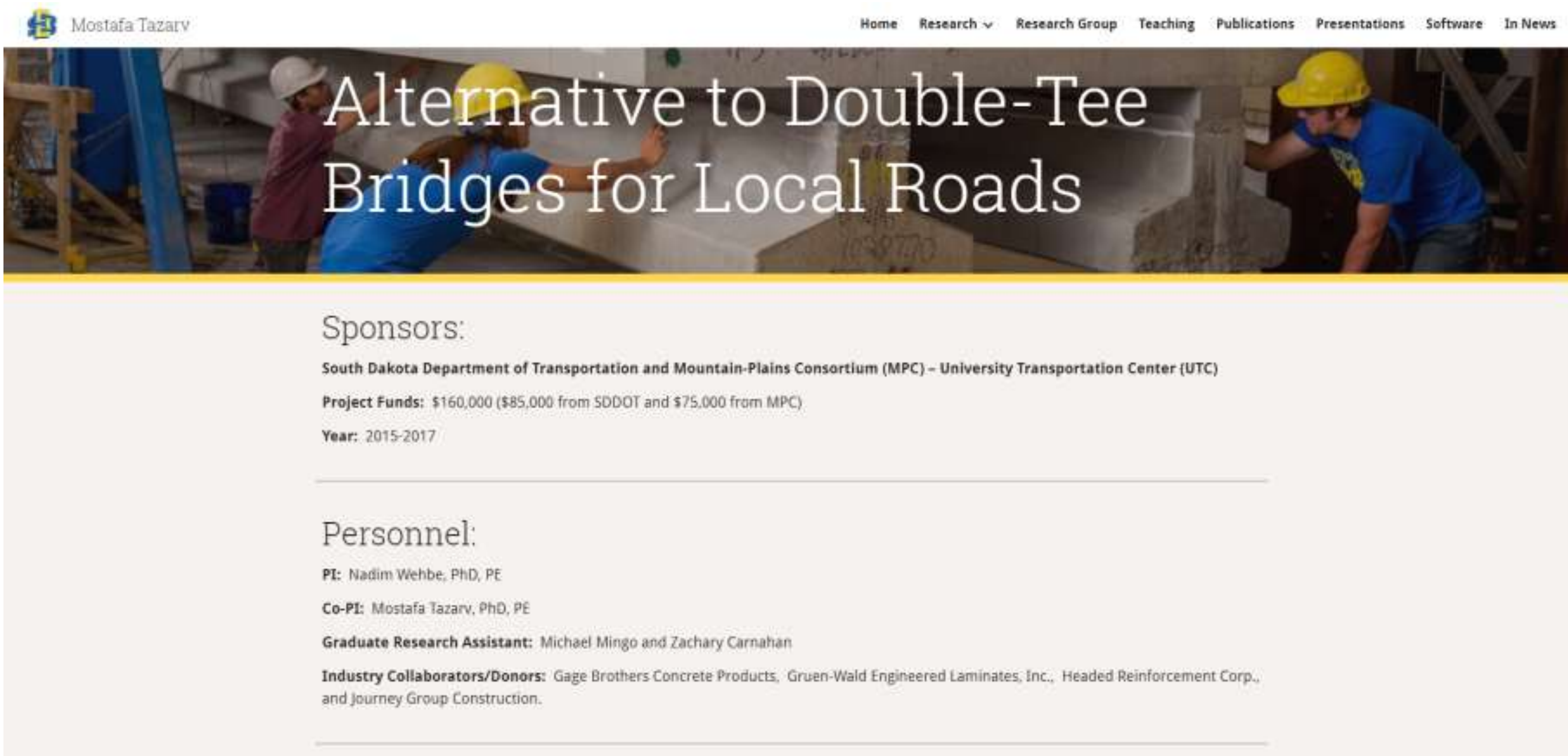
    1. 1-in. Saw-cut around perimeters.
    2. Hammer-chip at 45 degree slope, 20 degrees between pockets:
        a. 30-lb chippers for first 2.5 inches.
        b. 15-lb chippers around reinforcement.
    3. Hydro-demolition shall be permitted as an alternative.
    4. Joint surface shall be sand-blasted 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



Mostafa Tazarv

Home Research Research Group Teaching Publications Presentations Software In News

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

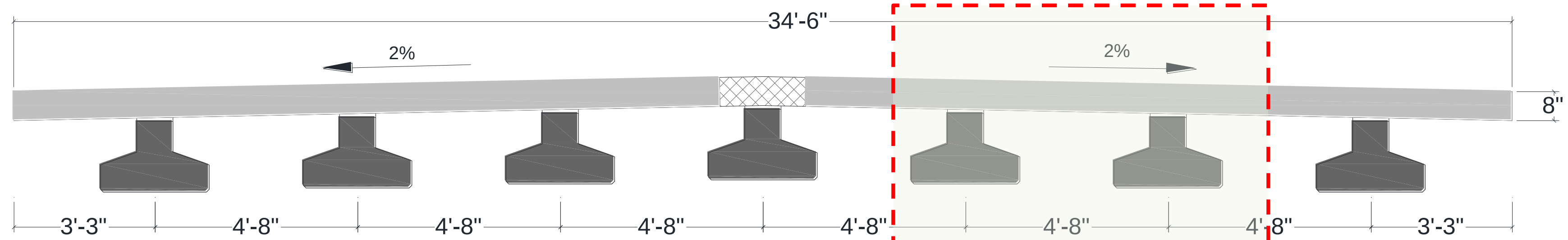
Co-PI: Mostafa Tazarv, PhD, PE

Graduate Research Assistant: Michael Mingo and Zachary Carnahan

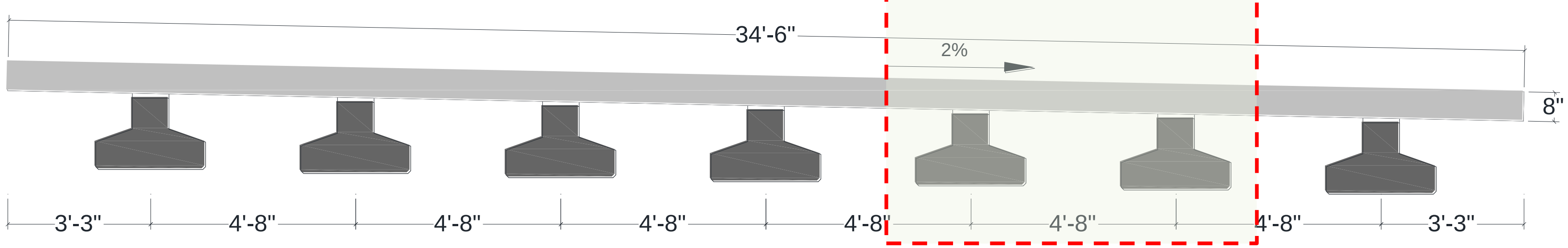
Industry Collaborators/Donors: Gage Brothers Concrete Products, Gruen-Wald Engineered Laminates, Inc., Headed Reinforcement Corp., and Journey Group Construction.

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

Fully-Precast Bridge – Prototype



Bridge Cross – Section Option 1



Bridge Cross – Section Option 2

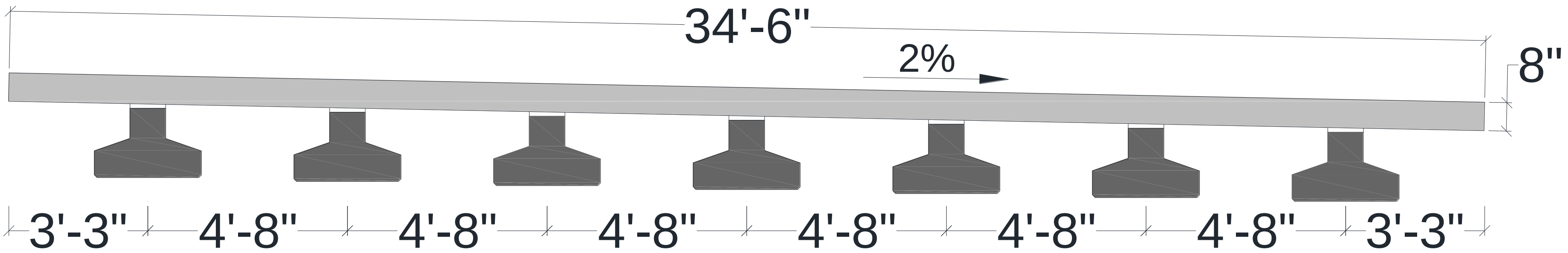
- 50-ft Long and 34.5-ft Wide.
- Seven Prestressed Inverted Bulb-Tee Girders.
- Precast Full-Depth Panels.

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.

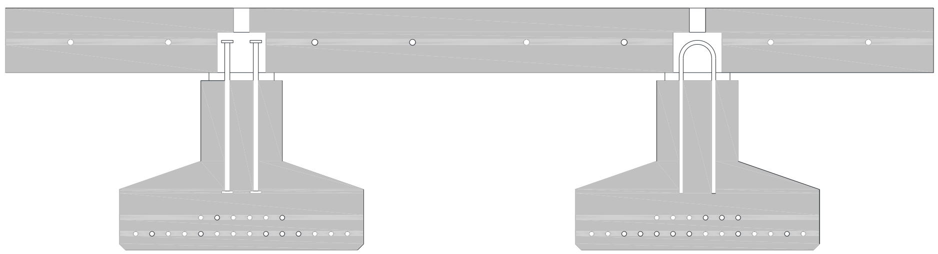
Recommendations Precast Bridge

- The deck panels should be full-width.

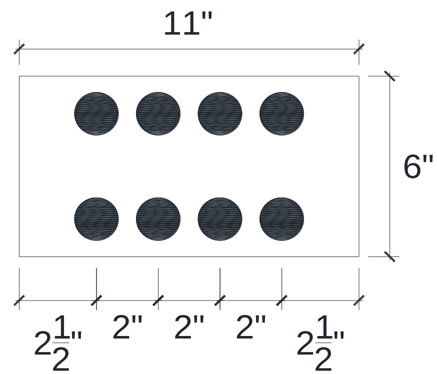


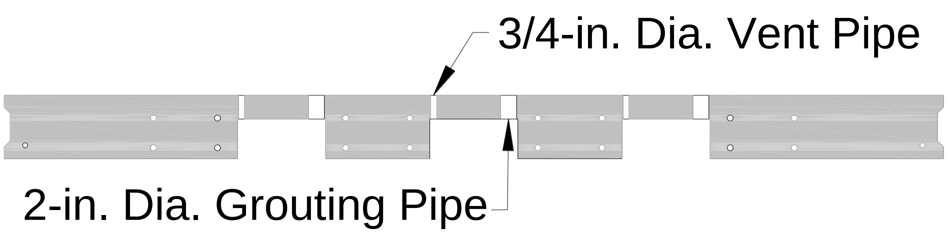
Bridge Cross-Section (Full-Width Panels)

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

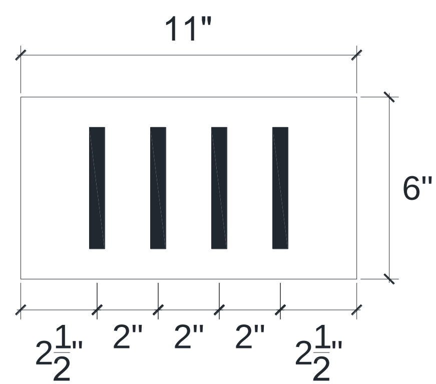


Hidden Pockets – Transverse Section View



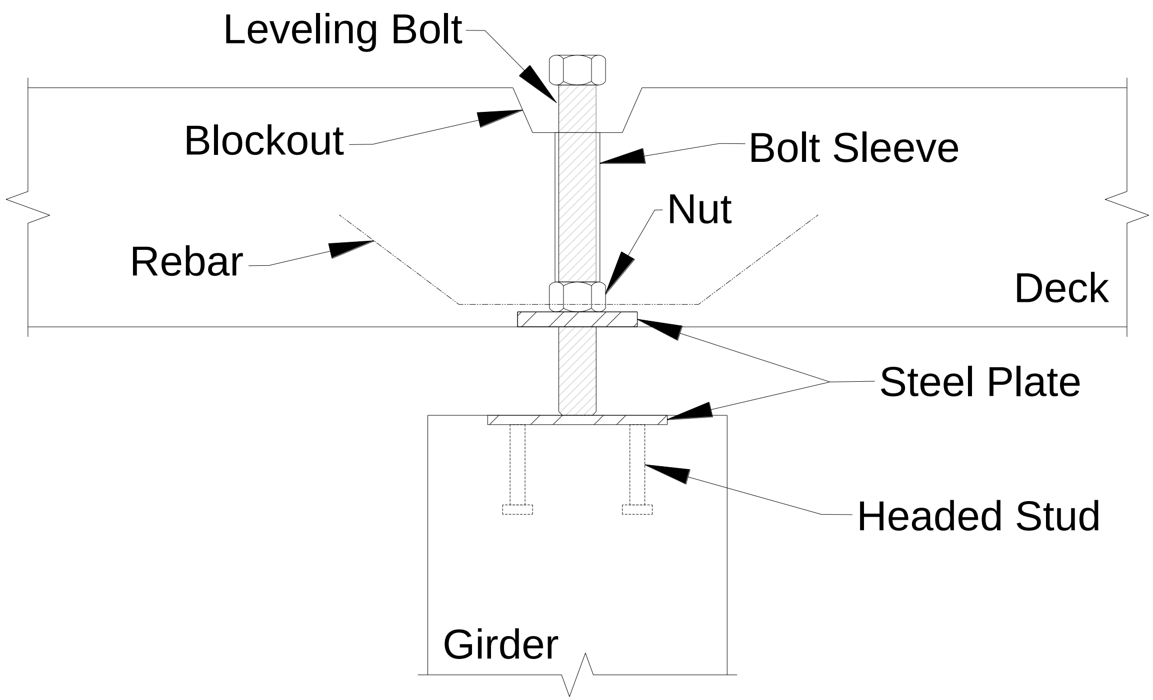


Hidden Pockets – Longitudinal Section View



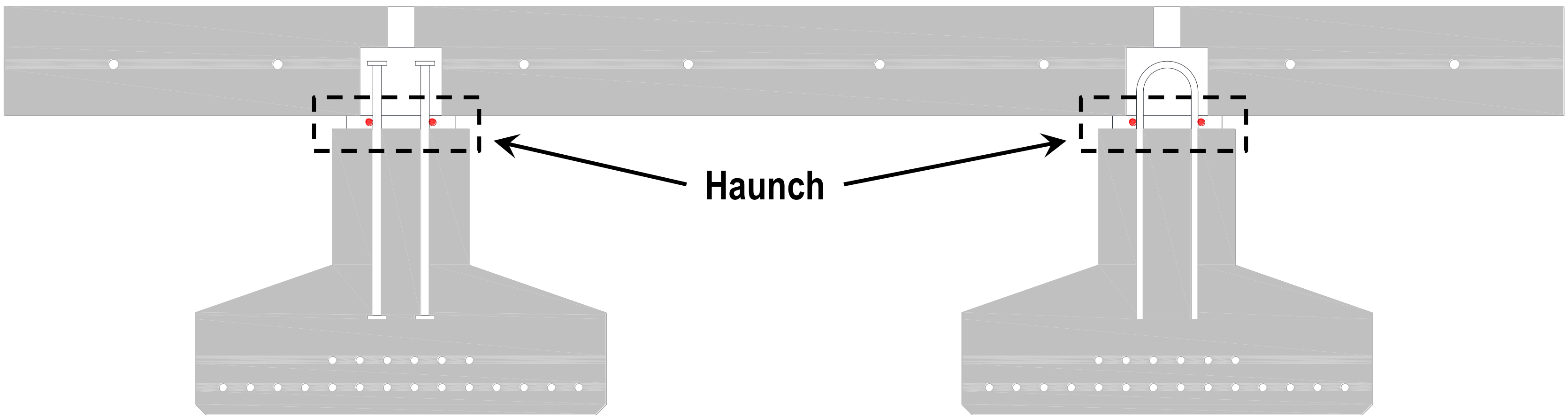
Recommendations Precast Bridge

- All deck steel reinforcement should be epoxy coated.
- The leveling bolts should be bolts (not threaded rods with nut).



Leveling Bolt Detailing

- Each grouted haunch should have two longitudinal steel bars for shrinkage.



Haunch Longitudinal Reinforcing Steel Bars Detailing

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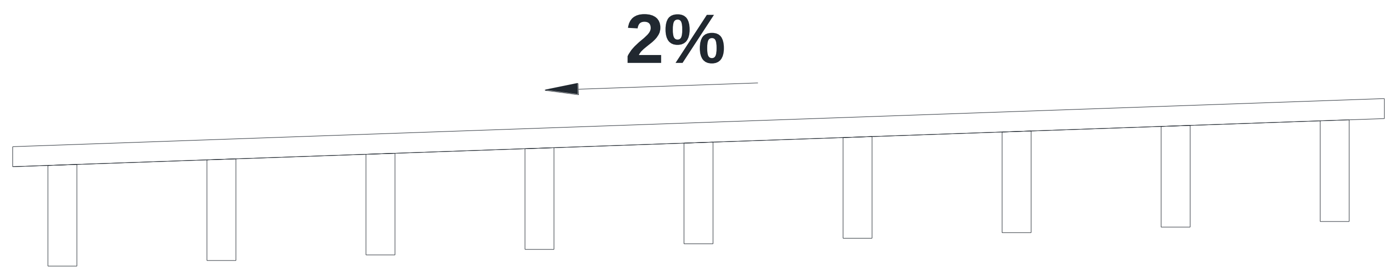
Recommendations for Girder Bridge

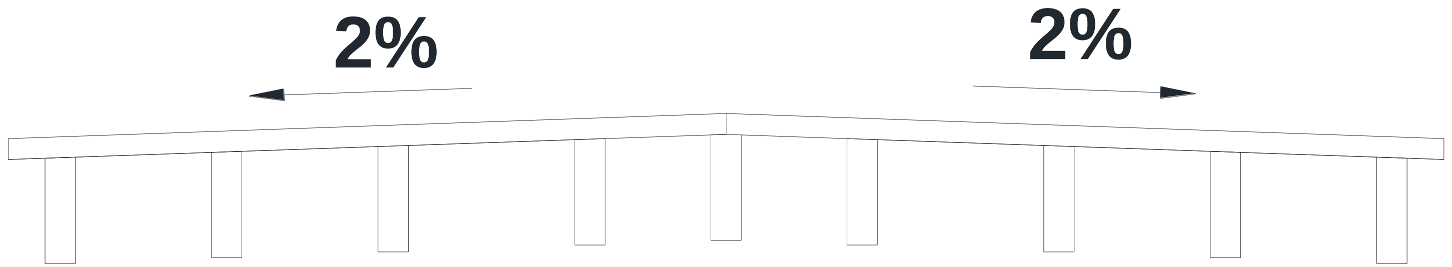
- Girders shall be designed fully non-composite according to AASHTO.
- The type, rating, treatment, and geometry of the wood shall be verified and approved by the designer before fabrication of the girders.
- Glulam deck panels shall be a minimum of 6 inches.
- The bridge shall be one or two grades as shown.

Recommendations for Girder Bridge

- The bridge shall be one or two grades as shown.

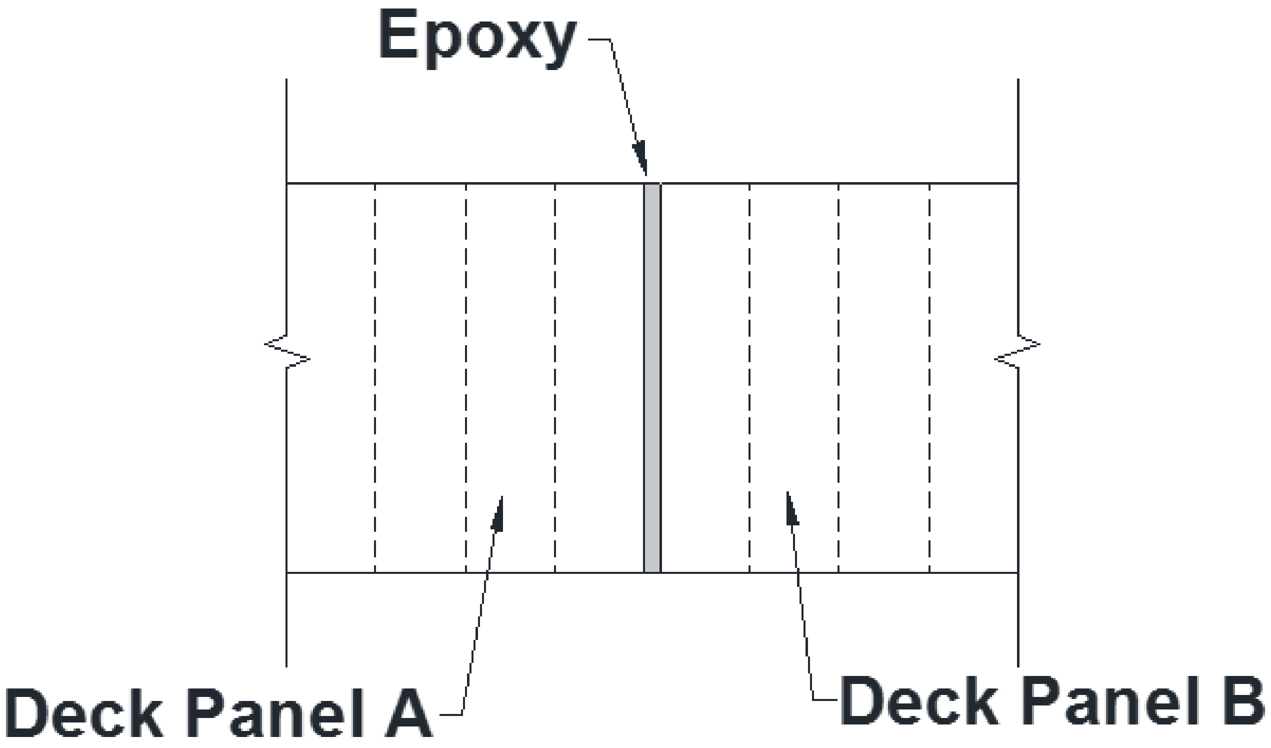


(a) Girder Bridge with Single Grade



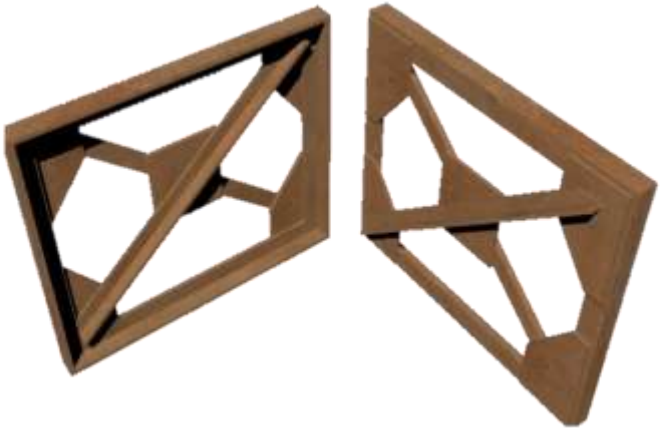
(b) Girder Bridge with Two Grades

- **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.**

(a) Asphalt Overlay

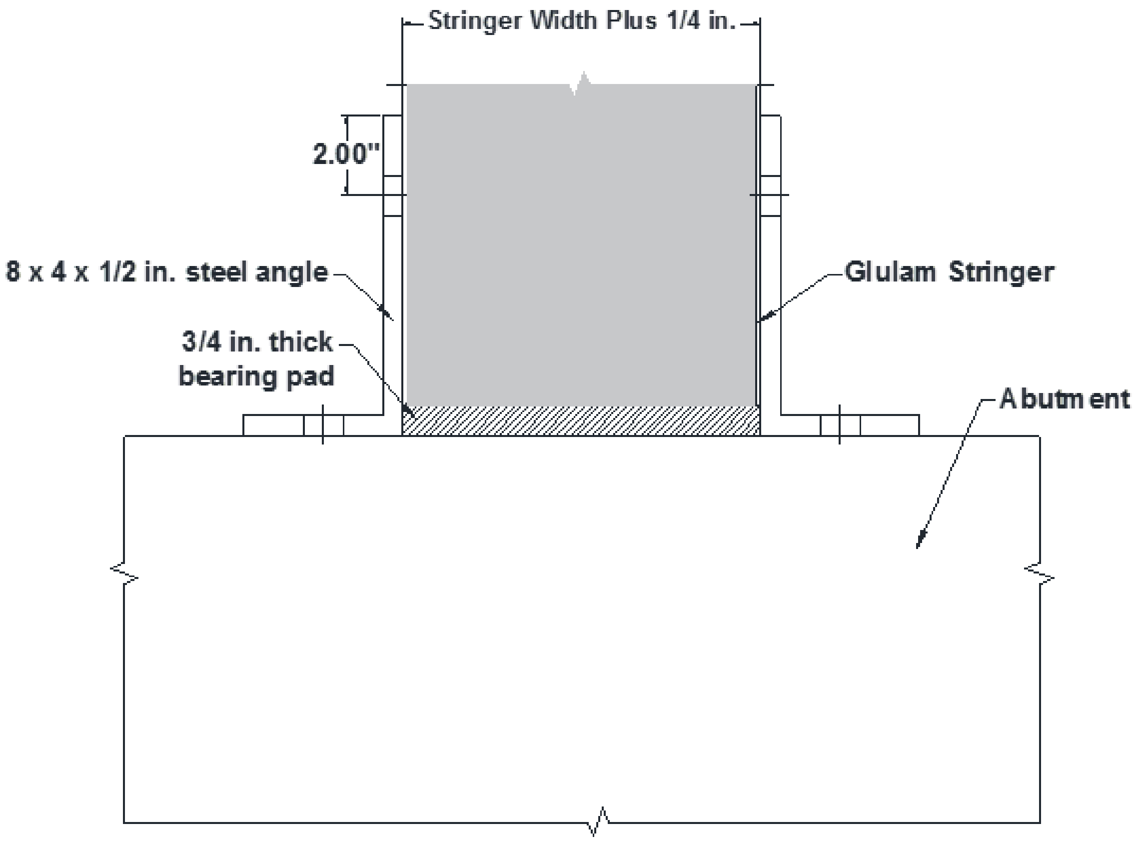
(b) Asphalt Chip Seal (Greenwald 2011)

(c) Aggregate Overlay

(d) 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.



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Glulam Bridges in Minnesota

9967

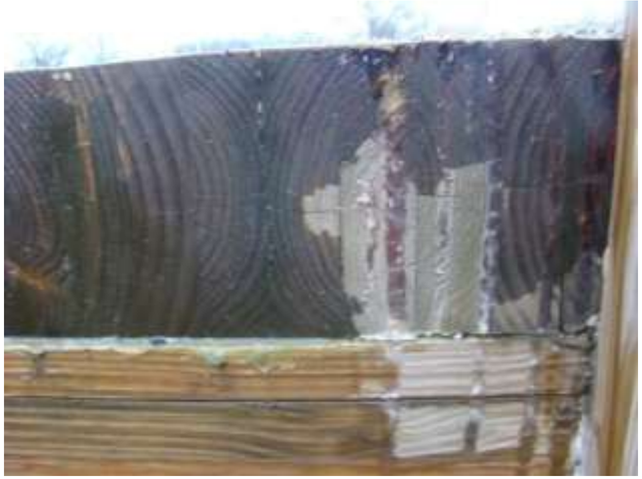
22508

22514

22518

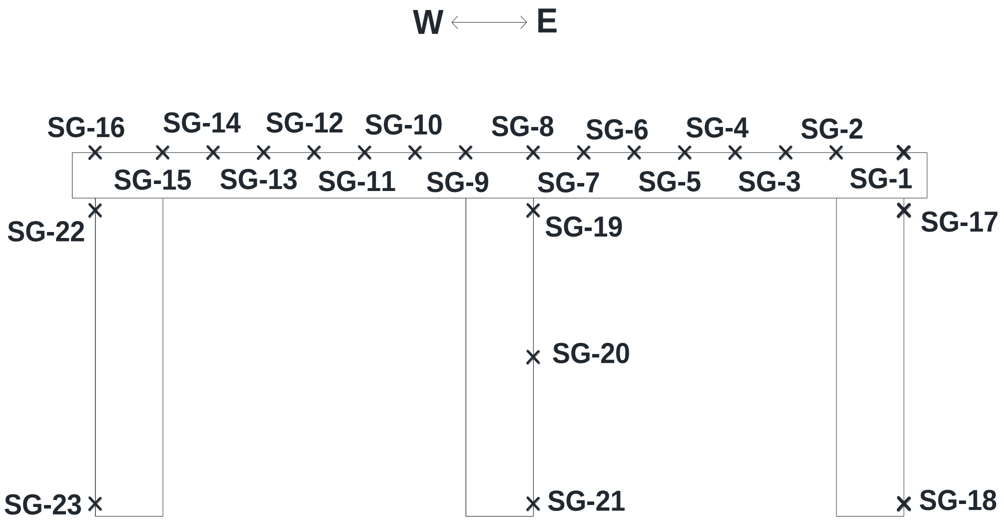
Cedar Rock Bridge

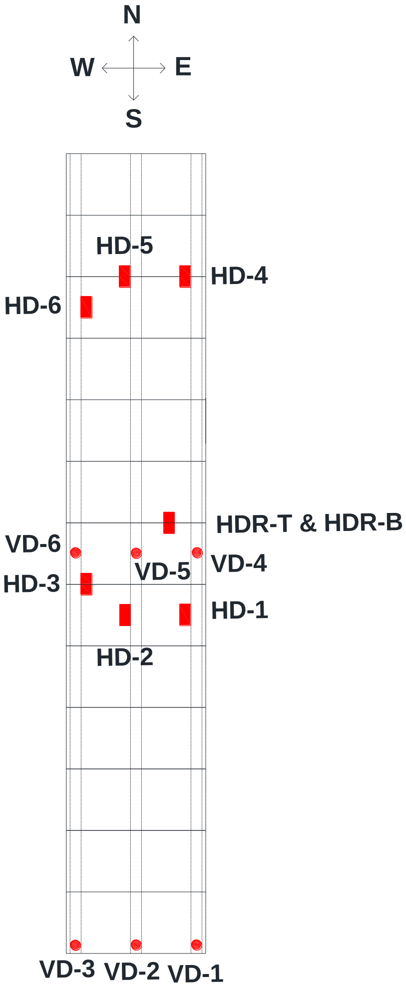
- Located in Buchanan County, Iowa
- Built in 2014
- 72 ft Long x 40 ft Wide

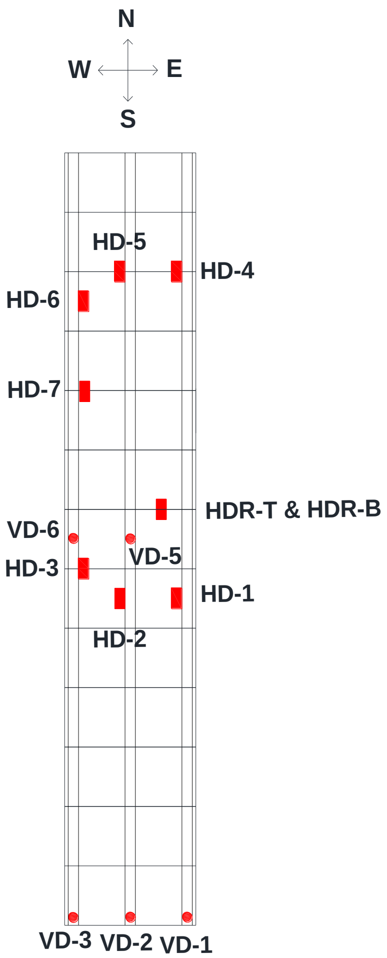


Delivery of Glulam Girder Bridge

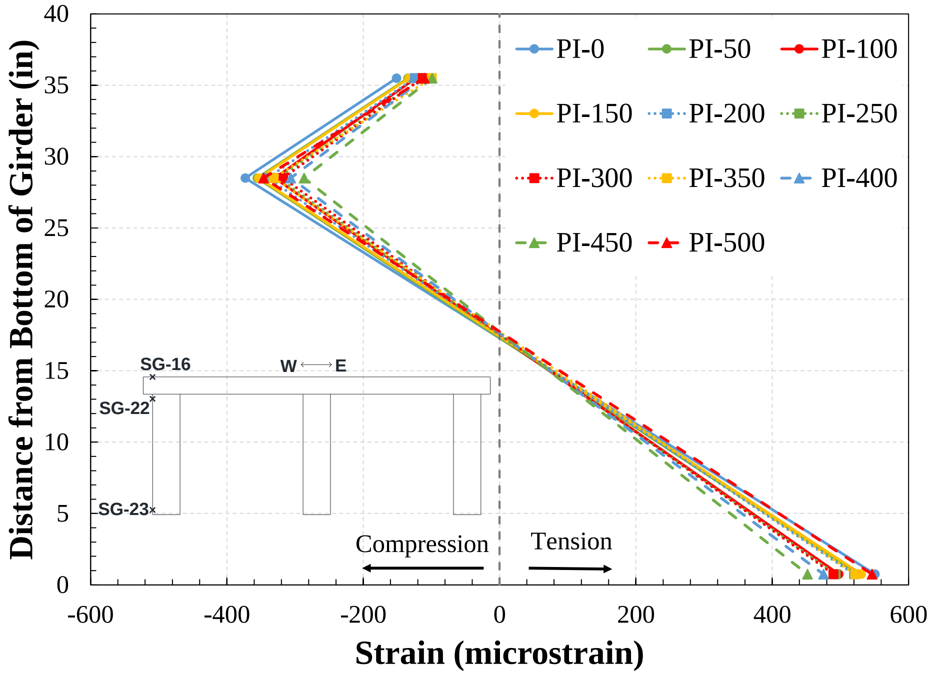
Instrumentation for Glulam Girder Bridge

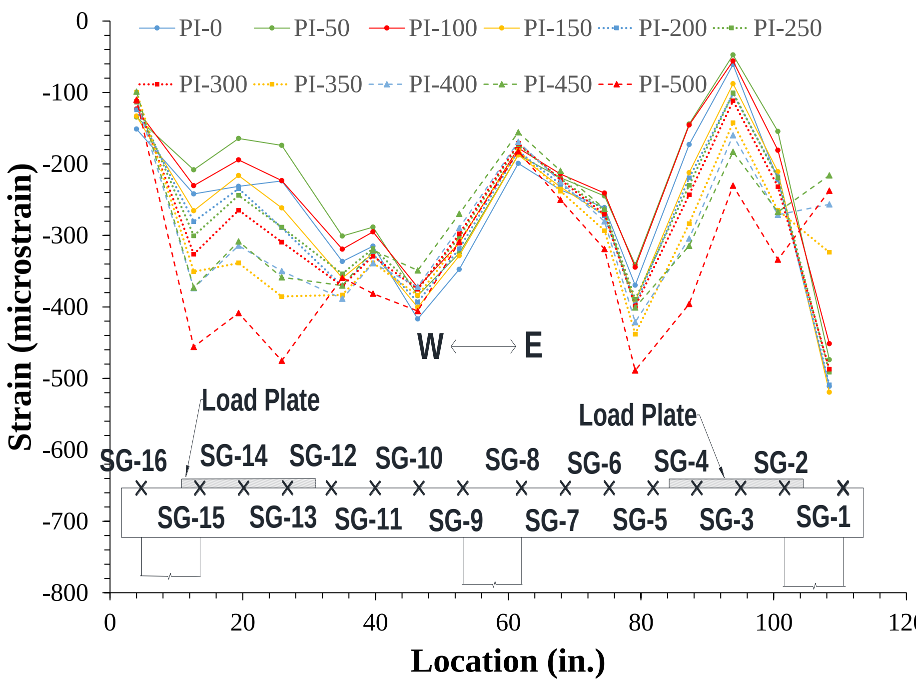






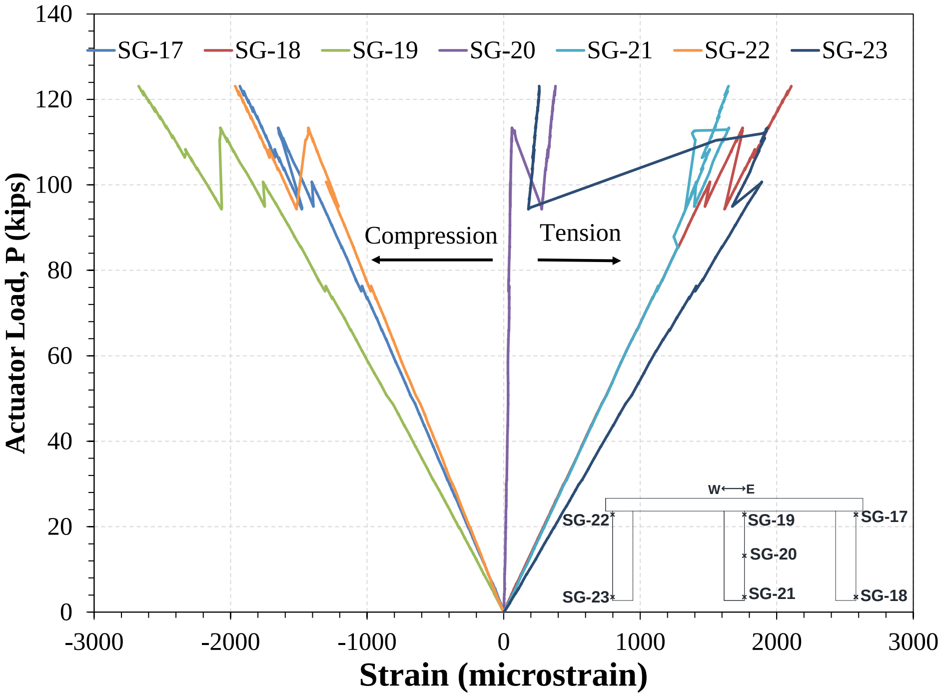
Girder Bridge Fatigue Test Results

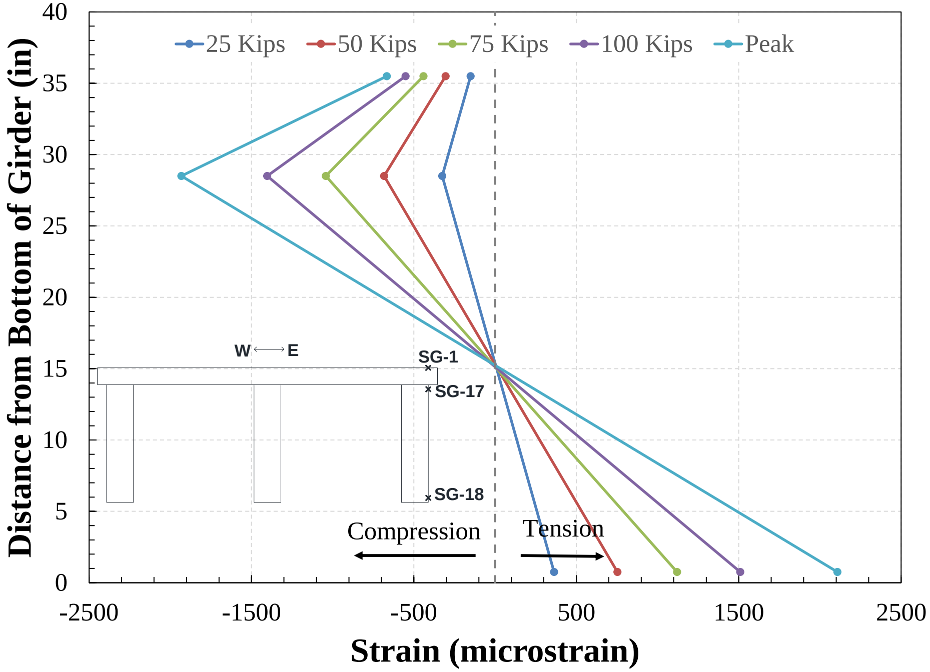




Girder Bridge Failure

Girder Bridge Ultimate Test Results





Girder Bridge Cost Comparison

Bridge System	Glulam Girder Bridge	Double-Tee Girder Bridge
Materials/Fabrication ($)	78,000	111,000
Total ($/sq. ft.)	45	64

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

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.

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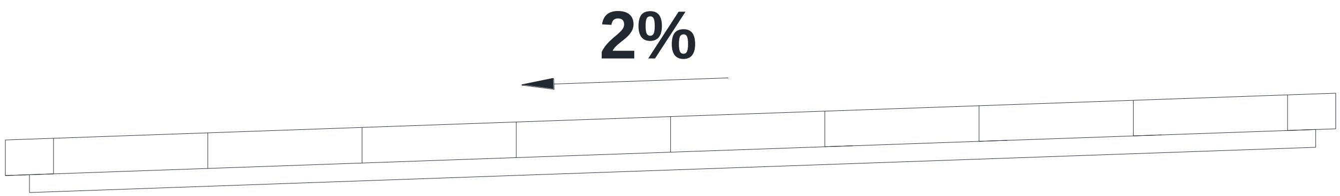
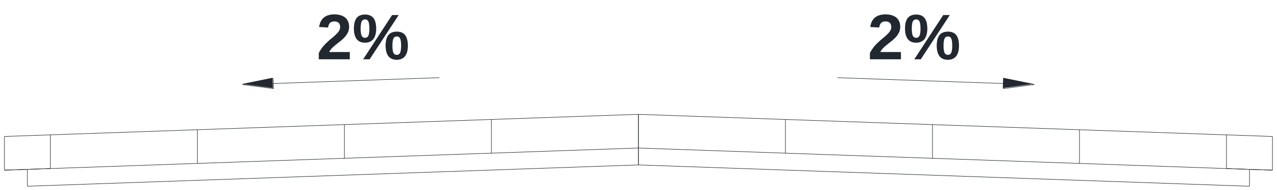
Recommendations for Slab Bridge

- **The bridge shall be one or two grades as shown.**



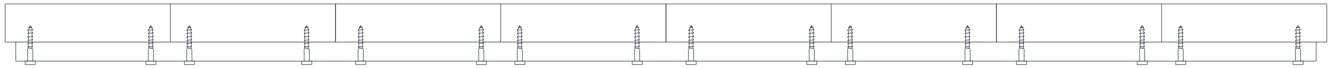
(a) Slab Bridge with Single Grade



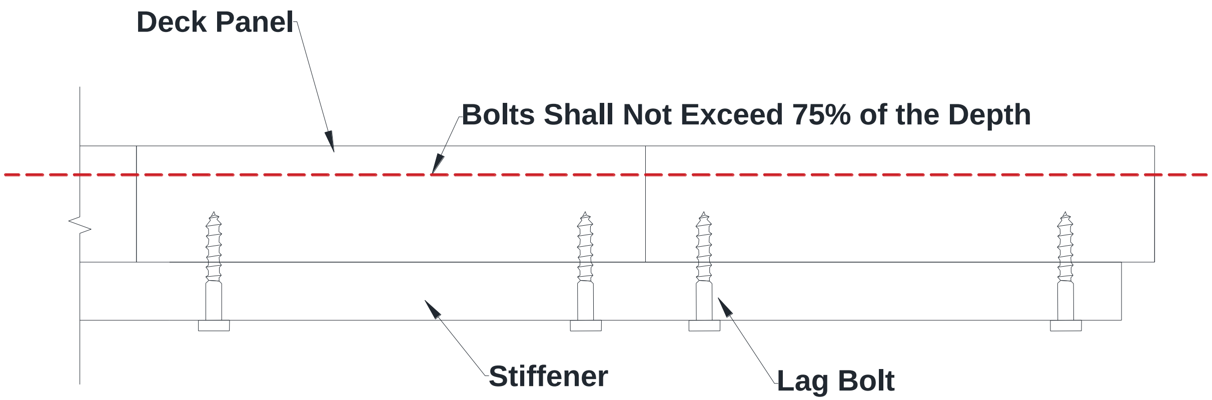
(b) Slab Bridge with Two Grades

- **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 is recommended to be 5 in.**

Recommendations for 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 a minimum of 12. long with a diameter of 0.75in.

Recommendations for Slab 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

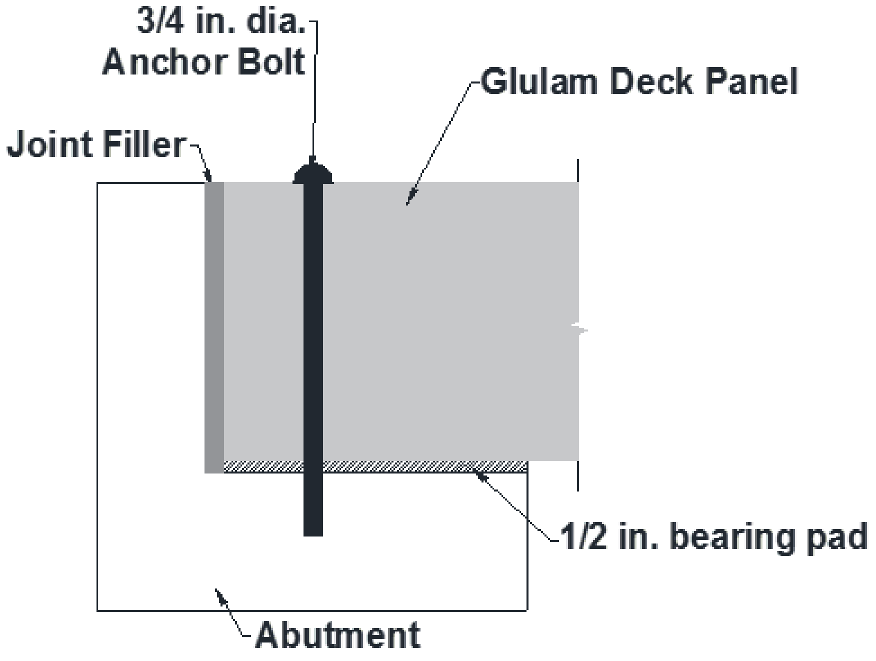
(b) Asphalt Chip Seal (Greenwald 2011)

(c) Aggregate Overlay

(d) Epoxy with Embedded Grit

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.



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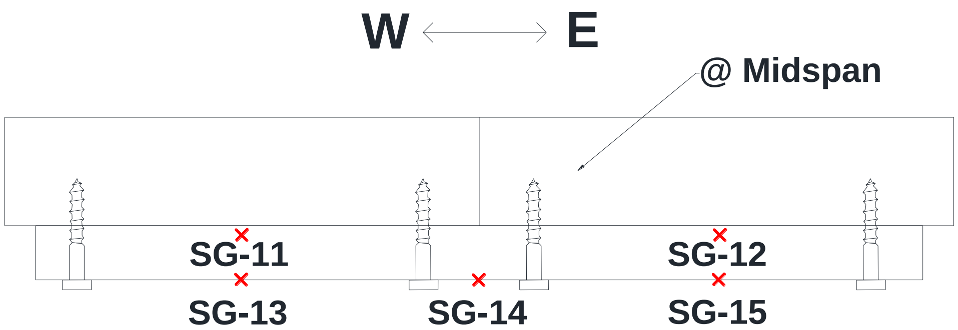
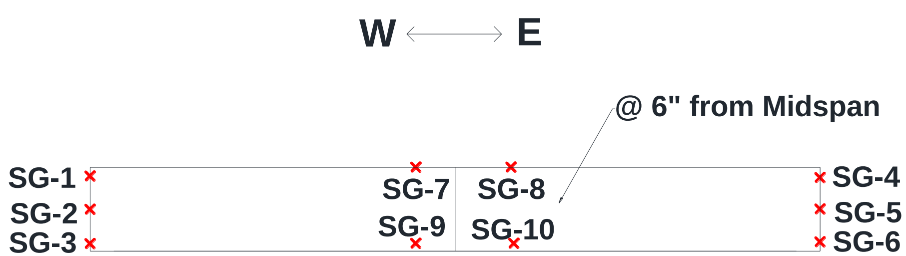
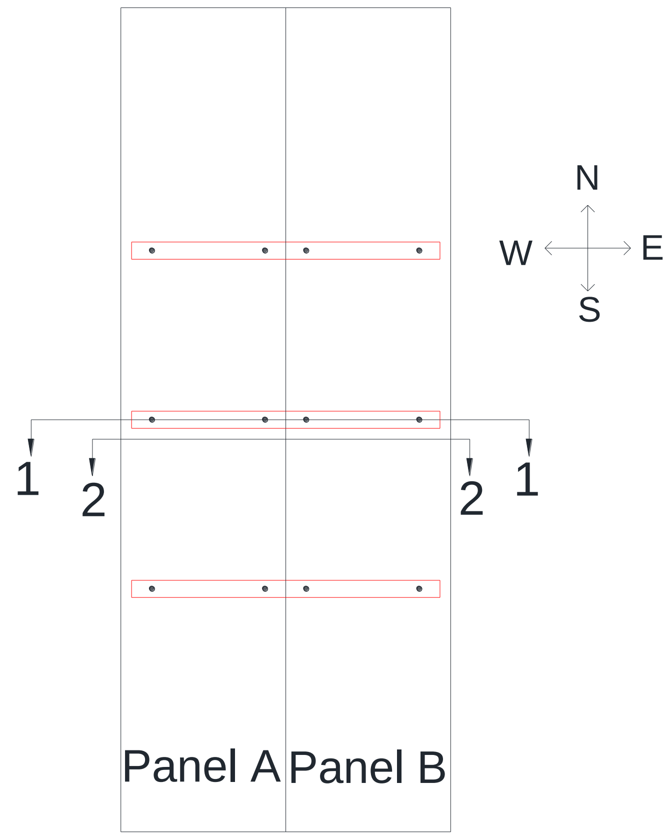
Slab Bridge Strain Gauges



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

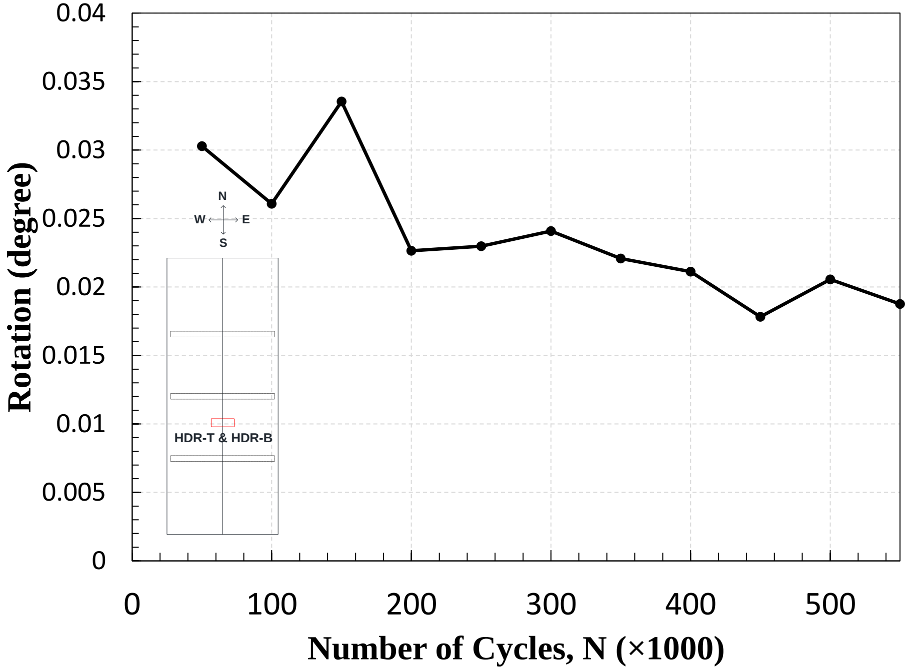


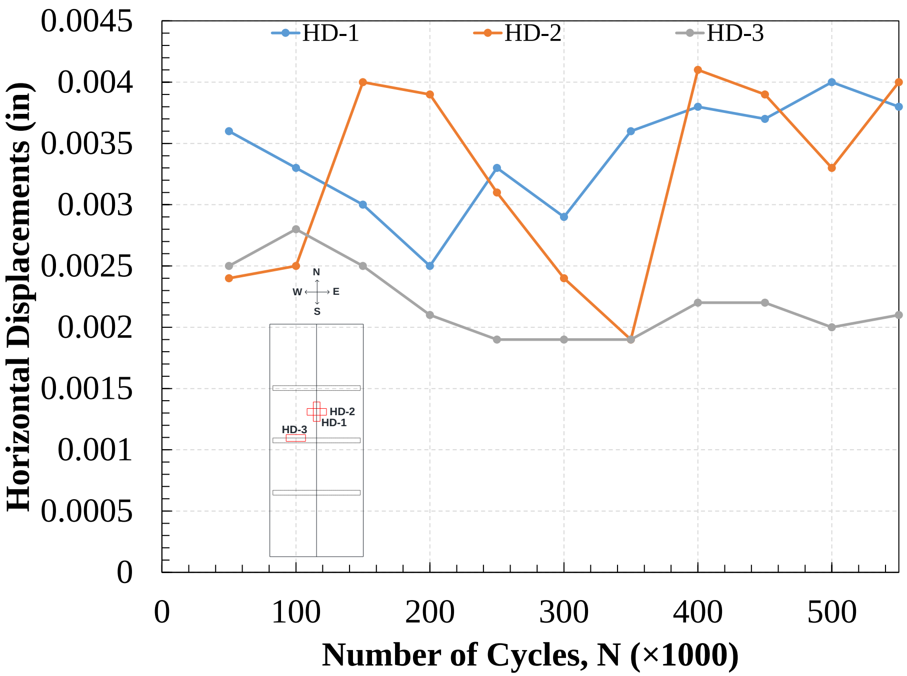
Section 2-2 (Stiffener Strain Gauges in Transverse Direction of Bridge)



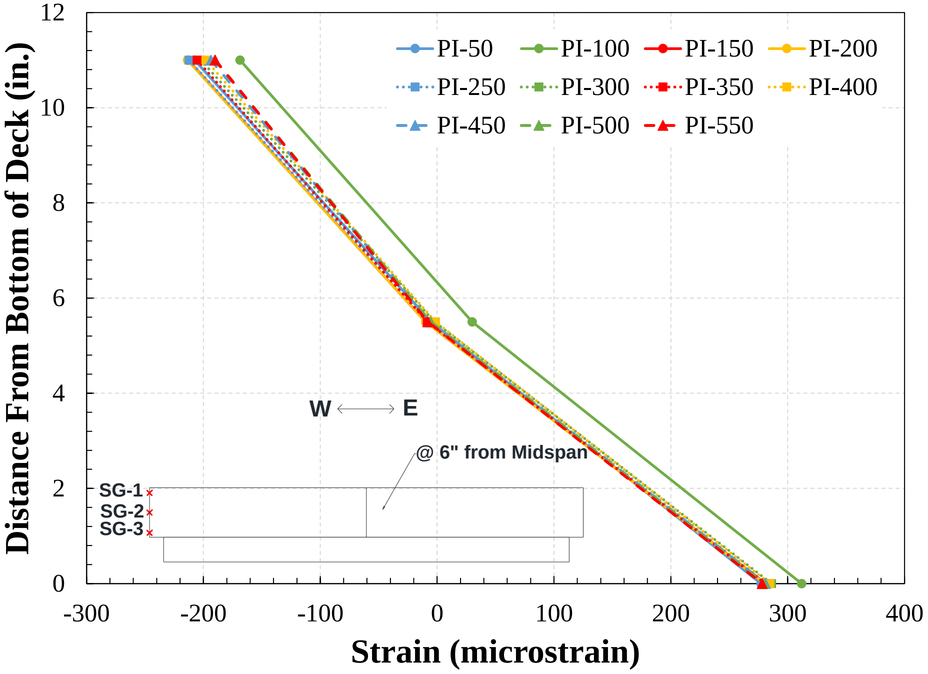
LVDTs

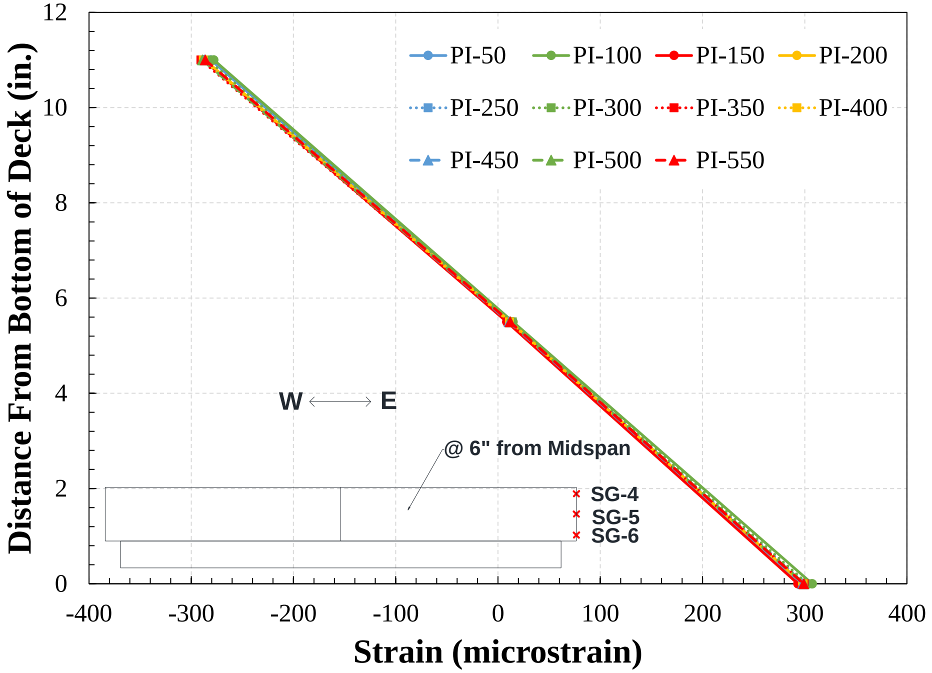
Slab Bridge Fatigue Test Results





Slab Bridge Fatigue Test Results





Slab Bridge Cost Comparison

Bridge System	Slab Bridge	Double-Tee Girders
Total ($/sq. ft.)	30	64

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

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.

Overall Conclusions

- **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.**

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