Development of the Smart Timber Bridge

A Partnership between the Forest Products Laboratory and Iowa State University

Conceptual Smart Timber Bridge

- Glued laminated girders plus deck
- Measurement attributes
  - Structural adequacy
    - “Load” side via changes in load distribution, dynamic load allowance, and life usage.
    - Serviceability to monitor functionality and changes in stiffness (i.e., damage)
      - Delamination, vehicular collision, etc.
  - Deterioration
    - Moisture intrusion
    - UV-based degradation
    - Corrosion-related damage

Conceptual Smart Timber Bridge

- Sensors
  - Use off-the-shelf technology where applicable.
- Communication and reporting
  - Processed and communicated in near-real time.
  - Provide instant notification when important events occur.
  - Condition summarized in easy-to-understand reporting format.

Developmental Milestones

- Methodology for reliably attaching sensors to timber members.
- Reliable, long-term moisture sensor integration.
- Sensors to detect ferric ions.
- Sensors to detect degradation of wood lignin.
- Data processing techniques for determining structural adequacy parameters.

Developmental Milestones

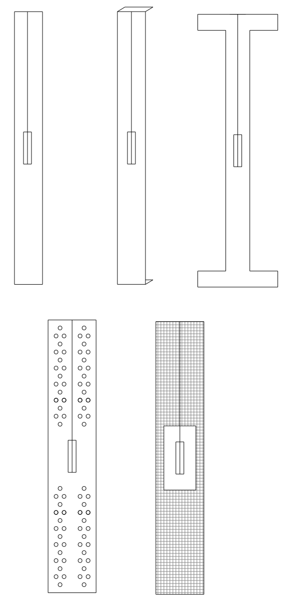
- Data processing techniques for determining changes in structural stiffness.
- Data processing techniques to determine vehicle characteristics
- Turnkey software.
- Demonstration

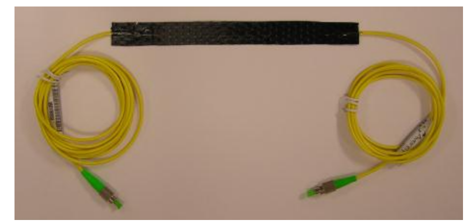
Development and Evaluation of Sensor Attachment Techniques

- Scope
  - Develop conceptual sensor packages
  - Small-scale testing
  - Selection of most promising techniques
  - Full-scale testing

Package Development

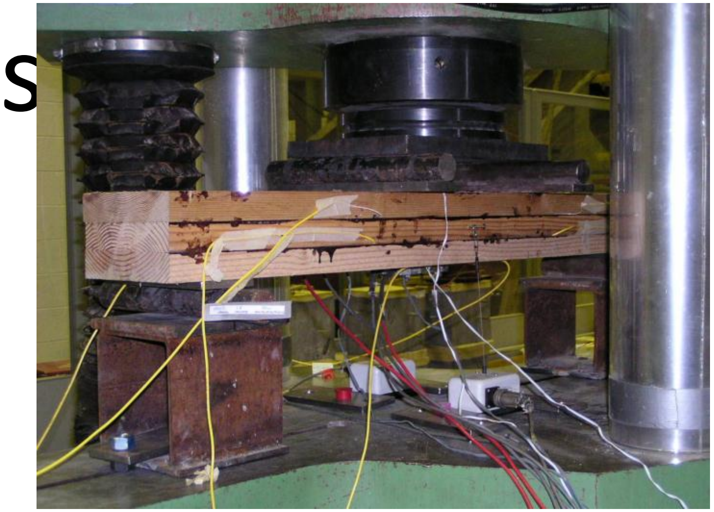
Specimens	*Adhesive*	*FBG Sensor Package*
Specimen 1	454 ™ Prism ®	CFPR and RS-SS
Specimen 2		CS-SS and IS-SS
Specimen 3		72H-SS and AS-SS
Specimen 4	426 ™ Prism ®	CFPR and RS-SS
Specimen 5		CS-SS and IS-SS
Specimen 6		72H-SS and AS-SS
Specimen 7	4212 ™ Prism ®	CFPR and RS-SS
Specimen 8		CS-SS and IS-SS
Specimen 9		72H-SS and AS-SS

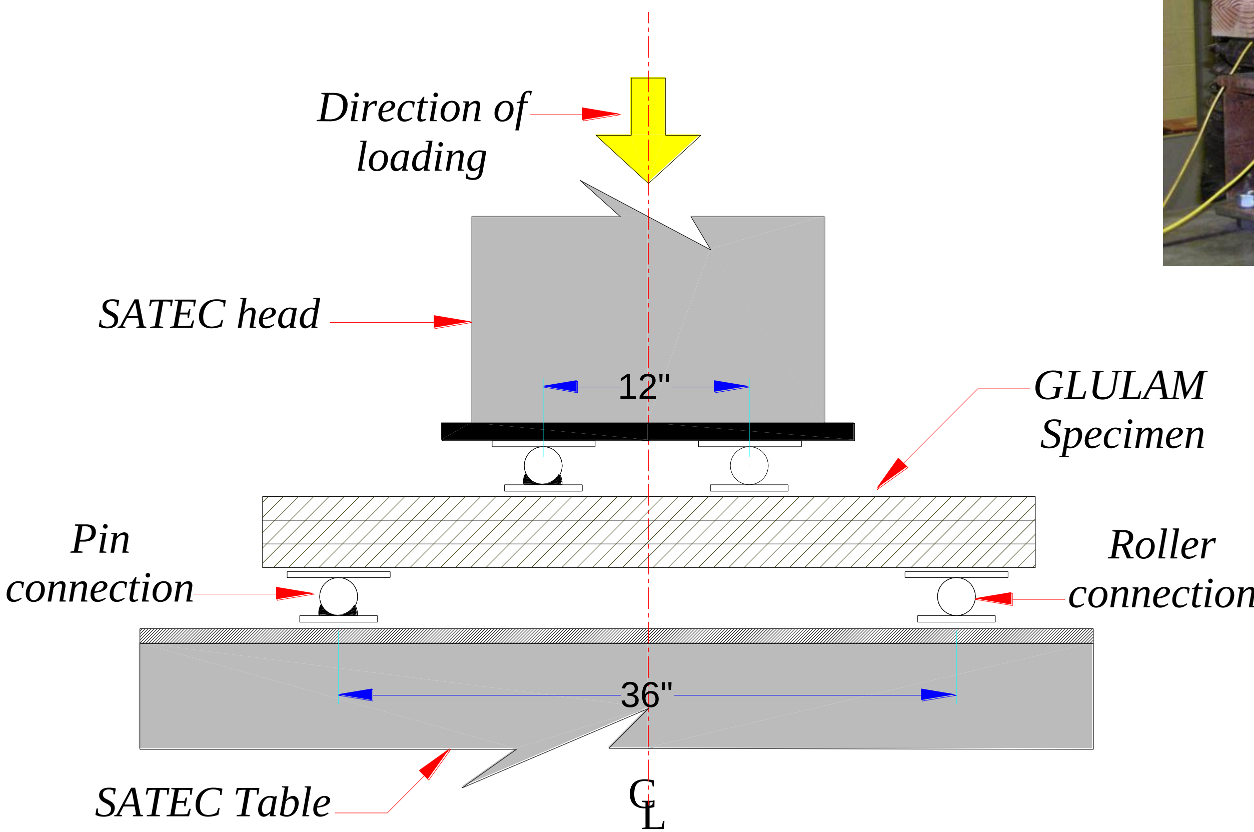


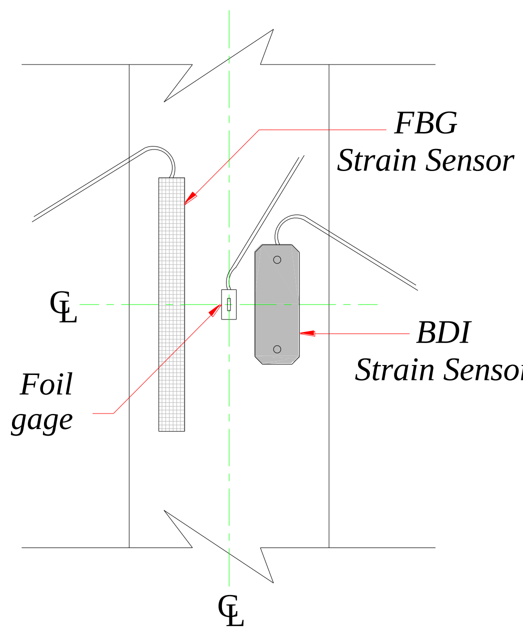


Small-scale Tes

2500 lbs



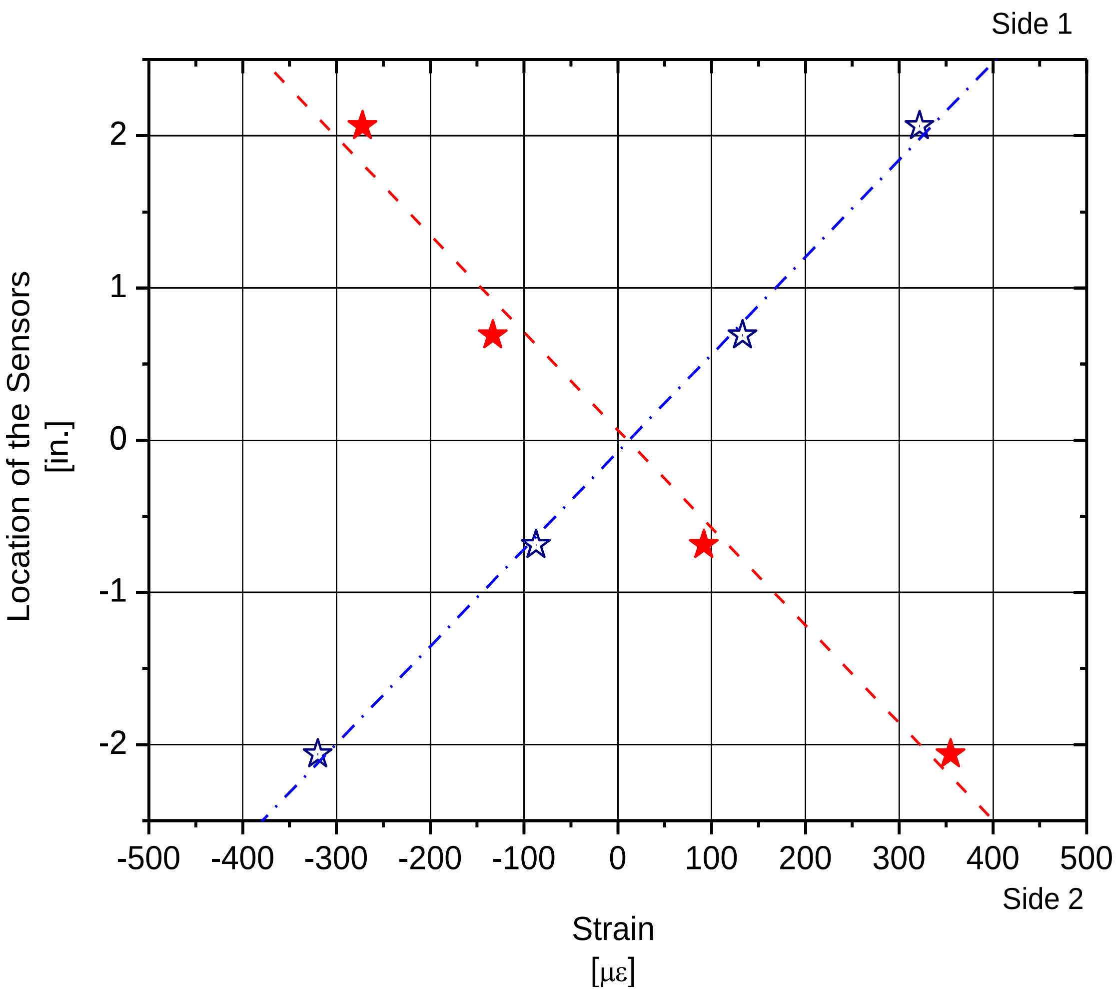


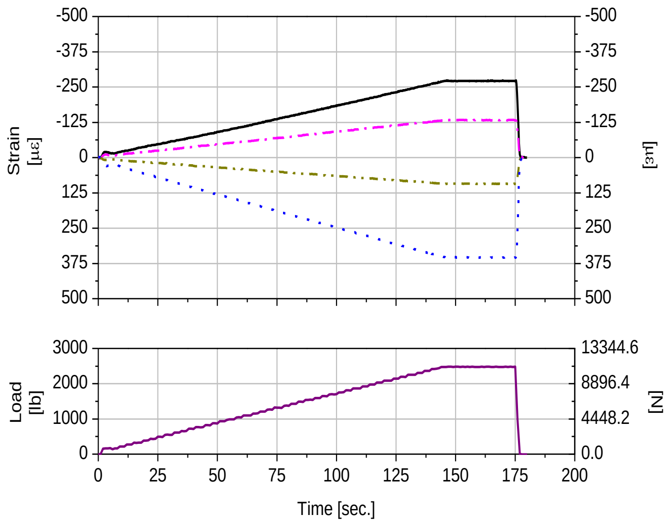


Test Program

- Bending
- Sustained load
- Accelerated load
- Psuedo cyclic load
- Heat and sustained load
- Cold and sustained load

Typical Bending Test

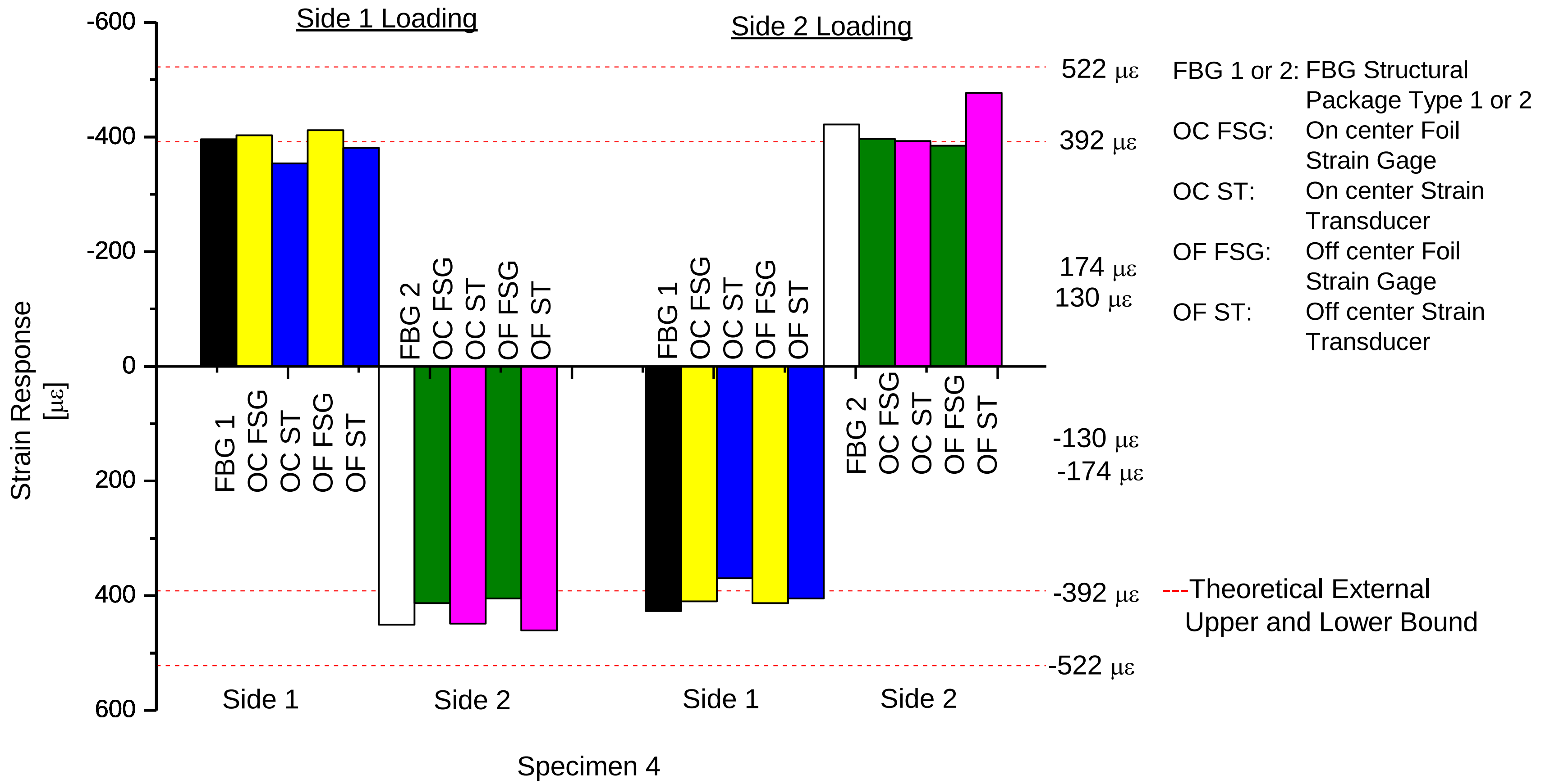




Specimen 1 - Adhesive Loctite 454

Package	Location	Side 1	Side 2
	[in.]	[με]	[με]
C-FRP	2.063	-272	322
C-FRP	0.688	-133	133
RS-SS	-0.688	93	-87
RS-SS	-2.063	355	-320

Sensor Comparisons



General Conclusions

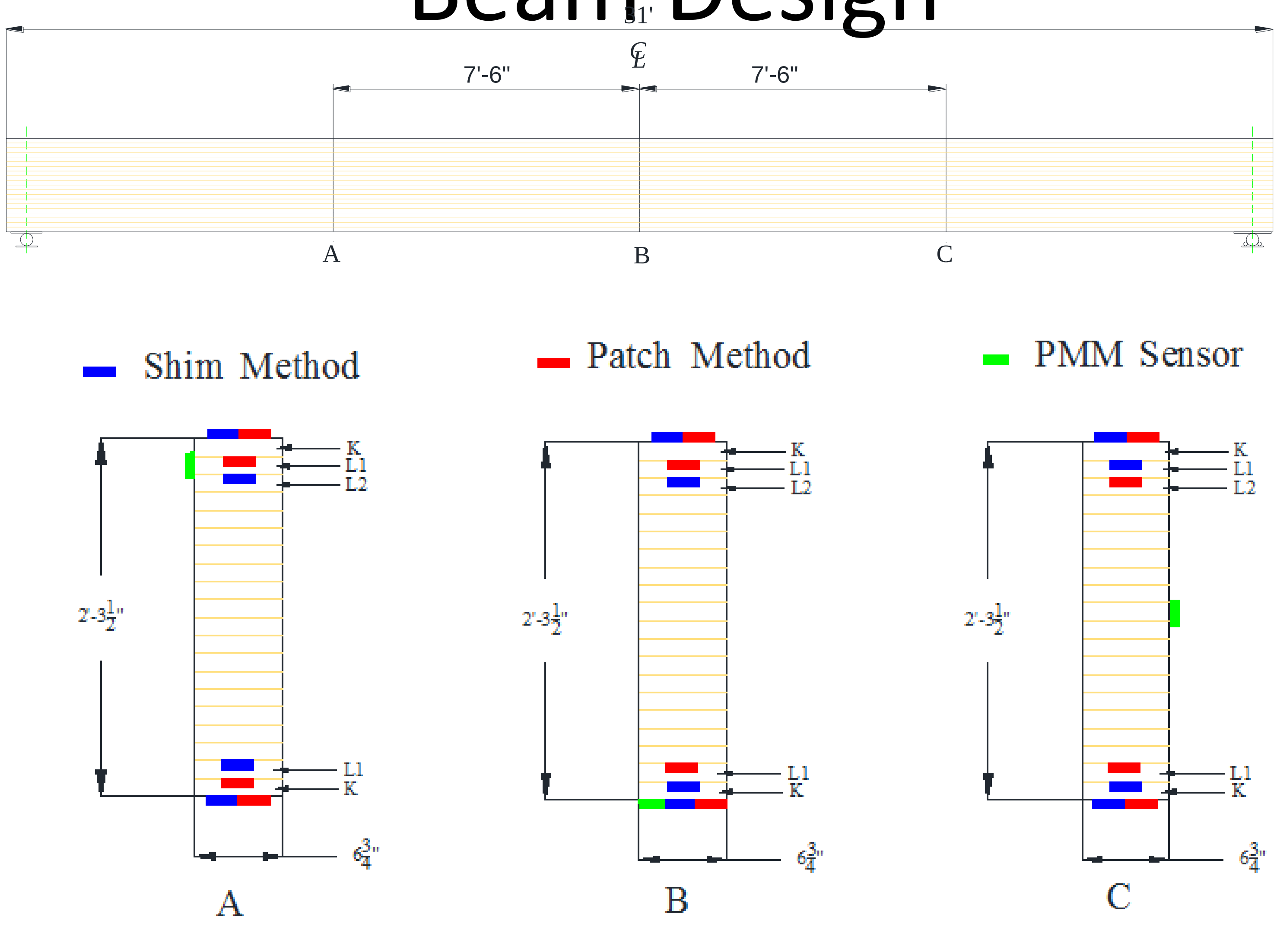
- Techniques for connecting sensors to timber can be achieved using proper adhesive and package design.
- Fiber optic sensor are not robust enough to withstand glulam fabrication processes.
  - Recommended to use traditional sensor types.

Full-scale testing

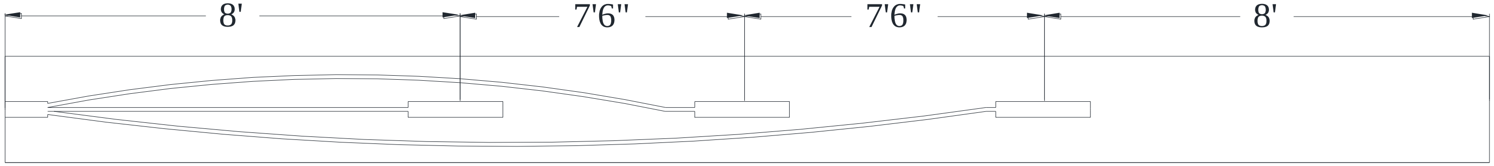
- More successfully integrate sensors into the fabrication process.
- Evaluate operability under repeated loadings.
- Also…investigate one additional attachment techniques – the patch method.

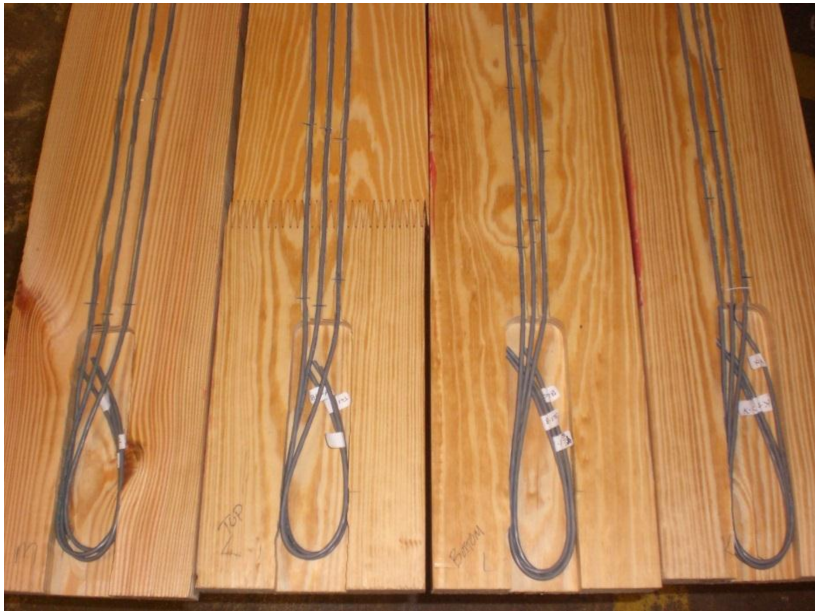
Shim and Patch

Beam Design


31'
℄
7'-6"
7'-6"
A
B
C
Shim Method
Patch Method
PMM Sensor
K
L1
L2
L1
K
2'-3½"
6¾"
A
B
C

Fabrication





Fabrication

a.) Aligning the laminates in the clamping aparatus

b.) Checking the gages with a volt meter

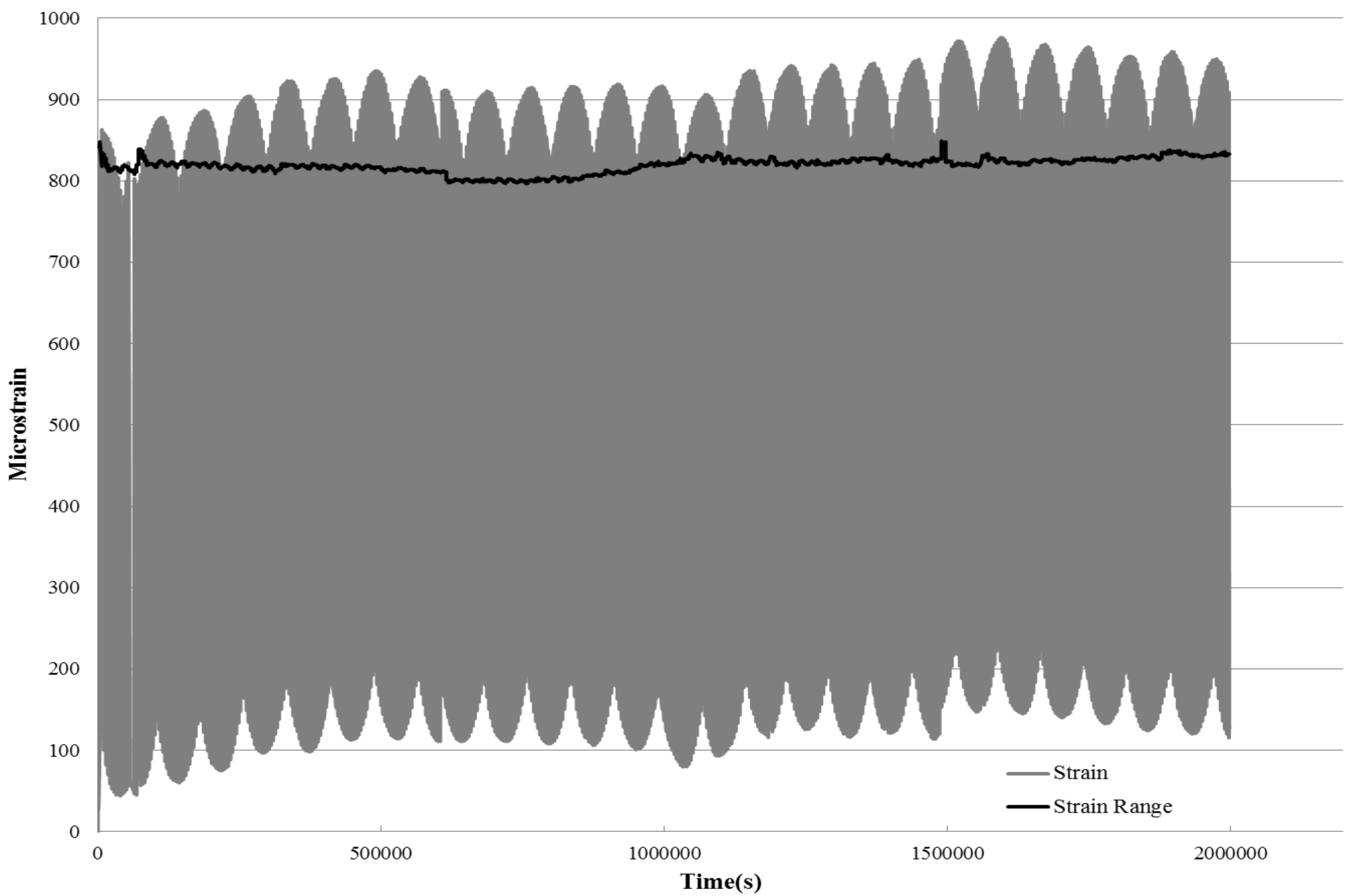
c.) Planing the beam

d.) Finished beam

Fatigue Testing

- 1,000,000 cycles at 0.5 Hz
- Two point loading method—24,000lb peak load

Typical results



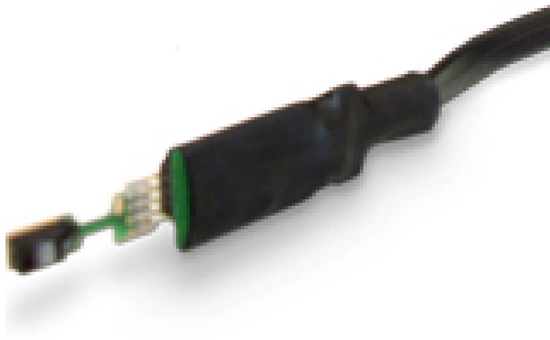
Results

	Sensor	Theoretical Peak Strain (microstrain)	Experimental Peak Strain (microstrain)	Percent Difference (%)
Shim Method	Top-A	705	512	27.4
	TL1-A	622	564	9.3
	K-A	686	685	0.1
	Bottom-A	705	819	16.1
	Top-B	987	811	17.9
	TL1-B	871	803	7.8
	BL1-B	808	769	4.8
	Bottom-B	987	867	12.2
	Top-C	705	638	9.5
	TL2-C	584	437	25.1
	BL1-C	611	604	1.1
	Bottom-C	705	645	8.5
Patch Method	Top-A	705	606	14.1
	Top-B	987	865	12.4
	Bottom-B	987	948	4.0
	Top-C	705	628	11.0
	Bottom-C	705	710	0.7

Moisture Sensor

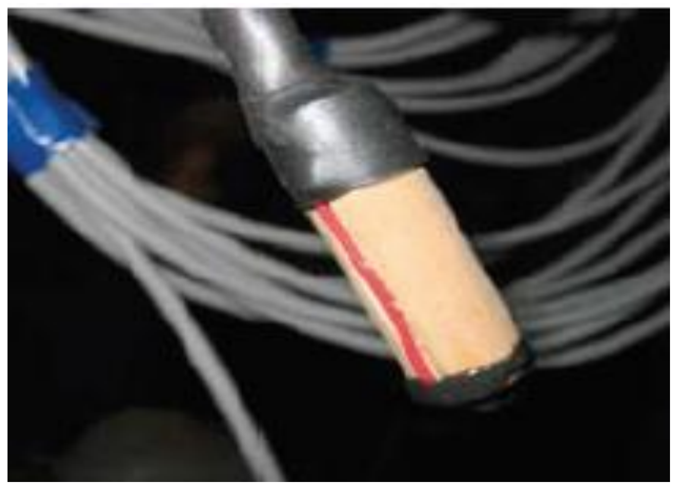
- Evaluate (and select?) a sensor for assessing changes in moisture content.
- Required to be able to be wired into off-the-shelf data acquisition systems.
- Reasonable accuracy in the range of 20% moisture content.

rs Cons



Relative humidity/Temperature

PMM Sensor

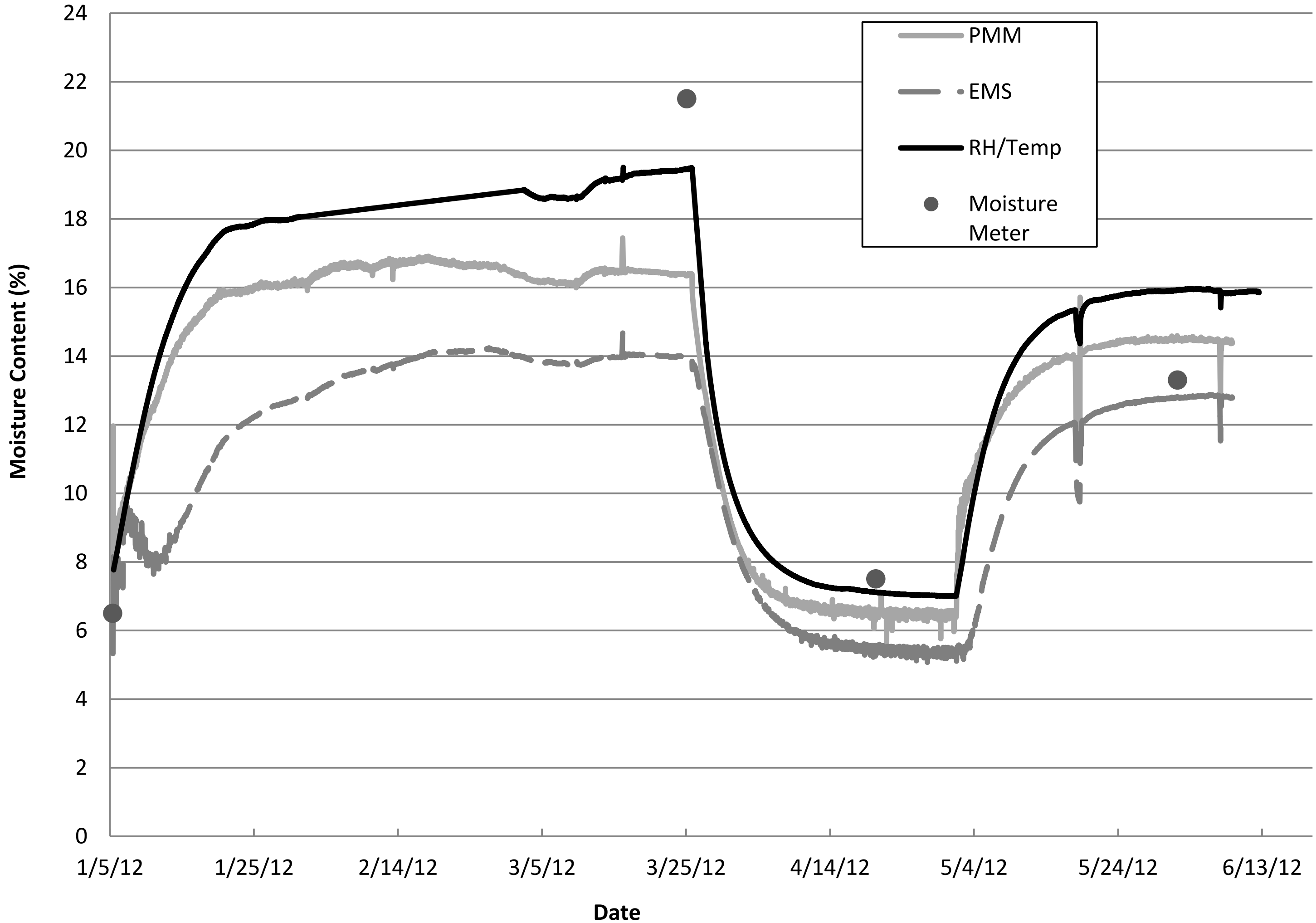


EM Sensor (EMS)

Testing

- Four 6”x6”x2” SYP specimens
- All three sensors installed
- Tested under various relative humidity and temperature conditions

Typical Results

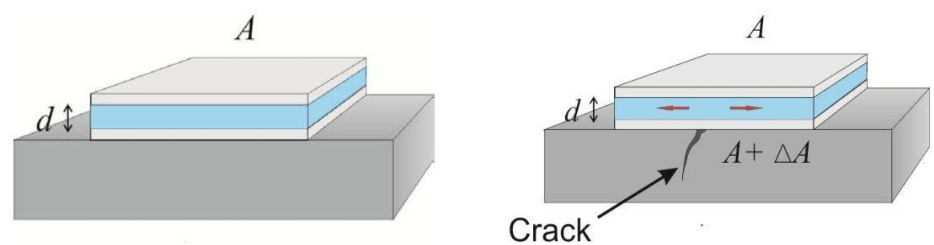


Conclusions

- PMM selected as most promising measurement approach
  - Successfully connected to traditional data loggers.
  - Simple installation procedure.
  - Responded well to varying conditions.
  - Reasonable accuracy.

Vehicle Characterization

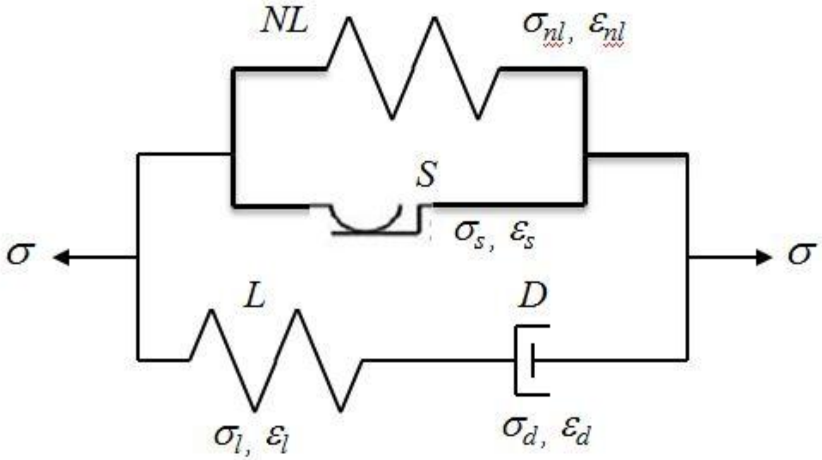
- Evaluate the efficacy of a soft elastomeric capacitor
  - Large scale surface strain gauge
  - Based on capacity sensing.
  - Sensitivity depends upon permittivity of medium and thickness of elastomer.



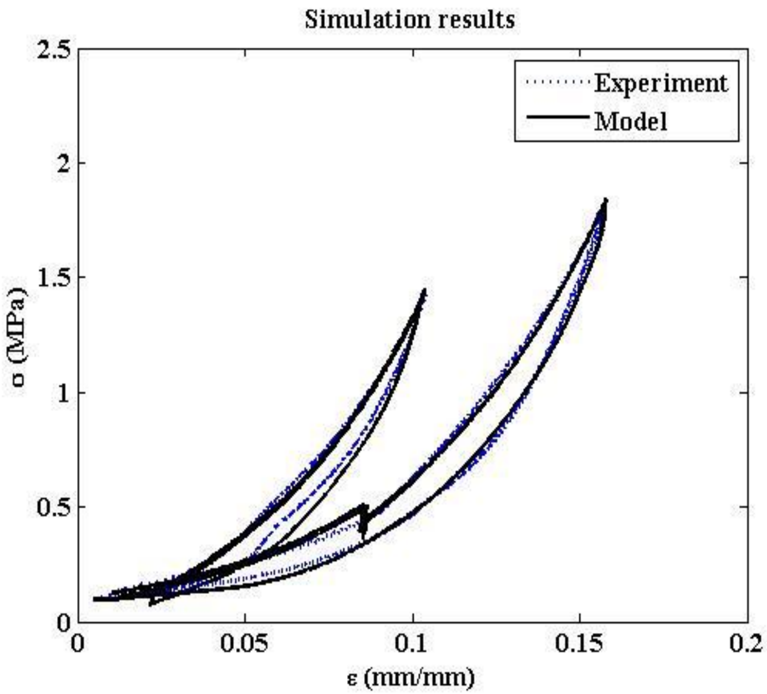
Capabilitites

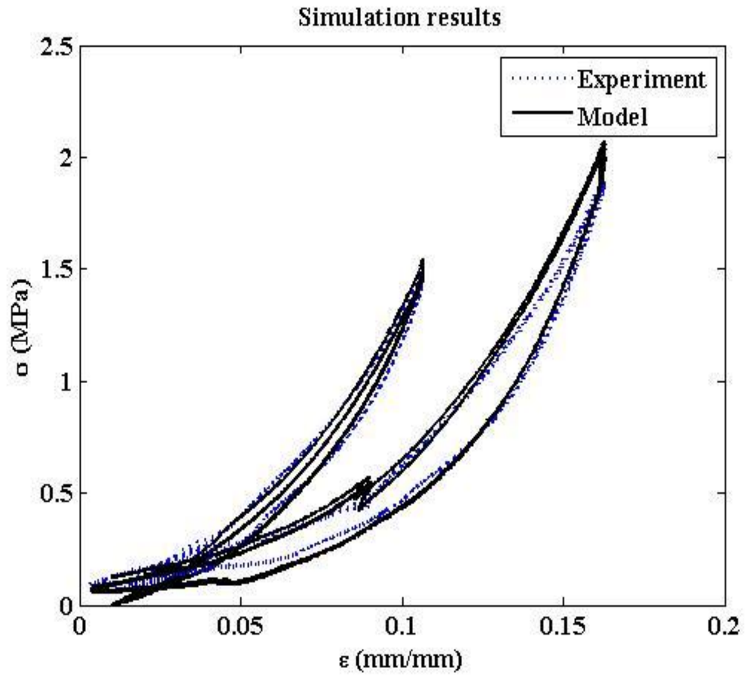
- Detect strain and surface cracks.
- Simplicity in shape – improved durability.
- Damage resistant.
- Possibilities of reconstructing deflection shapes.
- Comparable accuracy with traditional strain gauges.

Development of Rheology Model



Impact of Select Patch Characteristic

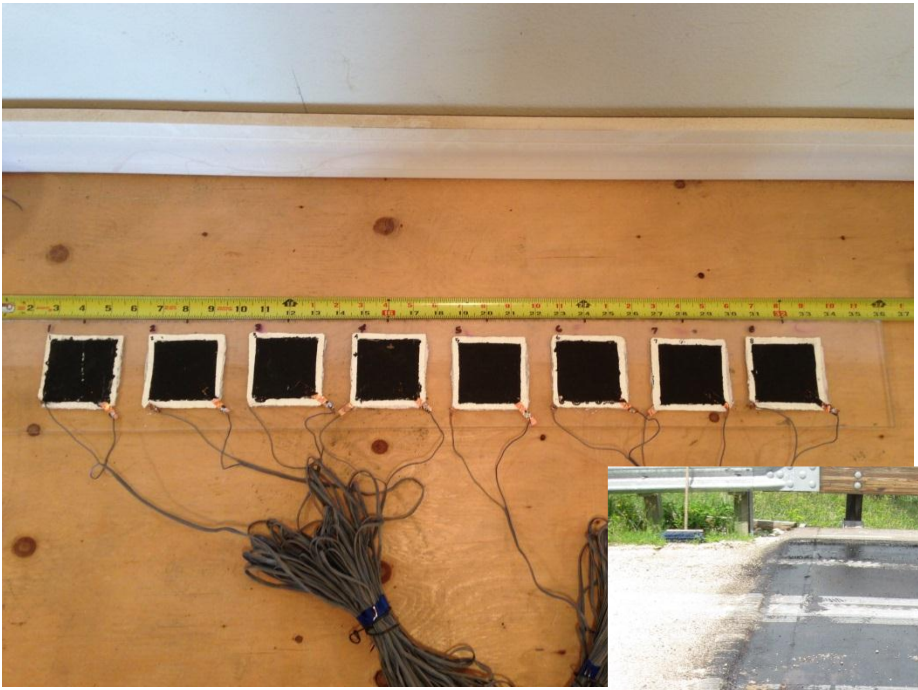




Conclusions

- Constitutive model developed.
- Effectively able to estimate observed stress with low errors.
- Developed proposed model ready for field trial.

Field Trial



Field Trial

Concluding Remarks

- Significant advances have been made in the development of a timber bridge that can report on its own condition and health.
- Using a combination of conventional and cutting-edge sensors.
- Combined with robust data processing techniques and a strong communication backbone.

Questions?

Thank You!