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

<table>
<thead>
<tr>
<th>Specimens</th>
<th>Adhesive</th>
<th>FBG Sensor Package</th>
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<tbody>
<tr>
<td>Specimen 1</td>
<td>454™ Prism ®</td>
<td>CFPR and RS-SS</td>
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<td>Specimen 2</td>
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<td>CS-SS and IS-SS</td>
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<td>Specimen 9</td>
<td>454™ Prism ®</td>
<td>72H-SS and AS-SS</td>
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</table>
Small-scale Test

2500 lbs

Direction of loading

SATEC head

Pin connection

SATEC Table

GLULAM Specimen

12"

12"

36"

Roller connection

Foil gage

FBG Strain Sensor

BDI Strain Sensor
Test Program

- Bending
- Sustained load
- Accelerated load
- Pseudo cyclic load
- Heat and sustained load
- Cold and sustained load
## Specimen 1 - Adhesive Loctite 454

### Package Location Side 1 Side 2

<table>
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<tr>
<th></th>
<th>[in.]</th>
<th>[με]</th>
<th>[με]</th>
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Sensor Comparisons

Strain Response $[\mu \varepsilon]$ for Specimen 4:

- **Side 1 Loading**
  - FBG 1: Off center Foil Strain Gage
  - OC ST: Off center Strain Transducer
- **Side 2 Loading**
  - FBG 1 or 2: FBG Structural Package Type 1 or 2
  - OC FSG: On center Foil Strain Gage
  - OC ST: On center Strain Transducer
  - OF FSG: Off center Foil Strain Gage
  - OF ST: Off center Strain Transducer

Theoretical External Upper and Lower Bound
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
Fabrication

[Diagram showing measurements of 8' 7'6" 7'6" 8']
Fabrication

a.) Aligning the laminates in the clamping apparatus

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

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Theoretical Peak Strain (microstrain)</th>
<th>Experimental Peak Strain (microstrain)</th>
<th>Percent Difference (%)</th>
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<tbody>
<tr>
<td>Shim Method</td>
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<tr>
<td>Top-A</td>
<td>705</td>
<td>512</td>
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<tr>
<td>Patch Method</td>
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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.
Sensors Considered

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
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.
Capabilities

- 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!