Rapid Modal Testing System for Live Load Rating of Highway Bridges

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Drexel University
• Introduction to THMPR™ System (Targeted Hits to Measure Performance Responses)
• Load Rating Procedures as per the AASHTO Manual for Bridge Evaluation
• Overview of the THMPR™ System (Targeted Hits to Measure Performance Responses)
  – Structural Identification and System Description
  – Validation of Modal Impact Testing Capabilities
  – FE Modeling, Model Updating, and Load Rating
• Applications to Northampton County, PA Bridges
• Summary and Discussion
THMPR™
(Targeted Hits to Measure Performance Responses)
AASHTO Manual for Bridge Evaluation

Engineering Judgment
- Driven by visual appearance
- Typically lacks appreciation for mechanics

Analytical Load Rating
- Simplified
- Refined

Physical Testing
- Static
- Dynamic
  - Diagnostic
  - Proof
    - Pull-release
    - Shaker
      - IMPACT
Section 6A.3

“Permitted Analysis Methods include: approximate methods, refined methods*, and analysis by field testing (load testing).”

*Article 4.4 of the AASHTO LRFD Bridge Design Specification defines finite element analyses as a refined method of analysis

Section 6A.3.4

“Bridges may be evaluated by field testing (load testing) if the evaluator feels that analytical approaches do not accurately represent the true behavior and load distribution of the structure and its components.”

Section 8.1.1

“Load testing is the observation and measurement of the response of a bridge subjected to controlled and predetermined loadings without causing changes in the elastic response of the structure.”
Section 8.1.2

“A dynamic load test is conducted with time-varying loads or moving loads that excite vibrations in the bridge. Dynamic tests may be performed to measure the modes of vibration, frequencies, dynamic load allowance, and to obtain load history and stress ranges for fatigue evaluation.”

Section 8.4.2.3

“Vibration tests may be conducted by means of portable sinusoidal shakers, sudden release of applied deflections, sudden stopping of vehicles by braking, and impulse devices such as hammers.”
THMPR™
(Targeted Hits to Measure Performance Responses)

**Step 1**
Rapid modal impact testing using a self-contained mobile device

**Step 2**
Semi-Automated pre- and post-processing to obtain global frequencies and mode shapes

**Step 3**
Automated FE modeling using NBI data and on-site assessment

**Step 4**
Automated FE model calibration and load rating

**Step 5**
Reporting
THMPR™ Comparison with MIMO*
*Best practices approach to modal impact testing

### CMIF - THMPR System

1 Mode solved per test at each frequency line

### CMIF – MIMO Sledge

8 Modes solved at each frequency line

<table>
<thead>
<tr>
<th>Mode</th>
<th>THMPR System [Hz]</th>
<th>MIMO [Hz]</th>
<th>% Diff</th>
</tr>
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<tr>
<td>1</td>
<td>4.289</td>
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<tr>
<td>2</td>
<td>4.873</td>
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<td>3</td>
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<td>15.944</td>
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<tr>
<td>6</td>
<td>18.971</td>
<td>19.001</td>
<td>-0.16%</td>
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<td>7</td>
<td>24.018</td>
<td>24.099</td>
<td>-0.34%</td>
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<td>8</td>
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<td>27.631</td>
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<tr>
<td>9</td>
<td>29.404</td>
<td>29.379</td>
<td>0.09%</td>
</tr>
<tr>
<td>10</td>
<td>33.454</td>
<td>33.491</td>
<td>-0.11%</td>
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</tbody>
</table>
THMPRTM Comparison with MIMO*
*Best practices approach to modal impact testing
Modeling, Updating, and Rating Approach

Modal Assurance Criterion

Creation of A priori model using design heuristics

Identify uncertain parameters (BC, CC, etc)

Computation of modal parameters

Update uncertain parameters

Calculate objective function

Comparison to in situ modal testing results

Ignore mechanisms that may not be reliable long-term

Calculate updated rating factors, distribution factors, etc.
Element-Level FE Modeling Approach

Model approach validated under NCHRP Project 12-103 through:
• Mesh sensitivity studies
• Comparison with benchmark problems
• Comparison with more refined FE modeling approaches
Overview of Northampton, PA Bridges

Bridge 041
Type = Concrete-encase Steel Multi-girder
Configuration = 2 Simple Spans
Max span length = 41.5 ft.
Skew = 60°
Posting = 20 ton

Bridge 063
Type = Concrete-encase Steel Multi-girder
Configuration = 3 Simple Spans
Max span length = 33.5 ft.
Skew = 0°
Posting = 16 ton

Bridge 076
Type = Concrete-encase steel through-girder
Configuration = 1 simple spans
Max span length = 41 ft.
Skew = 0°
Posting = None
Overview of Northampton, PA Bridges

Bridge 138
Type = Concrete-encase steel multi-girder
Configuration = 1 simple span
Max span length = 49 ft.
Skew = 0°
Posting = 20 ton

Bridge 200
Type = Concrete-encase steel multi-girder
Configuration = 1 simple span
Max span length = 45.8 ft.
Skew = 18°
Posting = 30 ton
## Test Execution

<table>
<thead>
<tr>
<th>Bridge Number</th>
<th>Test Date</th>
<th>Test Duration</th>
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</thead>
<tbody>
<tr>
<td>041</td>
<td>Nov 5</td>
<td>~ 60 min</td>
</tr>
<tr>
<td>063</td>
<td>Nov 4</td>
<td>~ 90 min</td>
</tr>
<tr>
<td>076</td>
<td>Nov 4</td>
<td>~ 30 min</td>
</tr>
<tr>
<td>138</td>
<td>Sept 8</td>
<td>~ 30 min</td>
</tr>
<tr>
<td>200</td>
<td>Nov 5</td>
<td>~ 30 min</td>
</tr>
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</table>
Sample Data and Identified Mode Shapes (Bridge 200)
• Concrete encasement, concrete barriers, and bearing restraints are included during updating, but *neglected* during load rating.

• Bridges 041, 063, and 138 – FE models were constructed from information included in previous load-rating reports developed by STV Inc.

• Bridge 076
  – Global dimensions were obtained through on-site measurements
  – All live loads and dead load of the wearing surface was assumed to be resisted by the concrete encasement
  – Steel girders were assumed to only carried the dead load of the concrete deck and concrete encasement

• Bridge 200
  – Steel girder dimensions were estimated through reverse engineering the bridge
  – This process assumed an H-15 design truck and an allowable stress design methodology
### Summary of Load Rating Results (Strength I)

*Strength I rating based on flexural tensile concrete cracking*

<table>
<thead>
<tr>
<th></th>
<th>A -Priori</th>
<th>Updated Model w/ Composite Action</th>
<th>Updated Model w/o Composite Action</th>
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<tbody>
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<td></td>
<td>Inv</td>
<td>Op</td>
<td>Inv</td>
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</tr>
<tr>
<td>Span 1</td>
<td>3.42</td>
<td>4.44</td>
<td>3.28</td>
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<tr>
<td>Span 2</td>
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<td>3.74</td>
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<td>1.62</td>
<td>1.23</td>
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<tr>
<td>Span 2</td>
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<td>1.33</td>
</tr>
<tr>
<td>Span 3</td>
<td>1.25</td>
<td>1.62</td>
<td>1.33</td>
</tr>
<tr>
<td><strong>Bridge 076</strong></td>
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</tr>
<tr>
<td>-</td>
<td>N.A.</td>
<td>N.A.</td>
<td>&gt; 1*</td>
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<tr>
<td><strong>Bridge 138</strong></td>
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<tr>
<td>-</td>
<td>1.63</td>
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<tr>
<td><strong>Bridge 200</strong></td>
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<tr>
<td>-</td>
<td>1.56</td>
<td>2.02</td>
<td>1.67</td>
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</tbody>
</table>
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Summary

- THMPR™ System produces load ratings via FE models calibrated to measured vibration frequencies and mode shapes.
- The process employed by THMPR™ was placed within the context of the load rating procedures presented by the AASHTO Manual for Bridge Evaluation.
- Applications to five bridges in Northampton County, PA were presented and the results indicated that all bridges rate for the Strength I Limit State (Op) within the AASHTO LRFR methodology (even if composite action is neglected).
Validation

- Validation efforts thus far have aimed at (1) comparison with ‘best practices’ modal impact testing procedures, and (2) ‘best practices’ FE modeling approaches.

- THMPR™ is part of the FHWA Long-Term Bridge Performance Program where additional validation will be performed.
Thank You

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