Software Calibration and Sensitivity Analysis of Ordinary Standard Bridge Response

Michael H. Scott\textsuperscript{1} and Kevin R. Mackie\textsuperscript{2}

\textsuperscript{1}Oregon State University
\textsuperscript{2}University of Central Florida

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Outline

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Nonlinear response history analysis capabilities are widespread for the assessment of bridge response to seismic loading

- Perform, SAP2000, CSiBridge, OpenSees
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Nonlinear response history analysis capabilities are widespread for the assessment of bridge response to seismic loading. Perform, SAP2000, CSiBridge, OpenSees. Response history analysis can be more accurate than other analysis approaches such as response spectrum and nonlinear static methods. Key factors that affect response history analysis:

- Modeling details and assumptions
- Element and constitutive model formulations
- Solution algorithms for dynamic equilibrium
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Response history analysis has been used for some special bridges in California, e.g., I-880 viaduct, Humboldt Bay bridge
Ordinary Standard Bridges (OSBs)

- The majority of CA bridges are ordinary, standard designs of 1-2 spans.
- Critical to post-earthquake recovery.
- Traditional analysis methods may give conservative estimates of the effect of cyclic energy dissipation and degradation.

(Image: Metropolitan Transportation Commission)
Knowledge Gaps in Bridge Modeling

- The difference in simulated response when using similar bridge models in separate software packages
- The effect of cyclic degradation of structural components on the dynamic response of bridges
- Discrepancies associated with the choice of nonlinear constitutive or element models and errors with respect to known benchmark solutions
- Ranking and prioritization of the modeling parameters that have the most significant influence on bridge response
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Research Questions:

1. Can CSiBridge and OpenSees give the same response for four OSBs selected by Caltrans?
2. Which modeling parameters have the most significant influence on bridge response?
OSB1 Model

Two 150 ft spans, single two-column bent

- Superstructure – Linear-elastic line elements
- Bent Columns – Material nonlinear frame elements available in each software
- Abutments – Simple rollers and EPP gap models considered
OSB2 – Two 150 ft spans, single one-column bent

OSB3 and OSB4
- OSB3 and OSB4 are similar to OSB1 and OSB2, respectively
- OSB3 and OSB4 have abutment and bent isolators
- Full details in report

For all OSBs, Caltrans provided CSiBridge models that we attempted to match in OpenSees
Reinforcing Steel Constitutive Model

- Multilinear stress-strain models in OpenSees and CSiBridge
- Min-max material in OpenSees to terminate stress-strain response at 0.1 strain
Concrete Constitutive Model

- OpenSees Concrete04
- CSiBridge Mander model
- Backbones match, which was our goal
- CSiBridge Mander model unloads at constant stiffness, accommodates large compressive strains, and gives compressive stress for tension strains
- OpenSees Concrete04 drops to zero stress at two times the peak compressive strain
Similar initial stiffness, yield strength, and post-yield stiffness

CSiBridge model provided by Caltrans had very small plastic hinge length, which was maintained in OpenSees model
Roller abutments to isolate nonlinear response to columns

Reasonable match between CSiBridge and OpenSees

Low level of yielding
Roller abutments

Large discrepancies after transverse deck displacement exceeds ~2 inch

High level of yielding relative to monotonic response
OSB1 Abutment Models

- Have shown discrepancies due to column constitutive models
- Are discrepancies magnified by inclusion of nonlinear abutment models?
- EPP abutment backbone matches in CSiBridge and OpenSees inputs
Discrepancies magnified for longitudinal response – EPP gap abutment

Transverse response remains similar – elastic abutment
Dynamic Response Sensitivity Analysis

What is the impact of changes in column parameters relative to changes in abutment parameters?
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Compute sensitivity of dynamic response to modeling parameters using the direct differentiation method (DDM)

\[ \frac{\partial u}{\partial \theta} \]

where \( \theta \) is the parameter of interest

Can also compute sensitivity with respect to forces

Quantify the effect of changes in modeling parameters on the simulated response

Combine with parameter variability (PDF) for applications in optimization and reliability
Dynamic Response Sensitivity Analysis

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OSB1 Dynamic Response Sensitivity Analysis

- Sensitivity with respect to yield strength of column longitudinal reinforcing steel
- Change in bent displacement for 10% change in $f_y$ (one st. dev.)
OSB1 Dynamic Response Sensitivity Analysis

- Sensitivity with respect to longitudinal abutment stiffness
- Change in bent displacement for 15% change in $k_{gap,l}$ (one st. dev.)
- Larger effect on transverse response than yield strength of reinforcing steel
OSB Dynamic Response Sensitivity Analysis

**OSB1 Dynamic Response Sensitivity**

- Maximum change in transverse and longitudinal deck displacement due to one st. dev. change in each parameter
- Abutment stiffness and strength have largest influence on response

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<th>Parameter</th>
<th>Transverse</th>
<th>Longitudinal</th>
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<tr>
<td>$F_{y,gap,l}$</td>
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M.H. Scott and K.R. Mackie

OSB Seismic Response
Conclusions

- Well-documented constitutive and element models are required in order to match stiffness and strength between different software packages.
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- An understanding of basic nonlinear analysis concepts and guidance on parameter selection and their consequences is required in order to use bridge software packages.

The authors thank Caltrans for supporting this research through Contract #65A0559. The views expressed here are those of the authors and are not necessarily the views of Caltrans.
Conclusions

- Well-documented constitutive and element models are required in order to match stiffness and strength between different software packages.
- An understanding of basic nonlinear analysis concepts and guidance on parameter selection and their consequences is required in order to use bridge software packages.
- For the OSBs considered, the abutment models have the largest influence on seismic response.
  - Column plasticity plays much smaller role.
  - Importance of abutments likely to decrease for multi-span bridges with longer spans.

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