Should Engineers be Concerned about Vulnerability of Highway Bridges to Potentially-Induced Seismic Hazards?

Farid Khosravikia

PhD Candidate, The University of Texas at Austin

Co-authors:

Andy Potter, Vyacheslav Prakhov, Patricia Clayton, and Eric Williamson
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Potentially-induced earthquakes in United States

Increased rate of human-induced seismicity
Seismic Events in Texas, Oklahoma, and Kansas

- 374 earthquakes occurring since 2005
- Zalachoris and Rathje (2017)

Geographic distribution of the events and stations
Histogram of characteristics of the Seismic Events

Small to moderate earthquakes

Shallow depth earthquakes

Maximum recorded PGA is 0.6 g (M5.0 Cushing, Oklahoma)
Pawnee, Oklahoma Earthquake

- September 3, 2016

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Magnitude</td>
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<td>Max recorded PGA (per g)</td>
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September 3, 2016 Pawnee, Oklahoma Earthquake

Observations of rock façade failure (From Clayton et al. (2016))
September 3, 2016 Pawnee, Oklahoma Earthquake

Observations of damage at the West Abutment of Belford Bridge (From Clayton et al. (2016))

- Concrete spalling of abutment
- Approx. 4 cm wide gap between backfill soil and abutment
Seismic Hazard in Areas with Induced Seismicity

- Predicting seismic hazard in areas with induced seismicity significantly changes from one year to another.

From USGS
Texas Bridge Inventory

~53,000 bridges & culverts in Texas
Texas Bridge Inventory

The population of Texas bridges is characterized by:

• Superstructure type

- 42% Prestressed Concrete Girder
- 17% Reinforced Concrete Girder
- 13% Steel Girder
- 13% Other
- 15% Reinforced Concrete Slab

Farid Khosravikia | http://sites.utexas.edu/faridkhosravikia/
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Schematic view of steel girder bridges
Fragility Functions

\[ P(\text{Damage State}) \]

\[ P(\text{Demand} > \text{Limit State} | \text{PGA}) \]

Seismic Intensity Measures = PGA

- Slight
- Moderate
- Extensive
- Complete
Analytical Fragility Functions

Ground Motions | Bridge Samples
Nonlinear Time History Analysis

Repeat For all Components

PGA, \(d_i\)

Probabilistic Seismic Demand Model

\(S_D, \beta_{D|PGA}\)

Probabilistic Seismic Capacity Model

\(S_C, \beta_C\)

Component Fragility Curves

Bridge Fragility Curves

\(P(\text{Damage State})\)

PGA
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Probabilistic Seismic Demand Model

$S_{D_i}, \beta_{D|PGA}$

Probabilistic Seismic Capacity Model

$S_{C_i}, \beta_{C}$

Component Fragility Curves

$P$(Damage State)

Bridge Fragility Curves

Civil, Architectural and Environmental Engineering
Cockrell School of Engineering

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Recall that...

1. Ground Motions → Bridge Samples → \( \text{PGA}, d_i \) → Probabilistic Seismic Demand Model → \( S_D, \beta_{D|PGA} \) → Probabilistic Seismic Capacity Model → \( S_C, \beta_C \) → Component Fragility Curves → Bridge Fragility Curves

2. Repeat For all Components
Fragility Curves for Steel Girder Bridges

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<tr>
<td>Slight</td>
<td>0.27</td>
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Pawnee, Oklahoma Earthquake

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Shake map produced by the United States Geological Survey (USGS), (PGA, in %g)
Fragility Curves for Steel Girder Bridges

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Maximum recorded PGA since 2005

83% 48% 24% <10%
Fragility Curves for Steel Girder Bridges

Central and Eastern United States (CEUS)

Increased rate of human-induced seismicity
Fragility Curves for Steel Girder Bridges

(from Neilson and DesRoches, 2008)
Reasons for Differences in Potential Damage

1. **Spectral Acceleration**
   - Mean
   - Mean plus one standard deviation

2. **Duration**

3. **Attenuation**
   - Texas, Oklahoma, and Kansas (Khosravikia et al., 2018)
   - New Madrid (Nielson, 2005)
   - $5.0 \leq M_w$

The PGA to distance relations
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Yes, there is a potential for significant damage.

But...

The expected damage is less than other larger magnitude CEUS seismic hazards for the same PGA.
Acknowledgement

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• The State of Texas through the TexNet Seismic Monitoring Project,
• The Center for Integrated Seismic Research (CISR)
Acknowledgement

- **Dr. Patricia Clayton (My supervisor)**
  Assistant Professor, Dept. of Civil, Architectural and Environmental Engineering, The University of Texas at Austin

- **Prof. Eric Williamson**
  Professor, Dept. of Civil, Architectural and Environmental Engineering, The University of Texas at Austin
Thanks for your attention. 😊
Fragility Curves for Steel Girder Bridges

- Slight
- Moderate
- Extensive
- Complete

Probability of damage vs. PGA for Texas and New Madrid

- Black line: Texas
- Red line: New Madrid
Comparison of the Proposed and Existing GMPEs for PGA

Texas, Oklahoma, and Kansas (Khosravikia et al., 2018)

New Madrid (Nielson, 2005)

The PGA to distance relations

$5.0 \leq M_w$
Texas Seismicity

Rate of earthquakes with magnitudes greater than 3

~53,000 bridges & culverts in Texas

(Courtesy of Cliff Frohlich)