Caltrans Bridge Seismic Screening Program

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ABSTRACT

California’s high seismicity makes bridges susceptible to earthquake damage that may lead to disrupted service or possible bridge failure. After the 1989 Loma Prieta earthquake, Caltrans initiated an ambitious seismic retrofit program to address seismically deficient bridges identified from a screening and prioritization of the California bridge inventory. Although the initial screening was based on the best information available at the time, not all seismically vulnerable bridges were identified. This paper summarizes past Caltrans seismic screening efforts and summarizes a recently completed effort to identify vulnerable bridges that may not have been captured by earlier screening efforts.
Caltrans Bridge Seismic Screening Program

Thomas A. Ostrom
Caltrans

1971 San Fernando EQ
1989 Loma Prieta EQ
1994 Northridge EQ

California Roads and Bridges

State Highways: ~ 15,200 miles
~ 13,000 bridges

Local Roads: ~ 168,000 miles
~ 13,500 bridges
The Seismic Advisory Board has urged Caltrans to periodically screen its bridge inventory for potential seismic vulnerabilities.

‘The SAB recommends that Caltrans re-screen all of California’s approximately 24,000 bridges for risk of collapse during future seismic events using updated screening algorithms.’ (The Race to Seismic Safety-2003)

‘Caltrans should regularly reassess the seismic hazard and engineering performance of bridges, including existing, retrofitted, and new structures.” (Closing the Gap-2010)
Caltrans Bridge Seismic Screening Program

Caltrans latest screening program is designed to evaluate bridges for seismic hazards that were not addressed during previous bridge screenings. These include:

- Bridges subject to deep basin and near fault effects
- Bridges near faults that have increased slip rates
- Bridges on liquefiable soil
- Bridges over active faults

We are also evaluating bridges for vulnerabilities that were not previously addressed. These include:

- Bridges with unbalanced stiffness
- Bridges with early retrofits that didn’t fully address lesson’s learned
- Bridges with short seats and stiff restrainers
- Bridges that are vulnerable to big displacements

| BRIDGES WITH INCREASED SHAKING. |
| All points are limited to $S_x(1) > 0.3g$ |
| The color coding is as follows: |
| $x = 2013 S_x(1) / 1996 S_x(1)$ |
| Green: $1.2 < x < 1.4$ |
| Blue: $1.4 < x < 1.7$ |
| Purple: $1.7 < x < 2.2$ |
| Red: $x > 2.2$ |
Bridges near faults with increased slip rates

Cajon Creek Bridge was retrofitted in 1996 with steel column casings but a large increase in the design spectra now requires a bent cap retrofit.

Bridges with unbalanced stiffness
Bridges retrofitted with partial column casings.

Bridges retrofitted with only some column casings.
Proceedings of the 11th US-Taiwan Bridge Engineering Workshop
Taipei, Taiwan, October 20–21, 2016

Caltrans Bridge Seismic Screening Program
11th U.S. – Taiwan Bridge Engineering Workshop

Bridges on Liquefiable Soil

Showa Bridge after the 1964 Niigata Earthquake (photo by Joe Penzien).
The California Geological Survey created maps with active faults and setbacks for the state. Caltrans Geotechnical Services 180 bridges were found within these setbacks, 138 bridges with fault offsets greater than 4” were identified, and 28 bridges with offsets > 4 ft were put on top for immediate retrofit.
Filtering Criteria

<table>
<thead>
<tr>
<th>Filter</th>
<th>Number of Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridges built prior to 1980 with 1 second spectral acceleration (1sec. $S_a$) $\geq 0.5$ g</td>
<td>3415</td>
</tr>
<tr>
<td>Retrofitted bridges with 1sec $S_a$ $\geq 0.7$ g and (2013 1sec. $S_a$)/(1996 1sec. $S_a$) $\geq 1.4$</td>
<td>177</td>
</tr>
<tr>
<td>Retrofitted bridges with 1sec $S_a$ $\geq 0.3$ g and the restraints may be deficient</td>
<td>342</td>
</tr>
<tr>
<td>Retrofitted bridges with 1sec $S_a$ $\geq 0.5$ g and only some columns are cased</td>
<td>433</td>
</tr>
<tr>
<td>Retrofitted bridges with 1sec $S_a$ $\geq 0.5$ g and with partial height column casings</td>
<td>34</td>
</tr>
<tr>
<td>Bridges evaluated for liquefaction hazard</td>
<td>453</td>
</tr>
<tr>
<td>Bridges over active faults that need to be evaluated for fault offset</td>
<td>138</td>
</tr>
<tr>
<td>Bridges in STRAIN that were rescreened using the new algorithm</td>
<td>16</td>
</tr>
<tr>
<td><strong>Number of bridges identified for vulnerability screening</strong></td>
<td><strong>5008</strong></td>
</tr>
</tbody>
</table>

RISK = (V) $\times$ (H) $\times$ (I)

Where V represents the vulnerability of the bridge, H represents the hazard at the bridge site, and I represents the importance or impact of the bridge.

$V = f(\text{Very Brittle, Brittle, Non Ductile, Other Vulnerabilities, Poor Details})$

$H = f(\text{1 Second Spectral Acceleration, Soil Factor, Surface Offset})$

$I = f(\text{Average Daily Traffic, Detour Length})$
Vulnerability = (Score Very Brittle + Score Brittle + Score Non-ductile + Score Other + Score Poor Detail)

Score Very Brittle = \[ \sum (3.0 \times \text{Very Brittle})^2 \leq 4.24 \]

Score Brittle = \[ \sum (1.0 \times \text{Brittle})^2 \leq 2.0 \]

Score Non-ductile = \[ \sum (0.5 \times \text{Non-ductile})^2 \leq 1.0 \]

Score Other Vulnerabilities = \[ \sum (0.3 \times \text{Other Vulnerabilities})^2 \leq 0.6 \]

Score Poor Details = \[ \sum (0.2 \times \text{Poor Details})^2 \leq 0.4 \]

Very Brittle originally had a maximum score of 3.0 (a single attribute topped it out). However, after the algorithm was modified (Task A2 and Task A3) it was determined that two attributes would be counted for a top score of 4.24.

**IMPACT (or Importance Factor)**

The third parameter for calculating the Risk is the bridge impact (or importance) characterization (I) based on the average daily traffic (ADT) and the detour length required if the bridge were to be closed.

\[ Impact = \left[ 1 + 0.223732 \exp(-\left(1.16588(\ln(ADT \times \text{Detour Length} \times 6^{-8})))\right)) \right]^{-1} \]
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Taipei, Taiwan, October 20-21, 2016
The changes in slope identify those bridges that are at very high seismic risk, high seismic risk, moderate seismic risk, and low seismic risk.

Bridges with Normalized Hazard x Vulnerability x Impact and Normalized Hazard x Vulnerability greater than 0.2 were reviewed and eventually added to bridges in STRAIN for Seismic Retrofit.
Bridges Bins – based on changing the number of Vulnerabilities and the Weight Factors

Task A1 – Bridges with High Ground Shaking (4084 Bridges)

H x V

H x V x 1
Task A2 – High Ground Shaking (4084 Bridges) – Increased Low Vulnerability Attributes

Task A3 – Bridges with High Ground Shaking (4084 Bridges) – Changes in Weight Factors and High Scores

Score Very Brittle = \sqrt{(0.8 \times \text{Brittle})^2} \leq 3.0 \text{ No Change}
Score Brittle = \sqrt{(1.4 \times \text{Brittle})^2} \leq 2.8
Score Nonbrittle = \sqrt{(0.8 \times \text{Nonbrittle})^2} \leq 1.6
Score Other Vulnerabilities = \sqrt{(0.6 \times \text{Other Vulnerabilities})^2} \leq 1.2
Score Poor Details = \sqrt{(0.8 \times \text{Poor Details})^2} \leq 0.8

At the time of this study, we were only allowing a single attribute to be counted for very brittle. After reviewing the results, for the ‘bump up’ for liquefaction fault offset, it was decided to allow two attributes.
The 574 bridges with Normalized Hazard x Vulnerability > 0.2 can be divided into three groups:

- Bridges in Normal Safe Condition, 187
- Bridges in Liq Cat 1 & Fault Cat 5, 334
- Bridges in Liq Cat 4 & Fault Cat 5, 35

### Deck Area for Different Types of Bridges Screened-In for Possible Retrofit

<table>
<thead>
<tr>
<th>Deck Area in SQ.FT</th>
<th>Percentage of State Bridge Deck Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.22%</td>
<td>3.22% of state bridge deck area</td>
</tr>
<tr>
<td>0.37%</td>
<td>0.37% of state bridge deck area</td>
</tr>
<tr>
<td>0.50%</td>
<td>0.50% of state bridge deck area</td>
</tr>
<tr>
<td>3.98%</td>
<td>3.98% of state bridge deck area</td>
</tr>
<tr>
<td>1.23%</td>
<td>1.23% of state bridge deck area</td>
</tr>
<tr>
<td>0.05%</td>
<td>0.05% of state bridge deck area</td>
</tr>
<tr>
<td>0.14%</td>
<td>0.14% of state bridge deck area</td>
</tr>
<tr>
<td>0.70%</td>
<td>0.70% of state bridge deck area</td>
</tr>
</tbody>
</table>

Total deck area for state bridges = 256,918,792 square feet
Total deck area for 574 bridges screened in = 27,055,808 square feet = 10.5%
Total deck area for 5000+ screened bridges = 120,294,620 square feet = 46.8%
Structure Replacement And Improvement Needs Report - STRAIN

Database for Barrier Rail Replacement, New Bridge Deck, and Seismic Retrofit

State Highway Operation Protection Program – SHOPP about $75 million a year for Seismic Retrofits

Retrofit Costs per Square Foot of Deck

<table>
<thead>
<tr>
<th>Retrofit Type</th>
<th>Cost per Sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hinge Retrofits</td>
<td>$20/Sq. Ft.</td>
</tr>
<tr>
<td>Superstructure Retrofits</td>
<td>$40/Sq. Ft.</td>
</tr>
<tr>
<td>Column + Hinge Retrofits</td>
<td>$60/Sq. Ft.</td>
</tr>
<tr>
<td>Superstructure + Pile Cap Retrofits</td>
<td>$100/Sq. Ft.</td>
</tr>
<tr>
<td>Superstructure + Add Piles Retrofits</td>
<td>$200/Sq. Ft.</td>
</tr>
<tr>
<td>Fault Crossings</td>
<td>Up to $400/Sq. Ft</td>
</tr>
</tbody>
</table>

Alameddine, F., Retrofit of California Bridges with Multi-Span Steel Superstructures vs Concrete Superstructures. American Society of Civil Engineers, Illinois Section Structural Group, 2009 Lecture Series, Structural Engineering In the 21st Century, 2009

Conclusions

1. Caltrans has rescreened its Bridge Inventory incorporating the latest information is seismic hazard, earthquake engineering practice, and bridge importance
2. The screening algorithm is calibrated to bridge displacement
3. It is a “smart” algorithm residing in our bridge maintenance database that is normalized to population of bridges screened
4. The algorithm has been rigorously validated
5. Bridges with potential liquefaction hazards are being deferred until new liquefaction and lateral spreading analysis and design procedures are in place
6. Re-evaluate the application of the importance factor. Consider using the larger of the ADT on or below the bridge
7. Evaluate the risk associated with unknown soil information for the 800 bridges.
8. Determine a probability of collapse score for the bridges screened based on fragility curves from the Vulnerability and Hazard Scores
9. Perform an additional study on how best to evaluate the impacts of severe bridge damage or collapse
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RESEARCH AND ACADEMIC INTERESTS
✓ Principles of public transportation management and administration.
✓ Principles and practices of structure design, construction, and maintenance.
✓ Seismic engineering policies and practices.

EDUCATION

CURRENT POSITION
State Bridge Engineer, Caltrans- 1 year
✓ Provides statewide direction and control of all bridge and structure standards.
✓ Oversees implementation of structure policies, specifications, criteria and procedures.
✓ Oversees the Caltrans structures seismic safety program and bridge quality management programs.
✓ Chairs the Caltrans Structure Policy Board.

WORK EXPERIENCES AND ACHIEVEMENTS
Chief of Earthquake Engineering, Analysis and Research, Caltrans- 3 years
✓ Directed the development of Caltrans earthquake engineering policy and seismic hazard standards.
✓ Lead the development of Caltrans seismic design criteria, bridge and building retrofit strategies, and vulnerability assessments.
✓ Directed the Caltrans geotechnical, structure and seismic research program.
✓ Managed the development and maintenance of Caltrans bridge engineering software.

Chief of Bridge Design North, Caltrans- 13 years
✓ Design Manager of over 200 California Bridge and Highway Structures.
✓ Responsible for the development and implementation of bridge design policies, methodologies and procedures.
✓ Managed the Caltrans adoption of the AASHTO LRFD bridge design specification.

PROFESSIONAL ASSOCIATIONS
✓ Registered Professional Engineer in Civil Engineering- California.
✓ AASHTO Subcommittee on Bridges and Structures.

HONORS AND AWARDS
The California Transportation James E. Roberts Award for Exemplary Contributions to the Field of Transportation, 2007.

SELECTED PUBLICATIONS