CUMULATIVE DAMAGE TO OKLAHOMA BRIDGES DUE TO LARGE NUMBER OF SMALL EARTHQUAKES

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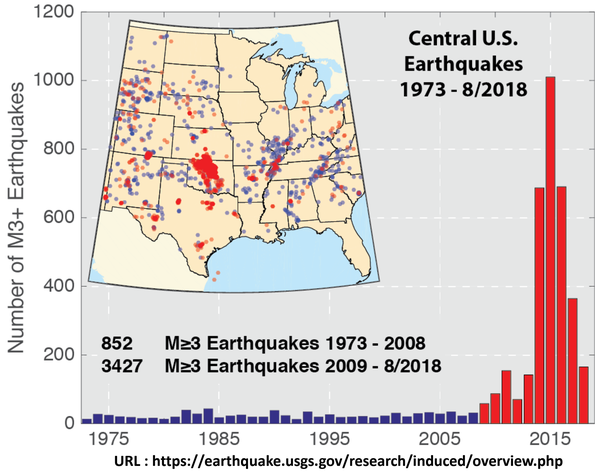
Background and Introduction

Over the last decade, the seismicity in the Central United States has increased due to non-tectonic earthquakes (or "induced seismicity"). States such as Oklahoma, Texas, Kansas and Arkansas historically have experienced only one or two tectonic earthquakes of magnitude 3.0 or larger per year, but these states are now experiencing earthquakes at an increased rate.



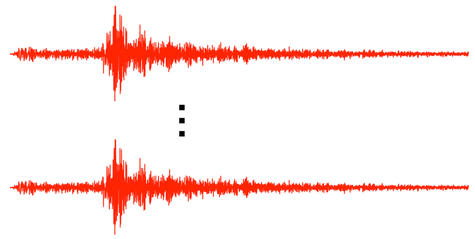
U.S. Geological Survey has incorporated the increased seismicity in these regions in the national seismic hazard maps, but not in seismic design provisions. Consequently, concerns have been raised about how the civil infrastructure that were originally designed for low seismic design loads in these regions will handle this increased seismic demand. State Departments of Transportation (DOTs) are concerned about the impact of increased seismicity on their bridges. While a bridge collapse is unlikely for an induced earthquake, cumulative effects of large number of small induced earthquakes compounded with an occasional moderate earthquake (magnitude 5.0 and larger) may lead to damages requiring rapid repairs/retrofit to avoid traffic control issues at the affected sites.

Research Objectives

- ✓ To address the knowledge gap on the effects of low level frequent earthquakes on the bridges.
- ✓ To propose a framework to assess the cumulative damage on bridges due to induced seismicity.
- ✓ To propose a quantitative measure to identify the accumulated damage in the bridge, in order to estimate the accumulated structural deterioration and the remaining service life.

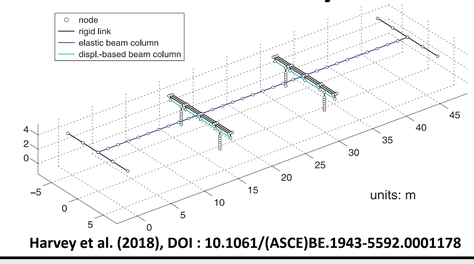
Description of the Proposed Framework

1. Ground-Motion Suite



Compile and organize the desired ground-motion sequence impacting the bridge during the time frame of interest.

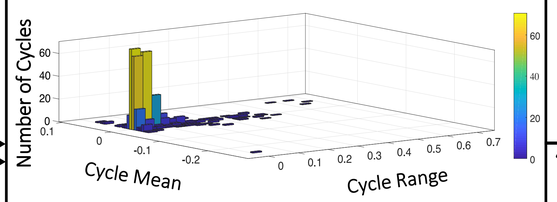
2. Modal Analysis



Harvey et al. (2018), DOI : 10.1061/(ASCE)BE.1943-5592.0001178

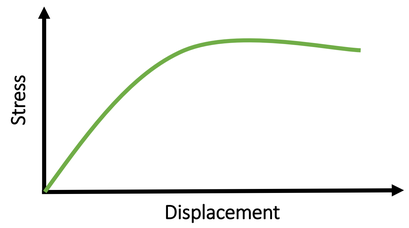
Perform a modal analysis of the bridge model in *OpenSees* to obtain the fundamental period (T_n).

3. Cumulative Demand (CD)



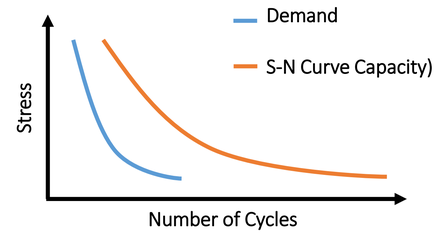
Consider a 5% damped, simple harmonic oscillator and quantify CD using *rainflow counting* based on *ASTM* standard.

4. Pushover Analysis



Perform a simple pushover analysis on the bridge and relate the displacement cycles to the stress cycles.

5. Demand Capacity Analysis



Identify S-N curves for column reinforcement and concrete. S-N curve represents number of cycles to failure at each cyclic stress level.

Miner's Rule

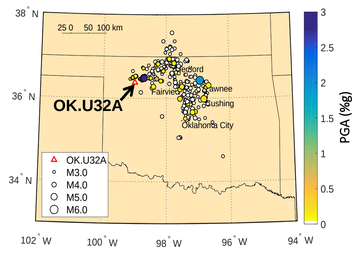
$$FDI = \sum_{i=1}^{k} \frac{n_i}{N_i}$$

where n_i is accumulated number of cycles, and N_i is cycles to failure at each cyclic stress level.

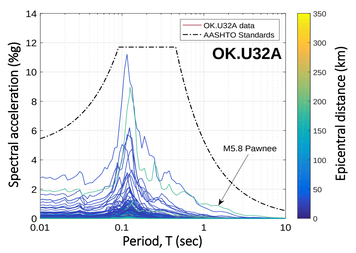
6. Fatigue Damage Index (FDI)

For a given ground-motion sequence, FDI will be used to capture the structural deterioration of the bridge due to accumulated seismic damage.

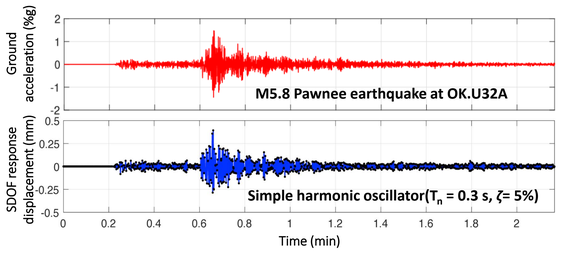
Case Study : A Typical Oklahoma Bridge (SH-99 Bridge over Tiger Creek)



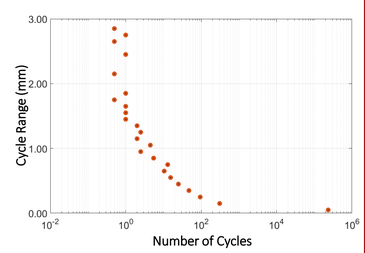
Framework Step 1 - Magnitude 3.0 and larger earthquakes in Oklahoma recorded at seismic station OK.U32A in the year of 2016.



Framework Step 1 (Continued) - Spectral response acceleration (5% damped) measured at station OK.U32A compared with the design response spectra per the 2009 AASHTO Guide specifications for LRFD seismic bridge design.



Framework Step 3 - Response of simple harmonic oscillator (T_n = 0.3 s, ζ = 5%) subject to the N-S component of the ground-motion acceleration recorded at station OK.U32A during the M5.8 Pawnee earthquake.



Framework Step 3 (Continued) - Response displacement cycle counts in terms of cycle range.

- ✓ Ongoing works focus on Steps 4, 5, and 6 of the proposed framework.

Conclusions

- ✓ A framework is proposed to assess the cumulative damage on bridges in Oklahoma and other induced earthquakes prone regions.
- ✓ A quantitative measure, FDI, was developed to capture structural deterioration of a bridge due to large number of small earthquakes, from which the remaining service life can be determined.

Acknowledgement

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