Representation of Probabilistic Seismic Risk Maps through Google Earth

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Abstract

The development of probabilistic seismic risk maps was recently proposed (e.g., see 2006 SCEC Annual Meeting abstract by Luco and Karaca), through combination of ground motion hazard curves from the USGS National Seismic Hazard Mapping Project (http://earthquake.usgs.gov/research/hazmaps/) with seismic hazard-compatible building fragility models based, in part, on FEMA's HAZUS-MH earthquake model for loss estimation (http://www.fema.gov/plan/prevent/hazus/). The proposed risk maps showed mean annual frequencies (MAFs) of exceeding different structural damage states (none, slight, moderate, extensive, and complete) for each of thirty-six different generic building types (e.g., wood light frame, mid-rise concrete shear wall, or high-rise steel frame) designed to four different code levels (high-, moderate-, low-, and pre-code).

In this effort, we make three significant improvements: First, we construct the probabilistic seismic risk maps in KML (Keyhole Markup Language) format, which is the file format used to display geographic data in Google Earth and Google Maps. Second, we incorporate new seismic hazard-compatible building fragility models (Ryu *et al.*, 2008) that are derived using multilinear capacity (or "pushover") curves with negative stiffness after an ultimate (capping) point, as an alternative to the curvilinear curves provided in HAZUS. Third, we incorporate the new (2008) hazard curves from the USGS National Seismic Hazard Mapping Project. We display the risk maps in terms of probabilities of exceeding different structural damages states over a 50, 30, or 1-year planning horizon, assuming a Poisson distribution of damage state exceedance in time, with nine contour levels of probabilities from 0% to 100%.

As an interactive way to convey the seismic risk maps to both the general public and seismic engineers, we also construct a website (http://earthquake.usgs.gov/research/hazmaps/risk/). Using the website, one can get the pre-computed probabilistic seismic risk map corresponding to a selected combination of building height, construction material (e.g., wood, concrete, or steel), structural system (e.g., shear wall or frame), seismic design level, degree of building damage or loss, and planning horizon. We assist the user in making these selections, and the resulting risk map is automatically viewed in Google Earth. Future improvements to the risk maps and website are planned.

Introduction

The probabilistic seismic risk maps, proposed by Luco and Karaca (2006), are aimed to convey the risk of damage to structures, through combination of ground motion hazard information (e.g., USGS hazard curves) and seismic hazard-compatible building fragility models (e.g., Karaca and Luco, 2008).

Methodology (Luco and Karaca, 2006)

For each HAZUS building type, seismic design level (high-, moderate-, low-, pre-code), structural damage state (none, slight, moderate, extensive, complete), and grid point on the USGS National Seismic Hazard Maps:

The rate of exceeding a damage state is computed as

$$\lambda[DS > ds] = \int_{sa} P[DS > ds \mid SA = sa] \, |d\lambda[SA > sa]|$$

where

$P[DS > ds \mid SA = sa] \equiv$ Conditional probability of exceeding the Damage State ds given an SA of sa (i.e., a building fragility curve)

$\lambda[SA > sa] \equiv$ Mean Annual Frequency (MAF) of exceeding a Spectral Acceleration (SA) of sa (i.e., a seismic hazard curve)

The probability of exceeding a damage state over a time period is computed as, assuming a Poisson distribution of damage state exceedance in time,

$$P\left[DS > ds \text{ in } t \text{ year(s)}\right] = 1 - \exp\left(-\lambda\left[DS > ds\right] \times t\right)$$

Three Significant Improvements

Luco and Karaca (2006)	This study
Static Map (JPG format)	*Interactive* Map (KML format)
Fragility Models derived using *Curvilinear* curves	Fragility Models derived using *Multilinear* curves
2002 Hazard curves	2008 Hazard curves

Construction of Probabilistic Seismic Risk Maps in KML format

KML is a file format used to display geographic data in an Earth browser such as Google Earth, Google Maps, and Google Maps for mobile. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard (http://code.google.com/apis/kml/documentation/kml_tut.html).

KML File Structure

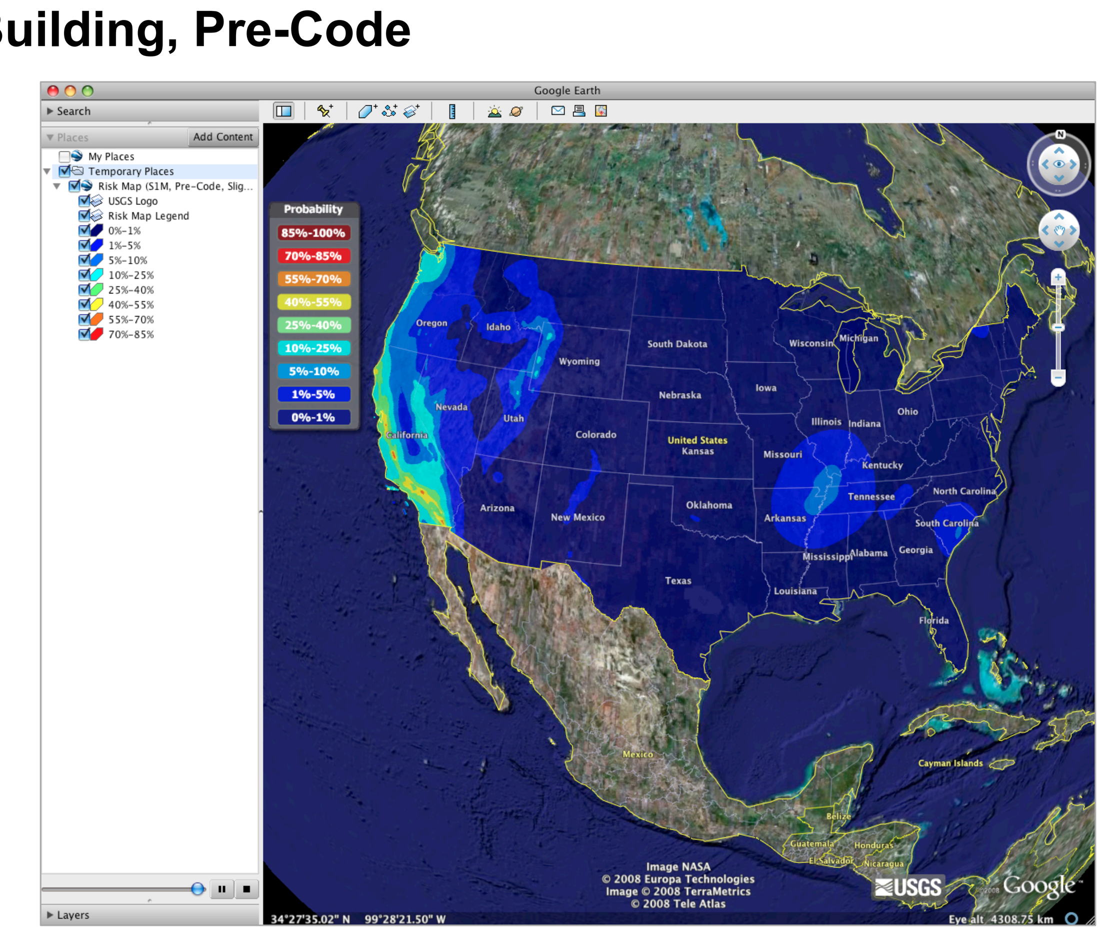
```
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://earth.google.com/kml/2.1">
<Document>
<name> ... </name>
<ScreenOverlay> ... </ScreenOverlay>
  <Placemark>
    <name> ... </name>
    <Style> ... </Style>
    <MultiGeometry>
      <Polygon>
        <outerBoundaryIs>
          <LinearRing>
            <coordinates>
              ...
            </coordinates>
          </LinearRing>
        </outerBoundaryIs>
        <innerBoundaryIs>
          <LinearRing>
            <coordinates>
              ...
            </coordinates>
          </LinearRing>
        </innerBoundaryIs>
      </Polygon>
    </MultiGeometry>
  </Placemark>
</Document>
</kml>
```

Repeat over the number of polygon

Procedure

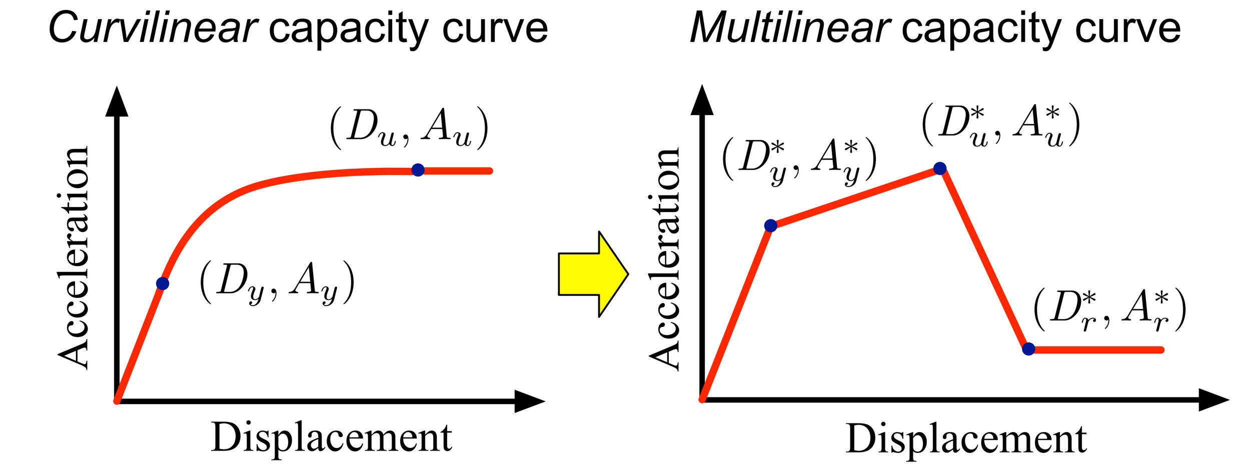
Seismic hazard curves + Seismic hazard-compatible fragility functions → MATLAB: a modified version of Google Earth toolbox → Probabilistic Seismic Risk Maps in KML format

Probability of Exceedance of Slight Damage State in 50 years for Mid-Rise Steel Moment-Frame Building, Pre-Code



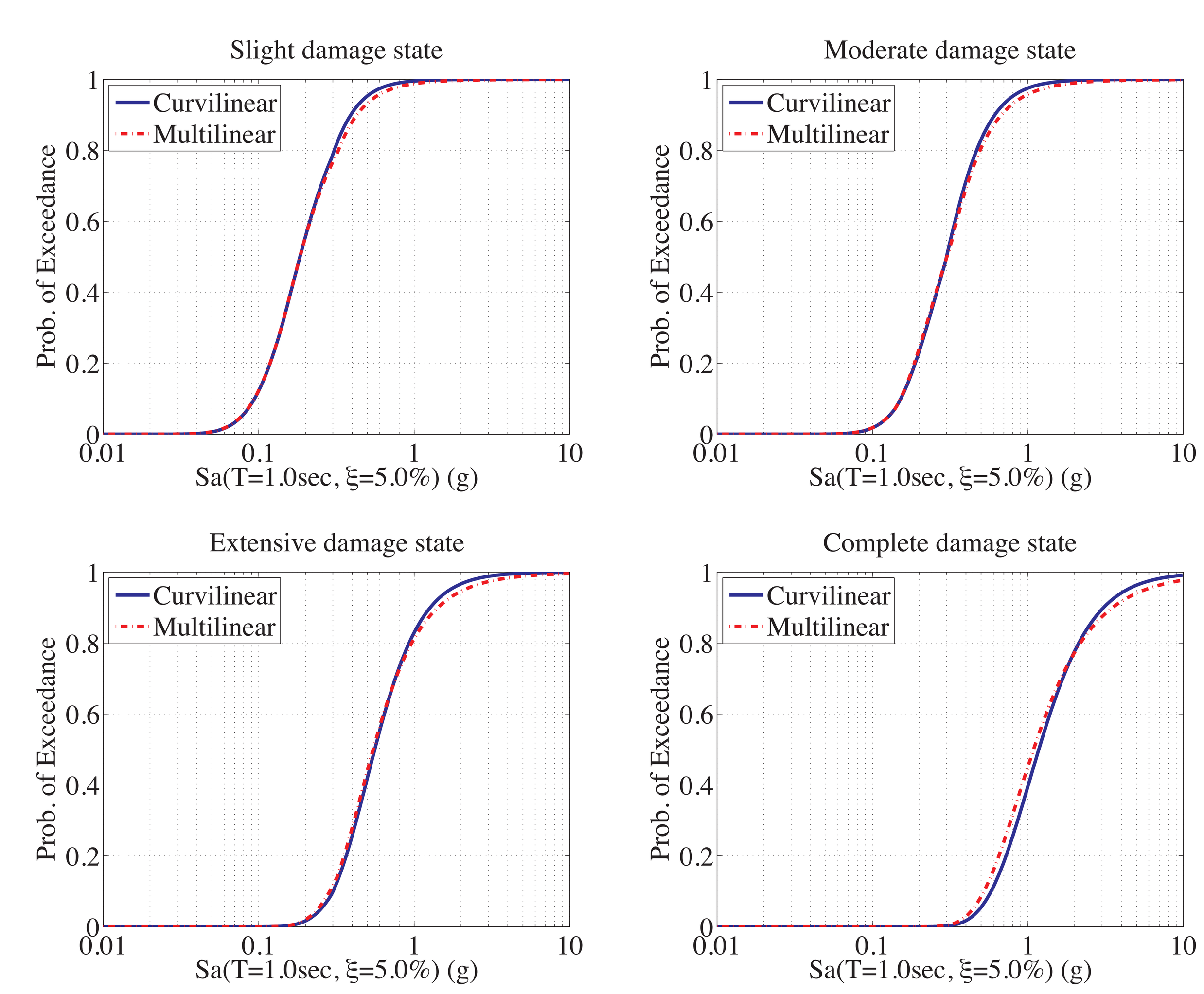
Incorporation of New Seismic Hazard-Compatible Building Fragility Models

Karaca and Luco (2008) used the curvilinear capacity curves provided in HAZUS in order to be consistent. However, those curves were intended to be used for the capacity spectrum method, rather than for nonlinear time history analysis. So we may improve seismic hazard-compatible building fragility models if we choose a more widely available and flexible capacity curve parameterization. In this study we use multilinear capacity curves instead of the curvilinear capacity curves provided in HAZUS, due to the following reasons: 1) There are many available structural analysis programs using multilinear back bones (e.g., OpenSees). In those programs, we can implement different hysteresis models such as pinching or Clough models. 2) With multilinear capacity curves we can introduce negative stiffness past the ultimate (capping) point, which can have significant effects on the response in nonlinear dynamic analyses (Ibarra, 2003). With negative post-capping stiffness and various hysteresis models, one can simulate strength and/or stiffness deterioration and collapse behavior.

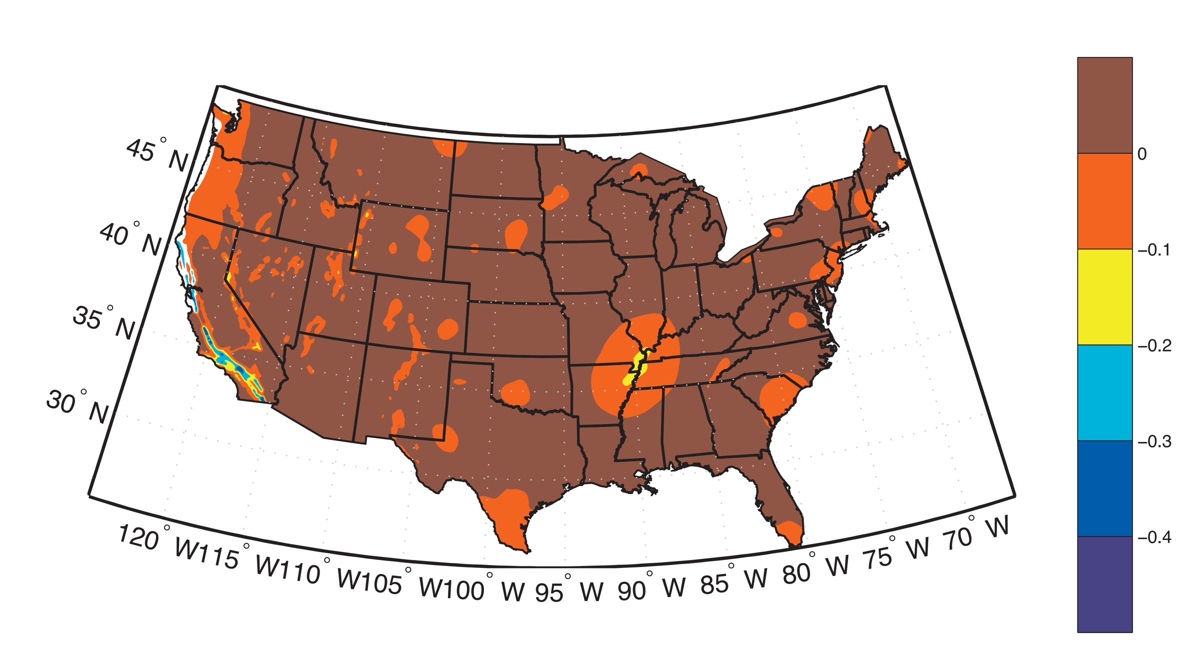


The SDOF systems with the multilinear capacity curves are subjected to a suite of 1554 ground motions from the PEER Next Generation Attenuation (NGA) database. We construct the fragility functions by combining building response and its variability from regression analysis for nonlinear displacement demand, with damage state thresholds provided in HAZUS. A more detailed description of the input ground motions, regression analysis procedure, and construction of fragility functions can be found in Karaca and Luco (2008).

Fragility Functions for Mid-Rise Steel Moment-Frame Building, Pre-Code



Difference of PE (i.e. $PE_{Multilinear}$-$PE_{Curvilinear}$)



2008 SCEC Annual Meeting
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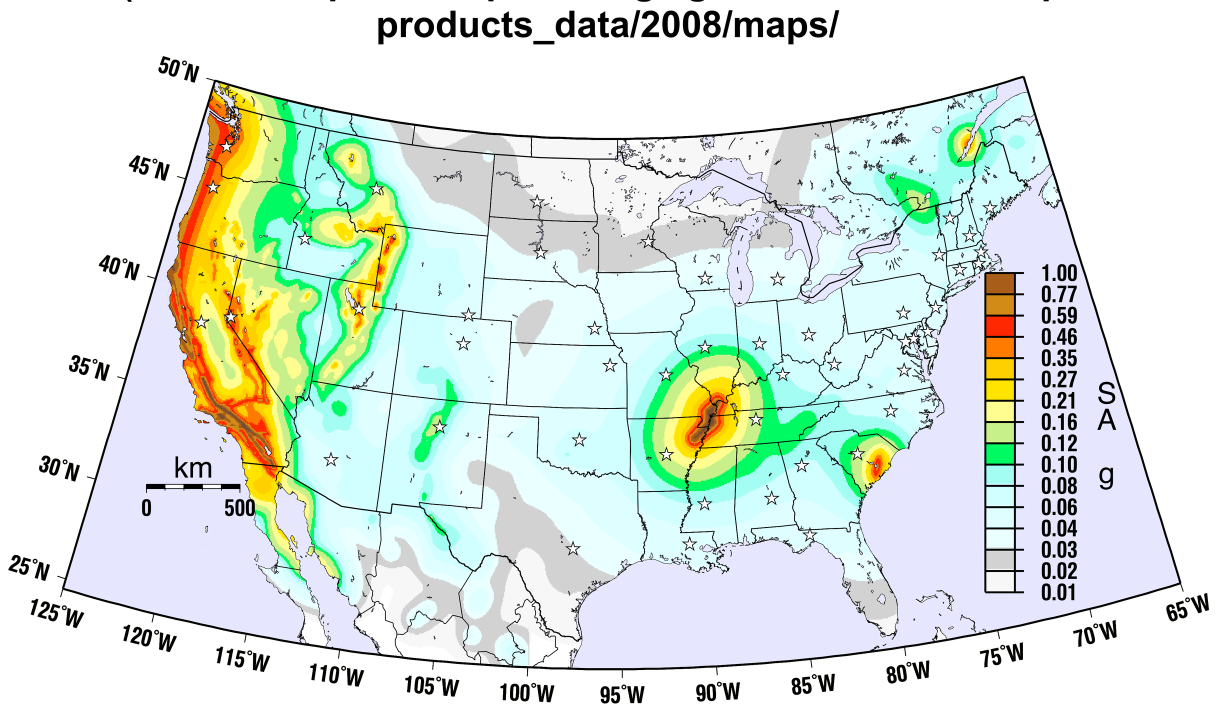
Incorporation of New (2008) Hazard Curves from USGS NSHMP

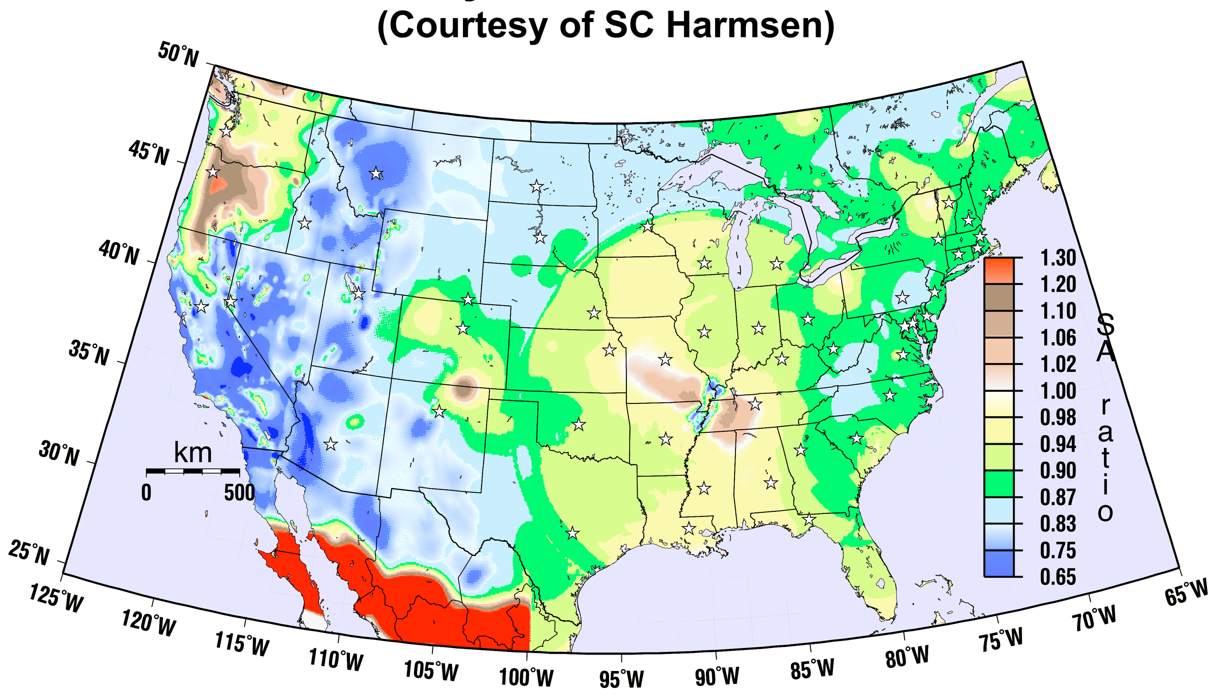
Sa(T=1.0sec) with 2% in 50 year PE, BC Rock, 2008

(Source: http://earthquake.usgs.gov/research/hazmaps/products_data/2008/maps/)



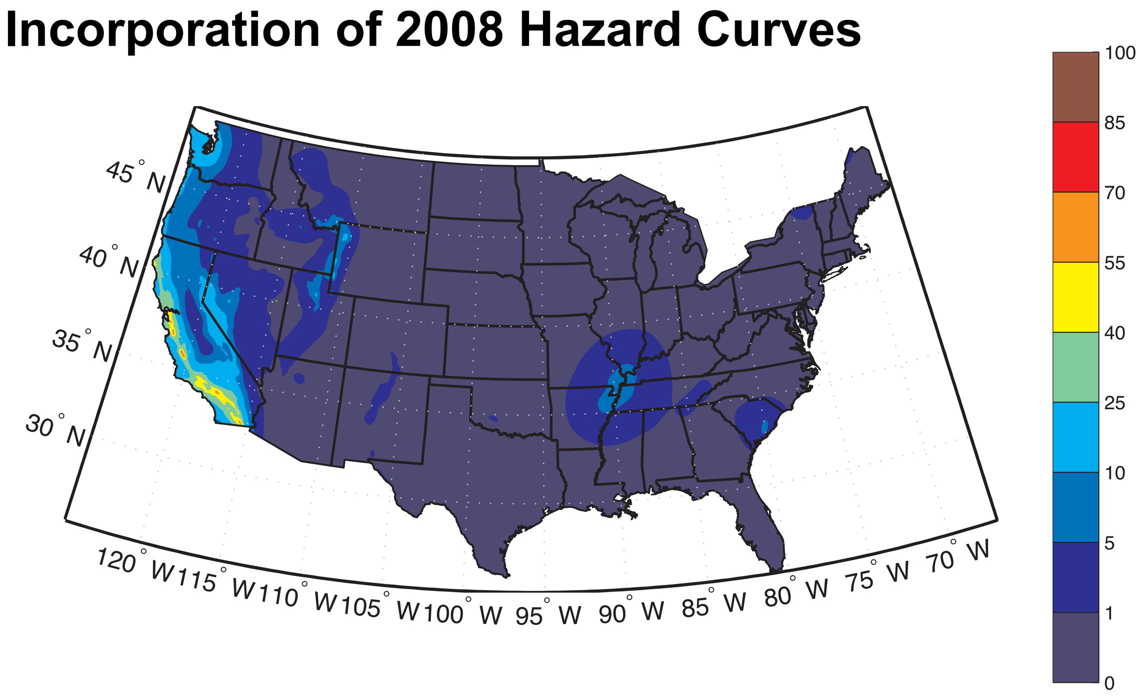
Sa(T=1.0sec) Ratio between 2008 and 2002 with 2% in 50 year PE, BC Rock

(Courtesy of SC Harmsen)

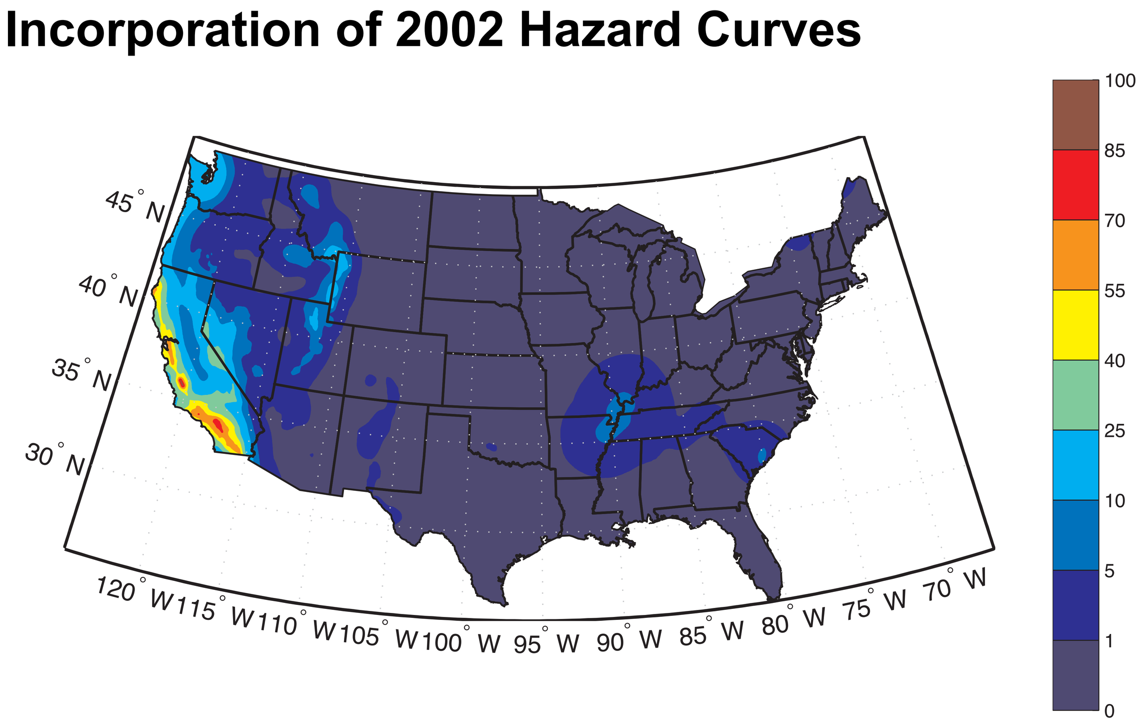


Probability of Exceedance of Slight Damage State in 50 years for Mid-Rise Steel Moment-Frame Building, Pre-Code

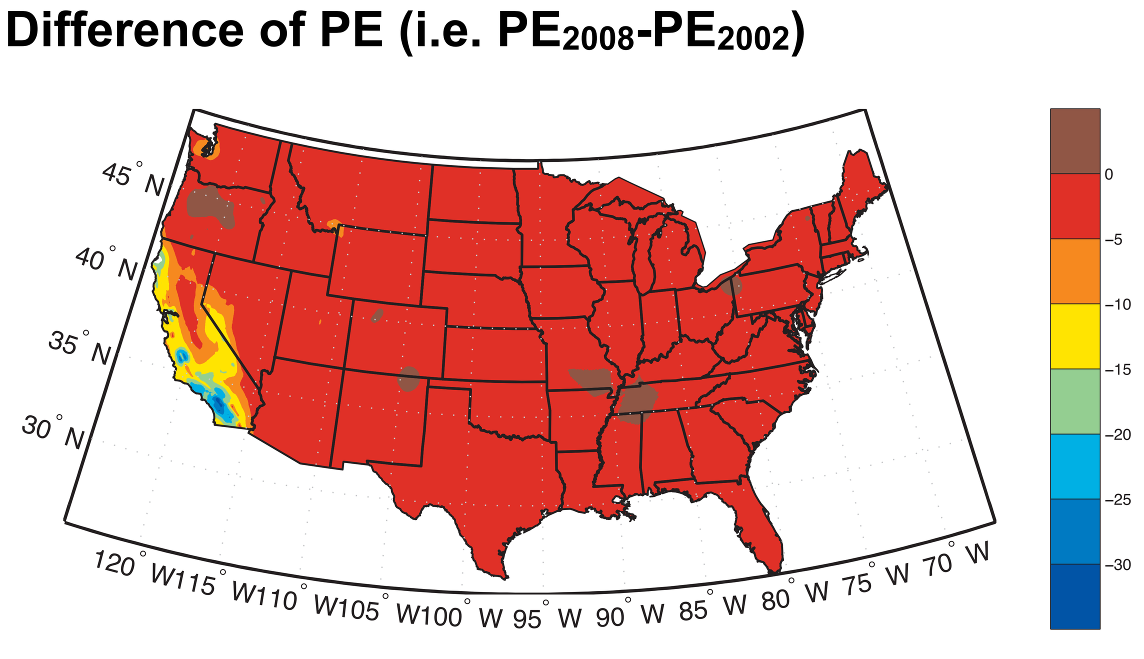
Incorporation of 2008 Hazard Curves



Incorporation of 2002 Hazard Curves



Difference of PE (i.e. PE_{2008}-PE_{2002})



Construction of a Website Containing Probabilistic Seismic Risk Maps in KML Format

(http://earthquake.usgs.gov/research/hazmaps/risk/)

The webpage provides "risk maps" for the conterminous United States that a user can view in Google Earth. Each map displays, for the kind of building a user selects, probabilities of exceeding a selected degree of earthquake damage over a 50, 30, or 1–year planning horizon. The tool is intended to be informative to both the general public and seismic engineers.

The risk maps provided by the web tool are extensions of the data behind the USGS National Seismic Hazard Maps which instead display ground motion accelerations that have a specified chance of being exceeded in (by convention) 50 years. The kinds of buildings users can select for the risk maps are based on those defined in HAZUS, FEMA's software program for estimating potential losses from disasters.

In the Building Selection step, users may select one of the 128 kinds of buildings, by choosing a height, construction material, structural system, and seismic design level.

In the Additional Selections step, users may choose a) the degree of building damage or loss and b) the planning horizon (number of years) they are concerned about.

Tree of Options for the Construction of Risk Maps

- 1. Building Selection
  - Height
    - Low-Rise (1-3 stories)
    - Mid-Rise (4-7 stories)
    - High-Rise (8+ stories)
  - Construction Material
    - Wood
    - Steel
    - Concrete
    - Masonry
    - Other
  - Structural System
    - Options determined based on Height and Construction Material
  - Seismic Design Level
    - Pre-Code
    - Low-Code
    - Moderate-Code
    - High-Code
- 2. Add'l Selections
  - Degree of Building Damage or Loss
    - Slight (0%~5% of Replacement Cost)
    - Moderate (5%~25% of Replacement Cost)
    - Extensive (25~100% of Replacement Cost)
    - Complete (~100% of Replacement Cost)
  - Planning Horizon
    - 50 years
    - 30 years
    - 1 year
- 3. View Risk Map in Google Earth

Development Roadmap for the Webpage

- Hazard Maps
  - 2002
  - 2008
- Fragility Models
  - Karaca and Luco (2008)
  - Ryu et al. (2008)
  - User Defined Fragility Models
- Risk Models
  - Based on Fragility Models
    - Pre-Computed
    - On-The-Fly
  - Based on Vulnerability Models
    - Pre-Computed
    - On-The-Fly
- Display
  - Google Earth
  - Google Maps
- Add'l Features
  - Site Classifications
  - Other Regions

Remark: Completed, Not yet completed, and Not yet started

- Hazard Maps
  - add risk maps incorporating 2008 USGS National Hazard Maps data.
- Fragility Models
  - add risk maps incorporating fragility models derived using the multilinear capacity curves (Ryu *et al.*, 2008).
  - add capability to allow users to incorporate user defined fragility models.
- Risk Models
  - add capability to generate risk maps "on-the-fly", thereby generating risk maps for more combinations of user-specified parameters (e.g., soil classifications other than firm rock).
  - add risk maps that are computed using vulnerability models (probabilistic loss ratios as a function of earthquake ground shaking intensity) and for user-specified degrees of monetary loss (as opposed to damage) expressed as the ratio of repair costs to replacement costs.
- Display
  - display risk maps in Google Maps and thereby enable users to click on the risk map and obtain the risk value.
- Additional Features
  - add site classifications
  - add risk maps for Alaska, Hawaii, and Puerto Rico & the U.S. Virgin Islands.

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