Mitigation of Seismic Risk pertaining to Non-Ductile Concrete Buildings using Seismic Risk Maps

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ABSTRACT

This poster presents the creation, improvement, and application of a web-based seismic risk map tool developed at the USGS in Golden, CO (http://earthquake.usgs.gov/research/hazmaps/risk).

Reinforced concrete buildings built prior to implementation of modern seismic code standards in 1976 behave in a non-ductile manner under seismic loading, potentially leading to catastrophic failure. The high degree of seismic activity in the western United States makes retrofitting such non-ductile concrete buildings a necessity. Due to the associated cost and time, it is virtually impossible to use a brute force approach to mitigate the seismic risk created by these older concrete buildings. This has motivated the development and improvement of a web-based seismic risk map tool as a way to quantify seismic risk. This tool provides a means to quickly identify the regions of the US where non-ductile concrete buildings are at a high risk of failure. Furthermore, with an inventory of non-ductile concrete buildings for a particular area, the buildings at the highest risk in that area can be pinpointed for seismic retrofit.

MOTIVATION

In 1971, an earthquake in the San Fernando area caused an estimated $500 million in property damage and 65 deaths, due mainly to the collapse of some older concrete buildings. Post-earthquake investigations revealed that a vast majority of the buildings that collapsed were built with too much spacing between stirrups and inadequate flexural reinforcement, which caused them to behave in a non-ductile manner and fail catastrophically. In response to the damage and casualties resulting from the 1971 San Fernando earthquake, building codes were updated to increase the ductility of concrete buildings during the cyclic loading caused by earthquakes.

Concrete buildings constructed after 1976 have a high degree of ductility, which lessens their risk of catastrophic failure. However, this problem still exists with buildings in the western United States constructed prior to the building code revisions. This introduces the necessity of seismic retrofit.

Due to the large number of these substandard buildings and the high cost of retrofit, an efficient strategy to identify high-risk buildings is crucial.

METHOD & MATERIALS

MATLAB & Google Earth
USGS Hazard Data
USGS or User-Specified Fragility Data
USGS or User-Specified
Vulnerability Data

A MATLAB code was created to generate seismic risk maps in the KML file format to be viewed using Google Earth. This code serves as a first-step toward an improved web-based seismic risk map tool. The MATLAB code will be translated into JAVA and incorporated into the existing USGS website at a later date.

BACKGROUND

HAZUS

HAZUS is a multi-hazard risk assessment software (http://www.fema.gov/plan/prevent/hazus/). HAZUS categorizes buildings in terms of construction material, height, lateral force-resisting system, level of seismic design, and occupancy type. The USGS risk maps currently consider only these building categories. The tables below and in the next column present a brief overview of some of the aspects of the HAZUS building categories (including only concrete structural types and excluding occupancy type). For more information on HAZUS, refer to the HAZUS Technical Manual.

HAZUS does not explicitly define a structural type corresponding to non-ductile concrete, but we assume that when any concrete structure is coupled with a pre-code level, it behaves in a non-ductile manner under seismic loading. Likewise, concrete structures built at a high-code level are considered ductile.

Partial Description of HAZUS Building Categories

Label	Description	Height	
		Name	# Stories
C1L	Concrete Moment Frame	Low-Rise	1 - 3
C1M		Mid-Rise	4 - 7
C1H		High-Rise	8+
C2L	Concrete Shear Walls	Low-Rise	1 - 3
C2M		Mid-Rise	4 - 7
C2H		High-Rise	8+
C3L	Concrete Frame with Unreinforced Masonry Infill Walls	Low-Rise	1 - 3
C3M		Mid-Rise	4 - 7
C3H		High-Rise	8+

Seismic Level of Design	Description	Affect on HAZUS Concrete Structures
Pre-Code	Minimal Strength Minimal Ductility	Non-Ductile
High-Code	High Strength	Ductile

SITE CLASS

• NEHRP defines site class in terms of shear wave velocity values to a depth of 30 meters (V_S30)
• Approximate V_S30 values can be determined from topography (Wald & Allen 2007) to estimate a site class distribution in the US (see Figure in next column)

NEHRP Site Class Definition

Site Class	Soil Profile Name	Soil shear wave velocity, V_S30 (m/s)
A	Hard rock	$V_S30 > 1500$
B	Rock	$1500 \geq V_S30 \geq 760$
C	Very dense soil and soft rock	$760 > V_S30 > 360$
D	Stiff soil profile	$360 \geq V_S30 > 180$
E	Soft soil profile	$180 \geq V_S30$

FURTHER INFORMATION

Refer to:
Zahr, M. J. (2009). "Mitigation of Seismic Risk pertaining to Non-Ductile Reinforced Concrete Buildings using Seismic Risk Maps."
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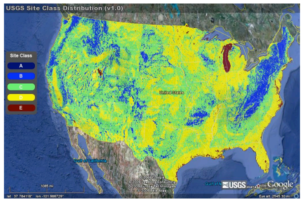
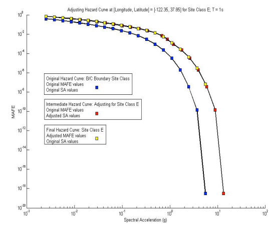
COMPONENTS OF RISK

HAZARD

•Mean annual frequency of ground motion (spectral acceleration at a particular period of oscillation) at a particular location exceeding some value.
• Highly dependent on the ground conditions, or site class, at a particular site





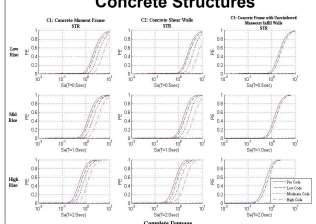
FRAGILITY/VULNERABILITY

• HAZUS divides building damage into four states. Due to our interest in catastrophic failure of non-ductile concrete structures, the complete damage state will be emphasized.
• Fragility is the probability of exceeding a particular damage state given a certain ground motion (spectral acceleration at a particular period of oscillation) for a specific building.
• Vulnerability is the expected value of the loss ratio (repair cost/replacement cost) for a given spectral acceleration.
• The USGS fragility/vulnerability functions used in the risk maps were derived by Karaca and Luco (2009).

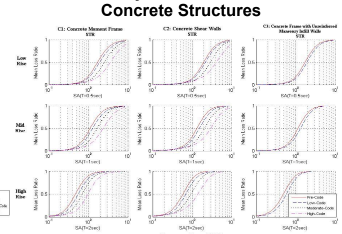
HAZUS Damage States

Damage State	Description	Quantification
Slight	Flexural or Shear hairline cracks in some beams/columns near or within joints	~0%-5% of Replacement Cost
Complete	Structure is collapsed or in imminent danger of collapse due to brittle failure of non-ductile elements.	~100% of Replacement Cost

Fragility Functions for HAZUS Concrete Structures



Vulnerability Functions for HAZUS Concrete Structures



RISK

FROM FRAGILITY AND HAZARD

• Hazard and fragility information can be combined using the risk summation (application of Total Probability Theorem) to define risk in terms of the mean annual frequency of exceeding a certain damage state
• The Poisson Process can then be used to extend the time interval, but due to the assumptions inherent in the Poisson Process, this is an approximation

Risk Summation using Fragility Functions

$$\lambda[DS_i] = \sum_{0}^{\infty} \underbrace{P[DS_i|SA=a]}_{\text{Fragility}} \, \underbrace{|\Delta(\lambda[SA>a])|}_{\text{Hazard}}$$

Poisson Process to Extend Time Interval

$$P(DS \geq ds \text{ in t years}) = 1 - \exp(-\lambda t)$$
λ = mean annual frequency of exceedance (MAFE)

FROM VULNERABILITY AND HAZARD

• Hazard and vulnerability information can also be combined using the risk summation, but this will define risk in terms of an expected annual loss ratio
• The expected annual loss ratio can be multiplied by the value of a building to quantify risk in terms of expected annual monetary loss, but this approach is not presented in this poster

Risk Summation using Vulnerability Functions

$$E[LR] = \sum_{0}^{\infty} \underbrace{E[LR|SA=a]}_{\text{Vulnerability}} \, \underbrace{|\Delta(\lambda[SA>a])|}_{\text{Hazard}}$$

RISK MAPS

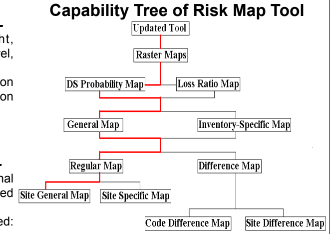
ORIGINAL RISK MAP TOOL

•Users specify structural type and height, construction material, planning horizon, code level, and damage state
• A general risk map is made with the assumption that this set of parameters exists at every point on the grid of the continental US
• Hazard curves for reference Site B/C only

UPDATED RISK MAP TOOL

• Designed to alleviate restrictions of the original tool by providing a wider array of user-specified options
• Allows for, but doesn't require, user-specified: Inventory and/or Fragility/Vulnerability Data
• New Features:
  • Difference Maps
  • Loss Ratio Maps
  • Inventory-Specific Maps

Capability Tree of Risk Map Tool



Entire Tree defines the capabilities of the updated version of the risk map tool. The red path outlines the capabilities of the original risk map tool.

RETROFIT INVESTIGATION METHODOLOGY

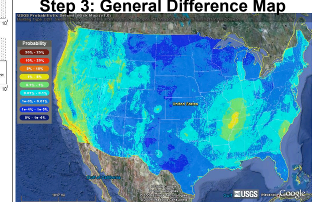
The updated USGS risk map tool described above can be used to carry out the following systematic approach to retrofitting non-ductile concrete buildings:

1) Locate the areas in the continental US that pose the greatest seismic risk using the General Risk Map option of the updated tool
2) Input inventories (e.g. of non-ductile concrete buildings) for these areas into the updated tool to pinpoint the highest risk buildings in the region
3) Using the difference map option of the updated tool, quantify the benefits of the retrofit for these regions and buildings

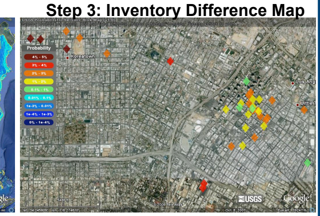
Step 1: General Risk Map

Step 2: Inventory Risk Map

Step 3: General Difference Map



Step 3: Inventory Difference Map



The inventory used in the maps on the right is a sample of a comprehensive non-ductile concrete building inventory in the Los Angeles area being developed by Anagnos et. al.

ACKNOWLEDGMENTS

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