Building-Code Applications of Seismic Hazard: Issues and Opportunities

National Academies of Sciences, Engineering, and Medicine Meeting of the Committee on Seismology and Geodynamics

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Research Structural Engineer
U.S. Geological Survey
Geologic Hazards Science Center
Golden, Colorado

Outline

- Brief history of U.S. building-code applications of seismic hazard
- BSSC/FEMA-USGS Project ’17 issues
- Opportunities for improvement

Applications/Users of USGS Seismic Hazard

Other seismic hazard modelers
(e.g., for insurance risk modeling)

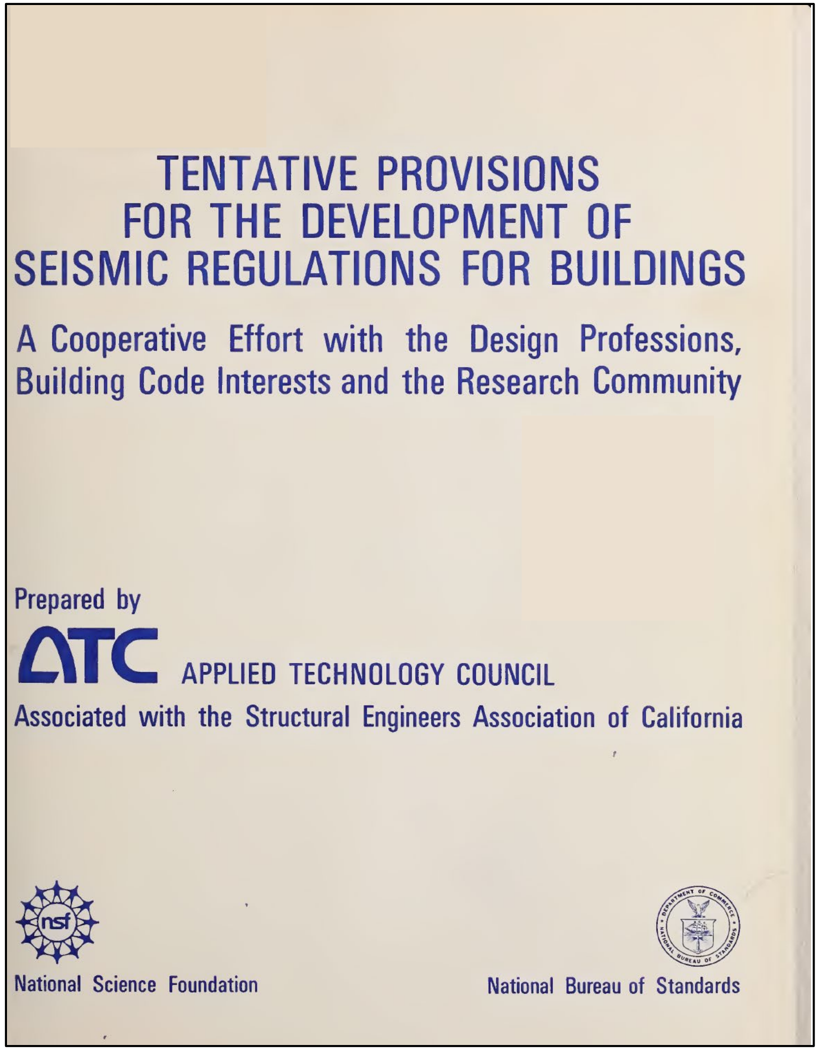
Earthquake engineers
(e.g., for building codes)

Primary focus of this presentation

Emergency-response planners
(e.g., HAZUS users)

The public
(e.g., the media, website users)

Since 1978 *ATC 3-06 Tentative Provisions* …



TENTATIVE PROVISIONS
FOR THE DEVELOPMENT OF
SEISMIC REGULATIONS FOR BUILDINGS

A Cooperative Effort with the Design Professions,
Building Code Interests and the Research Community

Prepared by

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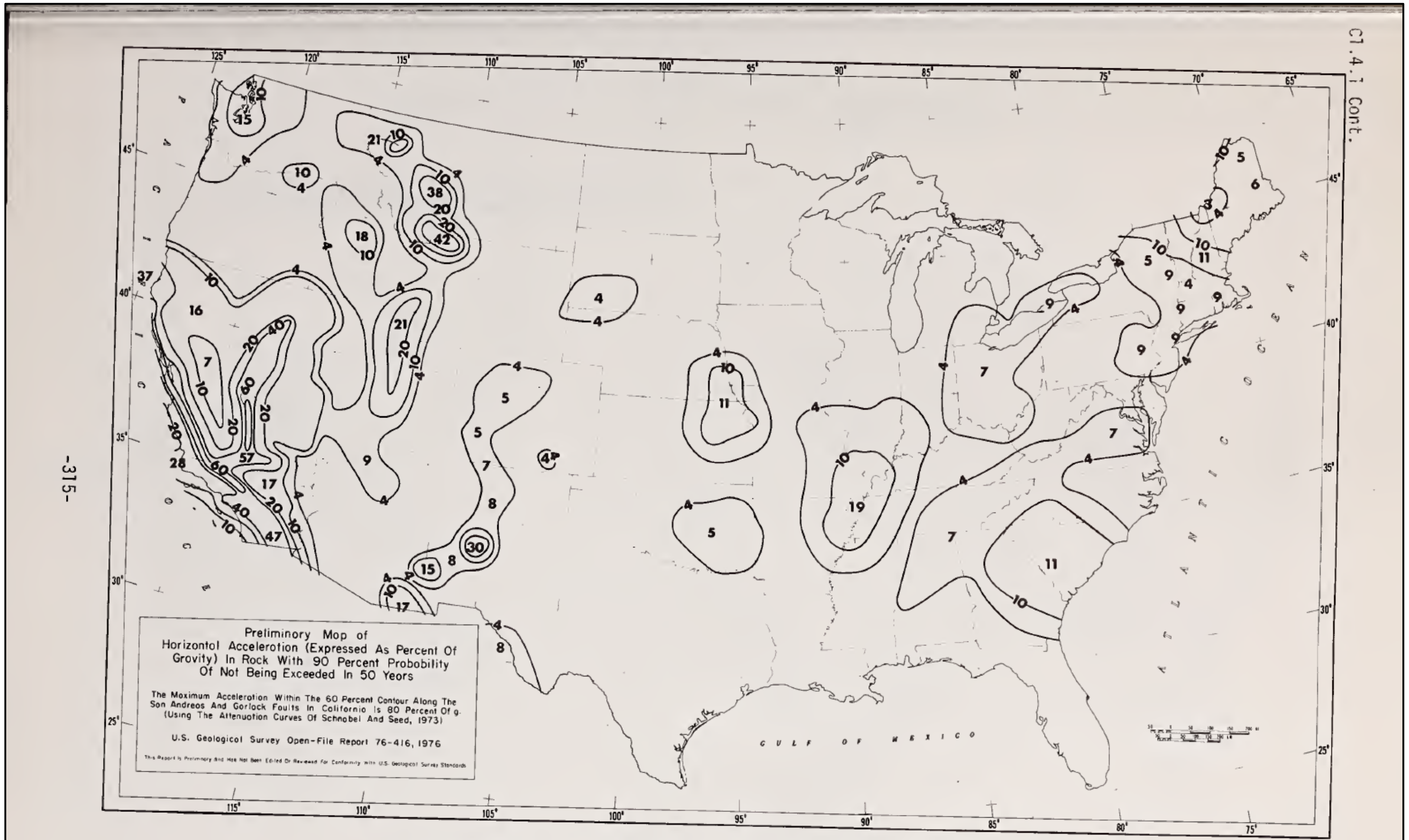
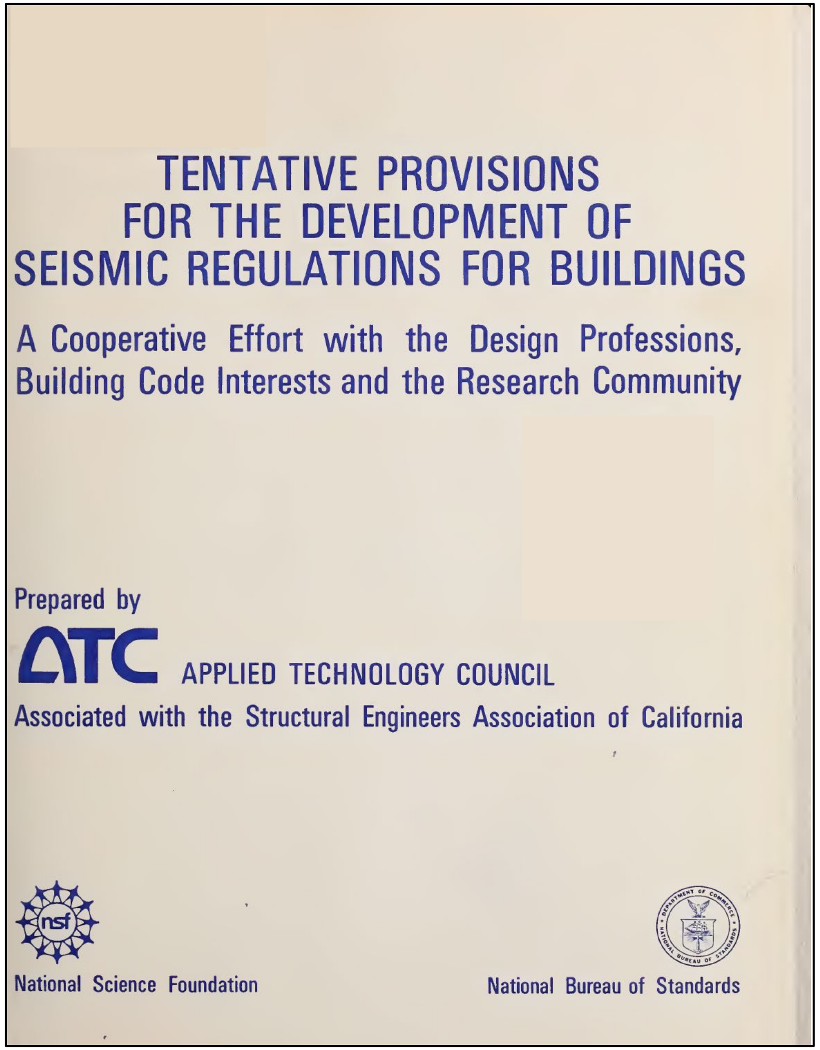


SEISMIC RISK DEVELOPED BY ALGERMISSEN AND PERKINS

FIGURE C1-2

Since 1978 *ATC 3-06 Tentative Provisions* …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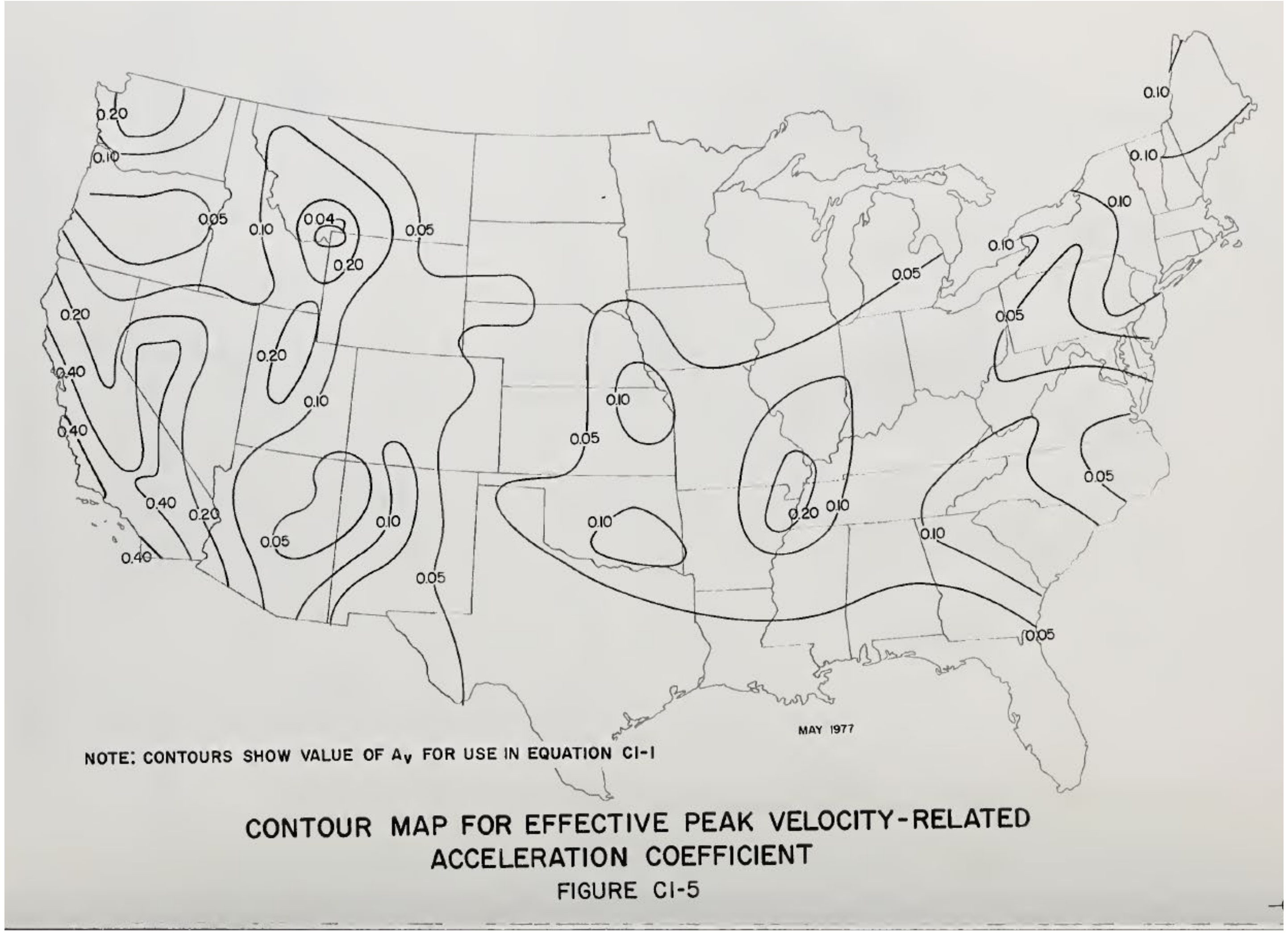
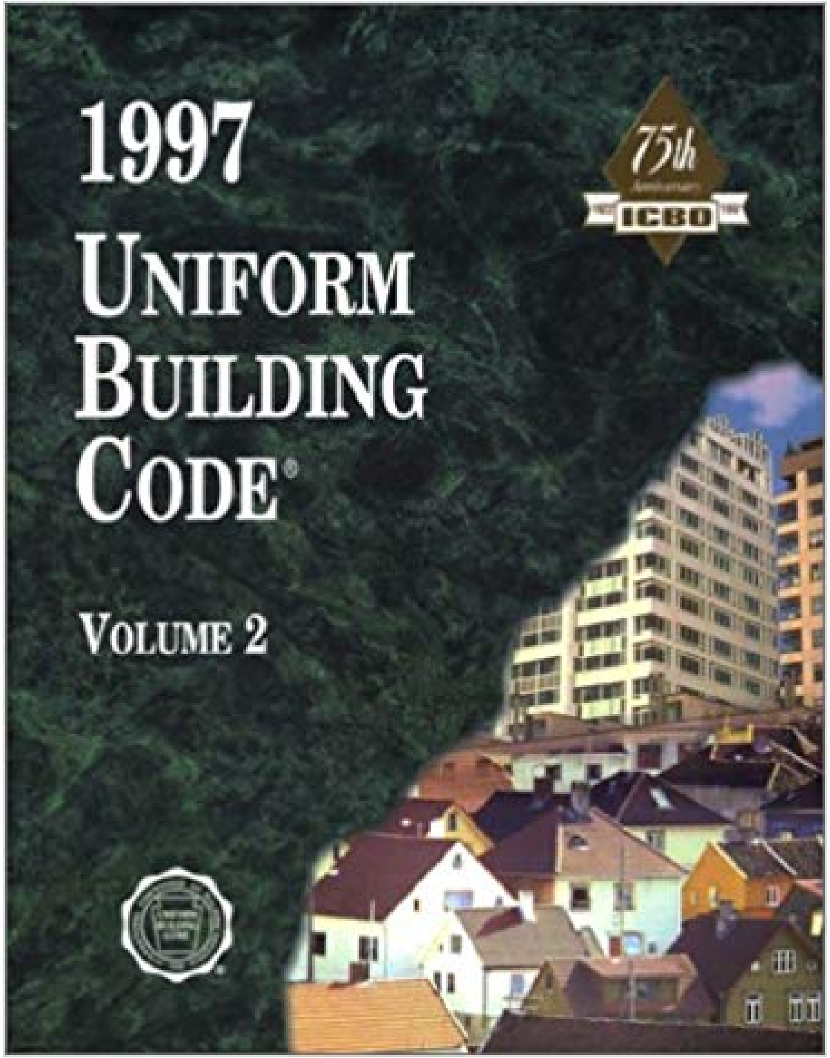
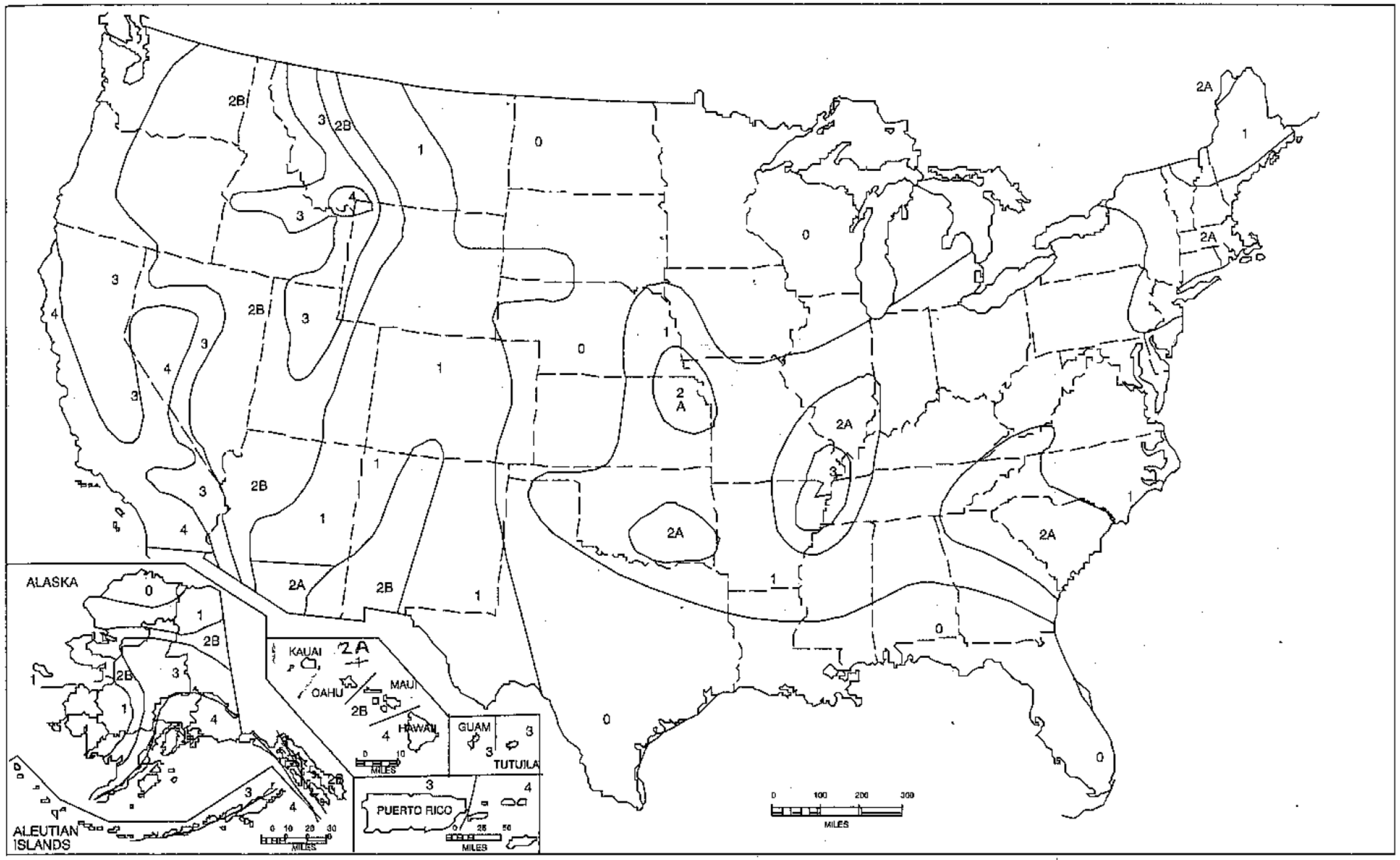


Until 1997 *Uniform Building Code* …





SEISMIC ZONE MAP

National Academies of Sciences, Engineering, and Medicine Meeting of the Committee on Seismology and Geodynamics

Since 1997 NEHRP Recommended Provisions …

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

National Seismic-Hazard Maps: Documentation June 1996

By Arthur Frankel
Charles Mueller
Theodore Barnhard
David Perkins
E.V. Leyendecker
Nancy Dickman
Stanley Hanson
and Margaret Hopper

Open-File Report 96-532

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Denver, CO

1996

+

BUILDING SEISMIC SAFETY COUNCIL

Program on Improved Seismic Safety Provisions

Of the National Institute of Building Sciences

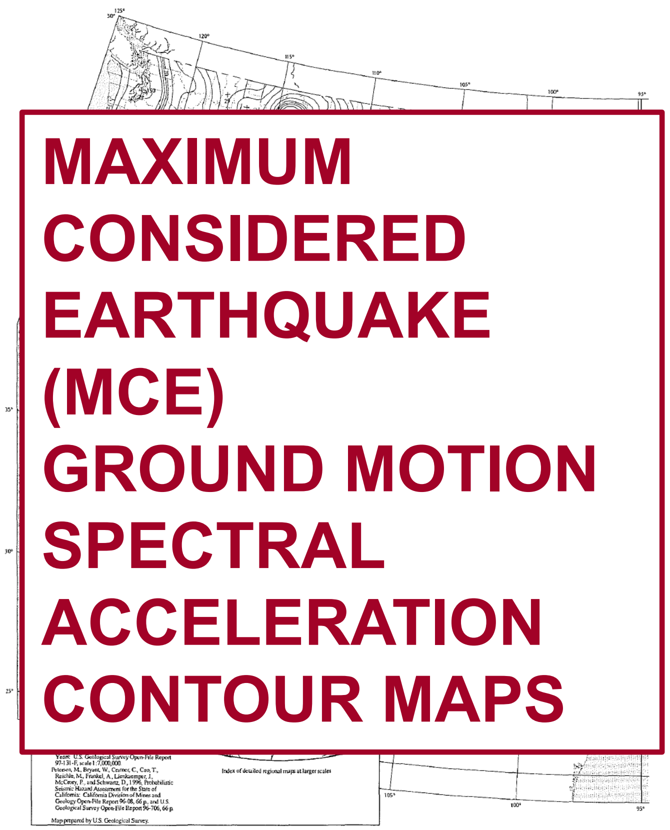
1997 Edition

NEHRP RECOMMENDED PROVISIONS
FOR SEISMIC REGULATIONS
FOR NEW BUILDINGS
AND OTHER STRUCTURES

Part 1: Provisions (FEMA 302)

=

MINIMUM DESIGN LOADS FOR BUILDINGS AND OTHER STRUCTURES

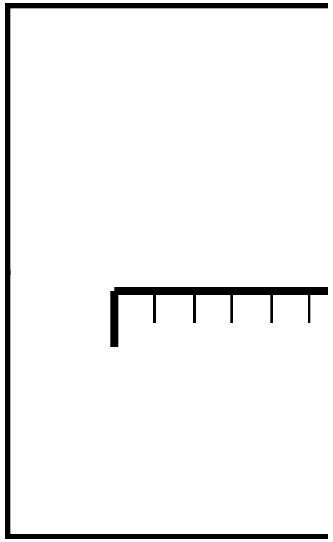


MAXIMUM CONSIDERED EARTHQUAKE (MCE) GROUND MOTION SPECTRAL ACCELERATION CONTOUR MAPS

FIGURE 9.4.1.1 (a). Maximum Considered Earthquake Ground Motion for Conterminous United States. Of 0.2 s Spectral Response Acceleration (5% of Critical Damping), Site Class B

100

Since *2009 NEHRP Recommended Provisions* …



<u>RISK-TARGETED</u> MAXIMUM CONSIDERED EARTHQUAKE (MCE_R) GROUND MOTION SPECTRAL ACCELERATION CONTOUR MAPS

What are (these) Risk-Targeted Ground Motions?

Uniform-Hazard Ground Motions	Risk-Targeted Ground Motions
e.g., 2,500-year (a.k.a., 2%-in-50-year)	e.g., 1%-in-50-years
i.e., Ground motions that each have a 2% **probability of being exceeded** in 50 years (the assumed life expectancy of a building).	i.e., Ground motions that, when used for design, result in buildings with a 1% **probability of collapse** in 50 years.

For *2020 NEHRP Provisions* – Project ‘17

- **Project ’97** – Established procedure for *directly* basing building-code maps on USGS hazard assessment.
- **Project ‘07** – Reassessed Project ‘97 procedure and introduced current “risk-targeted” maps.
- **Project ‘17** – Will propose new ground motion maps for, ultimately, the *2024 International Building Code*.

Project '17 Issues

Project 17 Final Report

September 26, 2018

by

National Institute of Building Sciences
Building Seismic Safety Council
Project 17 Committee (chair: Ron Hamburger)

Sponsored by

Federal Emergency Management Agency
in coordination with the
U.S. Geological Survey

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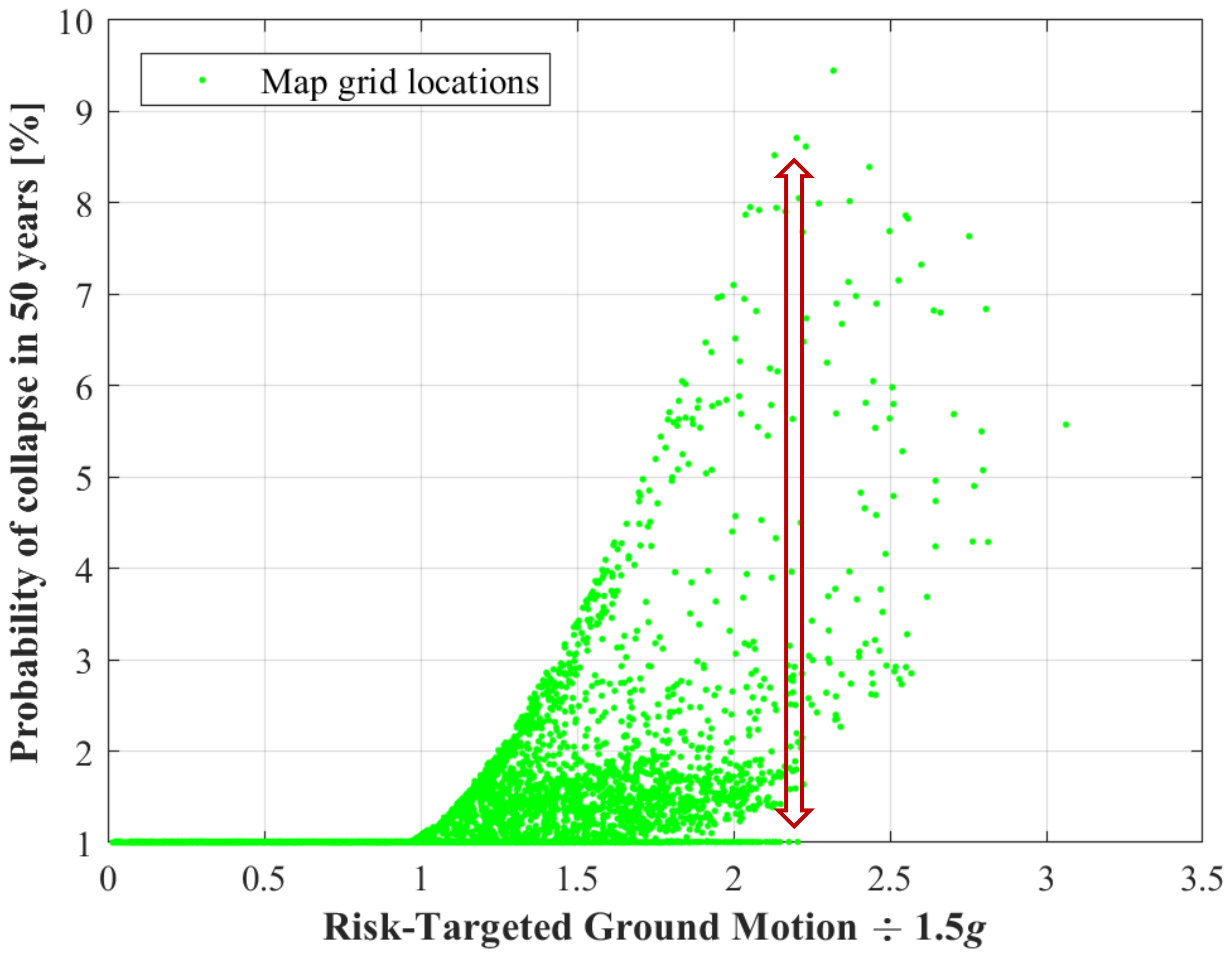
Contents

- **Acceptable Risk**
- **Deterministic Values**
- **Stabilizing Mapped Values**
- **Multi-Period Spectral Values**

Project ’17 – Acceptable Risk & Deterministic Values

Current probability of collapse in 50 years

Project ’17 – Acceptable Risk & Deterministic Values



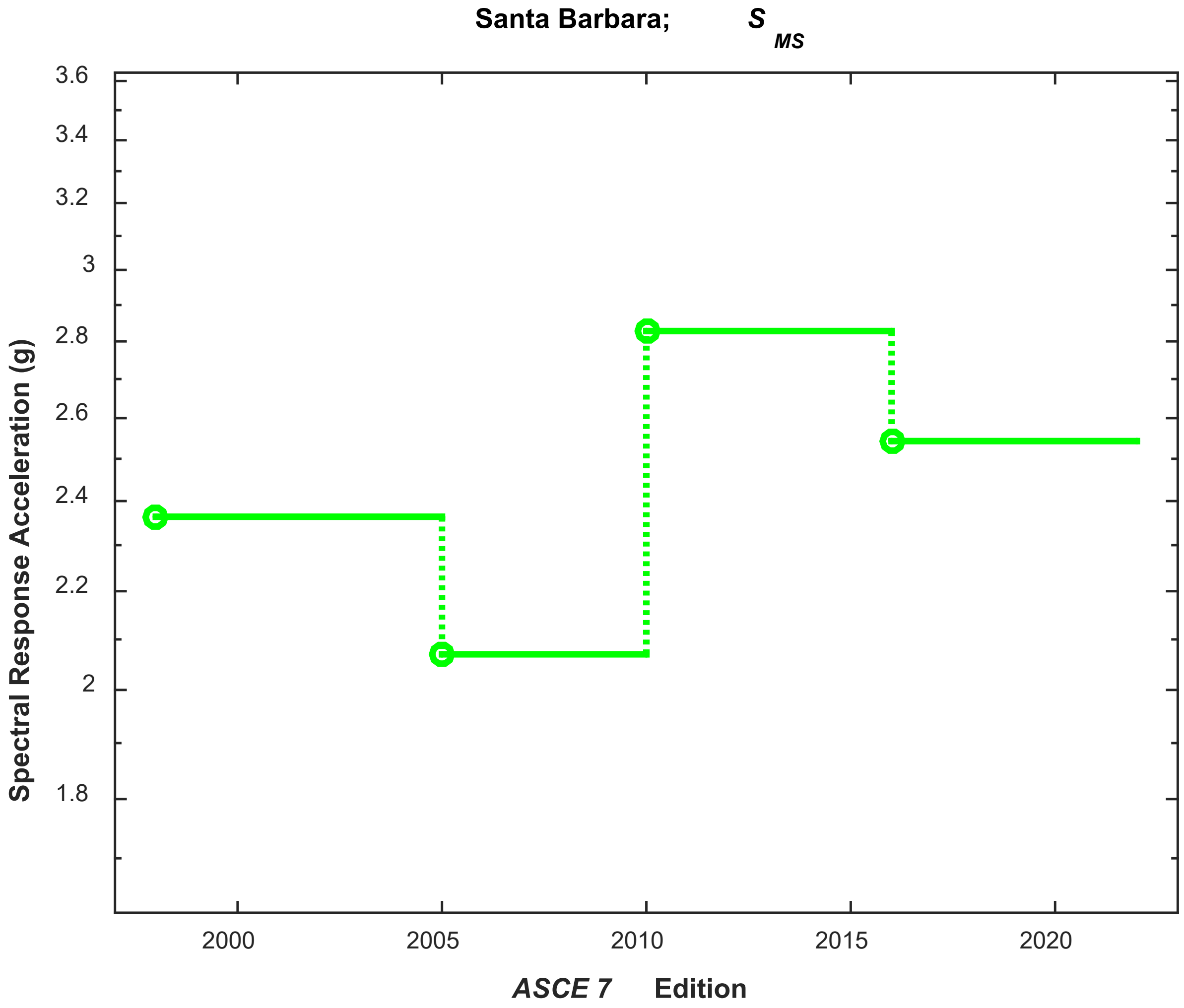
Acceptable Risk in Project ’27, Project ’37 ?

In the future, targeting casualty/fatality risk (and repair costs and downtime) will help in setting the acceptable level, via …

- comparisons across hazards
  (e.g., seismic vs. wind);
- comparisons across structures
  (e.g., buildings vs. bridges, new vs. existing);
- communication with stakeholders

Collapse risk targeting is a step in this direction.

Project ’17 – Stabilizing Mapped Values



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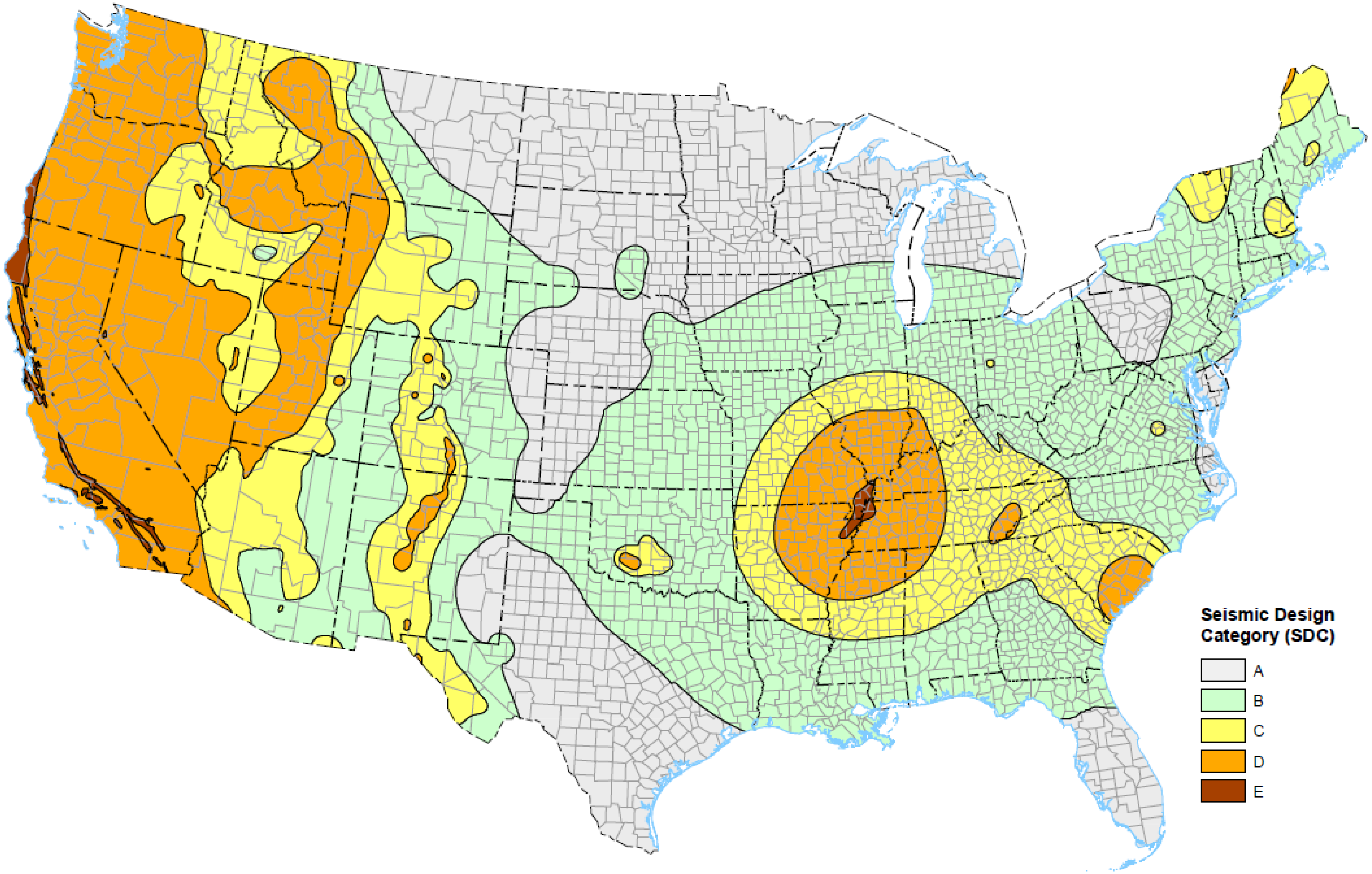
Project ’17 – Stabilizing Mapped Values

Table 11.6-1 Seismic Design Category Based on Short Period Response Acceleration Parameter

	Risk Category	
Value of S_{DS}	I or II or III	IV
$S_{DS} < 0.167$	A	A
$0.167 \le S_{DS} < 0.33$	B	C
$0.33 \le S_{DS} < 0.50$	C	D
$0.50 \le S_{DS}$	D	D

Table 11.6-2 Seismic Design Category Based on 1-S Period Response Acceleration Parameter

	Risk Category	
Value of S_{D1}	I or II or III	IV
$S_{D1} < 0.067$	A	A
$0.067 \le S_{D1} < 0.133$	B	C
$0.133 \le S_{D1} < 0.20$	C	D
$0.20 \le S_{D1}$	D	D



Project ’17 – Additional Issues

Project 17- Developing Next-Generation Seismic Design Value Maps

A Preliminary Planning Report

Prepared for the Federal Emergency Management Agency and U.S. Geological Survey by the Project 17 Planning Committee of National Institute Building Sciences Building Seismic Safety Council

September 28, 2015

nehrp FEMA USGS science for a changing world

3. ISSUES

The Project 17 Planning Committee initially identified the following issues as important for consideration in the Project 17 effort:

1. Timing for Updated Map Publication
2. Design Value Conveyance
3. Precision and Uncertainty
4. Acceptable Collapse Risk
5. Collapse Risk Definition
6. Maximum Direction Ground Motion Components
7. Multi-Period Spectral Values
8. Duration as a Mapped Parameter
9. Damping Levels
10. Vertical Motion Parameters
11. Use and Definition of Deterministic Parameters
12. Basin Effects
13. Use of 3-D Simulation to Develop Long Period Parameters

In addition to the above issues, the Planning Committee also considered several other potential issues including:

1. Providing Mapped Parameters for additional levels of hazard including potential Service and/or Function Level earthquakes.
2. Decoupling Seismic Design Categories from site class effects.
3. Inclusion of induced seismicity in seismic hazard calculation.

Use of 3-D Simulation for Long-Period Parameters

USGS
science for a changing world

2018 Report on Incorporating Sedimentary Basin Response into the Design of Tall Buildings in Seattle, Washington

By Erin A. Wirth, Susan W. Chang, and Arthur D. Frankel

Open-File Report 2018–1149

SRL Early Edition

OPINION

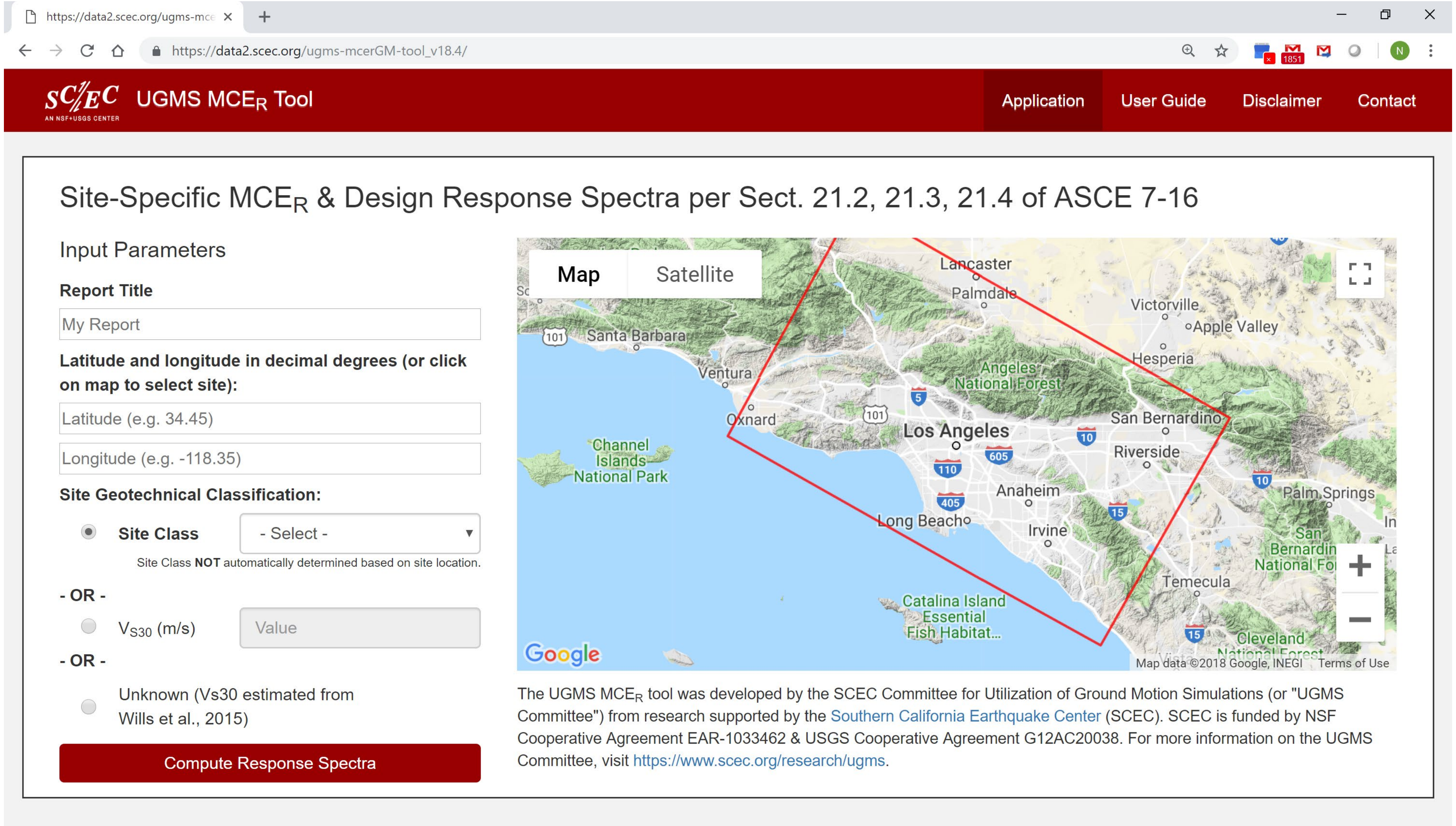
Integrate Urban-Scale Seismic Hazard Analyses with the U.S. National Seismic Hazard Model

Published Online 28 February 2018

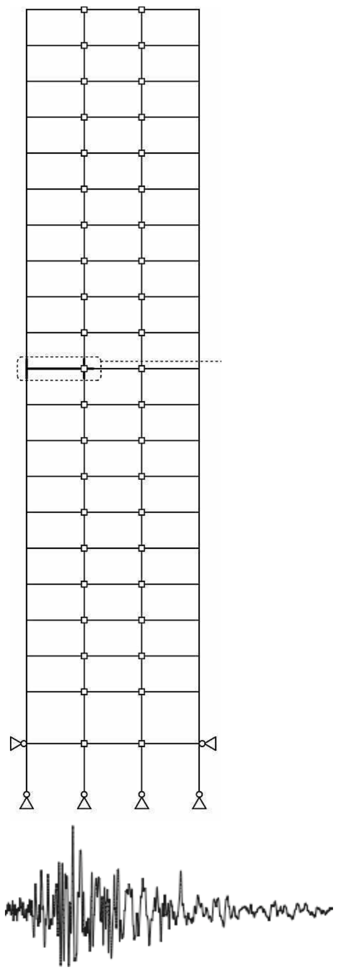
[1] U.S. Geological Survey Working Group on Urban Seismic Hazard Maps.

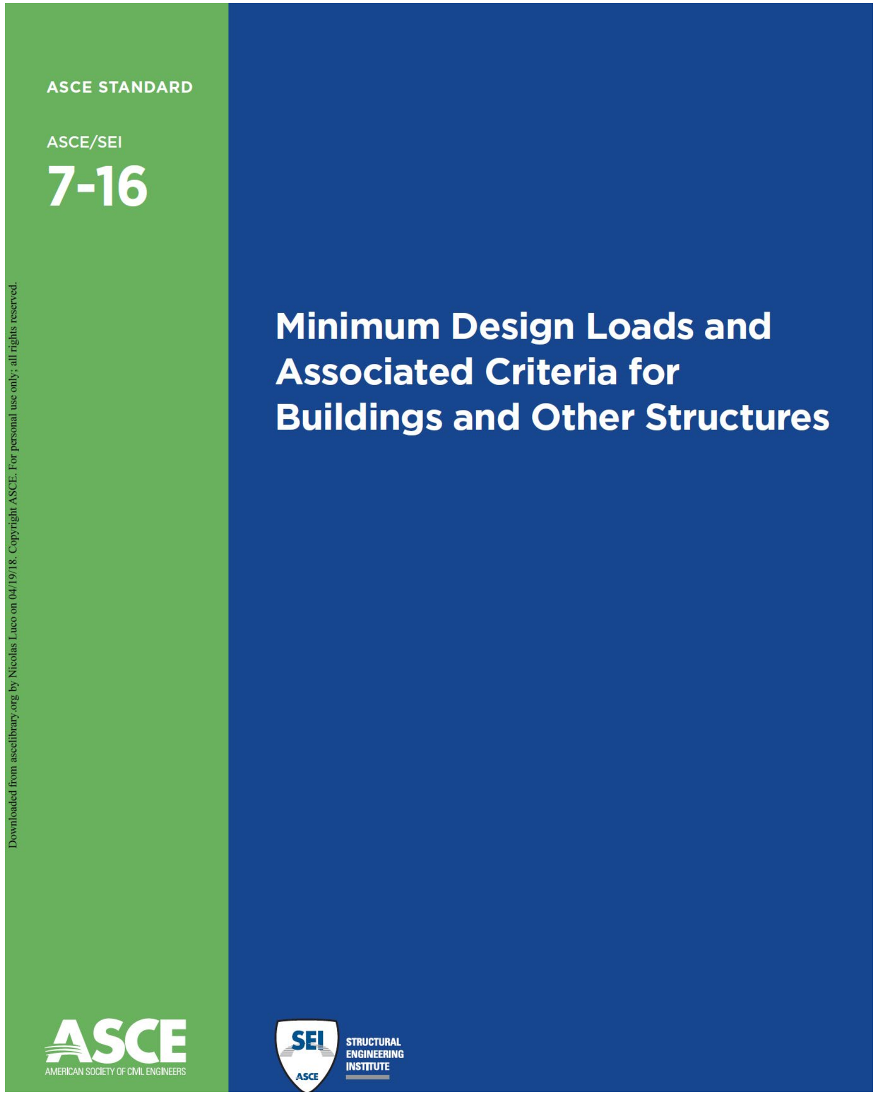
Use of 3-D Simulation for Long-Period Parameters

Southern California Earthquake Center (SCEC) Committee for Utilization of Ground Motion Simulations (UGMS)



Use of 3-D Simulation for Long-Period Seismograms



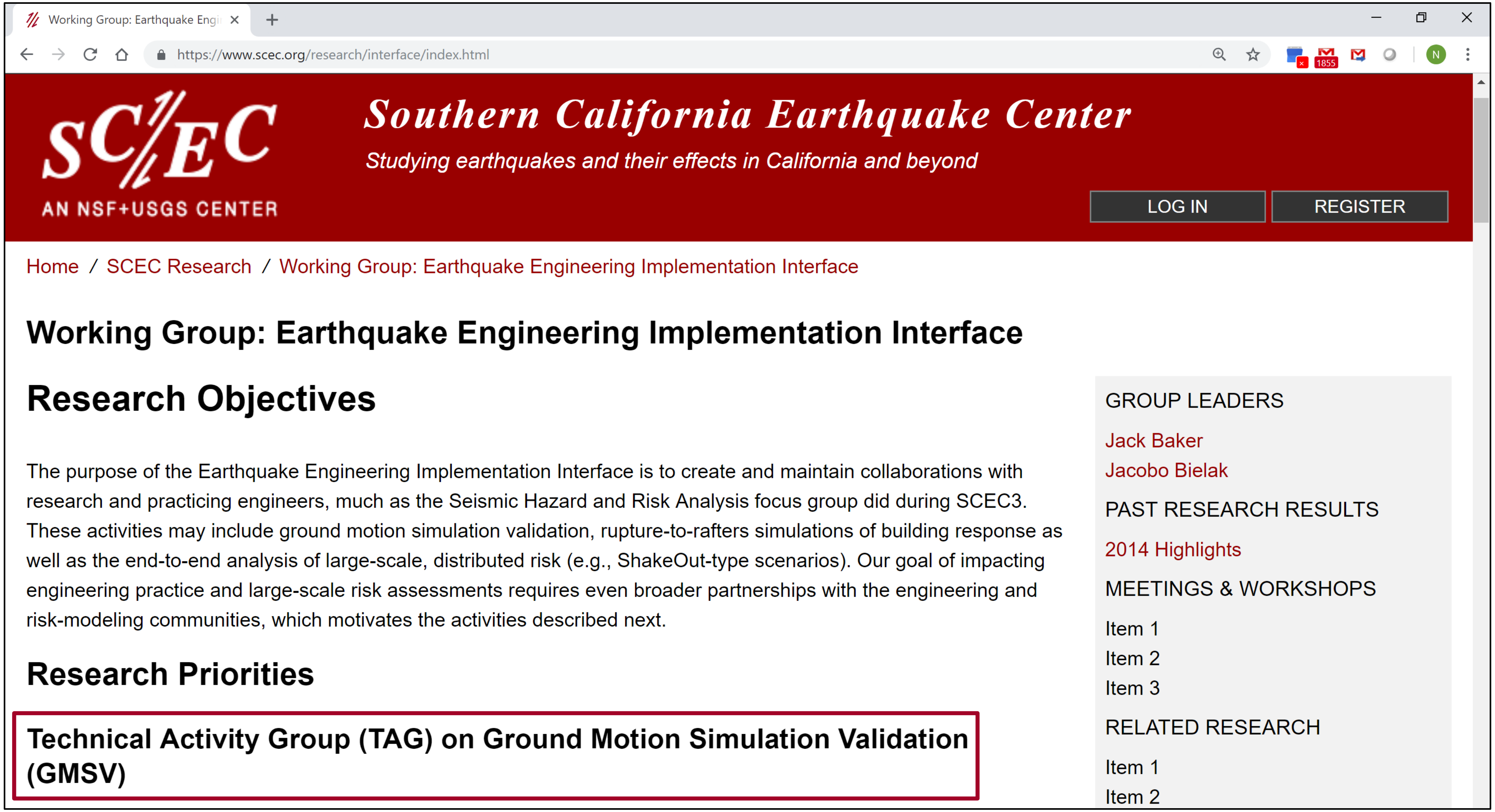


16.2.2 Ground Motion Selection. A suite of not less than 11 ground motions shall be selected for each target spectrum. Ground motions shall consist of pairs of orthogonal horizontal ground motion components and, where vertical earthquake effects are considered, a vertical ground motion component. Ground motions shall be selected from events within the same general tectonic regime and having generally consistent magnitudes and fault distances as those controlling the target spectrum and shall have similar spectral shape to the target spectrum. For near-fault sites, as defined in Section 11.4.1, and other sites where MCE_R shaking can exhibit directionality and impulsive characteristics, the proportion of ground motions with near-fault and rupture directivity effects shall represent the probability that MCE_R shaking will exhibit these effects. Where the required number of recorded ground motions is not available, it shall be permitted to supplement the available records with simulated ground motions. Ground motion simulations shall be consistent with the magnitudes, source characteristics, fault distances, and site conditions controlling the target spectrum.

16.2.3 Ground Motion Modification. Ground motions shall either be amplitude-scaled in accordance with the requirements of Section 16.2.3.2 or spectrally matched in accordance with the

164

Use of 3-D Simulation for Long-Period Seismograms



Working Group: Earthquake Engi

https://www.scec.org/research/interface/index.html

SCEC AN NSF+USGS CENTER

Southern California Earthquake Center

Studying earthquakes and their effects in California and beyond

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Working Group: Earthquake Engineering Implementation Interface

Research Objectives

The purpose of the Earthquake Engineering Implementation Interface is to create and maintain collaborations with research and practicing engineers, much as the Seismic Hazard and Risk Analysis focus group did during SCEC3. These activities may include ground motion simulation validation, rupture-to-rafters simulations of building response as well as the end-to-end analysis of large-scale, distributed risk (e.g., ShakeOut-type scenarios). Our goal of impacting engineering practice and large-scale risk assessments requires even broader partnerships with the engineering and risk-modeling communities, which motivates the activities described next.

Research Priorities

Technical Activity Group (TAG) on Ground Motion Simulation Validation (GMSV)

GROUP LEADERS

Jack Baker
Jacobo Bielak

PAST RESEARCH RESULTS

2014 Highlights

MEETINGS & WORKSHOPS

Item 1
Item 2
Item 3

RELATED RESEARCH

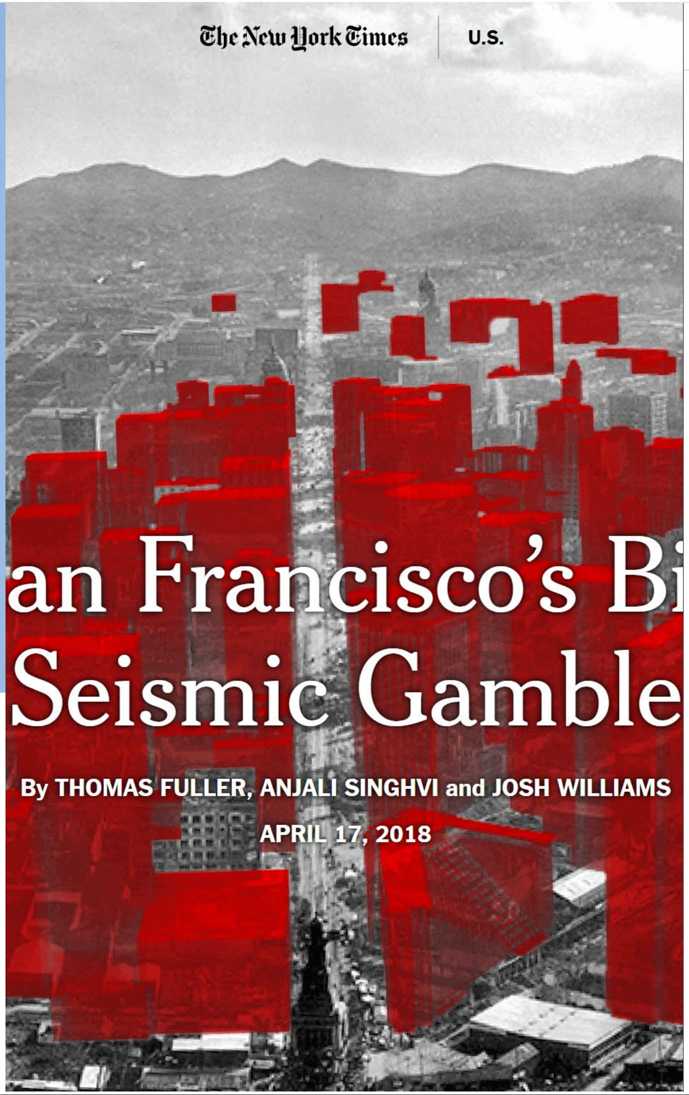
Item 1
Item 2

Use of 3-D Simulation for Long Periods

One Embarcadero Center and Two Embarcadero Center in San Francisco. Both are steel-frame buildings, constructed at a time when a flawed welding technique was widely employed.
Jim Wilson/The New York Times

At Risk in a Big Quake: 39 of San Francisco's Top High Rises

A report by the U.S. Geological Survey includes a list of buildings that are potentially vulnerable to a large quake. Some of San Francisco's most prominent high rises are on the list.



The New York Times

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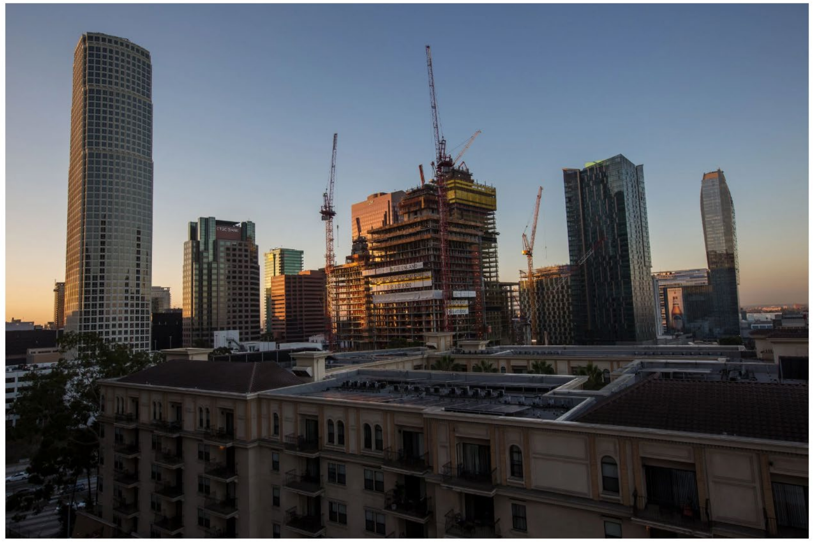
A Seismic Change in Predicting How Earthquakes Will Shake Tall Buildings



Earthquake engineers attending a conference in Los Angeles on Thursday were encouraged to communicate more effectively with the public.
Monica Almeida forThe New York Times

By Thomas Fuller

June 27, 2018

Inclusion of Induced Seismicity in Seismic Hazard

2018 One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes

by Mark D. Petersen, Charles S. Mueller, Morgan P. Moschetti, Susan M. Hoover, Kenneth S. Rukstales, Daniel E. McNamara, Robert A. Williams, Allison M. Shumway, Peter M. Powers, Paul S. Earle, Andrea L. Llenos, Andrew J. Michael, Justin L. Rubinstein, Jack H. Norbeck, and Elizabeth S. Cochran

ABSTRACT

This article describes the U.S. Geological Survey (USGS) 2018 one-year probabilistic seismic hazard forecast for the central and eastern United States from induced and natural earthquakes. For consistency, the updated 2018 forecast is developed using the same probabilistic seismicity-based methodology as applied in the two previous forecasts. Rates of earthquakes across the United States **M** ≥ 3.0 grew rapidly between 2008 and 2015 but have steadily declined over the past 3 years, especially in areas of Oklahoma and southern Kansas where fluid injection has decreased. The seismicity pattern in 2017 was complex with earthquakes more spatially dispersed than in the previous years. Some areas of west-central Oklahoma experienced increased activity rates where industrial activity increased. Earthquake rates in Oklahoma (429 earthquakes of **M** ≥ 3 and 4 **M** ≥ 4), Raton basin (Colorado/New Mexico border, six earthquakes **M** ≥ 3), and the New Madrid seismic zone (11 earthquakes **M** ≥ 3) continue to be higher than historical levels. Almost all of these earthquakes occurred within the highest hazard regions of the 2017 forecast. Even though rates declined over the past 3 years, the short-term hazard for damaging ground shaking across much of Oklahoma remains at high levels due to continuing high rates of smaller earthquakes that are still hundreds of times higher than at any time in the state's history. Fine details and variability between the 2016–2018 forecasts are obscured by significant uncertainties in the input model. These short-term hazard levels are similar to active regions in California. During 2017, **M** ≥ 3 earthquakes also occurred in or near Ohio, West Virginia, Missouri, Kentucky, Tennessee, Arkansas, Illinois, Oklahoma, Kansas, Colorado, New Mexico, Utah, and Wyoming.

INTRODUCTION

This article presents the U.S. Geological Survey (USGS) 2018 one-year seismic hazard forecast for the central and eastern United States (CEUS) from induced and natural earthquakes. Seismic hazard is defined as probabilistic ground shaking and can be displayed using various intensity measures (e.g., peak ground acceleration [PGA], spectral acceleration [SA], modified Mercalli intensity [MMI]; Wood and Neumann, 1931). In this analysis, we show maps that depict the chance of damaging shaking, which is not an estimate of damage but only the potential for shaking that could cause strong intensities of MMI VI+ (shaking that may result in minor damage) or MMI VII+ (shaking that may result in moderate damage). The 2018 model is developed using the same methodology as applied in 2016 (Petersen *et al.*, 2016a,b) and 2017 (Petersen *et al.*, 2017) forecasts. Methodologies, input data, and sensitivity studies were discussed at a 2014 user workshop held in Oklahoma with industry, regulatory, and academic institutions (Petersen, Mueller, *et al.*, 2015).

We apply the same methodology as in the past two assessments to provide a consistent comparison of the hazard near the three highest activity focus areas: (1) the induced earthquake activity of Oklahoma–southern Kansas, (2) the induced activity near the Raton basin of southern Colorado and northern New Mexico, and (3) the natural or tectonic earthquake activity of the New Madrid seismic zone (NMSZ; Petersen, Moschetti, *et al.*, 2015). This probabilistic methodology has been applied in the National Seismic Hazard Models (NSHMs) for the United States over the past 20 years and has been shown to be an effective way to forecast earthquake locations and rates (Cornell, 1968; Frankel, 1995; Zechar and Jordan, 2010). This forecast is based on the assumption that earthquake hazard is high in places where small-to-moderate (moment magnitude **M** 2.7 and larger) earthquakes have occurred in the recent past (Frankel, 1995; Moschetti *et al.*, 2016). Our model mostly assumes that the 1-year hazard can be forecasted using the previous year's earthquake catalog and a Gutenberg and Richter (1944) magnitude frequency

doi: 10.1785/0220180005 Seismological Research Letters Volume 89, Number 3 May/June 2018 1049

Issues Include …

1. One-year forecasts vs. 50-year life expectancy of buildings.
2. Maps for design of new buildings, evaluation and retrofit of existing buildings, or both?
3. Very large MCE_R ground motions due to large frequencies of earthquake occurrence.
4. Stability of design maps vs. uncertainty in forecasts.

Inclusion of Induced Seismicity in Seismic Hazard

Increases in Life-Safety Risks to Building Occupants from Induced Earthquakes in the Central United States

Taojun Liu,[a), b)] **Nicolas Luco,**[b)] M.EERI **and Abbie B. Liel,**[a)] M.EERI

Earthquake occurrence rates in some parts of the central United States have been elevated for a number of years; this increase has been widely attributed to deep wastewater injection associated with oil and gas activities. This induced seismicity has caused damage to buildings and infrastructure and substantial public concern. In March 2016, the U.S. Geological Survey (USGS) published its first earthquake ground motion hazard model that accounts for the elevated seismicity, producing a one-year forecast encompassing both induced and natural earthquakes. To assess the potential impacts of the elevated seismicity on buildings and the public, this paper quantifies forecasted risks of a) building collapse and b) falling of nonstructural building components, by combining the 2016 USGS hazard model with fragility curves for generic modern code-compliant buildings. The assessment shows significant increases in both types of risk compared to that due to non-induced earthquakes alone; the magnitudes of the increases vary from a few times to more than a 100 times, depending on location, building period (which is correlated to building height), alternatives for the hazard model, and the type of risk of interest. For exploratory purposes only, we also estimate revised values of the risk-targeted ground motion that are currently used for designing buildings.

Induced Seismicity in Groningen

Assessment of Hazard, Building Damage and Risk

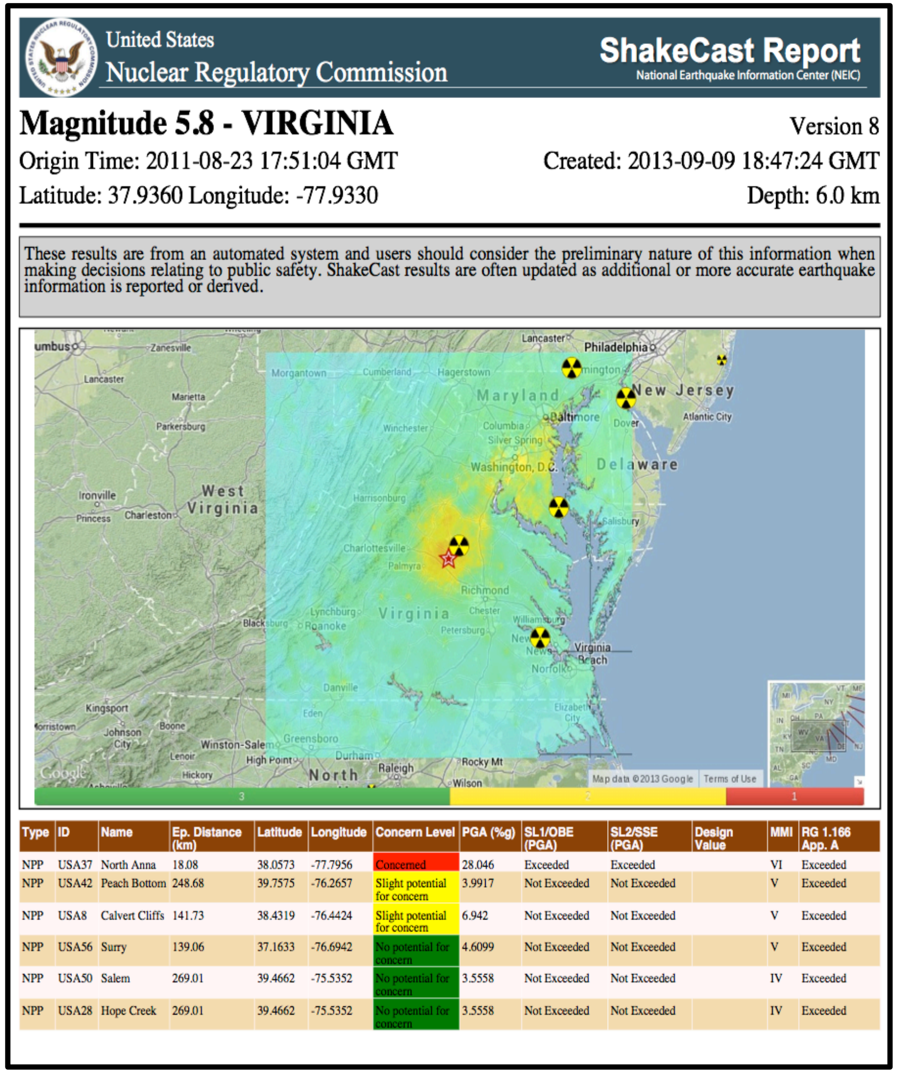
November 2017

By Jan van Elk and Dirk Doornhof

Opportunities for Improvement

- Multidisciplinary discussion of incorporation of induced seismicity in building-code applications
- Utilization of physics-based ground motion simulations for building-code maps and seismograms
- Quantification of uncertainty of seismic hazard, e.g. for stabilizing mapped values in building codes
- Decisions on acceptable seismic *risk*, for new and existing buildings and other structures

Engineering Applications of Real-Time Seismic Hazard



United States Nuclear Regulatory Commission

ShakeCast Report

National Earthquake Information Center (NEIC)

Magnitude 5.8 - VIRGINIA

Version 8

Origin Time: 2011-08-23 17:51:04 GMT

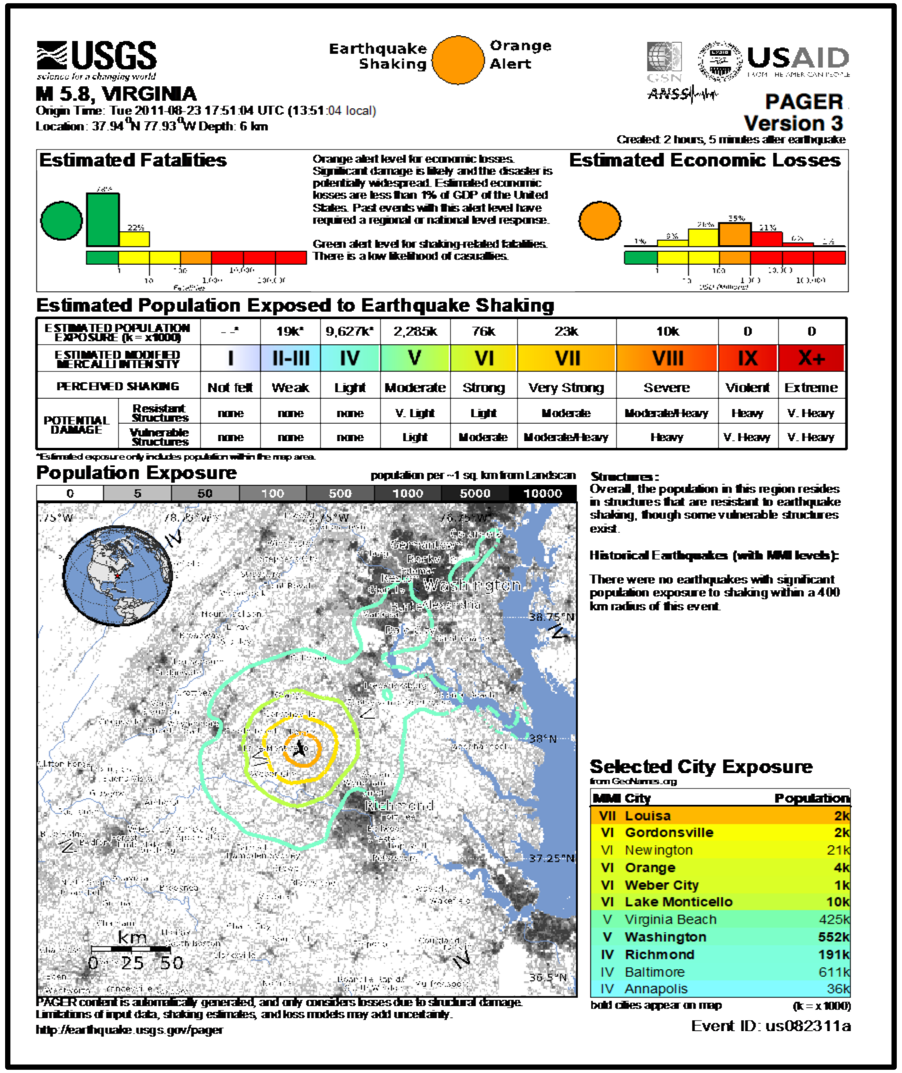
Created: 2013-09-09 18:47:24 GMT

Latitude: 37.9360 Longitude: -77.9330

Depth: 6.0 km

These results are from an automated system and users should consider the preliminary nature of this information when making decisions relating to public safety. ShakeCast results are often updated as additional or more accurate earthquake information is reported or derived.

Type	ID	Name	Ep. Distance (km)	Latitude	Longitude	Concern Level	PGA (%g)	SL1/OBE (PGA)	SL2/SSE (PGA)	Design Value	MMI	RG 1.166 App. A
NPP	USA37	North Anna	18.08	38.0573	-77.7956	Concerned	28.046	Exceeded	Exceeded		VI	Exceeded
NPP	USA42	Peach Bottom	248.68	39.7575	-76.2657	Slight potential for concern	3.9917	Not Exceeded	Not Exceeded		V	Exceeded
NPP	USA8	Calvert Cliffs	141.73	38.4319	-76.4424	Slight potential for concern	6.942	Not Exceeded	Not Exceeded		V	Exceeded
NPP	USA56	Surry	139.06	37.1633	-76.6942	No potential for concern	4.6099	Not Exceeded	Not Exceeded		V	Exceeded
NPP	USA50	Salem	269.01	39.4662	-75.5352	No potential for concern	3.5558	Not Exceeded	Not Exceeded		IV	Exceeded
NPP	USA28	Hope Creek	269.01	39.4662	-75.5352	No potential for concern	3.5558	Not Exceeded	Not Exceeded		IV	Exceeded



USGS science for a changing world

Earthquake Shaking Orange Alert

USAID

M 5.8, VIRGINIA

Origin Time: Tue 2011-08-23 17:51:04 UTC (13:51:04 local)

Location: 37.94°N 77.93°W Depth: 6 km

PAGER Version 3

Created: 2 hours, 5 minutes after earthquake

Estimated Fatalities

Orange alert level for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of the United States. Past events with this alert level have required a regional or national level response.

Green alert level for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Economic Losses

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	19k*	9,627k*	2,285k	76k	23k	10k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0 | 5 | 50 | 100 | 500 | 1000 | 5000 | 10000

Structures:

Overall, the population in this region resides in structures that are resistant to earthquake shaking, though some vulnerable structures exist.

Historical Earthquakes (with MMI levels):

There were no earthquakes with significant population exposure to shaking within a 400 km radius of this event.

Selected City Exposure

from GeoNames.org

MMI	City	Population
VII	Louisa	2k
VI	Gordonsville	2k
VI	Newington	21k
VI	Orange	4k
VI	Weber City	1k
VI	Lake Monticello	10k
V	Virginia Beach	425k
V	Washington	552k
IV	Richmond	191k
IV	Baltimore	611k
IV	Annapolis	36k

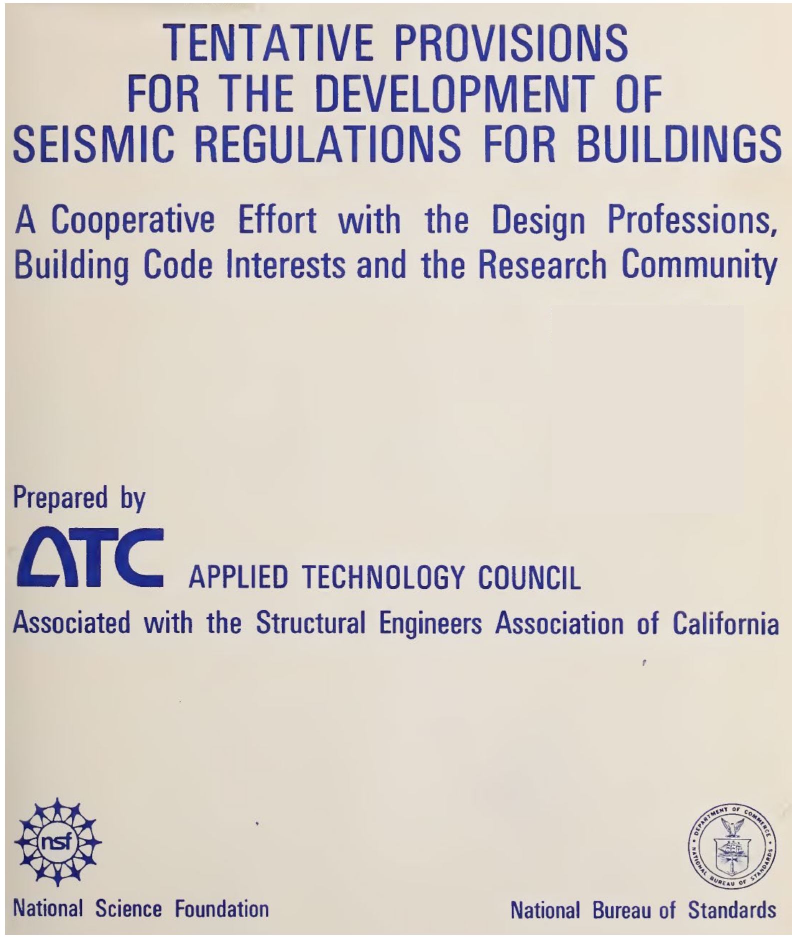
bold cities appear on map (k = x1000)

PAGER content is automatically generated, and only considers losses due to structural damage. Limitations of input data, shaking estimates, and loss models may add uncertainty.
http://earthquake.usgs.gov/pager

Event ID: us082311a

Additional Slides …

Why Risk-Targeted Ground Motions?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National Science Foundation

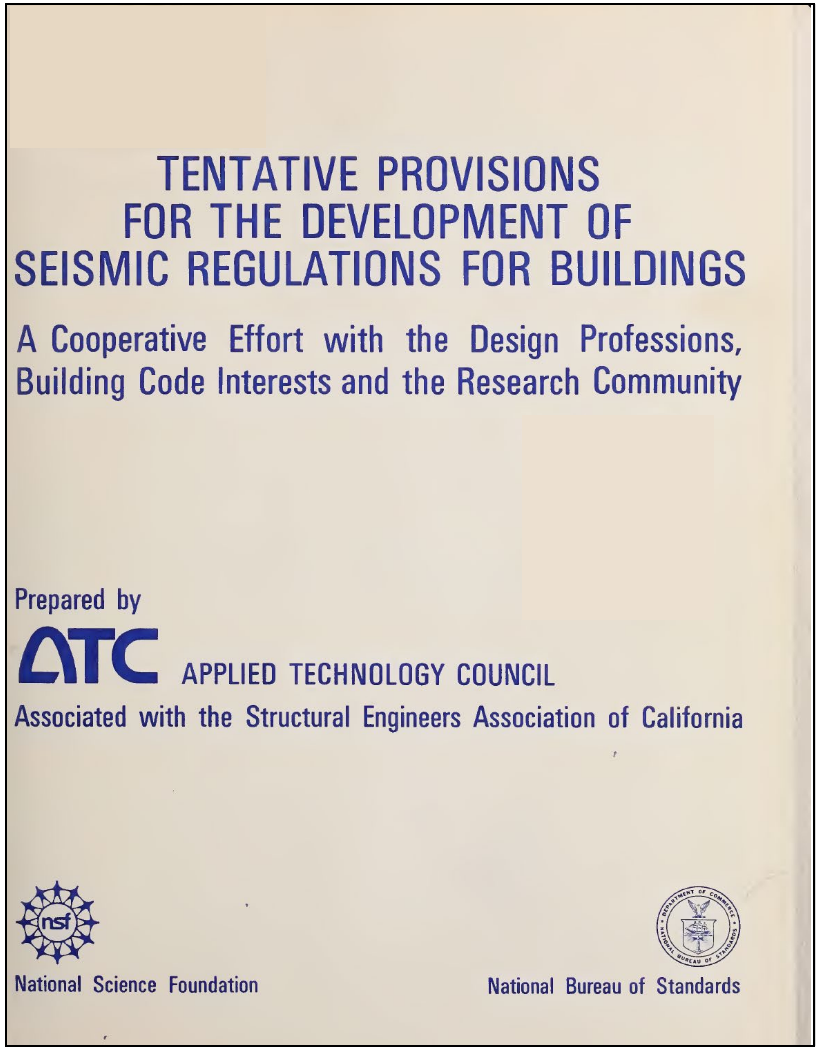
National Bureau of Standards

From ATC 3-06 (1978), Section 1.4.1:

*"… **it really is the probability of structural failure [i.e., the collapse risk] with resultant casualties that is of concern**, and the geographical distribution of that probability is not necessarily the same as the distribution of the probability of exceeding some ground motion [i.e., the ground-motion hazard]."*

"Thus [uniform ground-motion hazard] is not necessarily the ideal goal, but it is judged to be the most workable goal for the present time [i.e., 1978]."

Why Risk-Targeted Ground Motions?


TENTATIVE PROVISIONS
FOR THE DEVELOPMENT OF
SEISMIC REGULATIONS FOR BUILDINGS

A Cooperative Effort with the Design Professions, Building Code Interests and the Research Community

Prepared by

ATC APPLIED TECHNOLOGY COUNCIL

Associated with the Structural Engineers Association of California

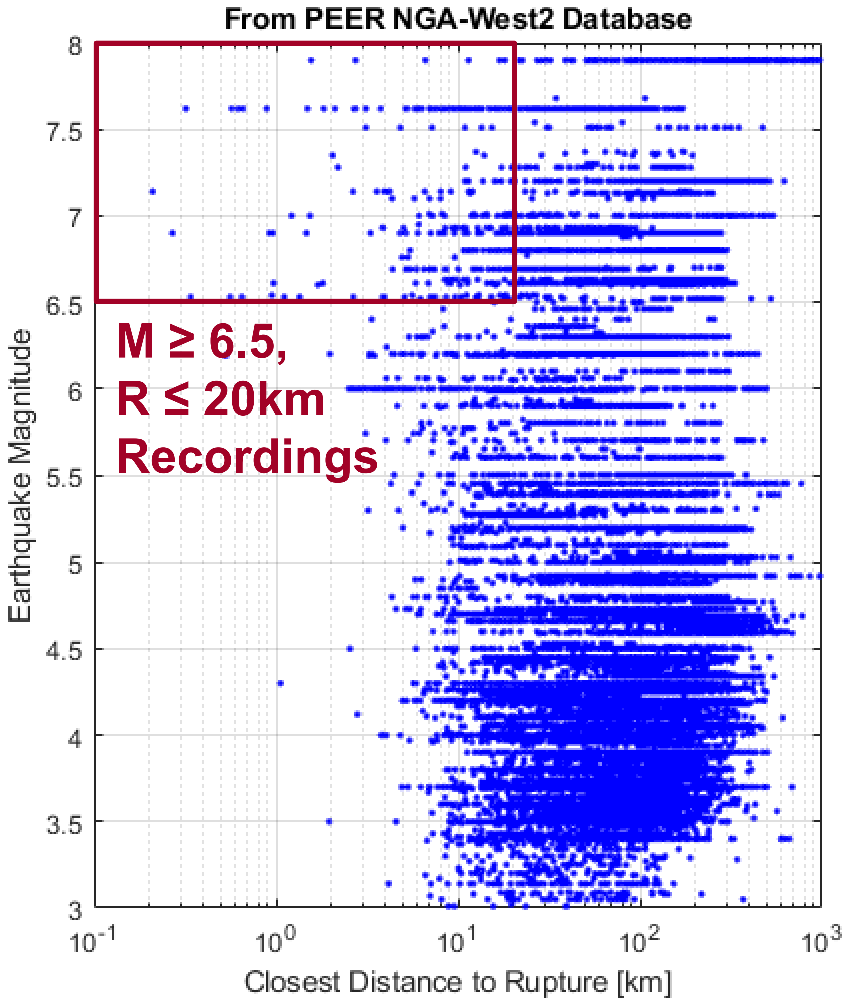
National Science Foundation

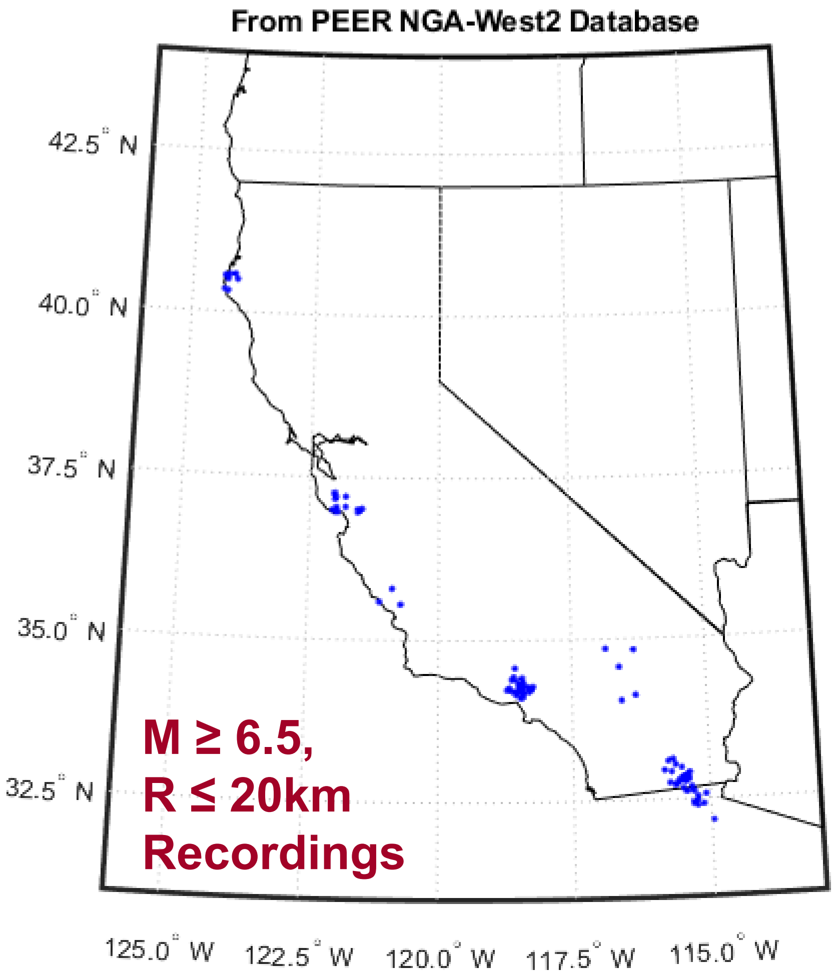
National Bureau of Standards

From ATC 3-06 (1978), Section 1.4.1:

"Often the courts become the final judge of whether a proposed course of action for mitigating a hazard is acceptable. The body of law that has been developed in the area of flood plain regulation is a useful guide to judicial reactions to hazard mitigation. The lesson is to match severity of the regulation to the severity of the risk. The courts follow the principle of the reasonable person who strives to achieve this balance, and uses data to support findings of the appropriate balance."

GM *Simulations* for Building Codes – Motivation





American Society of Civil Engineers (ASCE) Convention Technical Tour