Award No.: G15AP00031

Title: User-Needs Workshop for the National Seismic Hazard Mapping Project

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Award Term: 1 January to 31 December 2015

Abstract

On September 21 and 22, 2015, the Applied Technology Council/United States Geological Survey (ATC/USGS) Seismic Hazard User-Needs Workshop brought together over 100 geologists, engineers, and other professionals. The workshop participants represented the broad and varied groups of professionals who use seismic hazard information from the USGS National Seismic Hazard Mapping Project. These users range from practitioners who do their own seismic hazard analyses to structural engineers to public-sector professionals who interpret seismic hazard in the context of public policy.

Several broad user needs emerged and were reiterated at the two-day workshop. There was no question of the need for the work that the National Seismic Hazard Mapping Project does, including the collection and assessment of geological studies, ground motion models, and hazard algorithms—formalized as seismic hazard models—as well as the Project personnel themselves who are resources for the users of seismic hazard information. The seismic hazard products available at the Project's website are essential to most user groups. Users also identified the need for earthquake scenarios or deterministic ground motions. The overarching need described by the workshop participants was for fundamental information about seismic hazard with extensive documentation, available in well-designed, simple tools.

Executive Summary

On September 21 and 22, 2015, the Applied Technology Council/United States Geological Survey (ATC/USGS) Seismic Hazard User-Needs Workshop brought together over 100 geologists, engineers, and other professionals. The workshop participants represented the broad and varied groups of professionals who use seismic hazard information from the USGS National Seismic Hazard Mapping Project. These users range from practitioners who do their own seismic hazard analyses to structural engineers to public-sector professionals who interpret seismic hazard in the context of public policy. These Proceedings document the presentations and discussions at the workshop.

Several broad user needs emerged and were reiterated at the two-day workshop. There was no question of the need for the work that the National Seismic Hazard Mapping Project does, including the collection and assessment of geological studies, ground motion models, and hazard algorithms—formalized as seismic hazard models—as well as the Project personnel themselves who are resources for the users of seismic hazard information. The seismic hazard products available at the Project's website are essential to most user groups; the more technical users routinely use the Quaternary fault, hazard curve, deaggregation, and United States design maps tools. These users emphasized the importance of the timely update of the online hazard products for their work. Users also identified the need for earthquake scenarios or deterministic ground motions, which the Project currently develops only for a limited application. Earthquake scenarios would be used by technical and non-technical users, and the description of seismic hazard as a suite of deterministic ground motions could augment probabilistic hazard values, providing a parallel way to understand and communicate seismic hazard.

The overarching need described by the workshop participants was for fundamental information about seismic hazard with extensive documentation, available in well-designed, simple tools. Satisfying this need requires a concerted effort and sustained resources. The workshop participants were very supportive of ad-hoc working groups that might leverage the knowledge and experience of the wider seismic-hazard community. Two topics were identified readily for working groups: (1) the update and continued development of the quaternary fault database, and (2) the development of earthquake scenarios.

These Proceedings collect the many and varied uses of seismic hazard information and summarize suggestions for improvements to the transfer of seismic-hazard knowledge and numerical values from the USGS National Seismic Hazard Mapping Project to the wider seismic-hazard community.

Chapter 1

Introduction

On September 21 and 22, 2015, in Menlo Park, California, the Applied Technology Council (ATC) and the United States Geological Survey (USGS) convened the ATC/USGS Seismic Hazard User-Needs Workshop. One hundred structural engineering, geotechnical engineering, and earth science professionals attended the workshop in person, and an additional 17 professionals attended remotely by way of an internet-based broadcast ("webcast").

Like the First, Second, and Third National Earthquake Ground Motion Mapping Workshops convened by ATC and sponsored by the USGS (ATC, 1996; ATC, 2001; ATC, 2007), the Seismic Hazard User-Needs Workshop provided input from users in earthquake engineering communities on the USGS national seismic hazard maps and on products developed by the USGS National Seismic Hazard Mapping Project, which provide information on seismic hazard. Unlike these previous workshops, the present workshop occurred after the publication of the national seismic hazard maps, and thus the workshop did not provide input for the development of the most recent, 2014 update of the maps. Instead, the workshop was organized to: (1) elicit feedback from users of seismic hazard information and products; (2) provide a forum for the wider earthquake engineering community to discuss the transfer of seismic hazard results into engineering practice, seismic risk analysis, and public policy; and (3) make practical recommendations to the National Seismic Hazard Mapping Project.

A Steering Committee developed a workshop centered around the many and various groups that use seismic hazard information provided by the Hazard Mapping Project. The workshop was divided into four sessions, as shown in the workshop agenda at the end of this chapter.

In Session 1, "Seismic Hazard Products and Their Intended Users," representatives of the National Seismic Hazard Mapping Project provided an overview of the groups that use seismic hazard information, described the changes in the 2014 update of the maps, and showed the seismic hazard information and products currently available at the Project website (http://earthquake.usgs.gov/hazards/), as well as products under development.

In Sessions 2–4, "Use of Seismic Hazard at Individual Sites," "Use of Seismic Hazard at Distributed Sites," and "Additional Uses of Seismic Hazard Information," representatives of user groups described their use of hazard information from the USGS National Seismic Hazard Mapping Project. In each of these sessions, the speakers had an opportunity to:

1. describe how they currently *obtain and use* hazard information from the Project;
2. make practical recommendations to the Project on the development of existing hazard products (primarily at the Project's website) and on the development of new hazard products; and
3. suggest how to prioritize the development of existing and new hazard products.

Each speaker gave either a formal, 15–20 minute presentation or an informal, five-minute talk. Speakers giving formal presentations were asked to represent their user group by addressing the above three points on behalf of the user group, as well as address the three points based on their own use of seismic hazard information. Speakers giving informal talks were asked to address the above three points based on their own use of hazard information.

Open discussion periods at the end of Sessions 2–4 were an opportunity for all workshop participants to discuss ideas for improving the transfer of seismic hazard information from the USGS National Seismic Hazard Mapping Project to earthquake engineering communities.

The following chapters of this Proceedings describe Sessions 1–4, compile abstracts of the

formal presentations and informal talks, and summarize each session's discussions.

ATC/USGS SEISMIC HAZARD USER-NEEDS WORKSHOP
William Rambo Auditorium, U.S. Geological Survey, Menlo Park, California
September 21-22, 2015

WORKSHOP AGENDA

MONDAY, SEPTEMBER 21, 2015

8:30 a.m. Registration and coffee

9:00 a.m. *Welcome and Introductory Remarks*
Anna H. Olsen, Applied Technology Council, Redwood City, California

Session 1: Seismic Hazard Products and Their Intended Users
Moderator: Nicolas Luco, U.S. Geological Survey, Golden, Colorado

9:15 a.m. *Uses of the National Seismic Hazard Model (NSHM)*
Nicolas Luco, U.S. Geological Survey, Golden, Colorado

9:30 a.m. *2014 National Seismic Hazard Model: Changes With Respect to the 2008 NSHM*
Mark D. Petersen, U.S. Geological Survey, Golden, Colorado
(includes 15 minute question period)

10:30 a.m. Break

10:45 a.m. *Products and Tools from the National Seismic Hazard Model (NSHM)*
Peter M. Powers, U.S. Geological Survey, Golden, Colorado
(includes 15 minute question period)

12:00 p.m. Moderator Summary

12:05 p.m. Lunch

Session 2: Use of Seismic Hazard at Individual Sites
Moderator: C.B. Crouse, AECOM, Seattle, Washington

12:45 p.m. Moderator Introduction

12:50 p.m. *New Building Design Perspective*
John D. Hooper, Magnusson Klemencic Associates, Seattle, Washington

1:05 p.m. *Use Of and Issues With USGS Seismic Hazard Parameters in ASCE 41*
Robert G. Pekelnicky, Degenkolb Engineers, San Francisco, California

1:20 p.m. *Utilization of Seismic Hazard Information from USGS National Seismic Hazard Mapping Project by DSA**
Ronald W. LaPlante, California Division of the State Architect, San Diego, California

1:25 p.m. *Using ASCE 7-10 Performance Targets to Manage Seismic Risk in the Legal Arena**
Mark N. White, Law Offices of Mark N. White, Berkeley, California

1:30 p.m. *Use of USGS Seismic Design Maps to Identify Earthquake Siting Risk for Utility - Scale Wind Turbines**
Trevor R. Taylor, Vestas American Wind Technology, Portland, Oregon

1:35 p.m.	*Interactive Seismic Mapping to Convey Risk to the Public** Brittany Moffett and Anders Carlson, University of Southern California, Los Angeles, California
1:40 p.m.	*Needs/Issues for Site-Specific Geotechnical Applications of the NSHMP Maps and Tools* John A. Egan, SAGE Engineers, Oakland, California
1:55 p.m.	*The Travails of the Average Geotechnical Engineer Using the National Seismic Hazard Maps* Marshall Lew, AMEC Foster Wheeler, Los Angeles, California
2:10 p.m.	Break
2:25 p.m.	*Use of NSHMP Products for Site-Specific Hazard Analyses for Critical Structures* Norman Abrahamson, Pacific Gas & Electric Company, San Francisco, California
2:40 p.m.	*Use of USGS NSHMP products in USACE Dam and Levee Safety Programs and USACE Civil Works Projects* Keith Kelson, U.S. Army Corps of Engineers, Sacramento, California
2:55 p.m.	*Seismic Hazard for Commercial Nuclear Power Plants – Current Practice and Its Relationship to the NSHMP* Robert Youngs, AMEC Foster Wheeler, Oakland, California
3:15 p.m.	Open Discussion
4:10 p.m.	Moderator Summary
4:15 p.m.	Adjourn

TUESDAY, SEPTEMBER 22, 2015

8:30 a.m.	Registration and coffee
9:00 a.m.	*Second-Day Welcome and Introductory Remarks* Anna H. Olsen, Applied Technology Council, Redwood City, California

Session 3: Use of Seismic Hazard at Distributed Sites
Moderator: Chris D. Poland, Consulting Engineer, Canyon Lake, California

9:10 a.m.	Moderator Introduction
9:15 a.m.	*Caltrans Reliance on USGS National Seismic Hazard Mapping Program* Tom Shantz, California Department of Transportation, Sacramento, California
9:35 a.m.	*Use of Seismic Hazard Information in Water and Wastewater System Analysis* Don Ballantyne, Ballantyne Consulting, Tacoma, Washington
9:55 a.m.	*Seismic Hazard Analysis at the California Department of Water Resources* Don F. Hoirup, Jr., California Department of Water Resources, West Sacramento, California
10:15 a.m.	*Using Seismic Hazard Maps for PG&E Gas and Electric Systems* Kent S. Ferre, Pacific Gas & Electric Company, San Francisco, California
10:30 a.m.	Break

10:45 a.m.	*Use of USGS Seismic Hazard Data in the California High-Speed Rail Project* Kevin Thompson and Kenneth W. Campbell, California High Speed Rail Authority, Sacramento, California
11:05 a.m.	Chris Salkeld, AT&T Technology Operations, San Ramon, California*
11:10 a.m.	Open Discussion
12:10 p.m.	Moderator Summary
12:15 p.m.	Lunch
Session 4: Additional Uses of Seismic Hazard Information Moderator: Janiele Maffei, California Earthquake Authority, Sacramento, California	
1:00 p.m.	Moderator Introduction
1:05 p.m.	*The Science of Catastrophe Modeling: A Journey from Hazard to Risk* Maiclaire Bolton, CoreLogic, Oakland, California
1:25 p.m.	*USGS and AIR Worldwide: Leveraging Seismic Hazard as An Ingredient in Risk Modeling* C. Marc Ramirez, AIR Worldwide, San Francisco, California
1:35 p.m.	*Use of USGS Seismic Hazard Model in Catastrophe Modeling: RMS Perspective* Nilesh Shome, RMS, Newark, California
1:45 p.m.	*Current and Future Use of USGS Seismic Hazard Products at FM Global* Harold Magistrale, FM Global, Norwood, Massachusetts
1:50 p.m.	*Financial Sector* Charlotte Acton, RMS, London, England
2:10 p.m.	*Applying Seismic Hazard Information in Local and Regional Land-Use Planning* Laurie A. Johnson, Laurie Johnson Consulting | Research, San Rafael, California
2:30 p.m.	Break
2:45 p.m.	*The USGS National Seismic Hazard Mapping Project: Issues and Improvements** Zhenming Wang, Kentucky Geological Survey, Lexington, Kentucky
2:50 p.m.	*Utilization of Seismic Hazard Information from USGS National Seismic Hazard Mapping Project by CGS in Project Review** Jennifer Thornburg, California Geological Survey, Sacramento, California
2:55 p.m.	*Utilization of Seismic Hazard Information from USGS National Seismic Hazard Mapping Project by CGS in Loss Estimation, Hazard Zoning, and Scenario Development** Rui Chen, California Geological Survey, Sacramento, California
3:00 p.m.	Open Discussion
3:55 p.m.	Moderator Summary
4:00 p.m.	*Workshop Summary and Concluding Remarks* Anna H. Olsen, Applied Technology Council, Redwood City, California
4:15 p.m.	Adjourn
* Informal talk	

Chapter 2
Seismic Hazard Products and Their Intended Users

Session 1 of the ATC/USGS Seismic Hazard User-Needs Workshop, "Seismic Hazard Products and Their Intended Users," moderated by Nico Luco (USGS, Golden, Colorado), focused on the work of the USGS National Seismic Hazard Mapping Project. This project develops the national seismic hazard maps for the United States, as well as hazard maps in other areas of the world on occasion. To define the maps, the project characterizes seismic sources and evaluates and implements ground motion models, which have been known as "attenuation relations" or "ground motion prediction equations." The characterization of seismic sources and implementation of ground motion models combine to form a complete model of seismic hazard. This model can be queried to produce maps of seismic hazard or to find hazard information at one or more individual locations.

This chapter includes the abstracts submitted by the speakers in Session 1 of the workshop (Section 2.1) and a summary of the discussions during this session (Section 2.2).

2.1 Speakers' Abstracts

This section provides abstracts of the formal presentations in Session 1 of the workshop, "Seismic Hazard Products and Their Intended Users."

The national seismic hazard maps are used in a variety of applications and by many different user groups. Nico Luco provided an overview of these user groups and a description of how the project interacts with these users (Section 2.1.1).

The National Seismic Hazard Mapping Project most recently updated the national seismic hazard maps for the conterminous United States in 2014. At this workshop, Mark Petersen described the changes from the 2008 to the 2014 update (Section 2.1.2); Petersen et al. (2014) provides documentation for the 2014 update.

The primary source of hazard information from the National Seismic Hazard Mapping Project is its website (http://earthquake.usgs.gov/hazards/). Peter Powers presented the products and tools available at this website and showed products currently under development (Section 2.1.3).

2.1.1 Uses of the National Seismic Hazard Model

Nicolas Luco
U.S. Geological Survey
Golden, Colorado

Recently the National Seismic Hazard Mapping Project (NSHMP) has begun to more deliberately tailor its products to three audiences: (1) other seismic hazard modelers, such as those who conduct site-specific hazard analyses and those who model seismic hazard for portfolio risk analyses; (2) earthquake engineering users, such as structural engineers who evaluate or design buildings and other structures; and (3) the public, including the media and others who visit the NSHMP website. In addition, the NSHMP has begun to explore products for a fourth audience of users that includes emergency-response planners and others, in collaboration with the USGS Science Application for Risk Reduction (SAFRR) Project.

Because they are the primary focus of the ATC/USGS Seismic Hazard User-Needs Workshop, this presentation will concentrate on uses of the national seismic hazard model by other seismic hazard modelers and earthquake engineering users. Such uses can be grouped into three categories: (1) uses of the input and software that underlie the national seismic hazard model, e.g., to develop sets of earthquake

scenarios for risk analyses of lifeline systems or deterministic analyses; (2) uses of the primary output of the national seismic hazard model, namely hazard curves and maps, e.g., for risk analyses of individual structures or for ground motion maps used in designing structures; and (3) uses of other outputs of the national seismic hazard model, e.g., of deaggregation in selecting seismograms for response history analysis of structures or for liquefaction assessments.

Many of the uses of the national seismic hazard model by other seismic hazard modelers and earthquake engineering users motivate new research and development by the National Seismic Hazard Mapping Project and others. For example, the use of hazard maps at very short and very long return periods motivates, respectively, more research on the treatment of aftershocks in seismic hazard modeling and on non-ergodic modeling. This presentation gives additional examples of this symbiotic relationship between the NSHMP and users of the national seismic hazard model.

2.1.2 The 2014 Update of the United States National Seismic Hazard Models

Mark D. Petersen
U.S. Geological Survey
Golden, Colorado

During 2014 and 2015 the USGS updated the United States national seismic hazard models for the lower 48 states and developed new products to better communicate with end-users. The seismic hazard models are based on our assessment of the best available science at the time of the update and incorporate a broad range of models and parameters.

Several new datasets and models have been developed since the 2008 update. For the Central and Eastern United States, we implemented a new moment magnitude (M_w) catalog, updated the maximum magnitude distribution, updated the smoothing algorithms for estimating earthquake rates away from faults, and modified the sizes and rates of New Madrid seismic zone earthquakes. We also updated the model for induced seismicity triggered by manmade activities. In the Intermountain West we implemented new smoothing algorithms, fault geometries for normal faults, multiple Wasatch fault alternatives, and fault slip rates based on models obtained by inverting geodetic and geologic data. For the Pacific Northwest we developed new Cascadia fault rupture models that incorporate additional earthquakes in the south and modified the fault model. For California we implemented the new Uniform California Earthquake Rupture Forecast (UCERF3) source model, which allows for a more complete inventory of fault ruptures and is based on new deformation models, magnitude-area equations, and seismicity input parameters. We also applied several newly published ground motion models for shallow crustal earthquakes, subduction interface, and deep earthquakes. The improvements in input models resulted in small changes across most of the country, but have caused significant changes—up to ± 25% at 1 Hz and 5 Hz spectral accelerations—in localized areas.

2.1.3 Products and Tools from the National Seismic Hazard Model

Peter Powers
U.S. Geological Survey
Golden, Colorado

The U.S. Geological Survey produces probabilistic seismic hazard models for the 48 conterminous states, Alaska, Hawaii, and other United States territories. For the 48 conterminous states, the model is updated every six years, in sync with the update of reference building code documents, with the most recent update in 2014. The primary products associated with each model release are sets of hazard curves at regularly spaced points across a model region, and the codes and input files used to generate these data. Hazard curves are typically computed over a range of spectral periods and for a variety of site classes, with the complete set of curves increasing over time as models of ground motion have advanced.

In response to user requests, industry practice, and evolving technological capabilities, the National Seismic Hazard Mapping Project has added a variety of online products over time. These include, but are not limited to, services for: site-specific hazard curve and response spectra retrieval, design and risk value calculation and report generation, deaggregation of seismic hazard, earthquake probability map generators, source model maps and data miners, and services to directly access hazard data via hypertext transfer protocol (HTTP) requests. As the models and logic trees used to estimate mean

hazard have grown increasingly complex (the 2014 model being no exception), it has proved difficult to maintain quality and consistency across a broad array of products and services. To address these issues, we are developing a new, unified hazard codebase, upon which an updated suite of consolidated products and services are currently being built. This codebase will leverage many elements of prior codes (OpenSHA and USGS Fortran codes) and will permit much more detailed exploration of source and ground motion models and associated uncertainties.

This talk presents an overview of existing products and services from the national seismic hazard model, how these services are likely to change in the context of updated hazard codes, and new services that are up for consideration. It will also touch on broader scientific issues and challenges facing the National Seismic Hazard Mapping Project and lay some groundwork for further discussion at this workshop.

2.2 Summary of Discussions

In this session, "Seismic Hazard Products and Their Intended Users," representatives of the USGS National Seismic Hazard Mapping Project described their development of the national seismic hazard maps and associated products and tools. The Project identified several distinct audiences for seismic hazard information and is developing a variety of products to provide this information.

Many challenges arise in the communication of seismic hazard from the National Seismic Hazard Mapping Project to its users. In particular, the seismic hazard curves and maps from the Project report mean hazard values without associated uncertainty values. The Project acknowledged that better communication of uncertainty might facilitate the adoption of updates to the national seismic hazard maps. For example, engineers often want to know whether the hazard went up or down in major cities. Changes to hazard values in each update are complicated—not simply up or down within a city—and these changes may be better understood and accepted when described in the context of the uncertainties of hazard values. The Project also acknowledged that users often request more documentation of each update to the national seismic hazard maps. For the 2014 update, users have expressed frustration in particular with understanding and implementing the hazard model and values developed from the Uniform California Earthquake Rupture Forecast (version 3; UCERF3).

The National Seismic Hazard Mapping Project has developed a variety of products to provide seismic hazard information, and these products are difficult to maintain and revise with the 2014 update of the national seismic hazard maps. The Project is developing internal tools to consolidate the computer codes that implement the national seismic hazard model as well as a Unified Hazard Tool which will be available at the Project website and consolidate many of the existing hazard products. To inform and facilitate the development of these tools, a show-of-hands vote was taken at the workshop. The participants were asked to raise a hand to indicate whether they use each hazard product already available at the Project website. Table 2-1 shows the level of votes that each product received and whether the Project considers the product as primary, secondary, or other in their development efforts.

Table 2-1 Use of Seismic Hazard Products

All or Nearly All Participants
Fault Source Tool (Primary)
Gridded Hazard Data (Primary)
Open-File Reports (Primary)
Most Participants
Three-Dimensional Deaggregation and Tabular Values (Secondary)
Quaternary Fault Database (Other)
U.S. Seismic Design Maps (Secondary)
Roughly Half of Participants
Design Maps Summary Report (Secondary)
Geographical Information System (GIS) Data (Primary)
Hazard Curves (Secondary)
Uniform Hazard Response Spectra (Secondary)
Roughly One-Third of Participants
Conditional Mean Spectra (Secondary)

Geographical Deaggregation (Secondary)

Global V_{S30} Map Server (Other)

Hypertext Transfer Protocol (HTTP) Access (Secondary)

Several Participants

Earthquake Catalogs (Primary)

A Few Participants

Custom Hazard Maps (Secondary)

Custom Earthquake Probability Maps (Secondary)

Print Maps (Primary)

Source Code (Primary)

Worldwide Design Maps (Secondary)

No Participants

Banded Deaggregation (Secondary)

A second show-of-hands vote was taken in order to see to what extent there is interest in the development of additional maps and tools. Roughly one-third of the participants were interested in hazard maps for the vertical component of ground motion. Roughly one-third of the participants were also interested in hazard maps for spectral accelerations with damping ratios other than five percent; the damping values of particular interest are two, 10, and 20 percent. A few participants were interested in adding ground motions time histories to the online deaggregation tool.

The workshop participants provided some general comments regarding the communication of seismic hazard from the National Seismic Hazard Mapping Project. At present, the Project calculates hazard values at set, or static, grid points over the conterminous United States for a limited number of spectral periods and site classes. Workshop participants are interested in accessing hazard values calculated dynamically at user-specified points for additional spectral periods and site classes. Participants are still interested in static maps for the purpose of making regional comparisons, in particular for policy decisions. Some workshop participants are also interested in the development of maps for communication with the public, for example, using modified Mercalli intensity rather than the intensity measures of interest to engineers.

Workshop participants also provided some specific comments or requests:

- The Quaternary fault database could indicate if a fault is not used to calculate seismic hazard, along with the reason it is excluded.
- When tabulating or plotting annual frequency of exceedance, only plausible and meaningful values should be displayed. For example, values might be truncated near 10^{-6}, since the underlying hazard model generating these values may not be robust at extremely small annual frequencies of exceedance.
- When viewing hazard curves, engineers are more interested in values of peak ground acceleration on linear scales than on logarithmic scales.
- When viewing a response spectrum, engineers are interested in: an accompanying table of values; identifying the peak of the spectra, especially if the peak appears to be in the middle of two calculated values; and the option to plot the spectrum with respect to spectral period or frequency so that the details of either long- or short-period values may be discerned.
- The deaggregation tools could more explicitly indicate ε values—for example, at 1σ, 2σ, and 3σ—and indicate the attenuation relationships used.

Chapter 3
Use of Seismic Hazard at Individual Sites

Session 2 of the ATC/USGS Seismic Hazard User-Needs Workshop, "Use of Seismic Hazard at Individual Sites," moderated by C.B. Crouse (AECOM, Seattle, Washington), focused on groups that use seismic hazard information on a site-by-site basis. These user groups have projects that need a characterization of seismic hazard at an individual site, as opposed to hazard at multiple sites within a project.

The user groups identified by the Workshop Steering Committee for this session were informally split into two categories. The first category included the groups that use "standard" hazard values, that is, the values provided by the national seismic hazard maps. In this category, the user groups represented at the workshop were engineers who design new structures, engineers who evaluate and retrofit existing structures, and geotechnical engineers.

The second category of user groups in Session 2 of the workshop included those that use site-specific, low-probability hazard values. These user groups do not use the standard hazard values calculated by the USGS National Seismic Hazard Mapping Project. Instead, these groups use information from the seismic hazard model defined by the Project. In this category, the user groups represented at the workshop were professionals in the dam safety and levee community and in the nuclear-facility community.

This chapter includes the abstracts submitted by the speakers in Session 2 of the workshop (Section 3.1) and a summary of the discussions during this session (Section 3.2).

3.1 Speakers' Abstracts

This section provides abstracts of the formal presentations and informal talks in Session 2 of the workshop, "Use of Seismic Hazard at Individual Sites." The first nine abstracts are from users of the hazard values provided in the national seismic hazard maps. Sections 3.1.1 and 3.1.2 are abstracts of formal presentations by engineers representing the communities that design new buildings and evaluate and retrofit existing buildings. Sections 3.1.3–3.1.6 are abstracts of informal talks by professionals for the communities working with new and existing structures. Sections 3.1.7 and 3.1.8 are abstracts submitted by professionals particularly interested in the development and use of building code reference documents. Sections 3.1.9 and 3.1.10 are abstracts of formal presentations by geotechnical engineers.

The next three abstracts are from users of site-specific, low-probability hazard values. Sections 3.1.11–3.1.13 are abstracts of formal presentations on the use of these hazard values for critical structures generally, for dams and levees, and for nuclear facilities, respectively.

3.1.1 New Building Design Perspective

John Hooper
Magnusson Klemencic Associates
Seattle, Washington

The USGS National Seismic Hazard Mapping Project "U.S. Seismic Design Maps" tool is used in the majority of new, code-prescriptive building design projects. This is especially true in the Western United States, and seismically active regions in the Central and Eastern United States (CEUS), where the change in seismic design parameters is most pronounced. In fact, the American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI) 7-10 Standard, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), includes the following user note, which provides the USGS uniform resource locator (URL):

User Note: Electronic values of mapped acceleration parameters and other seismic design parameters are provided at the USGS website at http://earthquake.usgs.gov/design-maps, or through the SEI website at http://content.seinstitute.org.

For the remainder of the CEUS, the seismic design maps included in ASCE/SEI 7-10 are sometimes used due to the ease in determining the seismic design parameters directly from the maps.

Most of the USGS tools are found on the USGS Earthquake Hazards webpage. To determine their projects' seismic design parameters, engineers go to "Seismic Design Maps, Data, and Tools for Engineers." Once on this webpage, the engineer has several options, but the main option selected is "U.S. Seismic Design Maps" followed by "Use the Application." This is the webpage where the project information is defined. The engineer can select from various "Design Code Reference Documents," including the 2012 *International Building Code* (ICC, 2012) and ASCE/SEI 7-10. Both options will provide the same seismic design parameters for the selected project site. To identify the site location, two options are available: (1) project address; or (2) site latitude and longitude. The accompanying map visually depicts the location, ensuring that the proper location was selected. When the other input parameters have been selected (Site Soil Classification and Risk Category), "Compute Values" is then selected, which results in the "Design Maps Summary Report." There is also an option to view a detailed report, which shows the specific steps associated with determining the seismic design parameters.

The tool is very easy to use, and the information is typically generated by both the structural engineer and geotechnical engineer for the project. It is typical that the geotechnical engineer will provide the seismic design parameters as part of his/her final report.

Once the seismic design parameters have been defined, the engineer can begin the process of determining the seismic design forces for the project by applying the various equations in ASCE/SEI 7-10.

The following are some minor issues and suggestions for the U.S. Seismic Design Maps tool:

- "Pop-ups" can be create problems depending on the browser (this is especially true for Google Chrome). When this occurs, it generally causes the engineer to start the process over.
- When using the site latitude/longitude option for site location, many engineers forget to put in the negative ("-") sign for the longitude. It would be helpful if the negative sign was automatically changed and a note to this effect provided.
- It would be helpful if more than one Site Soil Classification could be selected. At the beginning of a project, this information might not be known, and it would be beneficial if more than one result could be produced without the need for using the "batch mode" or simply assuming the default Site Soil Classification.
- It would be helpful if a user-defined override for soil amplification factors F_a and F_v was available. On some projects, the geotechnical engineer will perform a site response analysis resulting in site-specific soil amplification factors. It would be helpful if this information could be included directly.
- On many projects, the modal response spectrum analysis method is the one selected for the seismic analysis. It would be helpful if the spectral acceleration versus period (S_a vs. T) data could be put in a table that could be input directly in the analysis.

As noted previously, the above discussion is for new, code-prescriptive building design projects. For projects that utilize performance-based seismic design (PBSD), the more sophisticated portions of the U.S. Seismic Design Maps tool can be used to help identify key parameters. PBSD is being used for the majority of high-rise building design projects on the west coast. For these special projects, the "Seismic Hazard Analysis Tools" on the USGS Earthquake Hazards webpage provide some useful information, especially "Interactive Deaggregations." This information assists geotechnical engineers in their development of site-specific ground motions as specified in ASCE/SEI 7-10, Chapter 21, for use in these projects. While the methods for selecting and scaling ground motions for use in PBSD have improved over the past decade, it would be great if, some day, the selection and scaling could be

done automatically. This would require that a definitive, consensus-based approach be developed, resulting in a more efficient PBSD process. Given that this won't likely occur for a decade (or two), providing links from the USGS Interactive Deaggregation tool to ground motion database websites would be a helpful first step.

Information from the interactive deaggregations is also useful in explaining the project's seismic hazard environment to sophisticated clients. This information can take a fairly complicated seismic hazard environment and graphically show the likely events (magnitude range and epicentral location) that the building might experience. Providing the probability of earthquakes within a specified time frame using the Earthquake Probability Mapping webpage can also help explain the seismic hazard environment. Allowing the radius to be input by the user, with 50 km as the default, would be helpful.

3.1.2 Use of and Issues with USGS Seismic Hazard Parameters in ASCE/SEI 41

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This presentation discusses the past and current use of the USGS seismic hazard parameters with the ASCE/SEI 41-13 Standard, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2014), and its predecessor documents. The talk discusses how new building parameters are adapted to ASCE/SEI 41 and how different parameters are used for existing buildings. Additionally, the talk presents some of the issues that arise with the use of the USGS seismic hazard parameters with existing buildings, such as the fluctuation in new building design hazard parameters and the deterministic caps.

3.1.3 Utilization of Seismic Hazard Information from USGS National Seismic Hazard Mapping Project by Division of State Architect

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This abstract summarizes the utilization of the seismic hazard information from the USGS National Seismic Hazard Mapping Project by the Division of the State Architect (DSA) in California.

DSA has the authority for plan review and supervision of construction for kindergarten through twelfth grade (K-12) public school, community colleges, and state-owned essential services facilities in the State of California. DSA uses the USGS Seismic Design Maps, which are a derivative of the USGS Seismic Hazard Maps, for the design review of new buildings, structures, and nonstructural components, and the seismic strengthening of existing buildings in accordance with the ASCE/SEI 7 and ASCE/SEI 41 Standards, respectively. DSA also uses the maps for the review of geohazards, such as slope stability, liquefaction, differential settlement, and surface fault rupture. In that capacity, DSA contracts with the California Geological Survey (CGS) to perform project-specific reviews of all geohazard reports and site-specific ground motion hazard analysis (GMHA). CGS also produces various custom seismic parameter maps derived from USGS data at the request of DSA for our stakeholders.

DSA requires that all projects located in seismic design categories E and F have a site-specific GMHA performed and utilized as part of the design. These GMHAs are performed by geotechnical engineers and the methodology allows a fair amount of interpretation of the data on their part. As the derivation of seismic hazard maps become more complex, there is a tendency for there to be greater discrepancy in the engineers' results. In order to promote consistency in the profession, the science and derivation methodology needs to be clear and well defined. While the need for GMHA will always exist for unique site conditions and local effects, the widespread use of it is diminished as the mapping becomes more detailed and sophisticated.

DSA reviews and approves pre-checked designs of various structures, such as modular buildings, shade structures, solar carports, bleachers, and scoreboards. The manufacturers of these structures design them with multiple seismic options so they can be economically placed on any site in the state. Similarly, DSA requires nonstructural components on essential service buildings and some components on public schools, such as fire pumps and emergency generators, to have seismic certification so they are functional following a

major earthquake. The equipment manufacturers also design the equipment for multiple levels of seismicity. These manufacturers rely on seismic design maps to assist them with selecting seismic design parameters with the broadest application of each seismic option. The USGS seismic design maps do not contain population data or fine enough contours in some regions for the manufacturers to make better educated decisions, so DSA has worked with CGS to produce maps with some of this information.

USGS is considering significant revisions to the next generation of maps, such as those being considered for Project 17. If those changes result in significantly more maps to define the hazards, then it will be difficult to assess the overall seismic hazard in regions, and the method for determining seismic parameters will need to be through an enhancement to the current web-based USGS tools. We suggest creating a web-based tool to view custom interactive contour maps that can be based on project- or building-specific parameters (such as soil type or building period). Furthermore, the scale of the maps in some regions, such as the Los Angeles basin, results in contours that are too coarse, and having a web-based interactive map tool would be of great benefit. Lastly, the seismic parameters that are mapped via contour lines or those that are reported from USGS calculators should not be reported in more significant digits than the science data supports. Based on our understanding of the statistical variation of the source data and the variation in seismic response coefficients in ASCE/SEI 7, our suggestion is to limit contours and reporting of seismic parameters to the nearest tenth (0.1), except in lower seismicity areas to the nearest hundredth (0.01).

3.1.4 Using ASCE/SEI 7-10 Performance Targets to Manage Seismic Risk in the Legal Arena

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During the last 10 years, developers have invested several billion dollars in new high-rises located in San Francisco, Los Angeles, and other urban centers with high seismicity. As part of the peer-review process for these high-rise projects, developers and their structural consultants have specified risk category II as the operative design parameter under the ASCE/SEI 7-10 Standard, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), or early versions thereof. One consequence of this choice is that both the developers and structural consultants will face a greater risk of being sued by third parties for poor performance during foreseeable earthquakes than if risk category III or IV had been selected. In most scenarios, choosing risk category III or IV would better accomplish the policy objectives underlying ASCE/SEI 7-10, and local building codes and ordinances. Before this risk-management choice is made, developers and structural consultants should understand with clarity what sworn expert testimony and lay testimony is likely to be presented to a jury in the event the new high-rise performs poorly in a foreseeable earthquake.

3.1.5 Use of USGS Seismic Design Maps to Identify Earthquake Siting Risk for Utility-Scale Wind Turbines

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The batch mode of the web-based USGS Seismic Design Maps application provides a valuable planning tool for the development of utility-scale wind turbine parks in high-seismic regions of the United States since it can be used to rapidly determine building code–mandated spectral response accelerations for multiple proposed turbine locations at one time.

Towers designed to support utility-scale wind turbines are typically developed in accordance with wind-based parameters specified in International Electrotechnical Commission (IEC) 61400-1 International Standard, *Wind Turbines—Part 1: Design Requirements* (IEC, 2005). Since standard tower designs usually—but do not always—accommodate design loads required by local building code, the planning and siting of these turbines requires an early-stage assessment of building-code compliance risk long before structural plan review—and often prior to completion of a site geotechnical engineering report—in order to identify locations where code requirements demand customized tower designs with additional cost and manufacturing lead time.

While seismicity is not typically design-driving for large-period, inverted pendulum–type wind turbine support structures that return relatively low response-spectrum loads, seismic loads spike when the non-building structure minimum seismic base-shear provisions of the ASCE/SEI 7-10 Standard, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), are triggered at or above S_1 = 0.6 g. Depending on the characteristics of the particular turbine and tower, these increased seismic loads can exceed standard IEC-based wind design loads on the tower.

Key features of the USGS Seismic Design Maps tool that would better facilitate the rapid early development–stage evaluation of earthquake code-compliance risk for utility-scale wind turbines include:

- Web-based batch mode with functionality to return spectral response acceleration parameters for up to 100 coordinate locations with a single input file. (Current functionality is generally limited to about 10 locations.)
- Functionality that provides for the creation of customized spectral acceleration maps (i.e., S_1) for user-selected regions.
- The possibility to incorporate gridded map data for post-processing into external software applications such as those used by wind turbine siting engineers.

3.1.6 Interactive Seismic Mapping to Convey Risk to the Public

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An obstacle standing between Los Angeles and preparation for "the Big One" is that building owners simultaneously overestimate the stability of their structures and underestimate the strength of a potential earthquake. An interactive seismic webmap would bring an unprecedented and comprehensive amount of seismic and building information to the fingertips of the public and would help policy makers, code officials, building owners and engineers alike develop cost effective measures to minimize future losses.

By integrating diverse datasets that include specific building characteristics, instrumentally recorded and interpolated past ground motions, and earthquake scenarios from the USGS National Seismic Hazard Mapping Project, this proposed freely accessible public resource offers to deconstruct risk for building owners in a novel, personalized manner. The interactive map will visualize what a building was designed to experience, has experienced, and is projected to experience. Built through ArcGIS with intended distribution through mobile and webpage platforms, the primary objective of this work is to increase risk awareness and encourage the seismic retrofit of buildings that are vulnerable but have no mandate to be upgraded. This information structure enables the tool to directly combat misconceptions about past earthquakes and dangerous overconfidence in vulnerable building types. This tool presents an opportunity to engage the public and visually convey evidence so that individuals can contextualize the earthquakes their building has experienced in the larger framework of possibilities. Additionally, this compilation of rich, multidisciplinary datasets would further USGS research and efforts to prevent earthquake hazards.

In this informal presentation, we outline our methodology and show a prototype of the product in order to illustrate how we are using seismic hazard information from USGS, how we are connecting to other spatial and non-spatial datasets, and the design decisions involved in mapping them in order to communicate personalized risk.

Our presentation will explore:

- The potential of using interactive mapping to combine and represent data from sources like the city building department, USGS, U.S. Census Bureau, and the Southern California Earthquake Center.
- The ability to highlight vulnerable zones and building types to concentrate retrofit efforts to save money, time, and lives by encouraging building owners to seek seismic retrofit or lawmakers to enforce it.
- Graphically communicating historical shaking as a basis to learn from and address misunderstandings among building owners and the public about what their buildings have withstood versus what the Big One or a

smaller one with concentrated directivity could do.

- The use by the engineering community to screen existing buildings based on year built and building type as part of preliminary seismic evaluations.
- The potential of interactive maps to bridge the gap between publishing large data sets and engaging the public.
- How the result of our tool could unfold trends between seismological data and building response from the San Fernando and Northridge earthquakes to direct further research and code changes.

Mapped information comparing what buildings have experienced versus what they are likely to experience will more clearly convey risks to building owners deciding between the financial burdens of retrofit or doing nothing. By visually representing the data, it can be more accessible for the viewer to efficiently understand the evidence as well as exhibit patterns that could direct further research or future ordinances. An individual could zoom out to the overall city or into a community, providing a groundwork for discussing retrofit on different scales.

The anticipated results of this project are that the map will provoke public dialogue, provide a groundwork to assess risk on a macro and micro scale, and highlight trends to pursue additional research. The lessons learned and the product created from this work are applicable far beyond the city boundaries of Los Angeles. This tool, the methodology that will build it, and the research discoveries we derive from it will be publically available in order to help other cities encourage their citizens towards seismic resilience.

3.1.7 Adoption of USGS Seismic Design Maps to Determine Seismic Design Category in the International Residential Code and International Building Code

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Traditionally, the building codes have included maps, now delineating the risk-targeted maximum considered earthquake (MCE_R) for 0.2 and 1.0 second spectral response accelerations in the *International Building Code* and short-period design spectral response acceleration (S_{DS}) values in the *International Residential Code*. Building departments are expected to list what the local seismic design category is for their jurisdiction, whether city or county. For most departments across the country, the entire jurisdiction is assigned one seismic design category by the department, the exception being high-seismic regions. For building designs that do not require an engineer or architect, the only check of the seismic design category is a builder's look at the jurisdiction's website. In regions of seismic design categories A and B, there is no further examination of MCE_R values. Therefore a printed map adopted by the codes is needed for these regions.

In locations with moderate or high seismic risk, an engineer does the evaluation of the risk and will typically use the USGS online tool to determine S_{DS} and S_{D1} values. The engineers tend to be somewhat to very seismic savvy and will be able to use either a simplified or expanded tool to a certain extent. Maintaining a simple tool similar to the current U.S. Seismic Design Maps tool will reduce errors.

In the *International Residential Code*, in seismic design categories A, B, and C for residential construction (one and two family), the structures do not have an engineer assigned to the project and are exempt from seismic considerations within the code. Again builders go to the building department website to identify the seismic design category. These departments only need the single printed map currently in the *International Residential Code*. The map shows the expected maximum percent-g for short-period design spectral response acceleration for the contiguous United States, Puerto Rico, Hawaii, and Alaska. These printed maps are the only resource used by most building departments.

For locations on the seismic design category C/D boundary or higher, an engineer is often not used in design of the building. The building department typically uses the U.S. Seismic Design Maps tool to determine local S_{DS} values, which are posted on the jurisdiction's webpage. Continuation of a tool similar to the current tool with a pop-up of "how to use the tool" on the tool webpage would be helpful. People don't seem to realize that the documentation describes how to use the tool. (Note that the most

common problem seems to be not clicking the arrow after inputting the street address.)

3.1.8 User Needs for Qualification Testing of Acceleration Sensitive Nonstructural Components

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Cybersecurity Related. Some advanced users developed proprietary applications to use USGS ground motion spectral response data in stand-alone applications back in the late 1990s before the USGS implemented on-line tools. Using the original USGS ground motion database in stand-alone applications also eliminated the need to deal with cybersecurity and validation issues.

As the ground motion parameters incorporate more layers of modification factors (e.g., maximum direction, risk targeted), those advanced users will most likely migrate towards automated web-served queries on USGS servers to simplify the process of deriving the site-specific response spectral components.

For audit and cybersecurity purposes it would be desirable to have the returned ground motion data digitally signed and traceable to the user's query to verify authenticity as being original USGS values for the reference conditions. As discussed during the workshop the current state, hypertext transfer protocol (HTTP) for USGS server query does not incorporate this capability (e.g., unique transactional encryption keys).

Site-Specific Design Spectra. Moving forward, all response spectra plots must be displayed in both the time domain and frequency domain. Response spectra only given in the time domain cannot be used for engineering purposes of acceleration sensitive systems.

Critical Research Need. Missing the dimension of time, the use of a response spectrum as the basis of an acceptance criterion for shake table–qualified, acceleration sensitive, rigid nonstructural components, by its nature, does not provide for a method to evaluate if a minimum damaging energy content was present in the table motion for random broadband time histories. To address this shortcoming, the commercial nuclear industry has proposed that cumulative absolute velocity (Campbell and Bozorgnia, 2011) be used as a threshold for United States nuclear power plant operational status. Based on the significant amount of review by the commercial nuclear industry, the use of cumulative absolute velocity is becoming accepted as the most relevant indicator of damaging energy, perhaps the only one that matters. Vetting of this methodology for commercial applications holds the only currently identified promise of overcoming the inherent limitation in the use of response spectra for shake table qualification.

It is recommended that a research initiative be undertaken to validate the acceptability of at least the use of cumulative absolute velocity as a supplement to accepted response spectra test protocols that can substantially increase the confidence of test table demands that can be linked directly to code demands.

Because of the theoretical nature and the broad application to all things nonstructural, this recommendation has all of the underpinnings of a grand challenge project requiring unbiased theoretical analysis and empirically validated independent academic research initiative. It is not a topic that can be dealt with in the code development process or by industry alone. Shake table fundamentals have changed little since the pioneering work into the structural dynamics of earthquake shake table research of the early 1930s at Stanford University. The response spectra acceptance criteria used by all equipment shake table qualification protocols were based on limits in the state of the art for time history instrumentation and analog signal analysis of the early 1960s. Today's shake tables are controlled by digital systems with data collection and analysis methods not even conceived of until the 1990s and can easily incorporate math intensive methods such as cumulative absolute velocity.

The lack of a direct indicator to measure damaging energy results in over-testing by perhaps an order of magnitude for acceleration sensitive rigid nonstructural components. The end result is qualification programs that are excessive, not real-world, and only create barriers to code compliance.

This is a critical issue because manufacturers rarely have any involvement in how their equipment is installed in a wide range of building code applications and therefore must implement product qualification strategies which are not earthquake, site, or building specific in order to "test once and use everywhere" to meet

competitive market realities. This is especially challenging when model codes introduce requirements that are for the most part never meaningfully enforced by local building departments. Even fifteen years after the introduction of clearly defined deliverables for the total construction cycle by the *International Building Code* in 2000, today they are only being enforced through the construction quality provisions by just one jurisdiction in the United States, for hospital construction in California.

The introduction of a relevant intensity measure of damaging energy would eliminate the gap in correlating the test demand to the code demand and bring realism into qualification testing by eliminating unnecessary and excessive over-testing.

3.1.9 Needs/Issues for Site-Specific Geotechnical Applications of the NSHMP Maps and Tools

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SAGE Engineers uses the National Seismic Hazard Mapping Project (NSHMP) tools as a check against site-specific probabilistic seismic hazard studies. We find that the tools provide valuable data and information to the engineering community, but there are too many tools and inconsistent methods for pulling data, as well as some discrepancy among the results from the different tools. This requires the user to access several products to extract all the information necessary for comparison to results from site-specific studies. The engineering community would benefit from a simpler mechanism for extracting hazard results from the NHSMP products accurately, including clearer labeling of which generation of the maps/data that are presented.

The typical geotechnical engineer utilizes the U.S. Seismic Design Map calculator to retrieve ground motion to define the generalized design response spectrum of current building codes and standards and peak ground acceleration that is used for geotechnical analyses. The outputs available from this tool are limited to risk-targeted values that are not applicable to all structures. We suggest allowing the user to choose whether or not results include the risk-targeted factors.

The NHSMP provides valuable data among the interactive deaggregations, hazard curves, and uniform-hazard response spectra. However, what is available for the user varies with regard to period and site response (site class or shear wave velocity profile), and it is not always clear how the data were derived, where they are coming from, and how the engineer should utilize that information.

3.1.10 The Travails of the Average Geotechnical Engineer Using the National Seismic Hazard Maps

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With the advancement of the state-of-practice and regulatory requirements of the building code, the average geotechnical engineer practicing in areas of significant seismic hazard has moved beyond drilling borings, recording soil sampler blow counts, characterizing the soil types, and providing recommendations for foundation support. Geotechnical engineers (and their engineering geologist colleagues) now also have to evaluate the risks due to seismic hazards. Unless a site-specific seismic hazard and risk analysis is performed, the national seismic hazard maps are a vitally important resource for the average geotechnical engineer to evaluate the risks associated with various seismic hazards.

This presentation does not address the use of the national seismic hazard maps for determining the maximum considered earthquake ground motions (MCE_R) for structural design. Instead, this presentation addresses the use of the national seismic hazard maps for evaluation of other seismic hazards associated with ground failure, such as liquefaction and seismically induced settlement of saturated and unsaturated soils. Also, the use of the maps as applied to the evaluation of seismically induced earth pressures on retaining wall structures will be discussed.

In the 2012 *International Building Code* (ICC, 2012) and ASCE/SEI 7-10 Standard, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010), the ground motion levels for design for ground failures has been designated to be for the maximum considered earthquake (MCE) ground motions; this is an increase of 50 percent over the previous editions

of these documents where evaluation of seismic hazards was set at the design-earthquake level, which was taken as two-thirds of the MCE ground motions. For the evaluation of ground-failure hazards and seismic earth pressures, use of risk-targeted, largest component, maximum considered earthquake (MCE_R) ground motions are not required. Instead, the use of the geometric mean maximum considered earthquake (MCE_G) ground motions is allowed per ASCE/SEI 7-10 Section 11.8.2; maps depicting the MCE_G ground motions for site class B in terms of peak ground acceleration (PGA) are provided in ASCE/SEI 7-10 Chapter 22, Figures 22-7 through 22-11.

It is uncertain if the MCE_G is completely determined by a probabilistic analysis, or is capped by a deterministic analysis using the deterministic mean plus one standard deviation PGA based on capable active faults near the site to cap the values.

For the evaluation of liquefaction, the most common procedure still used by the average geotechnical engineer is the so-called "Seed-Idriss simplified procedure" introduced by Seed and Idriss (1971). The evaluation is based on determining the liquefaction resistance of the soils by correlation with the standard penetration test blow count or "N-value." This resistance of the soils to liquefaction is compared to the induced seismic shear stresses in the soil for the MCE_G ground motion if the "code" approach is to be used. The cyclic shear ratio (CSR) is computed by the equation:

$$CSR = 0.65\left(\frac{\tau_{max}}{\sigma'_{vc}}\right) = 0.65\left(\frac{\sigma_{vc}}{\sigma'_{vc}}\right)\left(\frac{a_{max}}{\sigma'_{vc}}\right) \quad (3\text{-}1)$$

where a_{max} is the peak ground acceleration in units of gravity. However, it should be noted that the evaluation for liquefaction requires that the CSR be compared to the cyclic resistance ratio, CRR, which is the expected ratio that corresponds to triggering of liquefaction. The Seed-Idriss procedure has developed the CRR for earthquake motions having a moment magnitude of 7.5 because of calibration of the equation to the number of cycles of strong ground motion caused by a moment magnitude 7.5 earthquake needed to trigger liquefaction. Many geotechnical engineers will use the figures in Section 22 of the ASCE/SEI 7-10 Standard to determine the MCE_G ground acceleration for use in the CSR equation. What is not provided in ASCE/SEI 7-10 is the moment magnitude corresponding to the MCE_G ground acceleration; if that moment magnitude is not 7.5, the CSR value must be adjusted by a magnitude scaling factor (MSF) so that the number of cycles to induce liquefaction is properly accounted for based on the moment magnitude of the earthquake. This information would be found by a deaggregation analysis. A deaggregation analysis can be performed on the National Seismic Hazard Mapping Project website (http://earthquake.usgs. gov/hazards/). However, there is no guidance from ASCE/SEI 7-10 or the *International Building Code* that this resource is available to the average geotechnical engineer. It is reasonable to assume that most geotechnical engineers will just calculate the CSR directly with the CRR7.5 to determine the liquefaction potential. This may result in more-conservative or less-conservative results and will not give the correct evaluation of the liquefaction potential unless the PGA corresponds to a magnitude 7.5 event. Except for sites that are in close proximity to highly active faults, it is likely that the moment magnitude associated with the MCE_G ground acceleration is lower than 7.5; in this case, the CSR will be higher than the actual CSR thus predicting a lower factor of safety.

If there is found to be a potential for liquefaction, the geotechnical engineer will also need to perform an analysis to determine the consequences of ground failure. One of these manifestations is liquefaction-induced settlement of the saturated soils. If the analysis for liquefaction potential is not using the correct parameters, the evaluation of liquefaction-induced settlement by methods such as Tokimatsu and Seed (1987) or Ishihara and Yoshimine (1992) will also not be correct, as these methods are also calibrated to the number of cycles to liquefy for a magnitude 7.5 event. For the evaluation of settlement in unsaturated sands, the situation is similar. The Tokimatsu and Seed (1987) procedure is commonly used and is also calibrated to the number of cycles of ground motion induced by a magnitude 7.5 event.

The simple provision of the MCE_G PGA for liquefaction evaluation and settlement of saturated and unsaturated soils is not sufficient.

The same MCE_G PGA value is to be used for the evaluation of dynamic seismic earth pressures on basement and retaining walls

according to ASCE/SEI 7-10 Section 11.8.3. For some areas in California (near the San Andreas Fault), in the Central United States (the New Madrid seismic zone), in the Southeastern United States (near Charleston, South Carolina), and coastal southern Alaska, the PGAs are typically very high with values of 100 percent, and up to 150 percent, of gravity. One of the most common methods of analysis used by the average geotechnical engineer for evaluation of dynamic seismic earth pressures is the so-called Mononobe-Okabe (M-O) analysis technique which was described by Seed and Whitman (1970). For very high PGA values, the original M-O equations are not even stable and do not produce useable results. For practical purposes, Seed and Whitman proposed to separate the total maximum earth pressure into two components, the initial static (active) earth pressure and the dynamic earth pressure component. For the dynamic earth pressure component, Seed and Whitman did provide an approximation for the dynamic lateral earth pressure coefficient of:

$$\Delta K_{AE} \approx \tfrac{3}{4} k_h \qquad (3\text{-}2)$$

where k_h is the "horizontal ground acceleration divided by gravitational acceleration." For PGAs of 100 to 150 percent g, ΔK_{AE} would be approximately 0.75 to 1.125. Since a typical value for the lateral active earth pressure may be 0.25 to 0.30, the seismic lateral earth pressure may be some 3 to 4½ times the static lateral earth pressure; for the higher values, the seismic lateral earth pressure may exceed the density exerted by the soil if it were a fluid. This may not be the fault of the National Seismic Hazard Mapping Project, but it may represent some misuse of the maps for what some may have thought was some noble purpose, but obviously, someone forgot to do the quality assurance test or ask the question "Does this make any sense?"

The maps produced as part of the National Seismic Hazard Mapping Project can be useful. However, there should be a more thoughtful process used in the production of the maps and their use. The following should be considered:

- Are the maps needed?
- Will the maps provide meaningful results?
- Have the maps been vetted for the intended purposes?
- Have case histories been performed?
- Are the right people reviewing the results from use of the maps before they are forced on the average geotechnical engineer?
- Is there proper and adequate training available for the average geotechnical engineer to take full advantage of the mapping program?

3.1.11 Use of NSHMP Products for Site-Specific Hazard Analyses for Critical Structures

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For critical structures, a site-specific hazard analysis is usually required. Results from hazard maps that are intended for use in building codes, such as the National Seismic Hazard Mapping Project (NSHMP) maps, are generally not considered to be adequate for a site-specific analysis for critical structures. However, parts of the seismic source characterization models and ground motion characterization models used in broad studies may be used in the development of the seismic source characterization and ground motion characterization models for the site-specific hazard evaluation after the applicability of the information to the controlling sources at the site of interest has been reviewed. For example, for the seismic source characterization, the geometry and sense of slip of a fault given in the NSHMP seismic source characterization model may be adopted for the site-specific hazard analysis. Often additional epistemic uncertainty, beyond what is included in the NSHMP seismic source characterization model, is incorporated into the site-specific seismic source characterization model for the controlling sources. For the ground motion characterization, the evaluation of the ground motion prediction equations (GMPEs) for the site-specific hazard analysis considers the applicability of the alternative GMPEs to the controlling earthquake scenarios, rather than the applicability of the alternative GMPEs to the entire region. For example, if the site is located over the hanging wall, then the treatment of hanging-wall effects in the GMPEs is considered in the evaluation of the GMPEs.

Although the results from the NSHMP are not used directly for the site-specific seismic hazard analysis, the site-specific probabilistic

hazard results are typically compared to the NSHMP hazard results as a check. If the results are different, it does not indicate that the site-specific results are incorrect, but the reason for the difference should be understood and explained.

For critical structures, the hazard levels of interest may be much lower than considered for the building code. For example, for nuclear structures, the hazard is needed to hazard levels of 10^{-6} per year, and in some cases as low as 10^{-7} per year, to support seismic risk calculations. This puts more emphasis on the ground motion models and on the distribution of the aleatory variability at ε values greater than 2 than needed for the NSHMP maps. For example, fat-tail distributions of the ground motion, which have been proposed at ε values greater than 2.5, may be important for critical structures but may have no effect on the results for the 2 percent in 50 year hazard level used in the NSHMP.

For dams regulated by the Federal Energy Regulatory Commission or by the California Department of Water Resources Division of Safety of Dams, the regulatory criteria use deterministic seismic hazard analysis to develop the design ground motions, which limits the usefulness of the NSHMP products. Probabilistic seismic hazard analyses can be used to provide insights into the deterministic scenarios, but the design ground motion is deterministic. Moving forward, one issue will be the selection of the magnitude for the deterministic events given the current approaches of allowing for linked ruptures. This is also an issue for the deterministic cap in the NSHMP design maps.

3.1.12 Use of USGS NSHMP Products in USACE Dam and Levee Safety Programs and USACE Civil Works Projects

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Seismic hazard products from the USGS National Seismic Hazard Mapping Project (NSHMP) provide useful information for the U.S. Army Corps of Engineers (USACE) dam and levee safety and civil works programs. The dam and levee safety programs utilize a risk-informed decision making framework that assesses potential hazards, system response (fragility), and consequences to analyze risk and provide risk reduction for the entire portfolio of more than 700 dams and more than 14,500 miles of levees. Products available from the NSHMP are used for program-wide screening (hazard identification) and for site-specific risk analyses. At the nation-wide screening level, NSHMP website tools have been used to obtain 2,475 year and 9,975 year peak ground acceleration values for a representative sample of the dam sites. The NSHMP tools were used in conjunction with estimates of site class derived from a combination of USGS nationwide V_{S30} estimates (http://earthquake.usgs.gov/hazards/apps/vs30/) and site-specific geologic information. This screening-level effort assisted in prioritizing specific dam sites for additional detailed analyses, and helped focus resources on critical seismic-related risk drivers.

For dam-specific risk analyses, estimating hazard involves both hydrologic and seismic loadings at several levels of detail within the risk-informed framework. At the basic level are two limited-scope programs: (a) periodic assessments, which are completed for every dam on a 10 year cycle by local USACE district personnel; and (b) semi-quantitative risk assessments, which are completed as needed by or for USACE Risk Management Center personnel. For periodic and semi-quantitative risk assessments, seismic hazards are characterized primarily using NSHMP website tools to obtain mean and 84th percentile peak ground acceleration values for return periods of 144, 950, 2,475, 4,975, and 9,975 years. Using data from the NSHMP, the mean hazard curve for each site is developed for annual exceedance probabilities down to 1/100,000; the hazard curves developed at this level do not include uncertainty bounds (i.e., fractile curves). The periodic and semi-quantitative risk assessments currently utilize the 2008-vintage USGS deaggregation tools to help interpret primary-source contributors to seismic hazard. The periodic and semi-quantitative risk assessments typically accept the USGS seismic-source and ground-motion models, and do not attempt to capture possible local contributing sources or updated information not included in the USGS database at the time of analysis.

More detailed seismic hazard analyses are required for in-depth development of potential

failure modes and quantitative, probabilistic risk analysis at specific sites. For sites considered to have relatively high risk (considering seismic loading, hydrologic loading, fragility, and consequences), a more detailed issues evaluation study is completed. The issues evaluation study process typically collects seismic hazard information from the NSHMP website, but modifies this information to: include local or new seismic sources not in the USGS database, include fractile hazard curves, or help develop conditional mean spectra for specific structural components (i.e., tainter gates). Where risk assessments warrant consideration of mitigation, a dam safety modification study or preliminary engineering design phases may be initiated. In these cases, site-specific probabilistic seismic hazard analyses required for detailed loading estimates usually are developed through non-USGS providers, and commonly involve development of site-specific time histories and conditional mean spectra customized for specific facilities involved in likely risk-driving potential failure modes.

Recent seismicity related to mineral extraction (including associated wastewater injection wells) in specific regions of the United States are being considered in the risk-informed decision making process used by the USACE dam and levee programs. For semi-quantitative risk assessments or issues evaluation study seismic analyses at selected dam sites, the NSHMP website does not yet provide sufficient information on recent earthquake location, magnitude, stress drop, and intensity. Of particular interest would be ground motion prediction equations specifically developed for areas of possible induced seismicity, and assessment of maximum induced earthquake magnitude for these areas. The USACE would probably consider these data sets in assessing specific potential failure modes for probabilistic risk analyses of dam sites in areas of induced seismicity.

Seismic hazard characterization for USACE civil works projects conform to existing standards and regulations. For evaluation of existing buildings, USACE uses Engineering Regulation (ER) 1806, *Earthquake Design and Evaluation for Civil Works Projects* (USACE, 1995), and the ASCE/SEI 41-13 Standard, *Seismic Evaluation and Retrofit of Existing Buildings* (ASCE, 2014). For seismic design of new buildings, the USACE uses ER 1806 and the ASCE/SEI 7-10 Standard, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010). For the ER 1806 regulations, the USACE is required to obtain ground motion parameters and response spectra for the maximum credible earthquake using deterministic seismic hazard analysis methods informed by results from a probabilistic seismic hazard analysis, the operating basis earthquake (return period of 144 years), and the maximum design earthquake, which equals the maximum credible earthquake ground motions for critical structures. The ASCE/SEI 41-13 Standard is currently used for seismic evaluation of existing buildings. The design standard for new buildings is ASCE/SEI 7-10 and the Unified Facilities Criteria 3-310-04, *Seismic Design for Buildings* (USDoD, 2007). For building design, USACE uses the risk-targeted maximum considered earthquake spectral accelerations for 0.2 and 1.0 second.

For the USACE civil works and dam and levee safety seismic programs, our wish list of information currently not provided by the NSHMP website includes:

- deterministic ground motion parameters and probabilistic ground motion parameters for various probabilities of exceedance that range from 50 percent in 75 years to 1 percent in 100 years;
- calculated data and graphical depiction of mean hazard curves to annual exceedance probabilities of less than 1/10,000 (i.e., to a probability of 1/100,000), including fractile hazard curves to illustrate uncertainties at annual exceedance probabilities of 1/100,000 and more frequent;
- values of the seismic design parameters S_S and S_1 (spectral accelerations at 0.2 and 1.0 seconds, respectively, with 5 percent damping), for evaluating dams and levees;
- mapping with faults in a given site vicinity to help identify the likely source(s) of the deterministic maximum credible earthquake;
- historical seismicity for specific sites and regions;
- rapid dissemination of seismicity information in areas of possible injection- or extraction-induced seismicity, including depth, magnitude, stress drop, and (if

possible) temporal comparison with rates and volumes of wastewater injection;

- ground motion prediction equations specifically for injection- and extraction-induced seismicity; and
- maximum magnitude estimates for specific areas characterized by injection- or extraction-induced seismicity.

3.1.13 Seismic Hazard for Commercial Nuclear Power Plants: Current Practice and Its Relationship to the NSHMP

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The current guidance from the U.S. Nuclear Regulatory Commission expresses a strong preference that seismic hazard studies for commercial nuclear power plants be conducted following a senior seismic hazard analysis committee (SSHAC) process (Budnitz et al., 1997). Following the accident at the Fukushima Dai-ichi nuclear power plant resulting from the March 11, 2011, Tohoku earthquake, the Nuclear Regulatory Commission requested that all operating nuclear power plant operators provide updated seismic hazard assessments for their sites and specified that these assessments be based on SSHAC Level 3 studies (NRC, 2012).

As described in recent Nuclear Regulatory Commission guidance (Kammerer and Ake, 2012), a SSHAC Level 3 study follows a formal process to characterize the "center, body, and range" of "technically defensible interpretations" of the inputs to a probabilistic seismic hazard analysis. The process is intended to not only produce the best estimate of the seismic hazard, but also quantify the uncertainty in the hazard given current knowledge. The SSHAC process is conducted by a technical integration team that performs the assessment in two key phases:

1. "Evaluation: the consideration of the complete set of data, models, and methods proposed by the larger technical community that are relevant to the hazard analysis"; and
2. "Integration: representing the center, body, and range of technically defensible interpretations in light of the evaluation process (i.e., informed by the assessment of existing data, models, and methods)."

In a SSHAC Level 3 process, the evaluation phase occurs in part in formal workshops where experts are invited to present and defend data, models, and methods. In the integration phase the technical integration team then builds models and assigns probabilities to represent its collective assessment of the center, body, and range of the technically defensible interpretations.

A key component of a SSHAC Level 3 process is the presence of a participatory peer review panel that fulfills two roles. The first role is technical review to ensure that the full range of data, models, and methods has been duly considered in the assessment, and also that all technical decisions are adequately justified and documented. The second role is process review, which means ensuring that the project conforms to the requirements of the selected SSHAC process level.

The National Seismic Hazard Mapping Project (NSHMP) is not a SSHAC process and the national seismic hazard maps are not currently used to define the hazard at commercial nuclear power plants. However, the NSHMP program does fill an important role within the SSHAC process. The program and associated research projects contribute data, models, and methods for assessing seismic hazard. One example is that the 2008 NSHMP earthquake catalog was used as the starting point for the development of the earthquake catalog for the Central and Eastern United States Seismic Source Characterization model (Coppersmith et al., 2012) that forms the current basis for seismic hazard assessments at nuclear power plants in the Central and Eastern United States. NSHMP experts also participate in the formal SSHAC workshops, thus providing input into the evaluation process.

A second important role is the fact that the NSHMP is continually updating the seismic hazard assessment. These updates provide information to both the nuclear industry and to the Nuclear Regulatory Commission on changes to data, models, and methods that would provide input into any assessment of the need for an update, revision, or refinement to the existing hazard models. Kammerer and Ake (2012) provide a detailed discussion of this process.

3.2 Summary of Discussions

In Session 3 of the ATC/USGS Seismic Hazard User-Needs Workshop, "Use of Seismic Hazard at Individual Sites," the participants made both general comments relevant to the work of the USGS National Seismic Hazard Mapping Project and its hazard products, as well as comments specific to individual products.

Workshop participants agreed that the Project personnel are valuable resources. Although the national seismic hazard model, its documentation, and online hazard products are needed and useful, the Project personnel monitor and remain current on hazard issues that are relevant to the wider seismic hazard community. Through their work on committees and participation at workshops and conferences, the Project personnel help compile and disseminate relevant information about seismic hazard.

Workshop participants provided several general comments that are applicable to all hazard products developed by the National Seismic Hazard Mapping Project. The participants agreed that the Project should focus on developing products that provide fundamental information on seismic hazard, as opposed to developing products that are tailored to individual user groups. The tools may be designed such that they help or enable users to communicate and explain hazard to their clients or to writers of building code reference documents. Participants supported the development of a single tool to access hazard information, as there can be different hazard values in different tools. Also, participants noted that it is too easy to get single hazard values or curves from existing hazard products and interpret these values as certain; uncertainties should accompany the hazard values.

Users at the workshop were interested in both hazard values provided at individual sites and values over geographic regions. When reporting seismic hazard values, numbers should have the appropriate level of precision, i.e., the correct number of significant figures, in order to avoid a false appearance that hazard values are known precisely. Engineers using the Project website may not note the distinction between "hazard" and "design" values in this context, especially since "hazard" in the engineering context often refers to ground motion design parameters; all tools on the Project website might indicate whether or not factors used in engineering design or evaluation methods are included in the provided values. Workshop participants also encouraged the timely incorporation of new hazard values in the online seismic hazard products.

The workshop participants in this session were particularly interested in changes to the national seismic hazard model and how the changes are documented. Changes to hazard values cause problems for many participants: structural designs in long-term development may need to be re-designed, retrofits that conformed to building codes may no longer conform, and engineers may overwhelm a design review agency with projects before new hazard values take effect. These problems associated with changes in the hazard values can erode confidence in the underlying hazard model. Participants recommended that the National Seismic Hazard Mapping Project provide a short white paper justifying changes in the hazard values resulting from the update of the national seismic hazard model. The update's documentation should enable users to quickly find significant changes. Also, since some users of the model use its seismic source characterizations, not the hazard values, participants were also interested in documentation of the changes to source characterizations.

The workshop participants made several comments specific to the hazard products currently available at the website of the National Seismic Hazard Mapping Project. For hazard maps, participants asked that mapping tools provide finer contours as users zoom-in, the ability to specify a contour value of interest, and labeled contour values. Participants were also interested in hazard values for seismic design categories E and F. For the hazard curve tool, participants were interested in mean hazard curves plotted with fractile curves, the option of logarithmic-linear scales, and the capability to see how mean hazard curves vary with spectral period. Workshop participants were interested in the capability to see how site class affects the shapes of response spectra and the option to toggle between intensity-measure values calculated from the maximum horizontal direction or the geometric mean of the horizontal components. The participants find the three-dimensional and geographic

deaggregation tools very useful and asked that contributing faults be identified in the tools.

The workshop participants also made several comments specific to the online tools for engineering design practitioners. In the U.S. Design Maps tool, engineers reported that most projects specify the site address, not the current default of latitude and longitude coordinates, and the tool would be more user-friendly if it automatically changed positive longitudes to negative. Engineers would like the capabilities to specify more than one site soil class, specify a V_{S30} value, and override soil amplification factors with their own values. Users requested the abilities to toggle the deterministic cap on and off and toggle the intensity measure between the maximum horizontal component and the geometric mean. Engineers would like to see the spectral acceleration versus period values currently plotted also as a table and see an emphasis in the design summary report that the USGS is not doing design calculations for the engineer. Engineers suggested that the National Seismic Hazard Mapping Project develop a hazard mapping tool that is separate but parallel to the U.S. Design Maps tool, which allows the user to compare hazard values to risk-targeted ground motion values. The current risk-targeted ground motion calculator might show how the values vary with site class, similar to the current comparison by period.

Chapter 4

Use of Seismic Hazard at Distributed Sites

Session 3 of the ATC/USGS Seismic Hazard User-Needs Workshop, "Use of Seismic Hazard at Distributed Sites," moderated by Chris Poland (Consulting Engineer, Canyon Lake, California), focused on groups that use seismic hazard information for lifeline or distributed systems. These user groups have projects that need a characterization of seismic hazard at multiple sites, as opposed to hazard at only a single site for the project.

The user groups identified by the Workshop Steering Committee for this session were engineers or professionals working on highways and bridges, water and wastewater systems, utility systems, rail systems, and communication systems.

This chapter includes the abstracts submitted by the speakers in Session 3 of the workshop (Section 4.1) and a summary of the discussions during this session (Section 4.2).

4.1 Speakers' Abstracts

This section provides abstracts of the formal presentations in Session 3 of the workshop, "Use of Seismic Hazard at Distributed Sites." The following sections are abstracts from engineers or professionals who design or analyze bridges (Section 4.1.1), water or wastewater systems (Sections 4.1.2 and 4.1.3), gas and electric systems (Section 4.1.4), and a rail system (Section 4.1.5).

4.1.1 Caltrans Reliance on USGS National Seismic Hazard Mapping Program

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The California Department of Transportation (Caltrans) characterizes the level of shaking for seismic bridge design using a design response spectrum. The design response spectrum is based on the envelope of deterministically derived and probabilistically derived spectra. The probabilistic spectrum is based on a 5 percent in 50 year hazard level and controls for about 80 percent of California bridges.

Currently, Caltrans generates the probabilistic spectrum using data furnished by the USGS and is based on the 2008 hazard model. These data were provided at 11 spectral periods and four National Earthquake Hazard Reduction Program (NEHRP) site classes. Spatial resolution was 0.05 degree. These data are used in a web-based design tool called ARS Online (http://dap3.dot.ca.gov/ARS_Online/). This website is widely used by Caltrans, cities and counties, and various transportation providers.

Caltrans is also a big user of the USGS 2008 Interactive Deaggregations website (http://geohazards.usgs.gov/deaggint/2008/). The website is used to identify dominant hazard scenarios. Magnitude information is used for liquefaction screening, time-history selection, and fault rupture studies. Distance information is used to determine adjustment factors for near-fault effects.

Going forward, Caltrans has the following "wish list" for data or data-related products:

1. 2014 5 percent in 50 year hazard data provided at 11 spectral periods, four NEHRP site classes, and 0.05 degree spatial resolution.
2. Update the 2008 Interactive Deaggregations website to 2014.
3. Using Uniform California Earthquake Rupture Forecast (version 3; UCERF3) source models, generate a projected earthquake catalog for California for a period of several hundred thousand years.

This catalog will be very helpful in efforts to explore options for implementing Next Generation Attenuation West2 near-fault models in seismic hazard.

4.1.2 Use of Seismic Hazard Information in Water and Wastewater System Analysis

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This presentation focuses on seismology and geotechnical issues encountered during the seismic evaluation of existing water and wastewater systems using scenario-based analyses. The objective of these analyses is to estimate the likely performance of systems for a range of scenarios typically using mean hazard parameter values. Use of site-specific probabilistic ground motions throughout a water system service area tends to overestimate damage for a single event. Scenarios are selected trying to match 500 and 2,500 year return periods used for probabilistic-based building analyses. Peak ground accelerations are used to assess facilities often using HAZUS fragilities. Peak ground velocities are used to assess wave propagation–related pipe performance often using American Lifelines Alliance pipeline fragilities. ShakeMap scenarios are a handy source of this information. A significant question is the return period of a scenario, or a similar scenario where fault movement is on a different segment of the fault, or on a different splay in a fault zone (e.g., Southern Whidbey Island fault zone, Seattle or Tacoma faults). Also, for the Cascadia subduction zone, what is the difference in shaking intensities for a M 9.0 versus a M 8.5 earthquake if the fault rupture location closest to the system being evaluated is the same? Magnitude and return-period relationships for deep intraplate events (i.e., Benioff zone events) at a specific location are vague, even though these are the most common earthquakes in the Pacific Northwest. These probabilities of occurrence/return periods drive economic analyses.

Permanent ground deformation results in the highest pipeline failure rates. Understanding the surface fault rupture permanent ground deformations in normal faulting (e.g., Seattle or Tacoma faults) is more problematic than for strike-slip faults (e.g., Hayward fault). Liquefaction and associated lateral spreading often have the most significant system performance impacts. Existing liquefaction hazard mapping is often inconsistent from map to map, area to area. There is a very significant disconnect between the probability of liquefaction at a single location/bore hole [e.g., Seed and Idriss (1971)] compared to the areal extent of liquefaction/lateral spread in a mapped liquefaction deposit. The least-understood parameter is the areal extent—probability/percent of mapped area that will undergo lateral spreading. This parameter, estimated in HAZUS, has a dramatic effect on expected system performance. Liquefaction settlement, “rate of change over distance” (such as deposits with lenses of liquefiable material), is also a poorly understood parameter that affects pipe performance. Landslide mapping with associated probabilities and permanent ground deformation information is often used for pipeline damage estimates, but is far behind lateral spread permanent ground deformation mapping. Depending on the area, it can have a dramatic impact on pipe performance. Our understanding of sewer pipe flotation is also vague. How liquefiable/homogeneous does a deposit have to be to allow flotation? Lurching, the result of soil block movement along weak soil interfaces/sensitive clays (e.g., Oakland Hills, Northridge-Balboa, and Anchorage), is very expensive to map and is therefore not widely available over a large area. It can have comparable pipeline damage impacts to liquefaction-caused lateral spreading.

4.1.3 Seismic Hazard Analysis at the California Department of Water Resources

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The California State Water Project makes deliveries to two-thirds of California's population. It is maintained and operated by the California Department of Water Resources. The State Water Project is a water storage and delivery system of reservoirs, aqueducts, power plants and pumping plants. Its main purpose is to store water and distribute it to 29 urban and agricultural water suppliers (water contractors) in Northern California, the San Francisco Bay area, the San Joaquin Valley, the Central Coast,

and Southern California. Of the contracted water supply, 70 percent goes to urban users (about 25 million Californians) and 30 percent goes to agricultural users (about 750,000 acres of irrigated farmland). The State Water Project is also operated to improve water quality in the Sacramento-San Joaquin River Delta, control Feather River flood waters, provide recreation, and enhance fish and wildlife.

Initial construction of the State Water Project began in the late 1950s and into the 1970s, with subsequent facilities built in the 1980s and 1990s. Additional phases of construction continue today. Overall, the State Water Project includes: 34 water storage facilities, reservoirs, and lakes; 20 pumping plants; four pumping-generating plants; five hydroelectric power plants; and about 701 miles of open canals and pipelines stretching from the Upper Feather River basin in Plumas County of northern California to Perris Reservoir in Riverside County of southern California.

The primary reaches and some components of the State Water Project include: three Upper Feather River headwater basin dams; the Oroville-Thermalito dam complex; the North Bay aqueduct, the Clifton Court Forebay (water from the Delta); the South Bay aqueduct and dams; the California aqueduct, including the Sisk dam complex, Dos Amigos and Valley String pumping plants; the Coastal branch; the Tehachapi tunnel; the West branch; the East branch including Cedar Springs dam and Devil Canyon power plant; and the East branch extensions including the State Water Project terminus at Perris Reservoir and Cherry Valley. There are many other components to the State Water Project including electrical switch yards, tall surge tanks, blow-off structures, and other water conveyance structures prone to the effects of seismic hazards.

Potential seismic hazards impacting the State Water Project include surface fault rupture, strong ground motion, regional and local ground surface warping/tilting, liquefaction, lateral spread, landslide, and seiche.

The State Water Project crosses about 15 major Quaternary active surface faults at multiple locations. Most notably in southern California near the city of Palmdale along the East branch of the State Water Project where the canal runs parallel to and on top of the San Andreas fault zone for about 18 kilometers. Along the western edge of the San Joaquin Valley from the Delta south towards Kettleman City (about 240 kilometers), much of the California aqueduct lies on the hanging wall of the Great Valley blind thrust fault system.

Although infrastructure of the State Water Project has been built to withstand considerable seismic ground motions, secondary effects such as liquefaction have not been directly designed for. To better address these deficiencies, identify vulnerability, and to improve overall water delivery reliability, Department of Water Resources management created the Seismic Earthquake Engineering Resources Group, a small group of engineers and engineering geologists responsible for staying current with seismic hazard practice.

As dam owners/operators of both power generating and non-power generating facilities, the Department of Water Resources is regulated by the California Division of Safety of Dams and the Federal Energy Regulatory Commission. We therefore are required to operate in both a deterministic and probabilistic seismic hazard environment at our dam facilities. However, at State Water Project facilities outside of the regulatory authority, the Department of Water Resources primarily addresses seismic hazards probabilistically. For newer facility design and upgrades, a performance-based design approach is evaluated.

Deterministic Analysis for Ground Motion. For any given State Water Project dam, appurtenant structure, or other State Water Project facility, a review of current Quaternary fault databases are conducted. Typically, the USGS Quaternary Fault and Fold Database of the United States is used either in the geographical information system (GIS) form or the Google Earth form to measure several earthquake fault sources-to-site distances. Fault plane geometries and other related data are then determined from available information contained in the USGS/California Geological Survey/Southern California Earthquake Center Uniform California Earthquake Rupture Forecast (UCERF). Site conditions (V_{S30}) are determined by best available information. This information is tabulated and entered into the Pacific Earthquake Engineering Research Center Next Generation Attenuation-West2 ground motion prediction equation spreadsheet calculator to determine peak ground acceleration, peak ground velocity, and (pseudo)

spectral accelerations at the 50th, 67th, and 84th percentiles. Vertical ground motions are evaluated as well. The Department of Water Resources also estimates the maximum magnitude of earthquakes (M_{max}), surface fault rupture displacement, Arias intensity, significant duration, and directivity at our State Water Project facilities. These results are then given to our engineers who perform various analyses such as slope stability on dam embankment.

Unfortunately, the current USGS Quaternary fault database does not include blind thrust faults as GIS or Google Earth files, so other means must be used to apply estimated earthquake source-to-site distances required in the Next Generation Attenuation calculator. Also, other apparent Quaternary faults are not necessarily included in the fault database, such as the Indian Creek fault and Grizzly Valley fault of Plumas County. Little information on the Cascadia subduction zone seems available for California. Tools for estimating ground motions (deterministic and probabilistic) do not appear to be readily available.

Interactive probabilistic seismic hazard information is available from the USGS National Seismic Hazard Mapping Project. Similar interactive deterministic seismic hazard information and tools would be useful. As an output from such a deterministic tool, a more comprehensive list (than currently available on the interactive deaggregation output) of nearby faults (nearest to furthest) with their range of, for example, magnitude, distance, fault parameters, and slip rate, would be useful.

Deterministic and Probabilistic Analysis for Ground Motion. Colleagues at the Department of Water Resources summed up our needs for seismic hazard analysis tools best:

> Our comments/concerns are related to the ability of commercially available seismic hazard software to implement the Uniform California Earthquake Rupture Forecast (version 3; UCERF3) model. We believe that not only users of commercial software but users of in-house software will have the same concerns. Below is the response received from Risk Engineering, Inc., when we asked them when we might expect their implementation of UCERF3 into EZ-FRISK:
>
> The short answer is that the UCERF3 fault model cannot be implemented in EZ-FRISK due to the nature of the model.
>
> The UCERF3 model was developed using a regional grand inversion process, essentially modeling over 200 thousand scenarios. Whereas previous models (e.g., UCERF2) include faults with defined slip rates and segmentation models, for example, the UCERF3 model does not. The outputs of the UCERF3 model are in the form of participation rates, i.e., magnitude-frequency distributions, which include participation of adjoining faults. To create a site-specific probabilistic seismic hazard analysis using traditional seismic hazard software, control faults and participant faults must be defined and corrections made to the UCERF3 magnitude-frequency distributions to avoid double counting. As such, the model cannot be applied directly on a statewide basis like previous models. We have developed and applied (to a Senior Seismic Hazard Analysis Committee II–level project in California) a methodology for performing this moment balancing, however, it cannot be performed for arbitrary site coordinates, as definition of the control faults is judgment-based and will be dependent on the site location. As such, it cannot be part of the USGS 2014 model implementation that we are preparing for EZ-FRISK. We can provide our implementation of the UCERF3 fault model as a consulting service, in the form of a boilerplate probabilistic seismic hazard analysis data report including uniform hazard response spectra or 2013 California building code spectra, deaggregation figures, etc.

If we will no longer be able to use EZ-FRISK to perform probabilistic and deterministic seismic hazard analyses using the UCERF3 model then our "user needs" would be:

1. Ability to perform probabilistic and deterministic seismic hazard analyses using UCERF3

a. Ability to select period(s) for spectral output (0.01, 0.02, 0.03 second, etc.)

b. Ability to select various output (e.g., horizontal/vertical acceleration, maximum rotated component of horizontal acceleration, Arias intensity, cumulative absolute velocity)

c. Ability to customize uniform hazard spectra return period

2. Ability to select (or exclude) seismic sources

3. Ability to use any or all Next Generation Attenuation-West2 ground motion prediction equations (both horizontal and vertical)

   a. Ability to customize input to the various Next Generation Attenuation relations (e.g, V_{S30}, Z1, Z2.5)

4. Ability to include directivity

5. Ability to deaggregate the hazard

6. Ability to perform conditional mean spectra

4.1.4 Using Seismic Hazard Maps for PG&E Gas and Electric Systems

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Pacific Gas and Electric Company's policy is to reduce earthquake risks to an acceptable level considering the health and safety of workers and the public, minimizing property damage, and restoring service quickly and safely after a significant earthquake. Understanding the earthquake hazards and our system vulnerabilities, and mitigating these earthquake risks, is fundamental to the success of our reducing earthquake risk. Pacific Gas & Electric uses both deterministic and probabilistic hazard in assessing our structures, systems, and components. Although many of our sites perform site-specific earthquake hazard analyses, accessing and using the national seismic hazard maps is essential to our understanding and quantifying the earthquake hazards that threaten our systems. Analyses of our structures, systems, and components rely on easy access and accurate information from the maps. Periodic updates of the hazard maps as new empirical data are available are a high priority. Future mapping products to consider may include probabilistic fault and landslide displacements, lateral-spread contours from liquefaction, geo-referenced path-effect factors, and multiple earthquake scenario grid files for assessing geospatial systems and emergency response strategies. Pacific Gas & Electric's plan to place accelerometers in our electric smart meters may provide a "crowd source" data trove to refine future map products in our service territory.

4.1.5 Use of USGS Seismic Hazard Data in the California High-Speed Rail Project

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The California High-Speed Rail Project (CHSRP) will provide high-speed train service within the state of California between the San Francisco Bay area and Los Angeles. The system will eventually extend to Sacramento and San Diego, with a total of 800 miles of rail alignment and up to 24 stations. The high-speed train alignment passes through some of the most seismically active regions of California, including crossings of major fault systems. This presents some unique technical and engineering challenges that must be addressed in order to provide a safe and reliable state-wide system. The seismic vibratory ground motions are a critical consideration for the design of the CHSRP system infrastructure.

Use of seismic hazard data from the USGS National Seismic Hazard Mapping Project, which is also the official seismic hazard model adopted by the California Geological Survey, proved to be invaluable in developing seismic design ground motions for the CHSRP. The scarcity of detailed seismic hazard and site information along the rail alignment at the beginning of the project necessitated the use of existing data for the Central Valley contract bid documents. New site data would not be available until the design-build contract started. Fortunately, high-quality seismic hazard data from the 2008 national seismic hazard maps on a 0.05 degree grid of sites across the state of

California were available and were used for this purpose. Once the design-build contractor collected additional site data, such as geotechnical borings and shear-wave velocity measurements, the preliminary design ground motions were updated by the CHSRP Seismic Specialists Team to incorporate this newer site data. The seismic hazard was also updated at that time by calculating the hazard using the OpenSHA probabilistic seismic-hazard program for a dense array of locations along the rail alignment using the complete Uniform California Earthquake Rupture Forecast (version 2; UCERF2) logic tree of seismic sources together with those 2008 Next Generation Attenuation-West1 ground motion prediction equations that specifically included V_{S30} as a parameter. The use of OpenSHA, UCERF2, and Next Generation Attenuation-West1 ground motion prediction equations allowed the development of final design ground motions for specific values of V_{S30} rather than for discrete site categories and for specific geographic locations along the rail alignment rather than for discrete longitudes and latitudes. The Seismic Specialists Team performed similar seismic hazard assessments for special sites (e.g., river crossings), where site conditions were such that strong nonlinear soil behavior could be expected. In this latter case, design ground motions were developed for rock outcrop site conditions and a site-response analysis was performed by the design-build contractor to develop the final design ground motions at the ground surface.

It would have been impractical and extremely expensive to develop a seismic hazard model that could be used for the extensive geographic area covered by the CHSRP rail alignment. The availability of the USGS seismic hazard data and related products proved to be invaluable for development of preliminary and final design ground motions along the rail alignment and at the special sites. The availability of the full UCERF2 source model, which served as the basis for the National Seismic Hazard Mapping Project source model for California, allowed use of the full hazard logic tree and corresponding uncertainty in the probabilistic assessment of design ground motions. Some of the issues that were encountered with the use of the National Seismic Hazard Mapping Project and USGS data were:

1. the 2014 national seismic hazard model was in the process of being finalized and released, but delays in this release prevented the newer data from being used for the first two construction contracts;
2. running the full UCERF2 logic tree available on the OpenSHA website proved to be time consuming, especially when needing to incorporate epistemic uncertainty in some of the input parameters (e.g., V_{S30});
3. the CHSRP would like to incorporate the hazard results of the 2014 national seismic hazard model as soon as possible, but some of the products related to this model are not yet available; and
4. running the very complex and extensive UCERF3 logic tree on the OpenSHA website takes a prohibitively long time for routine consulting projects.

In conclusion, the USGS seismic hazard data and related products were found to be invaluable in the development of preliminary and final design ground motions for the CHSRP. The CHSRP Seismic Specialists Team and project management team cannot stress enough the importance of continuing the development of these products in a timely manner for use in the CHSRP and similar projects.

4.2 Summary of Discussions

The discussions in Session 3 of the workshop, "Use of Seismic Hazard at Distributed Sites," covered several aspects of the work at the USGS in the development of geological hazard information. These aspects included: the components of the national seismic hazard model, in particular, information on faults; the development of earthquake scenarios; general and specific features of seismic hazard products; and landslide and liquefaction hazards.

Regarding the national seismic hazard model, workshop participants were interested in an update of the Wells and Coppersmith (1994) relationships between earthquake magnitude and fault dimensions, more clarity on magnitude-frequency relations for deep intra-plate events, and path effects with site-specific factors.

Participants in this workshop session reiterated the importance of the Quaternary fault database for their work—in particular, the search feature, slip-rate information, and

references—and made suggestions for its improvement. Users identified some known faults that are not in the database and asked that these faults, as well as blind thrust faults, be included in the database. Participants in this session were particularly interested in more information about the Cascadia fault because a lot of infrastructure and lifelines are along the Pacific Northwest coast, despite the relatively low population. Since many organizations represented at the workshop have access to their own fault information, for example, the California Geological Survey, the Southern California Earthquake Center, and Pacific Gas and Electric Company, the participants suggested the formation of a working group to collate this information and update the USGS Quaternary fault database.

Another aspect of particular interest to the participants of this workshop session was earthquake scenarios. Workshop participants have used scenarios, for example, when designing infrastructure systems that cross major fault lines, developing mitigation projects, planning response exercises, and as input into Hazus. Participants in this session were interested in earthquake scenarios that inform a high-level assessment of seismic risk and scenarios that could be used to estimate losses from, say, a 500-year event. Specifically, participants identified scenarios on different fault segments and splays, scenarios of complex events, scenarios up and down faults, and scenarios at ground-motion levels other than the median as of interest.

Regarding the seismic hazard products available at the website of the National Seismic Hazard Mapping Project, workshop participants had both general and specific comments. Users saw great value in simple tools to provide hazard information and were interested in tools for deterministic ground motions similar to those for probabilistic ground motions. When hazard values are plotted, users would also like access to tables of the plotted values. Many participants would like to use the 2014 update of the national seismic hazard model in the current tools and encouraged the Project to update these tools as soon as possible and all at once, as opposed to one at a time. The deaggregation tools are particularly useful and important to update quickly, and participants requested information in these tools that assist the selection of ground motion time series. Users would like to have periodic updates to the national seismic hazard model when they are available. Some specific requests were for: a plausible earthquake catalog in California over the next, say, 300,000 years; information on the hazard of peak ground displacement; and information on the hazard of ground deformation, which is important for the analysis of buried systems.

Participants in this workshop session were interested in landslide and liquefaction hazards. They asked that the USGS organize the current knowledge of these two hazards and establish a consistent format for information on these hazards. The participants were looking for hazard products similar to those produced for seismic hazard: maps of liquefaction sites and areal extent useful for planning; hazard maps and maps of scenario events for landslide and liquefaction, including lateral-spread contours; and a consistent categorization of intensities and common return periods.

Chapter 5
Additional Uses of Seismic Hazard Information

Session 4 of the ATC/USGS Seismic Hazard User-Needs Workshop, "Additional Uses of Seismic Hazard Information," moderated by Janiele Maffei (California Earthquake Authority, Sacramento, California), focused on groups that use seismic hazard information for both individual and distributed sites. These user groups may have some projects that need a characterization of seismic hazard at a single site and other projects that need seismic hazard information at multiple sites.

The user groups identified by the Workshop Steering Committee for this session and represented at the workshop were commercial catastrophe modelers, professionals in the financial sector, urban planners, and scientists at state geological surveys.

This chapter includes the abstracts submitted by the speakers in Session 4 of the workshop (Section 5.1) and a summary of the discussions during this session (Section 5.2).

5.1 Speakers' Abstracts

This section provides abstracts of the formal presentations and informal talks in Session 4 of the workshop, "Additional Uses of Seismic Hazard Information." The first three sections are abstracts of formal presentations by representatives of commercial catastrophe-modeling firms (Sections 5.1.1–5.1.3). Section 5.1.4 is an abstract of an informal talk given by a professional in the property insurance industry. Section 5.1.5 is an abstract of a formal presentation by a professional working in the financial sector. The next three sections are abstracts of informal talks given by scientists at state geological surveys (Sections 5.1.6–5.1.8).

5.1.2 USGS and AIR Worldwide: Leveraging Seismic Hazard as An Ingredient in Risk Modeling

Marc Ramirez
AIR Worldwide
San Francisco, California

For almost 30 years, AIR Worldwide has been developing earthquake risk models that have relied on the expertise and information that USGS provides as a global leader in seismic hazard research. Throughout this time, AIR's earthquake models have been used to quantify the financial impact for the insurance/reinsurance industry, corporate risk managers, and the capital markets for insurance-linked security transactions. The data USGS has produced, through initiatives such as the Uniform California Earthquake Rupture Forecast model and the ShakeMaps program, formulate the underlying basis of AIR's models and continue to be the standard to which our work strives to match. In developing our models, our challenge is to balance the computational efficiency our clients demand while reflecting the USGS's robust view of seismic hazard in our risk metrics. It is through this lens that a summary of our collaboration and feedback on this process is provided.

5.1.3 Use of USGS Seismic Hazard Model in Catastrophe Modeling: RMS Perspective

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Risk Management Solutions (RMS) has developed the U.S. Earthquake (USEQ™) catastrophe model, which is used by insurers, financial markets, and public agencies to evaluate and manage seismic risks. RMS

generally updates the earthquake model following the release of the United States national seismic hazard model. The national seismic hazard model is de facto the industry standard for estimating hazard in the United States, and RMS has adopted the model as close as possible for risk calculations. The hazard is, however, one of the many components (e.g., building fragility) driving the risk. Hence the change in the risk of loss for a portfolio of buildings, sometimes, looks quite different from the change in hazard results at specific return periods, which are provided in the USGS technical documentation. Note that RMS and other modeling companies use the national seismic hazard model for estimating loss but don't use the hazard curves directly like building code applications.

The RMS model is used routinely (sometimes on a day-to-day basis) to manage the seismic risk of portfolios of buildings for insurance companies, unlike the hazard calculations by USGS, which are done only once at the end of the development cycle. Hence RMS makes a number of modifications to the national seismic hazard model to carry out loss calculations within a short period of time, and this introduces some difference in the hazard results at some locations. For example, RMS is planning to consider approximately 20 percent of the more than ½ million fault ruptures in the Uniform California Earthquake Rupture Forecast (version 3) model to represent the losses in California. In general, insurance companies and regulatory agencies routinely carry out model assessment by comparing the hazard from commercial catastrophe models like RMS with the hazard results from the USGS, and this forces the models to stay as close as possible to the national seismic hazard model.

One big difference between the USGS model and the commercial catastrophe models is the use of time-dependent models to quantify the earthquake probabilities. Since typical insurance contracts are valid for a year, the use of time-dependent models in the insurance industry is quite prevalent. The national seismic hazard model, on the other hand, uses only a time-independent model since the time horizon of the national seismic hazard maps is much longer. The typical building is designed for the seismic hazard that is assumed to remain similar over the next 50 years, and so the national seismic hazard model uses time-independent hazard.

In general, the national seismic hazard model is quite complex, and the model is getting more complex over the years. So the catastrophe modeling companies take a long time to implement the updated model and to assess the impact of those updates on loss results. Although the USGS has used similar input file formats over the last two model updates, there are, however, small changes in the input file in every update. This causes significant difficulty in adopting the model updates. Standardization of the input file and a clean OpenSHA for hazard calculations are essential for speedier adoption of national seismic hazard model in the insurance industry.

The other issue that has not been addressed in a systematic way by the USGS is assessment of epistemic uncertainty in the estimation of hazard. This arises due to uncertainty in the model parameters, multiple expert interpretations of different components of the hazard model, and statistical uncertainty due to limited or imperfect data. The national seismic hazard model captures most of this uncertainty through a logic tree framework, where different models or parameters are represented by logic tree branches and the weights associated with those branches. The uncertainty calculations help to improve assessing seismic risk and also can help to find out if the change in the risk perspective based on the updated national seismic hazard model is statistically significant.

5.1.4 Current and Future Use of USGS Seismic Hazard Products at FM Global

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FM Global
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FM Global, a leading insurer of worldwide commercial and industrial property, produces earthquake risk zone maps that display the return times of damaging ground motions. These maps are based on probabilistic seismic hazard analysis, with soil amplifications included. For the United States map, we download the USGS National Seismic Hazard Mapping Project hazard curves from the convenient website and select the spectral amplitudes of interest. The six-year update cycle is appropriately commensurate with advances in seismology.

The hazard posed by earthquakes induced by oil and gas production and wastewater disposal is of great interest. We look forward to an authoritative assessment of that hazard by the USGS in a useful format. This hazard analysis must be updated frequently (e.g., annually) to capture changes due to economic, regulatory, and political factors.

To ease the widespread distribution and use of USGS hazard products, it would be helpful to supply national seismic hazard model inputs formatted for OpenQuake, the hazard and risk software produced by the Global Earthquake Model project.

5.1.5 Financial Sector

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The reinsurance market is changing. Since 2002 the percentage of total reinsurance capacity sourced from the capital markets has increased from an estimated 5 to 20 percent, equivalent to approximately $60 billion, driven by an inflow of capital from end investors attracted by the uncorrelated nature of the risks to the financial markets. As a result specialized investors in insurance linked securities and collateralized reinsurance are an increasingly important end user of USGS products. This occurs through the usage of USGS output in the terms and definitions of securities, both in order to define what constitutes an event and to settle certain contract types, and through the usage of USGS hazard maps in the underwriting of earthquake risk in various forms.

In simple terms, insurance linked securities are financial instruments whose performance is based on insurance loss events of which, among the several different forms, the catastrophe bond is the most well-known. Catastrophe bonds are typically bonds of three to five years duration, issued by (re)insurers (or other entity seeking insurance) to investors, who receive a coupon in return for an investment of a principal amount. If a catastrophe occurs within the lifetime of the bond that exceeds certain defined levels, then the principal can be used by the issuer to pay claims or cover damages, and if not, then the principal is returned to investors at the end of the lifetime of the bond. They can be traded on the secondary market and whilst not highly liquid there is daily trading within the market. Ten years ago, catastrophe bonds were the most common product used to gain access to insurance risk by the capital flowing into the market.

Whilst the total volume of catastrophe bonds outstanding is still increasing, they have been outstripped by collateralized reinsurance as a means of transferring risk. Collateralized reinsurance allows unrated entities such as funds to underwrite insurance risk and participate in reinsurance programs, usually on an annual basis, by posting the collateral upfront. This provides investors with access to a greater range of risks but has the downside of not being tradable. The means by which investors can access insurance risk is ever increasing, from essentially direct investment in insurance companies through a range of structures to competing in the primary insurance market and offering cover directly to corporates and public bodies. As a result, specialist insurance linked security funds are growing increasingly sophisticated with some funds differentiating themselves by their ability to underwrite risks, whilst the overall growth of the market has meant more mainstream funds and pension funds are also entering the space.

Risk can be transferred in a number of different ways, both in the public catastrophe bond market and the private market. Most traditional insurance companies are now seeking coverage on an indemnity basis, where they receive a payout on their actual losses incurred, based on total claims made after a defined natural catastrophe event. However index-based structures, where payout is linked to total industry losses, and parametric structures, where payout is linked to the hazard level experienced during an event, e.g., peak ground motion from an earthquake, are increasingly prevalent. They are attractive due to their transparency and fast settlement, and are becoming particularly so for corporates and public bodies who may also be less readily able to access cover through an indemnity-based transaction.

The catastrophe bond market forms approximately $25 billion of the estimated $60 billion alternative market, but as the remaining $35 billion of private transactions are relatively opaque, statistics herein will be derived from public data. Roughly 60 percent of catastrophe-bond principal outstanding covers earthquake risk in some form, with approximately 80 percent of that principal exposed to United

States earthquake risk. Indemnity triggers are overwhelmingly the preferred mechanism, but over a billion U.S. dollars of earthquake cover is outstanding in parametric form.

An indemnity bond triggers if total claims after an event exceed a certain amount, as determined by the party accessing cover through the bond and audited by a claims reviewer. Such bonds may take two or three years after an event to settle as claims come in. Typically these losses are associated with a defined earthquake event, based on the event being reported by the USGS. The event also has a defined duration during which losses can occur, usually defined as a set number of hours after the USGS occurrence time or the duration of a cluster of "related earthquakes" or aftershocks, assessed using a procedure based around the USGS declustering methodology.

Parametric earthquake bonds take three main forms:

1. cat-in-a-box triggers, which are based on an earthquake occurring within specified boxes, with a magnitude and depth fulfilling certain conditions;
2. triggers based on ground motion at key locations, either measured directly by strong-motion seismometers or extracted from ShakeMap or a similar product; and
3. modeled loss triggers where event information is used to generate an earthquake hazard footprint which is fed into a catastrophe model to give the modeled loss to a specified set of exposures.

Parametric bonds can be settled on a timeline usually between one and six months. Each type of structure fulfills different needs and selection is usually a trade-off between simplicity and speed of settlement and the negative basis risk to the insured, defined as the risk of incurring a loss but the bond not paying out or not paying out enough to cover the loss. To an extent, the range of structures available is somewhat dictated by the availability and type of robust data. For example, cat-in-a-box triggers are based on epicenter, which is reported through the USGS Comprehensive Catalog (ComCat), but epicenter-based triggers may not appropriately deal with earthquakes occurring on large rupture zones where the area of interest is close to the rupture but distant from the epicenter.

In summary, USGS products are used in catastrophe bonds in four main ways:

1. in the definition of whether and when an earthquake has occurred through ComCat data;
2. in determining the event period and related aftershocks;
3. in derivative form through their use in catastrophe models in the analysis of the risk of the transaction; and
4. in calculating whether a payment has occurred for parametric and modeled loss transactions through ShakeMap and ComCat data.

The USGS is the preferred source of event and hazard data for catastrophe bonds covering United States earthquake risk (and some other earthquake regions) due to its reputation and status as the standard bearer. An essential part of the value in the service provided by the USGS is the status of the USGS as an independent third party offering an objective view of hazard and event occurrence, and the public availability of data. Robustness and timeliness of data are also key factors in selecting a reporting agency.

The majority of specialist insurance linked security funds also license one or more catastrophe models, and so are indirectly utilizing the USGS national seismic hazard model data which are built into the United States earthquake models. Practices vary widely between funds, but to varying degrees investors may also independently access the national seismic hazard model and other USGS products, whether that be to inform an investment decision, to drive an internal view of risk, or to validate licensed models. For example, hazard maps may be used to assess the accumulated value of exposure in high-risk seismic zones or to do due diligence on results produced by commercial catastrophe models. The timeline on which updated hazard maps are incorporated into commercial catastrophe models also means that assessment of updated national seismic hazard maps prior to a model update can be very valuable for change management and an up-to-date view of risk.

The capital markets user group bears a similarity to the (re)insurance user group in its focus on near-term time horizons, largely on an annual to five-year basis. As a result an

understanding of time dependence is of high importance. Additionally, the presence of the secondary market means that investors are able to react quickly to unfolding events or new information, with prices reacting quickly after an event. As a result the introduction of forecasting techniques would likely be of interest.

The user group would benefit from the USGS considering the following items:

1. future consideration of time dependency within the national seismic hazard model and a view of risk on an annual or five-year basis;
2. easy access to geographical information on likelihood of occurrence of earthquakes above certain magnitude thresholds, for example, by update and continuation of the Earthquake Probability Mapping tool (http://geohazards. usgs.gov/eqprob/2009/); and
3. documentation for non-expert users including reporting practices.

The use of USGS products such as ComCat and ShakeMap in catastrophe bonds and other similar structures could also be aided by:

1. version control on ShakeMap, including either archiving or date stamping of versions;
2. a more granular range of spectral accelerations output by ShakeMap (0.6 second is common in the industry); and
3. standardized reporting on rupture parameters in addition to epicenters.

As the market continues to grow, we will likely continue to see new types of parametric structures and accordingly new uses for USGS data in the capital markets. Interest is high around the usage of such products in underinsured regions like California.

5.1.6 The USGS National Seismic Hazard Mapping Project: Issues and Improvements

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The U.S. Geological Survey national seismic hazard maps provide the basis for many public and private policies regarding earthquakes, including seismic design regulations for buildings, bridges, highways, and other structures. For example, the maps were used in developing seismic provisions for new buildings and other structures by the Building Seismic Safety Council. These provisions were endorsed by the Federal Emergency Management Agency and thus became federal policies. The provisions were also adopted by state and local government agencies, as well as non-government organizations, such as the International Building Code Council, resulting in the International Building and Residential Codes. In Kentucky, the International Building and Residential Codes were revised and adopted by the Kentucky Department of Housing, Buildings and Construction and became the Kentucky Building and Residential Codes.

However, the uses of the national seismic hazard maps have resulted in many difficulties in adopting and implementing the policies. For example, the design ground motion map, developed from the national seismic hazard map with 2 percent probability of exceedance in 50 years, shows extremely high values in the New Madrid seismic zone—0.2 second spectral response acceleration of 3.06 g—whereas the highest design value in California is only 2.00 g. This extremely high design ground motion for the New Madrid seismic zone has led to intense debate in the region, and has significant impact on the region. Thus, the national seismic hazard maps, as well as the methodology being used to produce them, need to be critically reviewed.

The national seismic hazard maps were produced by the USGS using a probabilistic seismic hazard analysis (PSHA), a computer model developed by engineers in the 1970s. A comprehensive consensus process, involving geologists, seismologists, engineers, and others, was carried out to build a scientific database. The database was then used as inputs to produce the seismic hazard curves calculated on a grid showing sites across the United States that describe the frequency of exceeding a set of ground motions from PSHA. The curves provide a range of ground motion, for example, from 0.001 to 5.0 g peak ground acceleration, versus a range of annual frequencies of exceedance, from 1.0 to 0.00001 per year. Three points on the curves corresponding to annual frequencies of exceedance of 0.002, 0.001, and 0.0004 per year were picked to

produce the national seismic hazard maps. The reciprocals of the annual frequencies of exceedance of 0.002, 0.001, and 0.0004 per year, i.e., the return periods of 500, 1,000, and 2,500 years, were used to calculate the probabilities of exceedance of 10, 5, and 2 percent for buildings with an average life of 50 years. Figure 5-1 shows the flowchart for the development of the national seismic hazard maps.

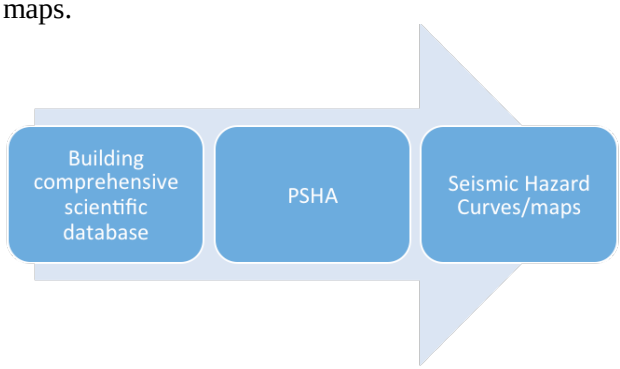

Figure 5-1 Flowchart for the development of the national seismic hazard maps.

As shown in Figure 5-1, PSHA is a critical element in producing the national seismic hazard maps. Although it has been widely discussed, reviewed, and used, PSHA contains some intrinsic problems. For example, PSHA is developed from the assumption that earthquake occurrence in time follows a Poisson distribution. But earthquake occurrence, for large earthquakes in particular, does not follow a Poisson distribution. Also, PSHA is based on a single point-source model for earthquakes, which is not valid for large earthquakes that are of safety concern. A large earthquake is now considered a complex finite fault rupture. Additionally, in PSHA, the annual probability of exceedance (i.e., the probability of exceedance in one year and a dimensionless quantity) has been erroneously equated to the annual frequency or rate of exceedance (i.e., the frequency or rate of exceedance and a dimensional quantity with the unit of per year). The error occurred in the original formulation of PSHA and led to the so-called ergodic assumption. Therefore, PSHA becomes a mathematical (computer) model without a sound earth science (physics) basis, and its results are artifacts and difficult to understand. So are the national seismic hazard maps.

The actual earthquake experience in coastal California is the basis for the development of seismic hazard mitigation policies in the United States, particularly the National Earthquake Hazard Reduction Program (NEHRP) provisions. However, the California experience shows that deterministic or scenario seismic hazard maps are more appropriate for engineering design considerations. For example, the design ground motion for coastal California has been the deterministic ground motions from the maximum considered earthquakes, not the probabilistic ground motions. In other words, the national seismic hazard maps produced from PSHA have never been used to develop the design ground motion in coastal California. Thus, deterministic or scenario seismic hazard analysis is more appropriate for the national seismic hazard mapping. Deterministic or scenario hazard maps address the ground motion from individual (i.e., maximum magnitude, maximum probable, or maximum credible) earthquakes, and have a clear physical and statistical meaning and are easy to communicate and understand.

5.1.7 Utilization of Seismic Hazard Information from USGS National Seismic Hazard Mapping Project by CGS in Project Review

Jennifer Thornburg
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This abstract summarizes utilization of the seismic hazard information from the USGS National Seismic Hazard Mapping Project (NSHMP) by the California Geological Survey in project-specific review. The California Geological Survey also uses USGS NSHMP products in regulatory zoning, statewide loss estimates, and earthquake scenario development. These aspects are summarized in another abstract by Rui Chen (Section 5.1.8).

The California Geological Survey, under contract with a variety of other state agencies, reviews geologic and seismic hazard reports prepared by private consultants for specific proposed developments. The standards vary significantly, as the proposed developments fall under different statutes, but we evaluate for technical adequacy and compliance with relevant regulations.

For site-specific ground motion evaluations, peak ground acceleration and spectral accelerations (up to 5.0 seconds) are needed. We usually get these parameters by working with NSHMP staff and running their probabilistic seismic hazard analysis computer program (i.e., the Fortran codes). In addition, we also use a variety of web-based NSHMP products (Hazard Curves, Interactive Deaggregation, Quaternary Fault and Fold Database, gridded hazard maps, gridded design maps, documentation, and Seismic Hazard Primers), and we share these resources with all stakeholders. Ongoing maintenance of these online resources, including support of outdated model results, will continue to be valuable.

Future building codes [e.g., the American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI) 7-16 Standard] foster the use of conditional mean spectra as targets for ground motion selection and scaling. For this reason, consulting seismologists will require site-specific deaggregation to identify several scenario earthquakes for which to develop compliant response spectra. I expect that this will increase the use of the NSHMP interactive deaggregation tools significantly. Ideally, the ability to deaggregate by both hazard level and spectral period will be valuable.

An important issue in California, and likely elsewhere, is that some regulations require hazard estimates that are no longer compatible with current science. The most extreme form in California are regulations that require "deterministic" earthquake scenarios including the language: "the time factor (known or expected frequency of occurrence) shall not be a parameter." These regulations never envisioned seismic hazard models like the Uniform California Earthquake Rupture Forecast (version 3; UCERF3), which includes events with an annual probability of occurrence in the range of 10^{-13}. Changing the regulations, though obviously needed, is difficult and time-consuming. An interim listing of "maximum earthquakes" from UCERF3 would help bridge the gap between current regulations and current science.

5.1.8 Utilization of Seismic Hazard Information from USGS National Seismic Hazard Mapping Project by CGS in Loss Estimation, Hazard Zoning, and Scenario Development

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This abstract summarizes utilization of the seismic hazard information from USGS National Seismic Hazard Mapping Project (NSHMP) by the California Geological Survey in statewide loss estimation, producing regulatory seismic hazard zone maps, and developing earthquake scenarios. The California Geological Survey also uses USGS NSHMP products in reviews of ground motions and other seismic hazards for the design and retrofit of hospitals and schools, which is summarized in another abstract by Jennifer Thornburg (Section 5.1.7).

For statewide annualized loss estimation, peak ground acceleration (PGA), peak ground velocity, and spectral accelerations at 0.3 and 1.0 second are needed on a coordinate grid covering California for multiple hazard levels. It is also desirable that site condition is incorporated in hazard calculations. These are not standard national seismic hazard model products. We usually get these parameters by working with NSHMP staff and running their probabilistic seismic hazard analysis computer program (i.e, the Fortran codes). An alternative approach is to extract hazard curve grid files, usually available on the NSHMP webpage, amplify hazard curves for site conditions, and then interpolate amplified hazard curves to obtain ground motion parameters needed for loss estimation.

In producing regulatory liquefaction and earthquake induced landslide hazard zone maps, California Geological Survey methodologies require pseudo PGA and modal magnitude, respectively. Pseudo PGA is obtained by scaling the PGA by earthquake magnitude to account for duration effect, which requires modification of the USGS probabilistic seismic hazard analysis codes so that PGA is scaled by each input magnitude. Modal magnitude is obtained from hazard deaggregation on a grid. In the past, we have worked with USGS staff to modify their probabilistic seismic hazard analysis codes to do magnitude scaling as well as grid-based deaggregation.

Also, the California Geological Survey has been developing earthquake scenarios for planning purposes since 1980. Others have done similar exercises, most notably the 2008 ShakeOut scenario on the southern San Andreas fault led by the USGS and a recently completed scenario for the greater Wasatch Front region by the Earthquake Engineering Research Institute Utah Chapter. In these efforts, deterministic ground motion calculations on a grid are essential. In the past, we have used a deterministic version of the USGS FORTRAN code developed by Art Frankel for this purpose. It would be great to keep that code updated or for the new USGS national seismic hazard model tools to include grid-based deterministic ground motion calculations for scenario earthquakes.

We realize that these are unusual applications of the national seismic hazard models. We have long appreciated the support provided by the USGS team, and we are looking forward to continuing collaboration.

5.1.1 The Science of Catastrophe Modeling: A Journey from Hazard to Risk

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Recent catastrophic events have highlighted the need for disaster preparedness. Natural catastrophe models quantify the impact of potential losses and are a vital planning tool for the insurance, financial, and real estate markets as well as government entities. One of the fundamental building blocks of catastrophe models is hazard data. In the context of earthquake risk modeling in the United States the National Seismic Hazard Mapping Project forms the basis of the hazard component of a probabilistic risk model.

Catastrophe risk models are comprised of three key components: the hazard, as well as vulnerability to estimate damage, and a financial loss model to estimate loss. This presentation focuses on how catastrophe risk models utilize hazard data and the methodology for estimating risk.

5.2 Summary of Discussions

The discussions in Session 4, “Additional Uses of Seismic Hazard Information,” involved seven general areas of interest to the workshop participants: (1) update and maintenance of seismic hazard products; (2) development of earthquake scenarios or deterministic ground motions; (3) documentation and communication of the national seismic hazard maps; (4) uncertainties in hazard values; (5) re-implementation of the national seismic hazard model; (6) hazard on short time scales; and (7) development of additional hazard information.

The workshop participants reiterated the usefulness and value of the current seismic hazard information products. The participants encouraged the USGS National Seismic Hazard Mapping Project to continue providing seismic hazard values from previous updates of the national seismic hazard maps, as well as update the online hazard products with the 2014 update as soon as possible. The deaggregation tool was mentioned again as particularly valuable.

Workshop participants stated an interest in earthquake scenarios or deterministic ground motions. This interest arises from the deterministic cap placed on hazard values used in design practice and from communications with non-technical audiences. The participants indicated that there are misunderstandings of the definition and consistent implementation of the deterministic cap. Non-technical audiences find earthquake scenarios easier to understand than probabilistic ground motions.

Many workshop participants often discuss seismic hazard with their clients or non-technical colleagues and thus have an interest in the documentation and communication of the national seismic hazard maps. Many participants in this workshop session were interested in a deep understanding of the hazard model and, especially, how it changes with each update. Documentation of the hazard model for non-expert users would be useful and may serve as a guide for the communication of seemingly esoteric probabilistic seismic hazard values. For example, policy decisions are increasingly made in the context of multiple hazards, and an understanding of seismic hazard with respect to other hazards may inform these decisions. The National Seismic Hazard Mapping Project has the opportunity to characterize seismic hazard in ways that are meaningful locally, regionally, and nationally by working with interested colleagues to transfer the Project’s knowledge of seismic hazard.

The workshop participants expressed an interest in the definition and characterization of uncertainty in the national seismic hazard model. The model has many sources of epistemic uncertainty, and users are interested in knowing which uncertainties may increase in future updates. Participants also asked for a consensus-based description of the uncertainty in hazard values for the purpose of informing developers of derivative products, and asked for guidance on best practices when interpreting uncertainty in hazard values.

Some user groups represented at the workshop re-implement the USGS national seismic hazard model (possibly with modifications) and compare the calculated hazard values in order to check the implementation. To facilitate this process, participants asked that the National Seismic Hazard Mapping Project standardize the hazard input files from one update to the next, more clearly document the magnitude-frequency distributions for background seismicity in different regions, provide a more user-friendly version of OpenSHA and possibly host a user exchange, and provide more intermediate hazard calculation results for comparison and validation.

Hazard on short time scales was of interest in this workshop session. In particular, there was interest in induced seismicity, time-dependent hazard in the next roughly one to five years, and the use of real-time observations to inform earthquake forecasting.

Looking forward to the next update of the national seismic hazard maps, workshop participants did not object to the schedule of updates every six years. Participants were interested in access to more information about site conditions and hazard provided in terms of intensity measures that may be more indicative of structural damage, for example, cumulative absolute velocity.

Appendix A
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