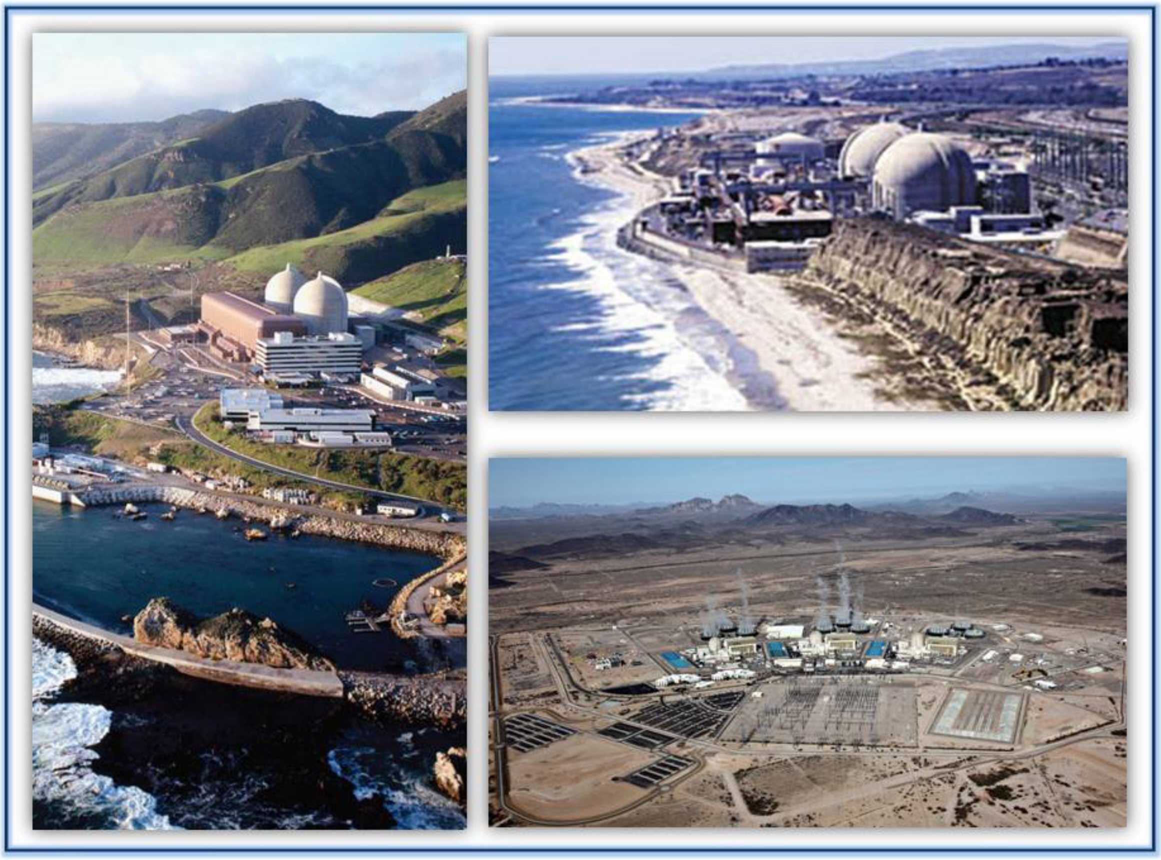
SOUTHWESTERN UNITED STATES GROUND MOTION CHARACTERIZATION SSHAC LEVEL 3

Workshop #1 Proceedings

Version 1.1



WORKSHOP #1 PROCEEDINGS:

Critical Issues and Data Needs

March 19-21, 2013

Hilton Oakland Airport, California

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LIST OF ABBREVIATIONS and COMMON ACRONYMS

ACR	Active Crustal Region
AFE	Annual Frequency of Exceedance
APS	Arizona Public Services
BBP	Broad Band Platform
CBR	Center, Body, and Range
CEA	California Earthquake Authority
CEC	California Energy Commission
CEUS	Central and Eastern United States
CFM	Community Fault Models
CFR	Code of Federal Regulations
CGS	California Geological Survey
CPUC	California Public Utilities Commission
DCPP	Diablo Canyon Power Plant
EE	Evaluator Expert
FGF	Fragile Geological Feature
FW	Foot Wall
GIS	Geographic Information System
GMC	Ground Motion Characterization
GMPE	Ground Motion Prediction Equation
GMRS	Ground Motion Response Spectrum
GPS	Global Positioning System
HID	Hazard Input Document
HC	Hazard Calculation
HW	Hanging Wall
Hz	Hertz
IPRG	Independent Peer Review Group
ITC	Informed Technical Community
LiDAR	Light Detection and Ranging
NGA	Next Generation Attenuation
NGA-West2	Project name for the update of the 2008 NGA models
NI	Newport Inglewood
NI/RC	Newport Inglewood / Rose Canyon
NPP	Nuclear Power Plant

NSHM	National Seismic Hazard Mapping
PE	Proponent Expert
PEER	Pacific Earthquake Engineering Research Center
PGA	Peak Ground Acceleration
PG&E	Pacific Gas & Electric
OBT	Oceanside Blind Thrust
PM	Project Manager
PPRP	Participatory Peer Review Panel
PSHA	Probabilistic Seismic Hazard Analysis
PTI	Project Technical Integrator
PV	Palos Verdes
PVNGS	Palo Verde Nuclear Generating Station
QA	Quality Assurance
RC	Rose Canyon
RE	Resource Expert
RG	Regulatory Guide
SCE	Southern California Edison
SCEC	Southern California Earthquake Center
SCFM	Statewide Community Fault Model
SCSN	Southern California Seismic Network
SONGS	San Onofre Nuclear General Station
SSC	Seismic Source Characterization
SSHAC	Senior Seismic Hazard Analysis Committee
SWUS	Southwest United States
TA	Transportable Array
TDI	Technically Defensible Interpretation
TI	Technical Integrator
UCERF2	Uniform California Earthquake Rupture Forecast, Version 2
UCERF3	Uniform California Earthquake Rupture Forecast, Version 3
USGS	United States Geological Society
U.S.NRC	U.S. Nuclear Regulatory Commission
USR	Unified Structural Representation
$V_{S,30}$	Shear Wave Velocity in the upper 30m
WGCEP	Working Group on California Earthquake Probabilities
WUS	Western United States

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WORKSHOP #1 INTRODUCTION

Pursuant to the Request for Information put forth on March 12, 2012 by the United States Nuclear Regulatory Commission in response to the Near-Term Task Force's (NTTF) evaluation of the Fukushima Dai-ichi accident, Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and Arizona Public Service (APS) are co-sponsoring a joint Southwestern U.S. (SWUS) Ground Motion Characterization (GMC) SSHAC Level 3 study for the Diablo Canyon Power Plant (DCPP), the San Onofre Nuclear Generating Station (SONGS), and the Palo Verde Nuclear Generating Station (PVNGS).

This is the first out of three Workshops that will be conducted in accordance with the applicable SSHAC Level 3 guidelines.

Purpose:

The specific goals of Workshop #1 are to:

1) Review the ground rules for the conduct of SSHAC workshops and expert roles within the project
2) Identify the technical issues of highest significance to the hazard analysis.
3) Review available data that will be considered for constructing the GMC model; this includes identification of data, information and/or additional work to be done on the continuing development of the project to address those issues. It will also address the evaluations to be performed in the period leading up to Workshop #2

Approach:

The goals of the Workshop have been accomplished by a series of presentations and discussions designed to provide the Technical Integration (TI) team with information pertaining to: (1) assessment of the main ground motion and uncertainty contributors to the ground motion shaking hazard at the three sites of interest, and (2) discussion on the availability, applications, and limitations of the available data. Presentations are also to address the new data collection efforts currently underway and those that will be completed throughout the next two years to support this SSHAC project. All the presentations are part of the project record.

At this stage of the project, the focus is on identifying the data that are available to address the hazard-significant technical issues. Interpretation of the available data in terms of alternative models or implications to the seismic hazard at the site is to be avoided; this will be the focus of Workshop #2.

Speakers have been provided with detailed guidance by the TI Lead to ensure that the presentations are oriented to the goals of the project and Workshop. When inclusion of interpretations cannot be avoided, the speakers have been asked to identify biases or limitations in the interpretation process.

At the end of each day, Observers (including members of the PPRP and representatives of the Sponsors) have been provided with an opportunity to make comments and/or raise questions.

Workshop #1 Agenda

Session	Time	Topic	Duration (min.)	Speaker
Day 1 - AM		10:00 AM – 12:15 PM		
WORKSHOP INTRODUCTION	10:00 AM – 11:05 AM	Welcome and introduction	10	Di Alessandro
		Sponsors' perspective	15	SWUS Utilities Representatives
		Project overview and objectives	20	Abrahamson
		Review SSHAC procedures and Workshop ground rules	20	Lettis
OVERVIEW of SEISMIC SOURCE CHARACTERIZATION	11:05 AM - 12:15 PM	Diablo Canyon Power Plan (DCPP)	20	Thompson
		San Onofre Nuclear Generating Station (SONGS)	20	Freeman
		Palo Verde Nuclear Generating Station (PVNGS)	20	Lindvall
		Clarifications and questions	10	Abrahamson leads;
12:15 PM – 1:15 PM		*Lunch*		
Day 1 - PM		1:15 PM – 5:20 PM		
GMC and SENSITIVITY ANALYSES	1:15 PM - 2:55 PM	GMC Logic tree V0	30	Wooddell
		Hazard sensitivity analyses for DCPP	20	Gregor
		Hazard sensitivity analyses for SONGS	20	Dinsick
		Hazard sensitivity analyses for PVNGS	20	Walling
		Discussions: List of key Hazard sensitive GM issues	15	Di Alessandro leads
2:55 PM – 3:15 PM		*Break*		
GROUND MOTION PREDICTION EQUATIONs	3:15 PM - 4:45 PM	GMPEs for active crustal regions: applicability for controlling sources	30	Stewart
		NGA-West2 Database	30	Darragh
		Discussion: Are Hazard sensitive sources well constrained by GMPEs?	30	Abrahamson leads; Additional REs: Boore, Bozorgnia, Kalkan, Baltay, Hanks, Silva
4:45 PM – 5:05 PM		Summary of GMC Day 1	20	Donahue
5:05 PM – 5:20 PM		Observers (PPRP and Sponsors) comments	15	
Day 1		End of Formal Workshop Proceedings		
Closed Meeting: PPRP, Sponsors, PM, TI Lead				

Session	Time	Topic	Duration (min.)	Speaker
Day 2 - AM		8:00 AM – 11:50 AM		
DATA to CONSTRAIN GMPEs in CRITICAL RANGES PART A	8:00 AM - 10:00 AM	Directivity	25	Watson-Lamprey
		Hanging Wall	20	Donahue
		Fling	15	Kamai
		Discussion on data to constrain near-fault effects	30	Wooddell leads; Additional REs: Somerville, Graves, Darragh, Baker
		Multi-fault rupture	30	Donahue
10:00 AM – 10:20 AM		*Break*		
DATA to CONSTRAIN GMPEs in CRITICAL RANGES PART B	10:20 AM - 11:10 AM	Splays and linkage: dynamic rupture modeling	25	Harris
		Questions and Discussions on multi-fault ruptures	25	Abrahamson leads; Additional REs: Somerville, Aagaard, Darragh
USE of SIMULATIONS for SWUS GMC PART A	11:10 AM - 11:50 AM	Review on simulation validation from SCEC	40	Goulet
11:50 AM – 12:50 PM		*Lunch*		
Day 2 - PM		12:50 PM – 4:45 PM		
USE of SIMULATIONS for SWUS GMC PART B	12:50 PM - 2:40 PM	*Discussion on simulation validation from SCEC*	50	Dreger leads; Additional REs: Olsen, Archuleta, Graves, Somerville, Bayless, Anderson, Jordan
		Discussions: Best uses of simulations (30 min) and Practical limitations (30 min) Objectives: develop list of simulation cases to help constrain/establish uncertainty in GMPEs (Identify scenarios to be implemented in the numerical simulations)	60	Abrahamson leads; Additional REs: Somerville, Bayless, Graves, Jordan, Maechling, Silva, Bozorgnia, Boore, Aagaard, Heaton
2:40 PM – 3:00 PM		*Break*		
ARIZONA GROUND MOTION DATA and ISSUES	3:00 PM - 4:10 PM	Available GM data from Transportable Array in Arizona for both nearby earthquakes in Arizona and distant earthquakes in California	25	Watson-Lamprey
		Additional GM data from Arizona from IRIS not part of the Transportable Array	15	Walling
		Discussions: Do we have sufficient data to resolve geometrical spreading, anelastic attenuation, kappa, and stress drop differences between California and Central Arizona?	30	Youngs leads; Additional REs: Brumbaugh, Lindvall, Young, Silva, a representative from CICESE(*)

Session (continued)	Time (cont.)	Topic (continued)	Duration (min. – cont.)	Speaker (continued)
4:10 PM – 4:30 PM		Summary of GMC Day 2	20	Wooddell
4:30 PM – 4:45 PM		Observers (PPRP and Sponsors) comments	15	
Day 2		End of Formal Workshop Proceedings		
Closed Meeting: PPRP, Sponsors, PM, TI Lead				

(*) Participation pending confirmation

Session	Time	Topic	Duration (min.)	Speaker
Day 3 - AM		8:00 AM – 12:00 PM		
CALIFORNIA GROUND MOTION DATA and ISSUES	8:00 AM - 9:30 AM	Regional GM data for DCPP	25	Wooddell
		Regional GM data for SONGS	25	Dinsick
		CyberShake simulations for path effects near SONGS	10	Wang
		Discussions on data to derive path specific corrections to GMPEs	30	Dreger leads; Additional REs: Helmberger, Heaton
FRAGILE GEOLOGIC FEATURES	9:30 AM - 10:00 AM	*Discussions on fragile geologic features to constrain the hazard*	30	Youngs leads; Additional REs: Thompson, Dinsick, Lindvall
10:00 AM – 10:20 AM		*Break*		
REFERENCE CONDITIONS	10:20 AM - 11:15 AM	Review of reference rock conditions	10	Donahue
		What is the kappa from the candidate GMPEs	15	Al-Atik
		Kappa sensitivity for PVNGS	10	Silva
		Discussions on data to constrain kappa	20	Donahue leads; Additional REs: Silva, Anderson, Ktenidou
ADDRESSING SIGMA FOR SWUS GMC PART A	11:15 AM - 12:00 PM	SWUS plan for Sigma: ergodic vs. single station	10	Abrahamson
		Review of available data for single station sigma models	35	Al-Atik
12:00 PM – 1:00 PM		*Lunch*		
Day 3 - PM		1:00 PM – 3:35 PM		
ADDRESSING SIGMA FOR SWUS GMC PART B	1:00 PM - 2:30 PM	World wide data available for single-station sigma and Φ_{S2S} differences.	30	Rodriguez-Marek
		Discussions: Data needs and issues with single-station sigma	60	Wooddell leads; Additional REs: Anderson, Rodriguez-Marek
2:30 PM – 2:50 PM		*Break*		
2:50 PM – 3:20 PM		Summary of GMC Day 3 and Review of Day 1 and Day 2	30	Abrahamson
3:20 PM – 3:35 PM		Observers (PPRP and Sponsors) comments	15	
Day 3		End of Formal Workshop Proceedings		
Closed Meeting: PPRP, Sponsors, PM, TI Lead				

Workshop #1 participants

Group	Individual	Affiliation
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	David Boore	U.S. Geological Survey, Menlo Park
	Tom Hanks	U.S. Geological Survey, Menlo Park
	Annemarie Baltay	U.S. Geological Survey, Menlo Park
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	Robert Darragh	Pacific Engineering and Analysis
	Ronnie Kamai	Univ. of California, Berkeley
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	Steve Thompson	Lettis Consultants International, Inc.
	Tom Freeman	GeoPentech, Inc.
	Scott Lindvall	Lettis Consultants International, Inc.
	Jeri Youngs	Arizona Geological Survey
	Thomas Heaton	California Institute of Technology
	David Brumbaugh (*)	Northern Arizona University
	Erol Kalkan	U.S. Geological Survey, Menlo Park
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	Brian Carlton	Univ. of California, Berkeley
	Justin Hollenback	Univ. of California, Berkeley
	Osman El Menchawi	Fugro Consultants, Inc.
	Rob Sewell	R.T. Sewell Associates

(*) Remote attendance

WORKSHOP #1 SUMMARY

Project background

Pursuant to the Request for Information put forth on March 12, 2012 by the United States Nuclear Regulatory Commission in response to the Near-Term Task Force's (NTTF) evaluation of the Fukushima Dai-ichi accident, Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and Arizona Public Service (APS) are co-sponsoring a joint Southwestern U.S. (SWUS) Ground Motion Characterization (GMC) SSHAC Level 3 study for the Diablo Canyon Power Plant (DCPP), the San Onofre Nuclear Generating Station (SONGS), and the Palo Verde Nuclear Generating Station (PVNGS). The ultimate deliverable for this study will be a ground motion model developed following the guidelines of the SSHAC Level 3 process (Budnitz et al., 1997; NRC, 2012).

General workshop summary

The first workshop of SWUS SSHAC was held at the Hilton Oakland Airport from March 19 to March 21, 2013. The introductory presentation delivered by the Project Manager, Dr. Carola Di Alessandro, served to highlight the focus of the workshop, i.e. to address the GMC data needs, with data defined as both raw data (e.g. seismicity, ground motion records, etc.) as well as outputs from ground motion simulations, and the critical GMC issues. Specific workshop goals included the identification of the technical issues of the highest significance to the hazard analysis and the review of available data that will be considered for constructing the GMC model. This includes the identification of data, information and/or additional work to be done on the continuing development of the project to address those issues. Evaluations to be performed prior to the second workshop were also identified and addressed.

Following the presentation about the Sponsors' Perspective, the TI Team Lead, Dr. Norman Abrahamson, presented an overview of the project schedule and scope, which includes derivation of ground motion logic trees and associated Hazard Input Documents (HIDs). The ground motion models need to be applicable to all of the relevant cases for the SSC for any of the three Nuclear Power Plants (NPPs). He also presented an overview of ground motion research being performed at the University level by Pacific Earthquake Engineering Research Center (PEER) and Southern California Earthquake Center (SCEC). The critical interface with the other PSHA-related tasks being conducted by the three Utilities was briefly addressed.

The workshop introduction on March 19 included a training session to review the SSHAC procedures, the Workshop 1 ground rules, and a representative from each of the respective Utilities presented an overview of their Seismic Source Characterization (SSC) model. This was followed by a presentation of the GMC Version 0 (V0) logic tree and the ground motion sensitivity analyses presented by each Utility's designated hazard analyst. For both DCPP and SONGS, the controlling sources are near-fault (less than 15 km) sources. DCPP hazard is controlled by two strike-slip faults (the Hosgri and Shoreline faults) and two reverse faults (Los Osos and San Louis Bay). SONGS is controlled by a combination of the Newport-Inglewood/Rose Canyon (NI/RC) fault and the Oceanside Blind Thrust (OBT) faults. For both DCPP and SONGS, multi-segment ruptures including splay fault and HW effects may be important. In contrast, the hazard at PVNGS is controlled by large magnitude events at great distances (e.g. greater than 200 km) and by moderate magnitude (e.g., M6-M6.5) normal and strike-slip events within 20 km.

The focus for the remainder of Workshop 1 was on the GMC data needs and critical issues. A summary of these technical presentations and discussions follows.

Topic 1: Ground Motion Prediction Equations (GMPEs)

Ground Motions Prediction Equations (GMPEs) are the empirical models used to calculate ground motion attenuation given earthquake magnitude, fault geometry, distance from the earthquake rupture to the site of interest, and site conditions ($V_{S,30}$). The standard practice in the western United States is to use the 2008 Next Generation Attenuation (NGA) models, however many alternative models exist and will be evaluated in addition to the 2008 NGA models as part of the SSHAC process.

Ground motion prediction equations are applicable to specific tectonic regions, and Dr. Jonathan Stewart presented a review of 15 GMPEs that are applicable in active crustal regions (or ACRs) such as the Southwestern U.S.; the set of models included both global models and regional models. The review focused on the parameterizations of the GMPEs and their ability to model the controlling fault sources for each Utility (DCPP, SONGS, and PVNGS) and the datasets from which they were derived. Dr. Robert Darragh presented the suite of earthquakes available in the NGA-West2 database to identify potential data gaps in regions critical for constraining the GMC hazard as identified by the sensitivity studies. His presentation highlighted the paucity of ground motions from normal-faulting events.

As part of these discussions, earthquakes that can provide additional constraints in the GMC hazard sensitivities were identified. Most of the key data discussed are either currently in the NGA-West2 dataset or will be processed by PEER for completion by the end of the summer 2013. The key earthquakes in the Japanese models are already included and there is a need to check the dataset used by Bindi et al. (2009 and 2010) for moderate magnitude normal faulting events from Italy. Additionally, the Fukushima-Hamadori normal faulting earthquake sequence in Japan (M~6.7 – 7.0) and the Wells, Nevada normal earthquake (M5.9) can be considered to augment the available data. The topics of magnitude saturation, how large magnitudes scale at high frequency and short distance, were discussed. Dr. David Boore presented empirical data showing oversaturation (larger ground motion amplitudes recorded from smaller magnitude earthquakes at short distance) at high frequency, and Dr. Annemarie Baltay presented scaling models showing full saturation (no scaling on ground motion with magnitude at short distance), though her models did not allow for oversaturation. The issue of full saturation versus over-saturation cannot be resolved by data alone and will require finite-fault simulations.

Finally, Dr. Erol Kalkan discussed which data have been considered to constrain the amplification of PGA in the near-field for the Graizer and Kalkan (2011 and 2012) GMPE. This model has a different distance scaling at short distance which leads to a decrease in ground motion at the faults. The robustness of the scaling should be evaluated using additional near-fault earthquake data.

Topic 2: Data to constrain GMPEs in Critical Ranges

A variety of topics were discussed in an attempt to identify data gaps in areas affecting specific terms of the GMPEs. Dr. Jennie Watson-Lamprey presented a summary of the available directivity models. Directivity describes the potential amplification of ground motions as rupture moves towards a site, which can significantly affect the low frequency ground motions at short distances. The key technical issue is whether the standard deviation of the GMPEs adequately captures the effects of directivity or not. This topic is being addressed as part of the PEER ground motion research.

Dr. Jennifer Donahue presented earthquakes that have been recorded on both the hanging wall (HW) and the footwall (FW) of earthquakes in the NGA-West2 database to help constrain the hanging wall term of the Ground Motion Prediction Equations. Data recorded on both the HW and FW in a single earthquake is sparse, and in particular M5.5 to M6.5 earthquakes, which may be significant for the hazard at DCPP and SONGS, are not well constrained by the NGA-West2 empirical data. The available finite fault simulations covered the magnitude range 6 to 7.8 but do not constrain the small magnitude scaling below M6.5 It was decided that simulations might help improve this constraint. Japanese data may also be useful if the metadata can be obtained.

Dr. Ronnie Kamai presented an analysis to determine what is the impact of standard processing in the NGA-West2 database, in particular focusing on the amount of static displacement (fling) preserved in the processed data. Her analysis showed that static displacements are preserved out to the 3 to 5 second range. As the aim of this SSHAC project is to provide results out to 5 seconds, it was determined that records in the 3 to 5 second range would be further evaluated.

Dr. Jennifer Donahue then presented available information on multi-fault ruptures either available within the NGA-West2 database or from other resources. There are very few multi-fault ruptures with near-fault data. Additional multi-fault ruptures cases were identified, mainly recent events such as Christchurch, Darfield, and El Mayor-Cucapah. Approaches for characterizing parameters for multi-fault ruptures were also discussed. Some of the cases shown included either pre-seismic or post-seismic slip/displacement which is not relevant for ground motions for multi-fault ruptures. The rupture models need to be revised to include only the coseismic displacement for splay faulting and multi-segment ruptures.

Dr. Ruth Harris presented the results of the branch faulting dynamic rupture code verification exercise, and it was shown that about 5 models are capable of producing results that are consistent with each other. The discussion of this topic included a suggestion to develop alternative distance metrics for complex faulting, such as general coordinates system 2 (GC2) proposed in the PEER directivity studies. The cases shown used a single rupture initiation point located on the main traces away from the juncture of the splay fault. Additional cases were suggested to consider scenarios where the rupture initiates on the splay and moves onto the main fault, as well as scenarios that include heterogeneous stress on the rupture plane.

Topic 3: Use of Simulations for SWUS GMC

Due to a lack of data in critical regions, broadband (BB) simulations can be used to develop constraint on the GMPEs. Dr. Christine Goulet provided a review of the SCEC BB Platform simulation validation exercise scheduled to be completed in 2013. A list of cases to run on the BB Platform was proposed in the discussion that followed the presentation. The purpose of these cases is to provide data in regions where empirical data does not exist or is deemed to be insufficient; the use of multiple methods in the ground motion simulations will account for epistemic uncertainty. The cases recommended for consideration are provided in the "Day 2 - Main Points" presentations available at the "Technical Integrator Team Summaries and actions" section (page 39).

Discussion involved ground motion from multi-fault ruptures, dependence on the location of hypocenters within and at junctures in fault models, definitions of GMPEs parameters (style of faulting, dip) for ruptures with variable slip direction, dip and strike. These features can be addressed through simulations.

Other uses of simulations are to constrain hanging wall scaling, splay faulting, slip partitioning, large magnitude scaling, low dip angle scaling, linked/multi-segment faulting, and large magnitude/long distance scaling.

Preparations for using simulation capability include documentation of methodology, fixed and optimized parameters and other user-required information, description of 1D velocity structures (including Q) for each region, and passing the part A and part B validations.

Topic 4: Arizona Ground Motion Data and Issues

Two presentations were given for the available data for the Palo Verde Nuclear Generating Station (PVNGS). The first presentation was given by Dr. Jennie Watson-Lamprey who provided the available data from the Transportable Array (TA) and other sources. The TA Earthscope stations near PVNGS captured 16 events, 1 with M≥3, 7 with M≥2 and 8 with M≥1 which occurred within the Sonora Basin and Range zone and within 100 km of the site. During the course of the presentation, it was revealed that improved site conditions at the recording stations was needed, to which Dr. Jeri Young of the AZGS is to provide depth to bedrock values. Given the number of small magnitude (M< 1.5) events available, it was postulated that the estimation of kappa_ds (otherwise known as kappa_mini) may be a possibility. Next the NGA-West2 database was reviewed for events in California and Baja California within 100, 200 and 400 km of Arizona. 32 events meet these criteria with possibly 20 events recorded by the TA Earthscope stations. An additional highlight of the presentation was that the available empirical data for long distance attenuation may be adequate, but a review of the regionalization may be needed for path adjustments.

Dr. Melanie Walling gave the second presentation regarding the Arizona ground motion issues. Additional empirical data and catalogue events were presented, and two additional events close to the transition zone but still potentially within the Sonora Basin and Range zone were recommended for considerations. The ground motions resulting from mine blasts may provide constrains on kappa and their applicability should be evaluated by reviewing previous studies.

In the general discussion, led by Dr. Robert Youngs, one of the topics was to compare the Little Skull Mtn. event with the NTS nuclear blast with the intent to look at kappa effects resulting from the shallow depth of the blasts and also mining related events. It was also suggested that historical intensities for Arizona should be reviewed and the catalogue may be made available by Prof. Brumbaugh. Additional data points for the El Mayor-Cucapah event may also be available at the Roosevelt Dam and the VA Hospital.

Topic 5: California Ground Motion Data and Issues

In contrast to the sparse data available at PVNGS, the available data for DCPP and SONGS was discussed. Ms. Wooddell presented available data for DCPP to include the recently recorded small magnitude events collected as part of the AB1632 DCPP onshore 3-D seismic survey. During the geophysical studies, small (0.6<M<1.7) events were well recorded by the geophones and can be used to focus on path effects from nearby offshore and onshore earthquakes. The 3-D velocity model by Dr. J. Hardeback (2009) was presented. An alternative 3-D model is expected to be completed this summer as part of the AB1632 studies. These studies should be considered in the development of the 1-D crustal models for implementation in the finite-fault simulations.

The available ground motion data for SONGS was presented by Mr. Andrew Dinsick. There are at least 28 events with M>3 within 200 km, recorded on the broadband (BB) instruments at SONGS. This information will be very useful going forward. Path effects may be important to SONGS and should be analyzed for both the NI/RC and OBT faults. Prof. Don Helmberger remarked that path effect at SONGS should be compared with the available data from other Southern California BB stations to determine if there is an atypical attenuation in the SONGS region. The nearby M<3 earthquakes at short distances may provide reliable estimate of kappa. Finally, the SCEC 3-D velocity model of the Unified Structural Representation for Southern California was presented.

CyberShake simulations provide a suite of 3-D finite fault simulations for the greater Los Angeles (L.A.) region including the SONGS site, which lies near the edge of the SCEC parameterization of the L.A. Basin. Mr. Feng Wang described the alternative 3-D crustal models and the available scenarios. Two scenarios capture the offshore sources that dominate the hazard at SONGS. These simulations can be used to evaluate potential 3-D path effects at SONGS. The two alternative 3-D crustal models (H and S4) have significant differences in the SONGS region that need to be evaluated. These large differences will have an effect on the long period motion near SONGS.

Topic 6: Fragile Geological Features

Fragile geologic features (FGFs), or precariously balanced rocks, are geologic structures that may be used to constrain probabilistic seismic hazard analysis. When properly dated, and mechanically analyzed for minimum toppling or damaging forces, these features can yield an estimate of the maximum level of ground shaking (with a given confidence level) that could have occurred at the site since the formation of the fragile structure. In this respect, they place constrains on the hazard at the site. At DCPP, one fragile geologic feature has been identified and should be considered for age dating and analysis.

At SONGS, no FGFs have been identified, but some constraints might be postulated considering that the foundation of the plant consists of sandstones older than 125k years which shows no signs of damage or dilation due to shaking.

At PVNGS, no FGF has been found. However, there might be a FGFs for consideration about 80km away which may have been subjected to M7.6 1887 earthquake ground motions, though no features have tumbled.

Topic 7: Reference Conditions

Reference conditions are parameters used in the SWUS logic tree, which will be considered for the Base Case. Each of the Utilities will then apply site-specific parameters to these reference conditions. The first reference condition considered was the $V_{S,30}$. Dr. Jennifer Donahue presented information regarding the use of 760 m/s as the reference rock condition. This is a commonly used value in the GMPEs and there is sufficient data in the NGA-West2 database to constrain the GMPEs at this velocity. However, it will be worth reconsidering a lower $V_{S,30}$ velocity, such as 500-600 m/s, since more empirical data is available within this range. The disadvantage of using a lower velocity is that a greater correction is required to scale the ground motion to hard-rock conditions.

Dr. Linda Al-Atik reviewed the kappas associated with the current GMPEs and the three available approaches for kappa adjustments: hybrid empirical, IRVT, and empirical. The kappa values associated with ACRs are in the range of 0.035 to 0.044 seconds for 760 m/s conditions

Next, Dr. Walt Silva presented his recent sensitivity analysis for kappa at PVNGS. He showed the effect of different values of the underling rock kappa combined with the soil column. The soil column contributed only a small additional kappa and he concluded that the high frequency ground motion was sensitive to the assumed kappa value. His analysis highlighted that the potential difference in kappa on rock between Arizona and California can lead to significant differences in the ground motion at PVNGS. From this discussion, it was determined that kappa will be key to ground motions for Arizona due to site response effects. Dr. Olga Ktenidou advised that when using $V_{S,30}$-kappa relationships, as many records per site are required to capture both the kappa at the site and the 'sigma' of (or variability in) the kappa.

As previously stated, small magnitude (M<1.5) events at all sites may be useful for estimating kappa for the PVNGS region. However, the stations located near PVNGS have a limited high frequency bandwidth (14 Hz) that will require careful consideration.

At DCPP, there are survey data with useable frequencies up to 300 – 350 Hz which can provide an excellent opportunity for estimating kappa from small magnitude events.

Topic 8: Addressing Sigma for SWUS GMC

Dr. Linda Al-Atik began the discussion of single station sigma, σ_{ss}, by addressing the associated terminology and equations. She then reviewed the available data within the NGA-West2 database with preliminary results based on magnitude dependence, distance dependence, magnitude and distance dependence, and $V_{S,30}$ dependence. Single station sigma models are being developed as part of the PEER research and will be available for Workshop 2.

Dr. Adrian Rodriquez-Marek then presented data available from sources outside of the NGA-West2 database to include Taiwan, Turkey, and Japan. He showed that for single station phi, ϕ_{ss}, there appears to be consistency across all regions (California, Taiwan, etc.) with no strong regional dependency or dependency on $V_{S,30}$. However, dependencies were shown to exist on magnitude and distance parameters. Conversely, the site-to-site term, ϕ_{s2s}, does vary between regions, and there may be a dependency on $V_{S,30}$. Within his presentation he included an additional term, $\phi_{ss,s}$ which is the single station standard deviation for estimates at only one station. This work is still developing through PEER and will be a topic for Workshop 2.

Finally, there was a discussion as to how site amplification would be estimated for each Utility site. At DCPP, the Utility plans to use empirical data, based on recordings at DCPP, but with the small number of recordings, the epistemic uncertainty may be large. At SONGS, an analytical approach will be used with a range of inputs that captures the uncertainties in the geotechnical parameters. If the site terms from nearby sites are consistent, this may aid in the development of the site term. PVNGS is in the process of evaluating how to integrate the site-specific terms.

Focused questions submitted to Workshop #1 Presenters

The following Tables 1 through 10 show the focused question that Workshop #1 Presenters were asked to address, subdivided by topic.

Table 1 Focused questions for Workshop #1 Presenters: Session "OVERVIEW of SEISMIC SOURCE CHARACTERIZATION"

Topic	Speaker	Questions / Topics to be addressed at WS #1
Diablo Canyon Power Plan (DCPP)	Thompson	Summarize tectonic setting. What is the range of dip angles (min and max) and faulting styles? What is the seismogenic thickness? Are you including deep ruptures in the upper mantle (~30 km)? What is the largest magnitude in your sources (due to linked faults)? Do you have a complex multi-segment rupture with different rake/dip along strike? Do you have splay faults or overlapping segments?
San Onofre Nuclear Generating Station (SONGS)	Freeman	Summarize tectonic setting. What is the range of dip angles (min and max) and faulting styles? What is the seismogenic thickness? Are you including deep ruptures in the upper mantle (~30 km)? What is the largest magnitude in your sources (due to linked faults)? Do you have a complex multi-segment rupture with different rake/dip along strike? Do you have splay faults or overlapping segments?
Palo Verde Nuclear Generating Station (PVNGS)	Lindvall	Summarize tectonic setting. What is the range of dip angles (min and max) and faulting styles? What is the seismogenic thickness? Are you including deep ruptures in the upper mantle (~30 km)? What is the largest magnitude in your sources (due to linked faults)? Do you have a complex multi-segment rupture with different rake/dip along strike? Do you have splay faults or overlapping segments?

Table 2 Focused questions for Workshop #1 Presenters: Session “GMC and SENSITIVITY ANALYSES”

Topic	Speaker	Questions / Topics to be addressed at WS #1
GMC Logic tree V0	Wooddell	Describe the GMC V0 Logic Tree. What are the limitations of the current V0 Logic Tree? What potential ground motion characteristics are not captured in the current V0 Logic Tree?
Hazard sensitivity analyses for the three sites	Gregor for DCPP / Dinsick for SONGS / Walling for PVNGS	Summarize the ground motion models used in the most recent seismic hazard study for the NPP site. What are uncertainties in the ground motion models that lead to the largest uncertainties in hazard at PGA, 20 Hz, 5 Hz and 0.5 Hz? What is the relative contribution of standard deviation uncertainties versus median uncertainties? For the median uncertainty, what type of faults (magnitude, distances, style of faulting etc…) or source parameters (dip, depth etc...) lead to the largest uncertainties?
Discussion: List of key Hazard sensitive GM Issues	All	What are the limitations on existing ground motion models? Have we captured all the relevant uncertainties?

Table 3 Focused questions for Workshop #1 Presenters: Session “GROUND MOTION PREDICTION EQUATIONs”

Topic	Speaker	Questions / Topics to be addressed at WS #1
GMPEs for active crustal regions: applicability for controlling sources	Stewart	What is the distribution of magnitude, distance, site conditions, style of faulting, period range for which the GMPEs are well constrained? Do the data include class 2 (aftershock) earthquakes? Summarize which model address HW effects and which do not? Summarize the base for the large magnitude scaling in those models (data available, theoretical bases or statistical extrapolation?).
NGA-West2 Database	Darragh	What is the distribution of magnitude, distance, site conditions, style of faulting, period range, depth distribution (Ztor, hypocentral depth etc…), dip angles, class 1 and class 2 in the NGA-West 2 Database? Show the correlations with magnitude and distance for the above parameters (i.e. break it up in several plots)
Discussion: Are Hazard sensitive sources well constrained by GMPEs?	All	Which Hazard sensitive sources are well constrained by GMPEs? Which are not well covered by the NGA-West2 Database?
	Boore	Is there adequate data to constrain oversaturation?
	Kalkan	Discuss the near-fault dataset (within 5 km) to constrain the median near-fault’s behavior of your model (reduction at very short distance).
	Baltay / Hanks	Describe the use of stress drop scaling (from small to large magnitudes) to constrain magnitude scaling. Do you see evidence for non-self similar scaling (i.e. not constant stress drop)?

Table 4 Focused questions for Workshop #1 Presenters: Session "DATA to CONSTRAIN GMPEs in CRITICAL RANGES"

Topic	Speaker	Questions / Topics to be addressed at WS #1
Directivity	Watson-Lamprey	Summarize the alternative directivity parameters from the NGA-West2 project. Describe the sampling of the directivity parameters with magnitude in the NGA-West2 Dataset. Show the correlation of the directivity parameters with magnitude, distance and site condition ($V_{S,30}$)
Hanging Wall	Donahue	Show the distribution of HW/FW recordings within 30 km event by event (plots of the HW effect for the events) in the NGA-West2 Database. What other HW data are available? Describe the HW data from SCEC simulations.
Fling	Kamai	Describe the dataset of records with both static displacement and standard processing in the NGA-West2 Database. Show the effect of standard processing on the response spectra for records with fling. Describe the currently available finite fault simulation dataset for fling effects.
Discussion on data to constrain near-fault effects	All	Are the available empirical recordings in NGA-West2 capturing the average directivity effect (centering)? Are the simulations centered for directivity effects? Are the static displacements data consistent with the finite-fault simulations in terms of permanent displacement?
	Graves	How was the range of source input parameters (distribution of hypocentral locations) for the simulations defined and what is the basis for it?
	Darragh	Be prepared to describe details of the static processed dataset if questions arise.
	Baker	Discuss the value of including the intermediate step of parameterizing the ground motion model in terms of magnitude, distance and pulse-period, rather than just parameterizing the ground motion model in terms of magnitude and distance.
Multi-fault rupture	Donahue	Summarize the complex multi-rupture events in the NGA-West2 Database in magnitude and distance space. What additional multi-fault cases are available that were not considered by NGA-West2 or where simplified into a simple fault rupture? Show plots of the stations and rupture geometry for each complex multi-fault rupture event (in NGA-West2 or other regions). Describe how dip, rake and depth are measured for complex ruptures.
Splays and linkage: dynamic rupture modeling	Harris	Describe the dynamic rupture verification effort for complex multi-fault segments ruptures. Are alternative methods leading to similar results? What is the schedule for the completion of the verification effort? What frequency bands are covered by the models?
Questions and Discussions on multi-fault ruptures	All	Are there additional complex multi-fault rupture cases with strong motion data that we have missed? What is the applicability of kinematic finite-fault simulations for multi-fault ruptures? Will the currently available simulation methods on the SCEC BBP work for complex multi-fault ruptures? Are there adequate data to validate simulations of complex ruptures?
	Somerville	If multi-fault ruptures are constructed from single-fault BBP simulations, what data are available to constrain the time delay between segments

	Continued	
	Aagaard	If multi-fault ruptures are constructed from single-fault BBP simulations, what data are available to constrain the time delay between segments
	Darragh	Be prepared to talk about the complex-ruptures in the NGA-West2 Database

Table 5 Focused questions for Workshop #1 Presenters: Session "USE of SIMULATIONS for SWUS GMC"

Topic	Speaker	Questions / Topics to be addressed at WS #1
Review on simulation validation from SCEC	Goulet	Describe the SCEC BBP validation exercise. Summarize (list-type) the methods being evaluated. What features are common among the methods? What features are unique among the methods? What is required in terms of source specification for each method? Provide examples of preliminary validation results. Include what is the schedule and planned process for the evaluation.
Discussion on simulation validation from SCEC	All	What are the current difficulties/challenges for the validation exercise for each modeler?
Discussions: Best uses of simulations (30 min) and Practical limitations (30 min)	All	What cases can the simulations provide the most benefit for SWUS (i.e. fill in the cases that are not well constrained by empirical data). What is the best use of numerical simulations (where do we trust simulation)? Do 1-D simulations satisfy the need?
	Jordan/ Maechling	What is the volume of simulations that can be run in the two-month time frame (multiple two-month time periods might be needed, up to three)?

Table 6 Focused questions for Workshop #1 Presenters: Session "ARIZONA GROUND MOTION DATA and ISSUES"

Topic	Speaker	Questions / Topics to be addressed at WS #1
Available GM data from Transportable Array in Arizona for both nearby earthquakes in Arizona and distant earthquakes in California	Watson-Lamprey	Describe the available data (magnitude, distance distribution) from the Transportable Array for central/southern Arizona at distances less than 100 km. Describe the available data (magnitude, distance distribution) from distant earthquakes in California and Mexico (at distances 200-300 km). Are these events from NGA-West2 or different datasets? Is site condition information available? What is the available event metadata (magnitude type, mechanism and depth)? What is the usable frequency band of the Arizona ground motions?
Additional GM data from Arizona from IRIS not part of the Transportable Array	Walling	Describe the available data (magnitude, distance distribution) from IRIS for central/southern Arizona, not part of the Transportable Array
Discussions: Do we have sufficient data to resolve geometrical spreading, anelastic attenuation, kappa, and stress drop differences between California and Central Arizona?	All	Do we have sufficient data to resolve geometrical spreading and stress drop differences between Arizona and California? Are there data with high-enough frequency content to resolve kappa? Do we have sufficient data to resolve anelastic attenuation differences in California and central Arizona? If not, are there any other sources of data? Do we need to expand to other regions (N. Arizona, Utah, Mexico)?
	Brumbaugh / Young	Are there any other ground motion data in Central Arizona that we have not considered?
	Lindvall	What is the tectonic relevance of N. Arizona and Utah to Central Arizona?
	Silva	Is there a point (or finite fault) source stochastic model developed for Arizona? If not, are the current data sufficient to derive one?
	A representative from CICESE	Discuss metadata (magnitude type, mechanism and depth) quality for earthquakes from Mexico recorded in Arizona. Do local earthquakes in the extension of the Basin&Range province in Mexico have similar ground motions to the ones in Central Arizona?

Table 7 Focused questions for Workshop #1 Presenters: Session "CALIFORNIA GROUND MOTION DATA and ISSUES"

Topic	Speaker	Questions / Topics to be addressed at WS #1
Regional GM data for DCPP	Wooddell	What are the regional ground motion data within 50 km from DCPP with M ≥ 3? Are there earthquakes with 5 and more recordings within 50 km? Present the ground motion data from DCPP free field station. What differences in the attenuation do you see with respect to the regional model? What are the 3D velocity structure models available for the site region within 30 km?
Regional GM data for SONGS	Dinsick	What are the regional ground motion data within 50 km from SONGS with M ≥ 3? Are there earthquakes with 5 and more recordings within 50 km? Present the ground motion data from SONGS free field station. What differences in the attenuation do you see with respect to the regional model? What are the 3D velocity structure models available for the site region within 30 km?

Continued		
CyberShake simulations for path effects near SONGS	Wang	Provide a summary of the CyberShake simulations, including employed rupture and velocity models for example. Do the SCEC 3D simulations show significant effects in the regions?
Discussions on data to derive path specific corrections to GMPEs	All	Considering both ground motion data and velocity structure, are there sufficient data to derive path specific correction to the GMPEs?
	Helmberger	Provide information on detailed modeling of the events close (within 30 km) to the NPP sites
	Heaton	Provide information on regional variability of geometrical spreading and attenuation characteristics within 100 km of NPP sites.

Table 8 Focused questions for Workshop #1 Presenters: Session "FRAGILE GEOLOGIC FEATURES"

Topic	Speaker	Questions / Topics to be addressed at WS #1
Discussions on fragile geologic features to constrain the hazard	Thompson for DCPP / Dinsick for SONGS / Lindlvall for PVNGS	Are there fragile geologic features at any of the sites whose age and failure ground motion would constrain the hazard at 10 -3 to 10 -6? Have there been surveys for FGF at or near any of the sites? If any features have been identified, what is the approximate age and failure ground motion?

Table 9 Focused questions for Workshop #1 Presenters: Session "REFERENCE CONDITIONS"

Topic	Speaker	Questions / Topics to be addressed at WS #1
Review of reference rock conditions	Donahue	What is the basis for selection of reference conditions? Cover the issues for using a common reference conditions at all three sites. Mention the need to specify the approach for adjusting the reference condition ground motions.
What is the kappa from the candidate GMPEs	Al-Atik	Describe the methods for estimating kappa for the candidate GMPEs and summarize the resulting kappa for each candidate GMPE
Kappa sensitivity for PVNGS	Silva	What is the kappa sensitivity at PVNGS?
Discussions on data to constrain kappa	All	Do we correct GMPEs to a single kappa? What data are available to constrain kappa? What data are available to constrain the rock kappa values at the 3 NPP sites?
	Silva	Does the Silva's kappa-VS,30 relation apply to Central Arizona?
	Anderson	Should there be regional differences in kappa for hard-rock sites (Central Arizona vs EUS)?
	Ktenidou	What are the main difficulties in estimating kappa that you have found from datasets you have evaluated (not from Arizona)? What is the variability in kappa estimates for a single site with recording from multiple earthquakes?

Table 10 Focused questions for Workshop #1 Presenters: Session "ADDRESSING SIGMA FOR SWUS GMC"

Topic	Speaker	Questions / Topics to be addressed at WS #1
SWUS plan for Sigma: ergodic vs. single station	Abrahamson	How will sigma be implemented at each of the sites? Ergodic or partially non-ergodic
Review of available data for single station sigma models	Al-Atik	What are the data available in the NGA-West2 Dataset for single station sigma? What are the 3D simulation data available for single station sigma?
World wide data available for single-station sigma and Φ_{S2S} differences.	Rodriguez-Marek	What are the world-wide data (non NGA-West2) available for single station sigma? What are the ranges for the Φ S2S values?
Discussions: Data needs and issues with single-station sigma	All	How would single station sigma be used at the 3 sites? What data (empirical or analytical) is available to estimate the site term at each site?

GROUND MOTION CHARACTERIZATION PRESENTATIONS

Day 1 Introduction

- Welcome and Introduction to the SWUS GMC WS #1 – Carola Di Alessandro (*GeoPentech, Inc.*)
- Sponsors' Perspective – Richard Klimczak (*Pacific Gas and Electric Company*) and Christopher Wandell (*Arizona Public Service*) in behalf of the SWUS Utilities Representatives
- Project Overview and Objectives – Norman Abrahamson (*Pacific Gas and Electric Company*)
- SSHAC Level 3 Training – William Lettis (*Lettis Consultants International, Inc.)*

Day 1 Resource Expert Presentations

- Overview of Seismic Source Characterization for the Diablo Canyon Power Plant – Steve Thompson (*Lettis Consultants International, Inc.*)
- SONGS SSC – Tom Freeman (*GeoPentech, Inc.*)
- Overview of the Seismic Source Characterization for the Palo Verde nuclear Generating Stations – Scott Lindvall (*Lettis Consultants International, Inc.*)
- Where are GMPEs well constrained – David Boore (*U.S. Geological Survey, Menlo Park*)
- Understanding NGA-West GMPEs: Smaller(er) Magnitude Theory and Trends – Annemarie Baltay (*U.S. Geological Survey, Menlo Park*)
- GK Model for Amplification of PGA at Near Field – Erol Kalkan (*U.S. Geological Survey, Menlo Park*)
- Ground Motion Characterization (GMC) Logic Tree (V0) – Kathryn Wooddell (*Pacific Gas and Electric Company*)
- Diablo Canyon SSHAC Level 3 Study, Hazard Sensitivity Analyses for DCPP – Nick Gregor (*NG Consulting*)
- SONGS GMC Sensitivity Analyses – Andrew Dinsick (*GeoPentech, Inc.*)
- Hazard Sensitivity for Palo Verde Nuclear Generating Station performed for South-Western United Stated (SWUS) Ground Motion Workshop 1 – Melanie Walling (*Lettis Consultants International, Inc.)*
- GMPEs for Active Crustal Regions: Applicability for Controlling Sources – Jonathan Stewart (*Univ. of California, Los Angeles*); includes material added during Day 2
- PEER NGA-West2 Database and Hazard Sensitive Sources – Robert Darragh (*Pacific Engineering & Analysis*)
- Hazard Sensitive Sources – Robert Darragh (*Pacific Engineering & Analysis*); Updated discussion material added during Day 2

Day 2 Resource Expert Presentations

- Directivity Parameters in the NGA West2 Dataset – Jennie Watson-Lamprey (*JWL Consulting*)
- Data to Constrain GMPEs in Critical Ranges – Hanging Walls – Jennifer Donahue (*Geosyntec*)

- Are Fling Effects Captured in NGA Models? – Ronnie Kamai (*PEER Center - Univ. of California, Berkeley*)
- Resource material: Processing of the PEER NGA-West2 Database – Robert Darragh (*Pacific Engineering & Analysis*)
- Resource material: Static Displacement (Fling) in the NGA-West2 Data Set - Robert Darragh (*Pacific Engineering & Analysis*)
- Data to Constrain GMPEs in Critical Ranges – Multi-Fault Ruptures – Jennifer Donahue (*Geosyntec*)
- The SCEC/USGS Rupture Dynamics Code Comparison Exercise – Ruth Harris (*U.S. Geological Survey, Menlo Park*)
- SWUS SSHAC Workshop 1, Broadband Ground Motion Simulations – Christine Goulet (*PEER Center - Univ. of California, Berkeley*)
- Broadband Computer estimates – Phil Maechling (*SCEC - Univ. of Southern California*)
- SWUS PVNGS Data Collection - Jennie Watson-Lamprey (*JWL Consulting*)
- South Western US Ground Motion Project Meeting – Melanie Walling *(Lettis Consultants International, Inc.*)

Day 3 Resource Expert Presentations

- California Ground Motion Data and Issues - Kathryn Wooddell (*Pacific Gas and Electric Company*)
- SONGS Ground Motion Data and Issues – Andrew Dinsick (*GeoPentech, Inc.*)
- Cyber Shake Simulations for Path Effects near SONGS – Feng Wang (*SCEC - Univ. of Southern California*)
- California Ground Motion Data and Issue – Doug Dreger (*Univ. California, Berkeley*)
- The Geophysics of Near Fault Ground Motions – Doug Dreger (*Univ. California, Berkeley*)
- Potential Use of Fragile Geologic Features – Robert Youngs (*AMEC*)
- Fragile Geologic Features Near Diablo Canyon Power Plant – Steve Thompson (*Lettis Consultants International, Inc.*)
- Review of Reference Rock – Jennifer Donahue (*Geosyntec*)
- Kappa for Candidate GMPEs – Linda Al Atik (*Al Atik Consulting*)
- Kappa Sensitivity for the PVNGS – Walt Silva (*Pacific Engineering & Analysis*)
- Seismic Ground Motion Hazards – John Anderson (*Univ. of Nevada, Reno*)
- Discussion of k issues – Olga-Joan Ktenidou *(ISTerre and PEER Center – Univ. of California, Berkeley*)
- Single-Station Sigma Using NGA-West2 Data – Linda Al Atik (*Al Atik Consulting*)
- World-wide Data Available for Single-Station Sigma and Regional Variation in the ϕ_{S2S} Term – Adrian Rodriquez-Mark (*Virginia Tech*)
- Resource material: Imperial P-Wave – Tom Heaton (*CalTech*)

TECHNICAL INTEGRATOR TEAM SUMMARIES and ACTIONS

Day 1 Summary

Speaker	Topic	Issue
Steve Thompson	DCPP Seismic Source Characterization	• Complex velocity model (3D vs. 1D) • Uncertainty with blind or buried faults • No technical basis to rule out splay faults • Not considering deep ruptures • Review deeper events, may have originated in slab (possible background source)
Tom Freeman	SONGS Seismic Source Characterization	• Inclusion of UCERF3 in the SSC may change rakes, dips, and seismic sources • Uncertainty regarding distance to closest fault: OBT and Offshore NI/RC faults • Splay faulting is coming up-dip • Horizontal splay faulting to be investigated as well • Not considering deep ruptures • Variability along strike, and dip
Scott Lindvall	PVNGS Seismic Source Characterization	• Mainly low slip rates • Background zones will dominate • Distances considered out to 400 km • Not considering deep ruptures • Mainly normal events, large magnitudes (up to M7.5), dips of 35-65

Speaker	Topic	Issue
Katie Wooddell	GMC Logic Tree V0	• Work in progress • Possible distance dependence of epistemic uncertainty
Nick Gregor	DCPP-Hazard Sensitivity analysis	• May need to include splay faults • Will include site-specific amplifications and single station sigma • Large range of current sigma models • Constraint on large uncertainty of epistemic uncertainty • Governed by faults within 10 km • Need a pdf for simulations at long periods (log-normal distribution)

Speaker	Topic	Issue
Andrew Dinsick	SONGS-Seismic Source Characterization	• Complex geometry (intercepting faults?) how to model in GMPEs? We need rules for complex rupture with the GMPEs • Review of simulation results for large magnitude, short distance, and long period • Review large differences in hanging wall effects • Will include directivity • Strike slip dist = 10km and reverse events Rjb = 0 • Will include single station sigma
Melanie Walling	PVNGS-Seismic Source Characterization	• Need hazard code consistent approach to HW effects for areal sources • Geometrical spreading, Regional Q • Large distance attenuation is required • Normal faulting events to M7 control hazard • Buried ruptures may be of issue

Speaker	Topic	Issue
J. Stewart	GMPEs for active crustal regions	• Review Japanese normal faulting event • Review Bindi Data for M>5 not captured in NGA-W2 dataset • Summary page of M-R pairs for all GMPEs • Mostly empirically based scaling for large magnitudes. • Hanging wall is mostly modeled by Rjb distance metric • About half of the datasets use aftershocks
B. Darragh	NGA-West2 Database	• Review Japanese M7.2 event (surface rupture, post-Tohoku) • Review Wells, Nevada M5.9 event, based on TA data • Remake graphs for M-R with $V_{s30} > 500$ m/s • For large magnitudes, there is not much improvement over NGA-W1
N. Abrahamson	Hazard sensitivities well constrained?	• How does saturation associate with ZTOR? (Somerville) • Data for near-fault bump for Imperial Valley, Northridge, Parkfield, Darfield • Empirical data showing oversaturation/saturation in source models (Boore), Oversaturation was rejected (Baltay)

Day 2 Summary

Speaker	Topic	Issue
Jennie Watson-Lamprey	Data to Constrain GMPEs in Critical Ranges: Directivity	• For simulations, use multiple methods (R. Graves) • Compare 1D and 3D directivity effects from simulations (K. Olsen) – Use existing 3D and compare with (new) 1D calculations. • Evaluate Wells EQ TQ array data for directionality (D. Dreger) • Pulse period correlated with Magnitude and only weakly with distance and site. • Directivity (un-normalized) strongly correlated with magnitude. Correlation needs to be addressed. • No data for large strike-slip case. Simulation data exists but directivity parameters have not yet been calculated. • Look at special cases, for example, normal/reverse events with significant slip along strike (D. Dreger)

Speaker	Topic	Issue
Jennifer Donahue	Data to Constrain GMPEs in Critical Ranges: Hanging Wall	• Graves ran strike-slip events with dip. We should evaluate the HW effects for dipping for strike-slip events from simulations (P. Somerville). Consider multiple simulation approaches. • Need to address HW effects for M5.5 to M6.5 not currently addressed for Japanese events. Will prob. Need to get at this through simulation. (A. Rodriguez – Marek) • Near source dynamic rupture is difficult to constrain. High uncertainty in this type of modeling (T. Heaton).

Speaker	Topic	Issue
Ronnie Kamai	Data to Constrain GMPEs in Critical ranges: Fling	• Missing data for large magnitudes at close distances • About 75 records have been processed to preserve static displacement. These are being supplemented with broadband simulations. • Many simulations available to supplement the data in the NGA database. • Filtering is impacting our results beyond about ~3 - 5 sec. If we are looking below 3 sec, the processing is not affecting our results much. Need to address potential effects in 3 – 5 sec range.

Speaker	Topic	Issue
Jennifer Donahue	Data to Constrain GMPEs in Critical ranges: Multi-Fault Ruptures	• Additional multi-fault cases that are available that were not considered by NGA-West2 (or were simplified into a simple fault rupture): John Bevin Darfield Model is more complex (get reference from Ralph A.), Christchurch and Darfield (could use more work – Bob. D.) • Need to update Superstition Hills (A&B) rupture model to remove non-mainshock slip. • Regarding Darfield: Bevin's mode had additional thrust segments on either end (more complicated than the current case). • Other approaches for parameterizing complex multi-fault ruptures: consider spatial variability in amplitude of the slip (not simple enough), RMS distance to segments (Brian suggests a different coordinate system GC2). • Graves – concern with distinguishing between geodetic and coseismic models

Speaker	Topic	Issue
Ruth Harris	Splays and Linkage: Dynamic Rupture Modeling	• Run case where hypocenter starts on the Shoreline • Run case where hypocenter is at junction between faults. • Verification for branched benchmark can be considered complete (5 models? Pass). • Run splay fault with heterogeneous stresses. This will require another benchmark. • Vary regional stress field to estimate how likely it is for one fault to rupture onto another (does it occur, how do we estimate the GM and frequency of occurrence)

Speaker	Topic	Issue
Christine Goulet	Splays and Linkage: Broadband Ground Motion Simulations	• 1D validation on track to be completed in June. • 3D effects will be considered in a broad sense in the uncertainties. Look at available 3D studies and augment with 1D • Acceptance out to 3 sec is probably ok. Out at long periods, the simulations may be providing a more accurate result. • Rupture generator reliable from M8 - M8.5? – large events from CyberShake. GM with very high Peak ground velocities (few rare events in CyberShake M8.4?). Check if rupture generators saturate.

Speaker	Topic	Issue
Doug Dreger	Discussion on Simulations: Summaries from Modeling Teams etc.	• Ralph Archuleta: Working out a frequency dependent Q is difficult. Every time you change kappa, you need a new greens function. Under-predicting spectral peak at 5 Hz (w.r.t. GMPE) • Kim Olsen: Hybrid method combining long period deterministic with high freq. stochastic based on Zeng et al crustal scattering. Have not considered freq. higher than 10 Hz. High freq. spectral accelerations adapted using low frequency level. If greens functions up to 1 Hz are not accurate enough, this could be a problem. 1D approach throws off the spectral level at 1 Hz. Scattering functions need to be convolved with slip rate functions at high frequencies (there are some candidate models for this). • John Anderson: Frequency dependent Q model is the current challenge. Kappa can be introduced in the end, but having a working Q model (that gives the right kappa) is preferable. Work on this is currently underway.

Speaker	Topic	Issue
Doug Dreger	Discussion on Simulations: Summaries from Modeling Teams	• Translating the Graves and Pitarka's src file into Irikura's asperity model with discrete asperities. Northridge and LP results don't seem very good using this approach. (P. Somerville). • Graves and Pitarka method: specifing the appropriate 1D velocity, Q model is difficult as you move to different regions. NO changes to the model are expected in the near term (R. Graves). • Kappa is a fixed parameter. With freq. dependent Q model, kappa0 will be calculated. Post processing will add the correction to kappa to get the effective kappa at the end that was specified. (R. Archuleta) • Definition of kappa is the slope of the FAS. In this project, kappa is extrapolating the slope back to zero km. If it is defined by FAS, freq. indepentent Q, then kappa is going to increase with distance (J. Anderson). • Japanese implementation of slip model is very deterministic. • High frequency Q is not controlled by data. • Multi-segment rupture is still not possible on BB Platform (lower priority).

Speaker	Topic	Issue
Abrahamson	Discussion: Best use of Simulations and Practical Limitations	• Look at data from 2 Japanese events (Kobe: M6.9 and Tottori: M6.6) – Zhao et al. • Check M5+ at within 50 km – Bindi et al.

Speaker	Topic	Issue
Jennie Watson-Lamprey	Available GM data from Transportable Array in Az for both nearby Eqs in AZ and distant Eqs in CA	• Additional AZ Data to Collect: Y13A data (will process), need to collect June 2012 M2.5 recordings, Jeri Young will send depth to bedrock values for nearby TA stations • Geometrical Spreading: good coverage for nearby stations (dist < 100 km) • Kappa: estimating Kappa_ds(mini) from these data should be possible, but need site conditions • Additional PVNGS Data to collect • Sufficient data near stations from CA and Baja Calif. Eqs to determine if the attenuation through Arizona differs significantly from CA • Need improved site characterization – geotechnical characterization (soil thickness and damping)

Speaker	Topic	Issue
Melanie Walling	Available GM data from Transportable Array in Az for both nearby Eqs in AZ and distant Eqs in CA	• Look into adding two additional events • This includes events in addition to catalog events • Are the additional events blasts or earthquakes: many mine blasts removed from the catalog (J. Young)

Speaker	Topic	Issue
Bob Youngs	Discussion	• Mine blasts may be useable data. Sue Hugh - Kappa from mine blasts in NV study (J. Anderson). Kappa higher because waves travel twice through highly attenuating zone rather than once. Not sure if mine blast will give 2*kappa • EQ clusters can be useful to evaluate sigma of kappa • Comparative study of little skull Mtn. and NTS Nuke (nearly co-located) could get at the kappa problem. • Should the Salton Trough be treated differently – large distance attenuation for AZ may need to be source region specific. • Importance of magnitude estimate in estimating kappa – should be simple, but there are alternative models. Involve the right people. (J. Anderson) • Datasets not yet considered: Historical intensities available for AZ (D. Brumbaugh) • One more potential datapoint: Rosevelt Dam & VA Hospital triggered on El Mayor – Cucapah (J. Young).

Day 3 Summary

DCPP region ground motion data

- Data for DCPP specific site effects (relative to GMPEs)
  - Strong motion data from 3 eqk
  - Basin waves seen from San Simeon earthquake recorded at DCPP
- Data for kappa for DCPP rock conditions
  - Deer Canyon
  - Small (M0.6 to M1.7) recorded on geophysical arrays
    - 25 to 300 Hz
- Path-Specific Effects
  - Focus on the path effects from nearby (15 km) offshore and onshore earthquakes (between Hosgri and Los Osos)
  - Few ground motions for these paths
  - Larger set of data from other paths within 100 km
    - Can be used to compare regional attenuation with GMPEs
- 3-D velocity models
  - Hardeback (2009) model from location of earthquake
  - New 3-D models being developed from recent onshore and offshore geophysical surveys (work by Dan O'Connell)
  - Need to use these studies to develop representative 1D models for use with Finite-fault simulations
    - Hosgri to DCPP
    - Los Osos to DCPP

SONGS Region ground motion data

- Data for SONGS specific site effects
  - Ground motions from distant earthquakes
  - At SONGS, about 1 km depth to V_S=3000 m/s
  - Broadband (BB) at SONGS:
    - 28 eqk M>3 within 200 km
    - Compare with other BB data in the southern California region
- Data for kappa for SONGS rock conditions
  - Look for M<3 events at short distance (< 30 km)
- Path-Specific Effects
  - Focus on the path effects from nearby (15 km) offshore earthquakes (out to Newport Inglewood) and directly below SONGS (OBT)
  - There is enough ground motion data from SoCal (Chino Hills) to check for regionalization of the attenuation (geometrical spreading) as compared to the GMPEs
- 3-D velocity models
  - SCEC 3-D model in SONGS region can be simplified to 1-D for this region

Simulations for Path Effects at SONGS

- CyberShake simulations
  - Large difference in 3D velocity models (S4 – H) in the SONGS region
    - Leads to significant difference in long period ground motion
  - Need to check if these velocity models apply to SONGS (near the edge of the SCEC region)
    - Can the ground motion data in the region provide a test of these two models?
    - Also, check consistency with the SONGS site-specific data for velocities
    - Is the gradient in from 760 m/s (ref) to 3000 m/s at SONGS consistent with the typical profile from data in the GMPEs?
  - Is the distance scaling from NI earthquakes (218, 219) to SONGS in CyberShake significantly different from the distance scaling in the GMPEs?
    - Focus on the long periods.

Other Data

- Look at OBS data to evaluate the distance scaling offshore in SONGS region (M. Kohler)
- Check the strong motion data sets for path differences in SONGS region
  - This data should be included in the NGA-west2 data set
- Theoretical modeling of the distance attenuation may be useful for understanding the short distance scaling of the GMPEs
  - Address this topic as part of Workshop 2

Fragile Geologic Features

- Are any FGF known to exist at any of the three NPP sites?
- DCPP
  - One promising FGF, but it is not ideal as compared to Yucca Mtn case
  - Needs age dating and fragility, and sensitivity on impacts on hazard
- SONGS
  - None identified by others, but no specific effort to look for FGF
  - SONGS foundation is on sandstone (San Mateo) with no damage (or dilation) to the sandstone over 125K years
    - Levels of shaking to damage sandstones not evaluated yet
    - Jack Daeman (UNR) may have looked at this along San Andreas, but not published.
- PVNGS
  - Some information on FGF in Arizona about 150 km north of PVNGS (Arrowsmith) – getting into the transition zone
  - FGF about 80 km from 1887 earthquake. Many non-toppled rocks

Reference Site Condition

- Consider a lower V_{S30} below 760 m/s
  - There is more data (better constrained GMPEs) at lower V_{S30} values (say 500-600 m/s)
- Kappa corrections are better constrained at high V_{S30} values
  - There is less correlation with kappa and site amplification for high V_{S30} sites
- What reference V_{S30} is best to use with the 3 sites consistent with site response approaches?

Kappa

- Potential differences in kappa on rock between Arizona and CA can lead to significant differences on the ground motion for PVNGS (Silva)
- Need to get an estimate of rock kappa for APS

Kappa discussion

- Use of small (M1) earthquakes to estimate kappa
  - May be useful, but consider multiple source models if working at freq below the corner freq (Anderson)
- Kappa for hard rock (EUS vs Arizona)
  - Also check regional Q for effects in the top 5 km, using freq dependent Q (Anderson)
  - If using kappa – V_{S30} relations:
    - Large scatter in kappa- V_{S30} relations for high V_{S30} values may reflect regional differences (Olga)
      - Try to get a relation for the specific region (not mixing regions)
    - Functional form may need lower limit at high V_{S30} for a specified region
    - May also depend on depth to bedrock
    - Need for good knowledge of the site in order to: (a) get a good estimate of V_{S30} (if k_0 - V_{S30} correlations are used)) and (b) be able to estimate/anticipate the 1D site amplification pattern, so as not to let resonant peaks distort the kappa estimate. (Olga)
  - Issues for site response effects on the kappa
    - Amplification peaks can distort the kappa estimate
    - Removing soil effects from surface motions to estimate (rock) kappa
  - Due to the large single-site variability shown for kappa, we need for as many records per site as possible to capture both the mean k_0 and the (possibly source-dependent) 'sigma' of the mean k_0 (Olga)

Kappa from small Mag

- Kappa for PVNGS region
  - Past experience estimating kappa from small magnitude events (M1-M2), with a limit of 14 Hz?
    - UNR studies for Yucca Mtn compared kappa from M1 with kappa from M4
- Kappa for DCPP region
  - Past experience with estimating kappa from small magnitudes events 25-300Hz?
    - None so far, but worth trying this approach

Data Needs and Issues for Single-Station Sigma

- Is there enough data to constrain PhiSS?
  - Data in NGA-West2
    - 364 eqk at 838 stations, dominated by CA data
    - Taiwan data in NGA-West2 is limited and may have a similar path effect
  - Data from world-wide data
    - Current paper: CA, Taiwan, Turkey, Japan
      - Data for distance dependent PhiSS
        - » Increase at short distances for small mag (M<5) only
      - Data for magnitude dependent PhiSS
        - » Best constrained by CA data set
    - New data set: Japanese data
      - M>4, about 30,000 records - data set will be complete at the end of summer 2013
      - Distances: Rrup for M>6.5, Rhypo for M<6.5
      - Will this lead to overestimation of PhiSS at short distances due to distance metric?

Data Needs and Issues for Single-Station Sigma

- Issues
  - To use PhiSS, epistemic uncertainty in the median site term needs to be included
  - Inclusion of epistemic uncertainty of PhiSS,s (how much does PhiSS change from site to site?)
    - This is a part of the epistemic uncertainty that has not been included in standard PSHA methodology
    - There is adequate data to estimate this for the entire data set, but unclear on site-specific application
    - So far, no attempt to look at the high PhiSS,s sites and understand what is causing the larger variability
      - Looking at the seismograms that may reveal what is happening
      - Is there something in the subsurface structure that would explain the high variability
      - Low variability sites may be from many earthquakes from the same path
      - It may partly reflect non-linearity (separately included in site response, be sure to avoid double counting
    - Topic for Workshop 2

How to Estimate Site Terms

- DCPP
  - Empirical, based on recordings at DCPP
  - Still small number of earthquakes, so large epistemic uncertainty
- SONGS
  - Analytical using uncertainty in the geotechnical parameters
  - May also have ground motion data at the SONGS site from new earthquakes from the new instrument
  - Are the site terms from nearby sites consistent? If so, they may help to inform site term at SONGS
- PVNGS
  - Plans to use a site specific site terms are being evaluated

Day 1 – Main points

- Import sources (M,R,F) for each site identified from hazard sensitivity (using existing models)
- Data sets (M,R,F) from which current GMPEs are derived
- NGA-West2 data (M,R,F)
  - Identified additional key events
    - M7.0 (Mw6.7) normal faulting Japanese earthquake (Fukushima Hamadori)
      - Additional (up to 10), M>5 in this sequence
    - Wells, Nevada eqk (normal)
    - Moderate mag normal events in Italy (check if included in NGA-West2)
    - Data for near-fault bump (GK model looks at 4 well recorded eqk)
- Large magnitude scaling
  - Oversaturation seen in empirical data at high freq (Boore)
  - See Full saturation for simple modeling of scaling (Baltay) – oversaturation not considered
  - Check if this is seen in new (planned) simulations?

Day 2 – Main Points

- HW
  - Include dipping Strike-Slip (some simulations exist)
  - HW effects for M5.5 to 6.5 not well constrained by NGA-West2 empirical data. Consider simulations. Japanese data may help, but need meta data
- Splay faulting
  - Still unclear what will be in source model
  - Consider alternative (distance) metrics for complex faulting
  - Review existing characterization of complex ruptures in NGA-West2
  - Implement dynamic rupture models,
    - Considering initiation of rupture on splay or down-strike on main fault
    - Add heterogeneous stresses

- Broadband simulations
  - Cases on spreadsheet (see next slide)
  - Care needed when using rupture generators for M>8

Model #	Issue	Magnitude	Distance (km)	Surface/ Buried, ZTOR (km)	Freq Range (Hz)	Addt. Notes
1	HW Scaling	5.5	0-15km	0, 5, 10	up to 10 Hz	Possibly only out to 10 km, and use dynamic ruptures
2	Splay Faulting	Main, 7 Splay, 6-6.5	0-15km		up to 10 Hz	Splay faults, key issue is timing between segments
3	Slip partitioning (T. Rockwell)	6.5-7.5	0-15km		up to 10 Hz	Specific for SONGS
4	Large mag scaling	7-8	0-15km		up to 10 Hz	Look at constraints at long periods, Wenchuan (low), ChiChi (high), oversaturation is at high frequencies
5	Low dip angle scaling (10 deg)	5.5-6.5	0-15km	5, 10	up to 10 Hz	Below 30 degrees, not constrained empirically, need buried, need close in
6	Linked, multi-segment faults (short distances)	8.5	0-15km		up to 10 Hz	Are rupture generators valid for M>8?, but expensive (time), oversaturation?
7	Large mag, long distances	7.5-8.5	400 km		1	Specific for PVNGS
	PDF - Long period energy at short distances (covered by #4)					

Arizona GM data

- Kappa
  - Need site conditions for key sites
  - Methods for small mag events with limited high freq bandwidth (14 Hz)
- Long distance attenuation
  - Empirical data adequate, but review needed for regionalization for path adjustment
- Consider use of intensity data as a check on GMPEs
  - Also check for additional GM data

LETTER COMMENTARY FROM THE PARTICIPATORY PEER REVIEW PANEL

April 21, 2013

Carola Di Alessandro, Ph.D.
Project Manager for the SWUS GMC SSHAC
GeoPentech, Inc.
525 N. Cabrillo Park Drive, Suite 280
Santa Ana, CA 92701

Dear Dr. Di Alessandro:

This letter provides comments from the Participatory Peer Review Panel (PPRP) on Workshop No. 1 (Significant Issues and Available Data) of the Southwestern U.S. Ground Motion Characterization (SWUS GMC) project. The PPRP wishes to thank the management team for the opportunity to participate in the workshop, which was held on March 19-21 in Oakland, California. The PPRP participated as observers, in order to be informed and to provide a review of both the process and the technical developments. All four members of the PPRP (K. Campbell, B. Chiou, S. Day, and T. Rockwell) attended, and the panel observed all aspects of the workshop. The workshop was organized in a very professional and effective manner, and we appreciate the hospitality shown to us by the project team.

Summary Comments

The technical program was organized and conducted with the highest level of professionalism. As appropriate for the first workshop of a SSHAC Level 3 study, the focus was on framing the hazard issues, identifying available data, and identifying key data needs. The workshop began with a summary of the project, including clear statements of its objectives and scope. The SWUS GMC project interfaces with the three separate Seismic Source Characterization (SSC) studies supported by the respective sponsoring utilities. A series of presentations on the first day of the workshop outlined the principal seismic source issues for each site, expressed in terms of hazard sensitivity. This introduction was very useful in setting the broader context for the GMC study and in enabling subsequent discussions to focus on data that are most relevant to hazard.

The resource-expert presentations that followed were well chosen, well structured, and comprehensive, and each included a list of references. All five members of the Technical Integration (TI) Team were fully engaged in the discussions of these presentations and each played a valuable role in interrogating the presenters. The PPRP is unaware of any relevant avenues that were not explored.

The TI Team did a commendable job of keeping the workshop focus on the data issues, as is appropriate for the first workshop of a SSHAC Level 3 study. Maintaining the right focus was challenging, because the line between data and interpretations or models is not a sharp one, but the team found the right balance. A clear separation of roles was maintained. For example, when occasionally a TI or PPRP Team member was required to comment in the role of a resource expert, that role was always clearly stated.

In summary, with respect to process, as well as with respect to technical quality and completeness, the workshop met all standards for a SSHAC Level 3 data workshop. A good foundation has been set for the exploration of proponent models in Workshop No. 2.

Specific comments and recommendations are given below. Those specific comments, suggestions, or recommendations that require a written response are underlined.

Recommendations

1. Site Kappa and Single-Station Sigma Terminology. Several resource experts presented very interesting and insightful information on the data needed to estimate the site attenuation parameter kappa and the ground motion standard deviation parameter single-site sigma. However, this material is quite technical and some of it is quite new. Not all participants and observers seemed to have a shared understanding of the terminologies being employed or how the estimated quantities can be applied in a self-consistent manner at each of the nuclear power plant sites where they will be used. Our concern comes partly from the lack of probing questions of the kappa and single-site sigma resource experts from the TI Team, partly from a lack of significant questions from the audience, and partly from questions expressed by members of the PPRP. <u>Therefore, the PPRP suggests that the TI Team write White Papers, i.e., authoritative technical notes, on site kappa and single-station sigma, respectively, that define the terms, indicate how they are going to be estimated, and how they are to be used in the seismic hazard analysis of each of the NPPs.</u> These documents would provide a common language and reference frame for future discussions and help allay concerns about possible double counting or other inconsistencies in these two parameters.

2. Splay Fault Modeling. The workshop included some discussion of dynamic rupture modeling of splay faulting, especially models leading to possible concurrent rupture of the Hosgri and Shoreline faults. Our understanding is that SCEC has been tasked with performing such modeling. We are concerned that this effort may not be as well interfaced with the relevant SSHAC projects (the DCPP and SONGS SSC studies and the SWUS GMC study) as it could be. In particular, the occurrence and extent of concurrent rupture on a splay depends quite strongly on the orientation of the maximum principal stress direction. It is likely also to be sensitive to rupture velocity. The SCEC team tasked for this work has been principally focused on canonical test problems for the purpose of code verification; it should not simply be assumed that the SCEC group has sufficient expertise and experience in the specific rupture dynamics questions being posed by the SSHAC projects to operate independently. The presentation at the workshop did not suggest that the SCEC team recognizes the importance of the principal stress orientations, nor the importance of exploring conditions conducive to a range of rupture velocities. We recommend that the SWUS GMC project and the other relevant SSHAC projects devise a plan to provide ongoing guidance and feedback to the SCEC modeling team.

3. *DCPP-SSC interface issue: Slab Earthquakes*. During the workshop, the possibility of earthquakes within a relic subducted slab beneath DCPP was broached during the presentation overviewing the DCPP SSC project. To our knowledge, this possibility of slab sources had not been mentioned at previous DCPP SSC workshops, and from the discussion at the workshop, it was not clear which project takes responsibility for assessing its technical defensibility and implications. Slab earthquakes are known to excite ground motion with systematically distinct characteristics relative to crustal sources. We recommend that the two projects clarify the lines of responsibility and establish effective communication on this subject so that the TI Team is not taken by surprise if slab events are characterized in the DCPP SSC.

4. *DCPP-SSC and SONGS-SSC interface issue: Maximum depth of rupture in crustal earthquakes*. During the DCPP-SSC overview presented at the workshop, the possibility was raised of deep rupture penetration, i.e., rupture extending to greater than 15-20 km depth, on some crustal faults in California. The SWUS-GMC TI Team seemed unaware that this was a possibility in the DCPP SSC project and it was not clear to us which project takes responsibility for the technical assessment of deep rupture. Furthermore, although this issue was not raised in the SONGS-SSC overview, similar depth-of-rupture considerations may pertain to both California sites. We recommend that the SWUS-GMC project work with the DCPP-SSC and SONGS-SSC projects, respectively, to clarify ownership of the depth-of-rupture problem and begin to communicate effectively and regularly about the status and implications of those ideas.

5. *Path-Specific Attenuation for Palo Verde*. The attenuation of ground motion between distant earthquakes and PVNPS may be quite strongly dependent upon the source location and might not be well represented by a single function of distance. The TI Team clearly recognizes this likelihood and has taken it into consideration in their plan to empirically estimate attenuation from distant sources to PVNPS using existing recordings from relevant source regions. We consider this a sound approach. However, the PPRP would suggest that the empirical approach be carefully applied in the light of a geological understanding of both the source and path regions (for example, it might be observed that paths crossing the Salton Trough are highly attenuative and geologic understanding might dictate that the same empirical correction not be applied to nearby sources that do not cross that province).

6. *Hand-off to Site-Specific Site-Response Analysis Team*. The GMC TI Team is proposing to characterize ground motions for a common reference rock condition with V_{S30} = 760 m/s and to adjust the base case GMC model to incorporate utility-specific differences in site characteristics and modeling approach. We understand that each utility will adjust the resulting rock hazards to the local site condition at each NPP site when deriving the Hazard-Consistent Ground Motion Response Spectra (GMRS). The TI Team have acknowledged the need for interaction between these two efforts and emphasized the importance of proper handoff of the GMC model to the team responsible for site-specific site-response analysis. Still, we want to further emphasize it here by cautioning that lack of clarity and precision in the communication between the GMC TI Team and the site response analysis team may make both vulnerable to misunderstandings and claims of inconsistency or double counting of effects. We recommend that the TI Team and the individual site projects collaborate to generate as soon as possible a reference document that describes the respective adjustments and procedures to be used at each site, and that explains the technical rationale in each case. As with the documents on kappa and single-site sigma recommended in Item 1 above, such a document would serve to guide future discussions, prevent

misunderstandings, and ensure that no relevant data or models are neglected due to uncertainties about which project is responsible.

Please feel free to contact us if you would like to discuss further our comments or recommendations.

Sincerely,

Steven M. Day Chair, PPRP	Kenneth Campbell Member, PPRP
Brian Chiou Member, PPRP	Thomas Rockwell Member, PPRP

TECHNICAL INTEGRATION TEAM LEAD RESPONSES TO PARTICIPATORY PEER REVIEW PANEL COMMENTS

May 5, 2013

Steven M. Day
Chair, Participatory Peer Review Panel
Department of Geological Sciences
San Diego State University
5500 Campanile Drive
San Diego, California 92182

Dear Prof. Day:

The TI Team and PM appreciate the valuable comments and suggestions received from the Participatory Peer Review Panel (PPRP), both during the Workshop No. 1 execution and in their formal letter commentary dated April 21, 2013. The present document serves to provide written responses to specific comments, suggestions, or recommendations that the PPRP identified (by underlining).

1. *Site Kappa and Single-Station Sigma Terminology*
   Several resource experts presented very interesting and insightful information on the data needed to estimate the site attenuation parameter kappa and the ground motion standard deviation parameter single-site sigma. However, this material is quite technical and some of it is quite new. Not all participants and observers seemed to have a shared understanding of the terminologies being employed or how the estimated quantities can be applied in a self-consistent manner at each of the nuclear power plant sites where they will be used. Our concern comes partly from the lack of probing questions of the kappa and single-site sigma resource experts from the TI Team, partly from a lack of significant questions from the audience, and partly from questions expressed by members of the PPRP. <u>Therefore, the PPRP suggests that the TI Team write White Papers, i.e., authoritative technical notes, on site kappa and single-station sigma, respectively, that define the terms, indicate how they are going to be estimated, and how they are to be used in the seismic hazard analysis of each of the NPPs.</u> These documents would provide a common language and reference frame for future

discussions and help allay concerns about possible double counting or other inconsistencies in these two parameters.

We agree. Our plan is to coordinate the preparation of the requested White Papers with the effort already initiated by Dr. Linda Al-Atik (a member of the TI Team Support group) for the Hanford site SSHAC project. In this way, in addition to providing a common understanding of the issues and terminology for the SWUS GMC project, we will address consistency with the other ongoing SSHAC projects conducted in the Western US region.

2. *Splay Fault Modeling*

   The workshop included some discussion of dynamic rupture modeling of splay faulting, especially models leading to possible concurrent rupture of the Hosgri and Shoreline faults. Our understanding is that SCEC has been tasked with performing such modeling. We are concerned that this effort may not be as well interfaced with the relevant SSHAC projects (the DCPP and SONGS SSC studies and the SWUS GMC study) as it could be. In particular, the occurrence and extent of concurrent rupture on a splay depends quite strongly on the orientation of the maximum principal stress direction. It is likely also to be sensitive to rupture velocity. The SCEC team tasked for this work has been principally focused on canonical test problems for the purpose of code verification; it should not simply be assumed that the SCEC group has sufficient expertise and experience in the specific rupture dynamics questions being posed by the SSHAC projects to operate independently. The presentation at the workshop did not suggest that the SCEC team recognizes the importance of the principal stress orientations, nor the importance of exploring conditions conducive to a range of rupture velocities. <u>We recommend that the SWUS GMC project and the other relevant SSHAC projects devise a plan to provide ongoing guidance and feedback to the SCEC modeling team.</u>

We note that SCEC has not been tasked with conducting dynamic rupture calculation for splay faulting for SWUS GMC. The activities at SCEC have focused only on code verification (i.e. to make sure codes are working as intended) for splay fault geometries that are relevant to DCPP and SONGS. Based on the results of the verification, we will identify potential groups for conducting dynamic rupture simulations for SWUS GMC Project. However, the decision on the extent of use of dynamic rupture simulations has not yet been made.

Our plan is for the TI Team (in particular Prof. Doug Dreger) to work in close contact with the SCEC dynamic rupture verification coordinator (Dr. Ruth Harris of USGS) to understand the role played by stress orientation and rupture velocity in the validation exercise. In addition, we will recommend that representatives from the SSC Teams meet with Ruth Harris to discuss the use of dynamic ruptures for constraining characteristics and frequencies of splay fault ruptures. This information can be used to constrain the source characterization for splay faulting.

3. *DCPP-SSC interface issue: Slab Earthquakes*
   During the workshop, the possibility of earthquakes within a relic subducted slab beneath DCPP was broached during the presentation overviewing the DCPP SSC project. To our knowledge, this possibility of slab sources had not been mentioned at previous DCPP SSC workshops, and from the discussion at the workshop, it was not clear which project takes responsibility for assessing its technical defensibility and implications. Slab earthquakes are known to excite ground motion with systematically distinct characteristics relative to crustal sources. We recommend that the two projects clarify the lines of responsibility and establish effective communication on this subject so that the TI Team is not taken by surprise if slab events are characterized in the DCPP SSC.

We agree and will engage the DCPP SSC Project Team to address the potential for slab earthquakes in the DCPP region. The final decision for inclusion or exclusion of slab earthquakes lies with the SCC Team but information from ground motion experts that maybe relevant to the SSC Team evaluation will be provided by the SWUS GMC project.

4. *DCPP-SSC and SONGS-SSC interface issue: Maximum depth of rupture in crustal earthquakes*
   During the DCPP SSC overview presented at the workshop, the possibility was raised of deep crustal earthquakes, i.e., greater than 15-20 km deep, on some crustal faults in California. The SWUS GMC TI Team seemed unaware that this was a possibility in the DCPP SSC project and it was not clear to us which project takes responsibility for the technical assessment of deep crustal earthquake modeling. We recommend that the two projects clarify ownership of the depth-of-faulting problem and begin to communicate effectively and regularly about the status and implications of those ideas.

We agree. Information on the maximum depth of rupture may be available from source inversions commonly used in ground motion studies that are not yet being considered by the DCPP and SONGS SSC TI Teams. Ensuring that this interface issue is addressed is the responsibility of the Project Technical Integrators (PTIs) for the SSC and GMC efforts for each site. We will provide examples of ground motion inversion studies to demonstrate the range of depth-of-ruptures implied by these studies so that the SSC TI Teams are fully informed. The final decision for the distribution of rupture depths lies with the individual SSC Teams.

5. *Path-Specific Attenuation for Palo Verde*
   The attenuation of ground motion between distant earthquakes and PVNPS may be quite strongly dependent upon the source location and might not be well represented by a single function of distance. The TI Team clearly recognizes this likelihood and has taken it into consideration in their plan to empirically estimate attenuation from distant sources to PVNPS using existing recordings from relevant source regions. We consider this a sound approach. However, the PPRP would suggest that the empirical approach be carefully applied in the light of a geological understanding of both the source and path regions (for example, it might be

observed that paths crossing the Salton Trough are highly attenuative and geologic understanding might dictate that the same empirical correction not be applied to nearby sources that do not cross that province).

We agree. The SWUS GMC TI Team will consider different regions (one being the Salton Trough region) when evaluating the residuals to derive empirical correction factors applicable to PVNGS. In order to preserve the statistical robustness of the analysis, we are expanding our ground motion dataset so to include more earthquakes generated in central California (up to 400 km from the Arizona border) and recorded by stations in Arizona located up to 100 km away from PVNGS, but still within the Sonoran Basin and Range zone as prescribed/mapped by the associated SSC effort. These additional earthquakes will allow us to evaluate the need for different path effects through the Salton Trough versus other path effects.

6. *Hand-off to Site-Specific Site-Response Analysis Team*

   The GMC TI Team is proposing to characterize ground motions for a common reference rock condition with V_{S30} = 760 m/s and to adjust the base case GMC model to incorporate utility-specific differences in site characteristics and modeling approach. We understand that each utility will adjust the resulting rock hazards to the local site condition at each NPP site when deriving the Hazard-Consistent Ground Motion Response Spectra (GMRS). The TI Team have acknowledged need for interaction between these two efforts and emphasized the importance of proper handoff of the GMC model to the team responsible for site-specific site-response analysis. Still we want to further emphasize it here by cautioning that lack of clarity and precision in the communication between the GMC TI Team and the site response analysis team may make both vulnerable to misunderstandings and claims of inconsistency or double counting of effects. We recommend that the TI Team and the individual site projects collaborate to generate as soon as possible a reference document that describes the respective adjustments and procedures to be used at each site and that explains the technical rationale in each case. As with the documents on kappa and single-site sigma recommended in Item 1 above, such a document would serve to guide future discussions, prevent misunderstandings, and ensure that no relevant data or models are neglected due to uncertainties about which project is responsible.

We agree. Although site response is not part of the deliverable for SWUS GMC, the approaches being used for site response at the three NPP sites need to be understood and clearly documented to ensure a consistent interface between the base case ground motion and site response. The final decision on site response approaches lies with the individual NPP sites.

We plan on issuing a White Paper describing the site-response approaches being used at each of the three sites; this document will include the technical base for the selection of the reference rock conditions.

We hope this letter clarifies the questions and comments stated in the April 21, 2013 PPRP Commentary Letter. We wish to express our gratitude to the PPRP again for their efforts and cooperation, and for making this project a success.

Sincerely,

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Norman A. Abrahamson,
SWUS GMC TI Team Lead

CC: PPRP Panel, TI Team, PTIs

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