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DCPP's Seismic Risk is bounded by the Predicted Energy Released by Hosgri Fault

For the convenience of the California Energy Commission, attached find some relevant files merged into a single document from the Central Coast Seismic Imaging Project (CCCSIP.) The provenance of all of the files is documented within.
The purpose of this submission is to form a portion of my planned rebuttal to the 08 May 2015 submission to this docket by Attorney John Geesman and Intervenor Rochelle Becker. These files support the contention that DCPP will continue to operate safely with an adequate safety margin in the event of any nearby earthquake. As one of my filings dated 29 April 2015 (TN 204429) noted, the Nuclear Regulatory Commission and their panel of seismologists reaffirmed this DCPP safety-related conclusion in a hearing that occurred on 28 April 2015.

Additional submitted attachment is included below.

http://www.pge.com/en/safety/systemworks/dcpp/seismicsafety/report.page Archived 09 10 14 by Gene A. Nelson, Ph.D. Each document includes source web link.

Central Coastal California Seismic Imaging Project

File information for all these 42 downloaded files on my computer: 798 MB (837,412,713 bytes)

Part One: Marine Studies

Part Two: Land Studies

Part Three: Geotechnical Studies

Conclusions

TECHNICAL SUMMARY

Between 2010 and 2012, the Pacific Gas and Electric Company (PG&E) performed a series of three-dimensional (3D) and two-dimensional (2D) low-energy and high-energy seismic-reflection surveys, along with other geological and geophysical investigations, to explore fault zones near the Diablo Canyon Power Plant (DCPP), as recommended in the California Energy Commission's (CEC) 2008 report "An Assessment of California's Nuclear Power Plants: AB 1632 Report" (referred to herein as the "AB 1632 Report"). PG&E has documented its activities performed in accordance with the CEC recommendation in the "Central Coastal California Seismic Imaging Project Report" ("CCCSIP Report"), and compares the results with the deterministic seismic hazard assessment presented in the 2011 Shoreline Fault Zone Report (PG&E, 2011a).

Background

The following reviews the regulatory history of Assembly Bill 1632 (AB1632), the CCCSIP, and the role of the California Public Utility Commission's Independent Peer Review Panel.

Regulatory

Assembly Bill 1632 (Blakeslee, Chapter 722, Statutes of 2006) directed the CEC to assess the potential vulnerability of California's large-baseload power-generation facilities (1,700 megawatts or greater) to a major disruption due to a seismic event or plant aging. The AB 1632 Report contained a recommendation from the CEC that PG&E use 3D geophysical seismic-reflection mapping and other advanced techniques to explore fault zones near the DCPP. This recommendation was made to supplement PG&E's Long Term Seismic Program (LTSP) and help resolve uncertainties surrounding the seismic hazard at the DCPP (CEC, 2008).

PG&E filed Application (A.) 10-01-014 with the California Public Utilities Commission (CPUC) on 15 January 2010 for cost recovery of $16.73 million associated with the enhanced seismic studies recommended by the AB 1632 Report. PG&E proposed the following three programs of the CCCSIP:

- Marine 2D/3D seismic-reflection surveys: low-energy and high-energy.
- Land 2D/3D seismic-reflection surveys: shallow- (low-energy) and deep-penetration (high-energy).
- Ocean bottom seismometer (OBS) array installation.

The CPUC issued Decision (D.) 10-08-003 to perform these studies on 12 August 2010. On 13 September 2011, PG&E filed a motion to reopen A. 10-01-014 to request additional funding for increased costs of conducting enhanced seismic studies at the DCPP. The CPUC issued D.12-09-008 on 12 September 2012 authorizing PG&E to recover an additional $47.5 million above the $16.73 million already approved in D. 10-08-003, for a total of $64.25 million.

Independent Peer Review Panel

CPUC D. 10-08-003 established an Independent Peer Review Panel (IPRP) to evaluate and report on PG&E's study plans and review the findings and/or results associated with the seismic studies, and D. 12-09-008 ordered the CPUC Energy Division Director to coordinate these tasks. The IPRP is composed of representatives from the following state agencies:

- California Coastal Commission
- California Emergency Management Agency
- California Energy Commission
- California Geological Survey
- California Public Utilities Commission
- California Seismic Safety Commission

A representative from the County of San Luis Obispo was added to the IPRP in 2012.

Technical

The following sections summarize the identification and selection of CCCSIP survey activities to address and reduce the uncertainty for specific hazard-significant parameters, and the key findings and results of the CCCSIP effort with regard to those hazard-significant parameters.

Previous Geologic/Geophysical Studies

Following the initial identification of the Shoreline fault offshore of the DCPP in 2008 (PG&E, 2010), PG&E conducted an extensive program in 2009 and 2010 to acquire, analyze, and interpret new geologic, geophysical, seismologic, and bathymetric data as part of the ongoing PG&E LTSP Update. The Shoreline Fault Zone Report (PG&E, 2011a) focused on constraining four main source-characterization parameters needed for a seismic hazard assessment: geometry (fault length, fault dip, down dip width), segmentation, distance offshore from DCPP, and slip rate. Probabilistic seismic hazard analysis (PSHA) determined that the Hosgri Fault Zone (HFZ) was the largest contributor to seismic hazard at the DCPP, with lesser, but significant contributions from the Los Osos, Shoreline, and San Luis Bay faults (PG&E, 2011a).

CCCSIP Geologic/Geophysical Studies

Geologic and geophysical surveys conducted by PG&E as part of the CCCSIP between 2010 and 2012 provided new geologic and geophysical data to further improve the source characterization of the Hosgri, Los Osos, San Luis Bay, and Shoreline fault zones. Marine and land survey activities were prioritized with input from the IPRP. The prioritization was based on (1) identification of the key seismic source parameters that had a significant impact to probabilistic seismic hazard at the DCPP site and (2) the overall likelihood that information from the proposed survey would reduce the uncertainty associated with each parameter. The following hazard-significant parameters were considered for investigation:

1. HFZ slip rate
2. HFZ dip
3. Shoreline fault zone slip rate
4. Hosgri–San Simeon fault zone step-over
5. Los Osos fault zone dip
6. Los Osos fault zone sense of slip
7. Los Osos fault zone slip rate
8. Hosgri/ Shoreline fault zone rupture
9. Shoreline fault zone southern end
10. Shoreline fault zone segmentation

A series of 2D and 3D offshore and onshore low-energy and high-energy seismic surveys (LESS and HESS, respectively) were proposed to collect information related to these parameters. Onshore and offshore LESS studies targeted shallow geologic structures and recent geomorphic features in order to evaluate recent fault activity. Onshore high energy studies imaged the deeper crustal structure of the Irish Hills. Offshore HESS studies were proposed to image deeper crustal structure to further constrain the geometry of and interactions between the Hosgri, Shoreline, and other offshore faults. The California State Lands Commission (CSLC) granted the Geophysical Survey Permit needed to conduct the HESS activities in August 2012; however, the California Coastal Commission (CCC) denied PG&E's application in November 2012 due to concerns about the environmental impact of these studies. In lieu of conducting the HESS, data from other geophysical investigations were used to constrain fault geometries and interactions at depth.

PG&E installed an array of four three-component broadband ocean bottom seismometers and accelerometers in the region offshore of the DCPP in 2013. The objective of the OBS array is to improve earthquake detection capability and location accuracy for earthquakes on the continental shelf adjacent to the Hosgri and Shoreline fault zones as well as constrain the path effects from these offshore events to the DCPP. Data are streamed in real time to the PG&E Central Coast Seismic Network for distribution to the U.S. Geological Survey (USGS) and the California Integrated Seismic Network.

Besides the investigations conducted as described above, two issues were raised during the course of the CCCSIP. The first issue was related to testimony submitted by the Alliance for Nuclear Responsibility on behalf of Dr. Douglas H. Hamilton concerning the Diablo Cove fault and the postulated San Luis Range/ Inferred Offshore fault. PG&E committed to addressing Dr. Hamilton's concerns using the data collected by the CCCSIP (CPUC D.12-09-008). The second issue concerned site response at the DCPP and was raised in IPRP Report #6 (IPRP, 2013). The IPRP requested that PG&E validate the shear-wave-velocity profile under the DCPP and justify the site factors used to develop the ground motions provided in the Shoreline Fault Zone Report (PG&E, 2011a).

The CCCSIP report, along with all associated data, will be provided to the DCPP Seismic Source Characterization (SSC) Level 3 Senior Seismic Hazard Analysis Committee (SSHAC) Technical Integration Team to evaluate and integrate into an SSC model for input into the NRC-required March 2015 probabilistic seismic hazard analysis (PSHA) update for the DCPP. The 2D and 3D marine seismic data collected by the CCCSIP are available from the USGS National Archive for Marine Seismic Surveys at http://walrus.wr.usgs.gov/NAMSS/. The 2D and 3D land seismic data are available from the Data Management Center of the Incorporated Research Institutions for Seismology at www.iris.edu/dms/nodes/dmc/.

Study Results

This section summarizes the key findings and results of the CCCSIP effort with regard to the hazard-significant parameters. CCCSIP Report chapters are identified that contain further discussion. Table 1 compares the SSC parameters used in the 2011 Shoreline Fault Zone Report and Hazard Sensitivity Study Report (PG&E, 2011a, 2011b) with the revised parameters presented in this report.

1. Hosgri Fault Slip Rate

- The preferred slip rate for the Hosgri fault, based on the LESS mapping, is 1.6 to 1.8 mm/yr. This range is similar to, but less than, the preferred slip rate of 2.25 mm/yr used in the Shoreline Fault Zone Report (see Chapter 3).

Reducing the uncertainty in the rate of fault slip of the Hosgri Fault Zone (HFZ) was ranked highest of all the study targets identified. High-resolution 3D LESS mapping of marine channels offset by the HFZ at two locations (western Estero Bay and offshore Point Sal) was used to measure fault offsets and estimate fault slip rates. Although there are only broad constraints on the ages of the offset channels in western Estero Bay and offshore Point Sal, the data preclude a maximum slip rate of 6 mm/yr. that was used in the Shoreline Fault Zone Report and, instead, favor a slip rate that is slightly lower than the slip rate used in that report.

2. Hosgri Fault Dip

- Potential field and seismicity studies support the range of dip angles (80°- 90° NE) for the HFZ used in the Shoreline Fault Zone Report (see Chapter 6).

Potential field mapping in Estero Bay (north of the DCPP) and Point Sal (south of the DCPP) and earthquake relocations (Hardebeck, 2010, 2013) indicate that the HFZ has a vertical to steep dip in the upper 12 km of crust. Older deep-penetration common-depth-point (CDP) seismic-reflection and seismic-refraction data also indicate a vertical to steeply (>75°) east-dipping Hosgri fault at shallower depths (< 5 km).

3. Shoreline Fault Slip Rate

- The LESS study determined slip rates for the southern Shoreline fault in San Luis Obispo Bay. Although there are only broad constraints on the ages of the offset channels used to define these slip rates, the data preclude a slip rate as high as 1 mm/yr and support a lower rate of 0.06 m/yr. (Chapter 3).

As with the HFZ, uncertainty in the rate of fault slip along the Shoreline fault zone has a significant impact on hazard (PG&E, 2011b). High-resolution 3D LESS mapping in San Luis Obispo Bay identified the Shoreline fault as a through going structure and identified a number of piercing points (buried fluvial channels and paleoshorelines) for offset measurements and slip rate estimates (Chapter 3).

4. Hosgri–San Simeon Step-Over

- Connectivity between the Hosgri and San Simeon fault zones could accommodate the occurrence of longer, more infrequent earthquakes with a potentially larger magnitude (M 7.3) than was previously considered in the Shoreline Fault Zone Report (M 7.1). The ground motions resulting from these larger earthquakes are discussed in Chapter 13.

The LTSP Report (PG&E, 1988) identified a step-over or segmentation point between the Hosgri and San Simeon faults, offshore of Point Estero, which was interpreted to be a barrier to through going earthquake rupture. Consequently, the maximum length of a Hosgri fault earthquake was limited to 110 km, and the corresponding maximum magnitude was M 7.2. Review of recently collected 2D LESS data by the USGS and older deep-penetration CDP marine seismic-reflection profiling data in Chapter 4 indicates that while a structural connection most likely exists between the eastern strand of the Hosgri fault and the San Simeon fault, the evidence for recent fault rupture at this intersection is not well imaged. Nevertheless, possible linkage between the San Simeon and Hosgri faults is addressed in Chapter 13, *Hazard Sensitivity and Impact Evaluation.*

5. Los Osos Fault Dip

- Steep (55°–82°) south-dipping faults are interpreted in seismic-reflection profiles to project updip along the northeastern front of the Irish Hills to mapped surface traces of the Los Osos fault. These fault dips are generally consistent with the range of Los Osos fault dip angles (45°–75°) used in the Shoreline Fault Zone Report, but with a steeper minimum dip (55° verses 45°). Seismic-reflection data indicate that the Los Osos fault becomes a blind or buried fault beneath the north-central and northwestern Irish Hills, and that it may die out westward beneath a west-plunging anticline.

Chapter 7 discusses the land 2D and 3D low- and high-energy seismic-reflection results for the Los Osos fault zone. In addition to reducing the parametric uncertainty in the hazard sensitivity study discussed in Chapter 13, the seismic-reflection data for the Los Osos fault will be considered in the update to the SSC SSHAC model.

6. Los Osos Fault Sense of Slip

- The sense-of-slip values used in the Shoreline Fault Zone Report for a reverse-oblique slip fault were retained for use in the sensitivity presented in Chapter 13.

Geologic mapping performed in support of the onshore seismic studies (Chapter 9) reviewed and refined the earlier mapping of the Los Osos fault by Lettis and Hall (1994). Among the topics addressed by mapping was an assessment of whether the Los Osos fault zone may be a strike-slip fault instead of a reverse-oblique slip fault, as previously interpreted. LiDAR- and field-reconnaissance-based evaluation of streams crossing lineaments and faults associated with the east central reach of the Los Osos fault zone along the northeastern margin of the Irish Hills show no systematic lateral deflection of streams crossing the lineaments or bedrock fault traces.

7. Los Osos Fault Slip Rate

- The Los Osos fault slip rates used in the Shoreline Fault Zone Report were retained for use in this study.

While fault slip-rate data are not used in the deterministic hazard sensitivity analysis (Chapter 13), the Los Osos fault slip rates are being evaluated based on other data as part of the SSHAC program.

8. Hosgri/ Shoreline Fault Zone Rupture

The high-resolution 2D and 3D LESS study offshore of Point Buchon (Chapter 2) shows that, with in resolution of a few hundred meters, the Hosgri and Point Buchon-Shoreline faults intersect. The high-resolution 2D and 3D LESS study offshore of Point Buchon (Chapter 2) mapped the Point Buchon fault zone (identified as the N40°W fault in PG&E, 2011a) and its relationship to the Hosgri fault zone, the northern Shoreline seismicity lineament (Hardebeck, 2010, 2013; PG&E, 2011a) and the Shoreline fault. Fault splays at the northern end of the Point Buchon fault were mapped to link with a north-south-trending graben, about 400 to 500 m east of the Hosgri fault zone, that is truncated at its northwestern extent by a north trending fault that may be part of the HFZ.

Global examples (Wesnousky, 2006) suggest that the Hosgri and Point Buchon-Shoreline faults may rupture together given their close proximity in the near surface and at depth (Hardebeck, 2010, 2013). The Shoreline Fault Zone Report concluded that the branching geometry between the Shoreline and Hosgri faults offshore of Point Buchon inhibited joint rupture. Dynamic rupture modeling showed that if rupture on the Hosgri stepped on to the Point Buchon-Shoreline fault, the rupture would continue for only a few kilometers at most. Similarly, ruptures on the Shoreline fault stepping onto the Hosgri fault would continue for only a few kilometers (Kame et al., 2003; PG&E, 2011a, Appendix J).

The relatively low slip rate of the Shoreline fault zone and unfavorable branching geometry indicate that joint Hosgri/ Shoreline ruptures are infrequent events. As a sensitivity, a deterministic model with a full rupture of the Shoreline fault linked to a rupture of the Hosgri fault extending north to the end of the San Simeon fault is examined in Chapter 13. The frequency of joint Hosgri/ Shoreline ruptures will be addressed in the 2015 SSC SSHAC model, which will be input into an updated PSHA.

9. Shoreline Southern End

- The southern extension of the Shoreline fault in San Luis Obispo Bay is extended 22 km in length beyond the southern end point identified in the Shoreline Fault Zone Report.

Chapter 3 describes high-resolution 3D LESS mapping in San Luis Obispo Bay that identifies the Shoreline fault as a through going structure extending southeastward though the entire 3D survey area, 5.3 km south of the southern end (Node S1) identified in PG&E (2011a). The Shoreline fault is inferred to extend an additional 13.7 km from the southeast edge of the 3D LESS area toward an unnamed, 3 km long, fault mapped in the onshore Guadalupe Oil Field (CDOGGR, 1992) using lower-resolution USGS 2D LESS and older deep-penetration (CDP) marine seismic-reflection data.

10. Shoreline Segmentation

- The mapping described in Chapters 2 and 3 revises the overall length of the Shoreline fault from 23 to 45 km, based primarily on the mapping in San Luis Obispo Bay.

The Shoreline Fault Zone Report assigned a total length of up to 23 km to the Shoreline fault and subdivided the fault into three geometric segments (north, central, and south) based on similarities and differences in surface geology, geophysical characteristics, and seismicity that could limit rupture.

- Marine seismic-reflection data support the interpretation that the northern segment of the Shoreline fault zone is coincident with the main trace of the Point Buchon fault (Chapter 2). To the south, the Point Buchon fault may connect to the central segment of the Shoreline fault zone, although no identifiable connection has been observed in the 2D/3D seismic-reflection data.
- Farther south, marine seismic-reflection data indicate that the intersection of the Shoreline fault with two of the Southwest Boundary zone faults (Oceano and Los Berros) represents a zone of fault interaction and possible segmentation point (Chapter 3). The impact that this zone of fault interaction between the Shoreline and Southwest Boundary zone faults has on ground motions at the DCPP will be further evaluated in the SSHAC study.

Ocean Bottom Seismometer Array

- An array of four three-component broadband ocean bottom seismometers and accelerometers was successfully installed offshore of the DCPP in 2013.

The primary objectives of the Point Buchon OBS Project are to increase detection capability and provide full waveform recording for small ($M < 3$) earthquakes, as well as on-scale acceleration recordings of larger ($M > 3$) events in the offshore area. Broader azimuthal station coverage will improve earthquake locations and focal mechanisms in the region offshore of the DCPP and, in particular, will constrain the geometry and sense of slip of the Hosgri and Shoreline faults offshore of Point Buchon. These data will also be used to constrain the path effects from offshore earthquakes to the DCPP (Chapter 5).

Geophysical Surveys of the Hosgri Fault Zone

Chapter 6 addresses the AB 1632 Report comments concerning the tectonic setting of the HFZ, the characterization of the HFZ as either a strike-slip fault or a thrust fault and the geometry of the HFZ at depth. The role of the HFZ as an uplift rate boundary for the Irish Hills is discussed in Chapter 12.

- High-energy marine seismic-reflection, potential field, and seismicity data are all consistent with a steeply (>75°) northeast-dipping, right-lateral strike-slip HFZ in the vicinity of the DCPP.

A HESS investigation was proposed by PG&E to collect additional information related to the deep crustal geometry of the offshore faults (in particular, the dip of the HFZ) and interactions or linkages between the San Simeon, Hosgri, Shoreline, and other offshore and onshore faults. The CSLC granted the Geophysical Survey Permit needed to conduct the HESS activities in August 2012; however, the CCC denied PG&E's application in November 2012 due to concerns about the environmental impact of these studies. While no new deep penetration offshore HESS data were collected as part of the CCCSIP, older high-energy deep penetration marine seismic-reflection profiles as well as other geophysical survey data that have been collected or published since the LTSP Report (PG&E, 1988) were used extensively to constrain the key interpretations presented in this report.

- Although potential fault linkages are more appropriately addressed in a PSHA, a deterministic sensitivity analysis for linkage of the San Simeon, Hosgri, and Shoreline faults is provided in Chapter 13. Fault linkage scenarios will also be addressed as part of the SSC SSHAC model to develop an updated PSHA for the NRC in March 2015.

Both the type of faulting and dip of the HFZ have been determined based on the above data. Fault linkage scenarios were addressed deterministically and will be further addressed probabilistically. PG&E does not see the need to further pursue 3D HESS offshore studies and has concluded that the further reduction in SSC uncertainties would be outweighed by the potential effects of conducting these studies in environmentally sensitive areas.

DCPP Shear-Wave-Velocity Model

- The shear-wave velocity profile (V_{S30}) at the power block and turbine building were assumed to be the same (1,200 meters per second [m/s]) in the Shoreline Fault Zone Report. Chapter 10 demonstrates that there is significant variability in V_{S30} over the DCPP region due to variations in near surface geology. V_{S30} at the power-block foundation elevation (53 ft.) is 1,260 ± 100 m/s and 980 ± 100 m/s at the turbine-building foundation elevation (62 ft.).

Chapter 10 provides a 3D shear-wave (V_S) velocity model for the DCPP foundation area in response to IPRP Report #6 (IPRP, 2013). High-resolution seismic profiling data collected in 2012 were used to construct 3D acoustic-wave (V_P) velocity models and one-dimensional (1D) V_S depth profiles constrained by surface-wave dispersion. V_S profiles for the DCPP site region show variability that will be addressed as part of the soil-structure interaction analyses for determination of building fragility. Building fragility will be input into a future probabilistic seismic risk assessment.

DCPP Site Conditions Evaluation

Site amplification at the DCPP power-block and turbine-building foundation levels is computed in Chapter 11 using new shear-wave-velocity profiles (Chapter 10), recorded ground motions at the DCPP free-field sites, and new NGA-West2 ground-motion-prediction equations to account for the differences in the V_S profiles between the free-field sites and the power-block and the turbine-building foundations.

- DCPP site-specific data indicate that there is a site resonance in the 1.5 –2.5 hertz (Hz) range and that the DCPP site has stronger amplification at low frequencies and weaker amplification at high frequencies than an average rock site in California.

Hamilton Testimony

CPUC D.12-09-008 also included testimony from the Alliance for Nuclear Responsibility (A4NR) and Dr. Douglas Hamilton concerning a previously recognized fault mapped under the turbine building and Unit 1 containment structure (the Diablo Cove fault) and a proposed fault named the San Luis Range/Inferred Offshore fault. Chapter 12 presents an analysis of Dr. Hamilton's characterization of the two faults based on his testimony, presentations at technical conferences, and a presentation at a SSHAC workshop in November 2012. The major PG&E findings in Chapter 12 are that summarized in the following statements:

- The Diablo Cove fault does not represent a seismic hazard (i.e. vibratory ground motion or surface faulting) to the DCPP
- The geological and geophysical data supporting Dr. Hamilton's definition of San Luis Range/Inferred Offshore fault are equivocal. General aspects of his model will, however, will be considered in a probabilistic seismic hazard analysis.

Dr. Hamilton's proposes that the Diablo Cove fault is a seismic hazard, based on lateral continuity with the Shoreline fault, continuity at depth with the San Luis Range/Inferred Offshore fault, and association with microseismicity. Our evaluation showed that all three of these inferences are conjectural and not supported by the available data. Our analysis included a review of previously collected information about the Diablo Cove fault during the original siting and preconstruction activities, more recently collected and compiled geologic map (Chapter 9), recently collected high-resolution bathymetric data, and recently collected onshore high-resolution 3D seismic-reflection data (Chapter 8).

Trench and excavation mapping conducted before construction of the DCPP indicates that the Diablo Cove fault is discontinuous and that it does not displace marine terrace deposits that are 120,000 years ago. Geologic mapping onshore and mapping and analysis of high-resolution multibeam bathymetry offshore do not support connecting the Diablo Cove fault offshore to the Shoreline fault zone. Evaluation of the location and accuracy of microseismicity show that proposed connections between microseismicity and the Diablo Cove fault are not supported by the data. Geologic mapping and high-resolution seismic data support a model that the fault is related to shallow folds and is confined to depths no greater than several tens of meters to hundreds of meters below ground surface.

The analysis of the San Luis Range/ Inferred Offshore fault proposed by Dr. Hamilton interpreted 2D and 3D low-energy and high-energy land seismic-reflection data (Chapters 7 and 8), seismicity and potential field data (Chapter 6), and topographic and bathymetric data and analysis conducted recently during the Shoreline fault zone study (PG&E, 2011a). Interpretation of high-resolution 3D and lower-resolution 2D seismic data in the southwestern Irish Hills does not identify a moderately northeast-dipping fault at shallow depths as Dr. Hamilton proposed. The seismicity data beneath the Irish Hills show no clear alignments and are subject to several alternative interpretations, which are not a good basis for defining a fault plane with a high degree of confidence. The model proposed by Dr. Hamilton predicts boundaries of differential late Quaternary uplift rates that are not supported by available geologic data. In contrast, past seismic hazard models for the DCPP (PG&E, 2011a) do incorporate faults that are consistent with the available geologic data and late Quaternary uplift rate boundaries.

SSC efforts being conducted using the SSHAC process are considering a moderately north-to-northeast-dipping reverse fault beneath the southwestern margin of the Irish Hills that is a modification of the geometry being proposed by Dr. Hamilton; this alternative fault geometry may explain the current tectonic uplift beneath the DCPP.

Hazard Sensitivity and Impact Evaluation

Chapter 13 evaluates the sensitivity of deterministic ground motions to the new seismic source characterizations for the Shoreline and Hosgri faults developed by the CCCSIP (Table 1-1) and new ground-motion models developed as part of the PEER NGA-West2 program (PEER, 2013). For the Shoreline fault, the length is extended farther to the south than in the Shoreline Fault Zone Report, increasing the magnitude from M 6.5 to M 6.7. For the Hosgri fault, the step-over between the Hosgri and San Simeon faults is small enough that the two faults are assumed to rupture together rather than separately (PG&E, 1988, 2011a), with the magnitude increasing from M 7.1 to M 7.3. Seismic source characterizations for the Los Osos and San Luis Bay faults were slightly modified from the values used in the Shoreline fault zone study (PG&E, 2011a). An additional sensitivity study for a linked M 7.3 Shoreline and Hosgri–San Simeon fault rupture is also evaluated.

- The 84th percentile deterministic ground motions for the Hosgri–San Simeon, Shoreline, Los Osos, and San Luis Bay faults are bounded by the 1977 Hosgri earthquake and 1991 LTSP/SSER 34 spectra on Figures 1 and 2 for the DCPP power block and turbine building.
- A deterministic hazard sensitivity analysis for the case of a Shoreline fault rupture linked to the Hosgri–San Simeon faults remains bounded by the 1977 Hosgri earthquake and 1991 LTSP/SSER 34 spectra on Figure 3 for the DCPP power block and turbine building.

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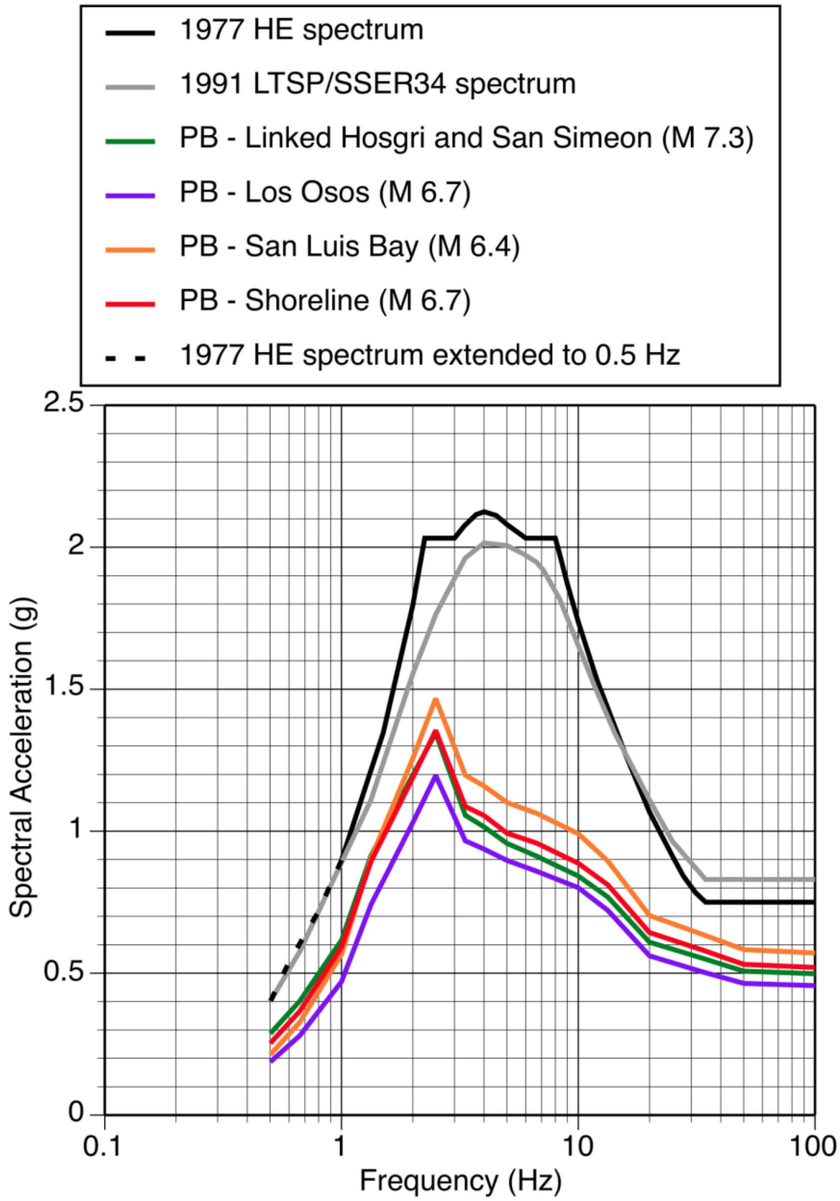
Table 1. Comparison of Seismic Source Parameters

Parameter (or Issue)	PG&E (2011a, 2011b)	PG&E (2014)
Hosgri slip rate	Preferred slip rate of 2.25 mm/yr	Point Sal: preferred slip rate of 1.8 mm/yr Estero Bay: preferred slip rate of 1.6 mm/yr
Hosgri dip	Range: 70°–90° NE	Range: 75°–90° NE
Shoreline slip rate	Preferred slip rate of 0.27 mm/yr	San Luis Obispo Bay: preferred slip rate of 0.06 mm/yr
Could Hosgri fault ruptures continue north of San Simeon?	No; ruptures terminate at Hosgri–San Simeon step-over. Deterministic length = 110 km Magnitude = M 7.1	Yes; Hosgri–San Simeon step-over is not a permanent barrier to rupture. Deterministic length = 171 km Magnitude = M 7.3 * 1977 Hosgri Design = M 7.5
Los Osos dip	Range of 45°–75° SW	Northeastern Irish Hills: preferred range of 55°–82° SW in the upper 1–3 km
Los Osos rake	Reverse; Reverse/Oblique	Reverse; Reverse/Oblique
Could there be a linked Hosgri-Shoreline fault rupture?	No based on the unfavorable intersection angle between the Hosgri and Shoreline faults	Yes; Hosgri-Shoreline linked rupture cannot be precluded based on fault mapping, but remains unfavorable based on intersection angle. Deterministic length = 145 km Magnitude = M 7.3* 1977 Hosgri Design = M 7.5
Los Osos slip rate	*Reverse* V 0.2–0.4 mm/yr *Reverse/Oblique* V 0.2/ H 0.1 mm/yr to V 0.4/ H 0.2 mm/yr	No new direct information
Total Shoreline fault zone length (and corresponding deterministic earthquake magnitude)	23 km (M 6.5)	45 km (M 6.7)
Shoreline southern extension	PG&E (2011b) added 10 km to fault end in PG&E (2011a)	Added 22 km to fault end in PG&E (2011a)

* Deterministic sensitivity analysis of linkage of the Hosgri–San Simeon and Hosgri and Shoreline faults is provided in Chapter 13.



The 84th Percentile Deterministic Ground Motions for Four Fault Scenarios Compared to the 1977 Hosgri Earthquake (HE) and the 1991 LTSP/SSER 34 Spectra for the DCPP Power Block

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Pacific Gas and Electric Company | Figure **1-1**

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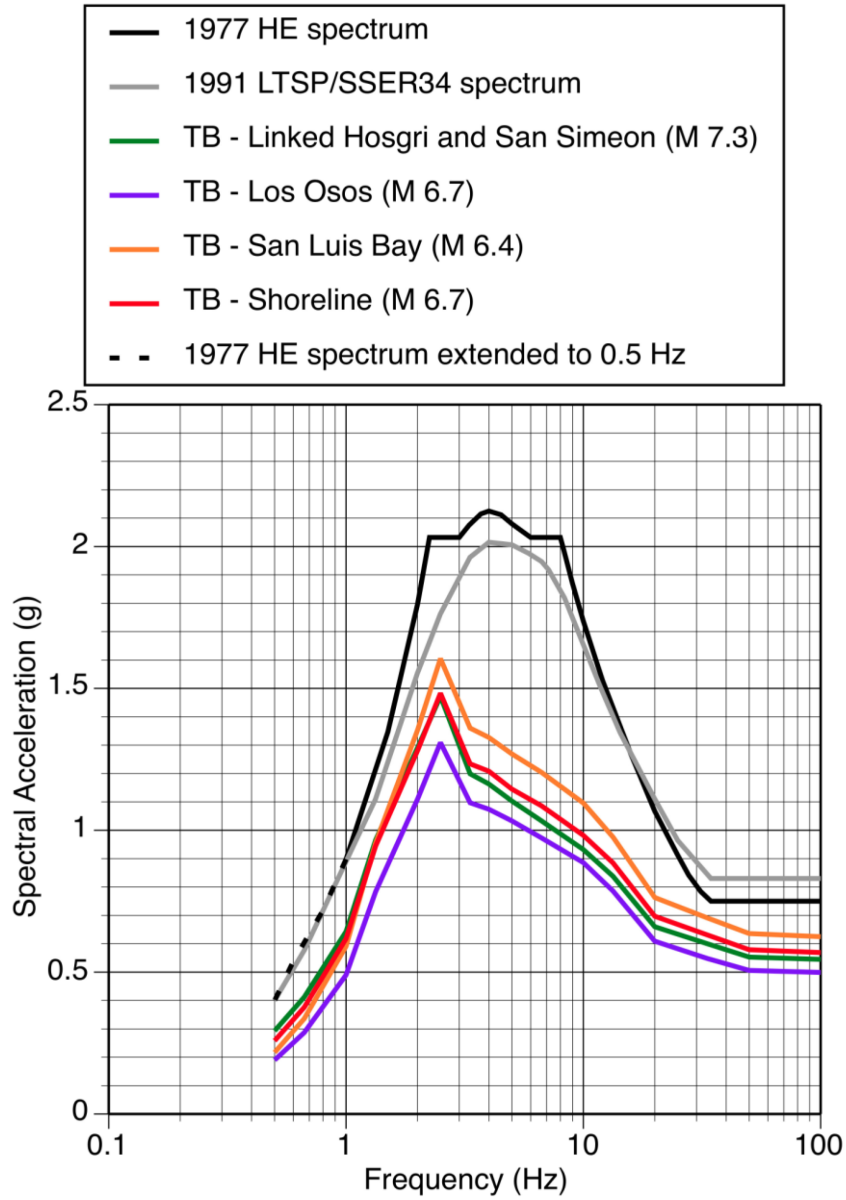
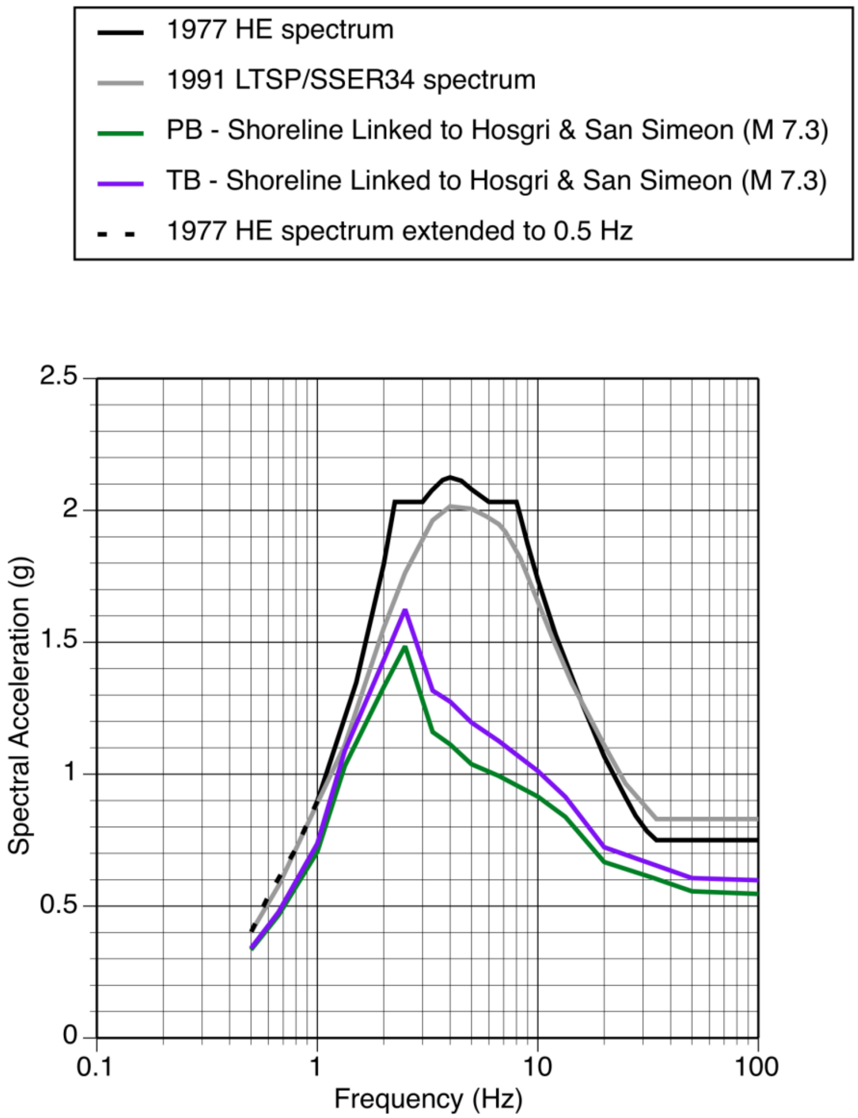


The 84th Percentile Deterministic Ground Motions for Four Fault Scenarios Compared to the 1977 Hosgri Earthquake (HE) and the 1991 LTSP/SSER 34 Spectra for the DCPP Turbine Building

CCCSIP REPORT

Pacific Gas and Electric Company | Figure **1-2**



The 84th Percentile Deterministic Ground Motions for Joint Shoreline and Hosgri-San Simeon Fault Rupture Compared to the 1977 Hosgri Earthquake and the 1991 LTSP/SSER 34 Spectra for the DCPP Power Block and Turbine Buildings

CCCSIP REPORT

Pacific Gas and Electric Company | Figure **1-3**

PACIFIC GAS AND ELECTRIC COMPANY
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ABBREVIATIONS AND ACRONYMS

AB	Assembly Bill
CCCSIP	Central Coastal California Seismic Imaging Project
DCPP	Diablo Canyon Power Plant
GMPE	ground-motion-prediction equation
Hz	hertz
km	kilometer
LN	natural logarithm
LTSP	Long Term Seismic Program
m/s	meters per second
NGA	Next Generation Attenuation
NRC	U.S. Nuclear Regulatory Commission
PEER	Pacific Earthquake Engineering Research Center
PG&E	Pacific Gas and Electric Company
SSHAC	Senior Seismic Hazard Analysis Committee
SWUS	Southwestern United States
V_S	shear-wave velocity
V_{S30}	shear-wave velocity for the upper 30 meters
Z_1	soil depth to Vs = 1.0 km/s
$Z_{2.5}$	soil depth to Vs = 2.5 km/s

1.0 INTRODUCTION

As part of the Central Coastal California Seismic Imaging Project (CCCSIP), Pacific Gas and Electric Company (PG&E) evaluated the sensitivity of the deterministic ground motions at the Diablo Canyon Power Plant (DCPP) to the new information collected. These deterministic hazard sensitivities considered the results of two recent studies: new information developed as part of the Assembly Bill (AB) 1632 studies and new ground-motion-prediction equations (GMPEs) developed as part of the Pacific Earthquake Engineering Research (PEER) Center's Next Generation Attenuation (NGA) West2 project. The effect of the new information on the probabilistic seismic hazard for the DCPP is being evaluated separately for the U.S. Nuclear Regulatory Commission's (NRC) required Senior Seismic Hazard Analysis Committee (SSHAC) seismic source characterization and ground-motion-characterization studies that are due in March 2015. This study was conducted under PG&E DCPP QA program, as required by 10CFR appendix B.

The source parameters used for the deterministic evaluation in the 2011 Shoreline Fault Zone Report (PG&E, 2011) and the updated source parameters from the AB 1632 studies are compared in Table 1-1. In the 2011 Shoreline Fault Zone Report, the full logic tree was used to estimate the magnitude for the deterministic scenarios. These logic trees are currently being reassessed as part of the SSHAC source characterization study. For this hazard sensitivity study, a simplified approach is used to compute the magnitude of the deterministic scenarios: the magnitude is computed using the magnitude-area scaling relation of Leonard (2010), with the maximum length, minimum dip, and a seismogenic crustal thickness of 12 kilometers (km).

Table 1-1. Comparison of Source Characterizations for the Deterministic Ground-Motion Evaluation

	2011 Shoreline Report			Updated Parameters		
Fault	Maximum Length (km)	Minimum Dip (degrees)	Mag. (90th fractile)	Maximum Length (km)	Minimum Dip (degrees)	Mag.*
Shoreline	23	90	6.5	45	90	6.7
Hosgri	110	80	7.1	171	75	7.3
Los Osos	36	45	6.8	36	55	6.7
San Luis Bay	16	50	6.3	16	50	6.4

* The updated magnitudes are based on the Leonard (2010) magnitude-area scaling relation, using the maximum length and the minimum dip with a seismogenic crustal thickness of 12 km.

The Leonard (2010) magnitude-area relations for strike-slip and dip-slip faults are given in Equations 1-1 and 1-2:

$$M = 3.99 + \log_{10}(\text{area}) \text{ for strike-slip} \quad (1\text{-}1)$$

$$M = 4.00 + \log_{10}(\text{area}) \text{ for dip-slip} \quad (1\text{-}2)$$

where *area* is the rupture area in square kilometers.

The AB 1632 studies of the southern end of the Shoreline fault found that the fault extended an additional 22 km to the south, thereby increasing the fault length from 23 km used in the 2011 Shoreline Fault Zone Report to 45 km. With this increased length, the magnitude, based on Leonard (2010), increased from 6.5 to 6.7 as shown in Table 1-1.

For the Hosgri fault, the step-over between the Hosgri and San Simeon faults is small enough that the two faults are assumed to rupture together. The northern end of the San Simeon fault was not addressed in the AB 1632 studies. The length of the combined Hosgri and San Simeon faults, 171 km, was defined using the Hosgri fault length from the U.S. Geological Survey (Petersen et al., 2008, Table I-3) which treated the San Simeon and Hosgri faults as a single fault called the Hosgri fault. This increased length leads to a magnitude of 7.3.

The AB 1632 studies for the Los Osos fault, found that the minimum dip consistent with the newly collected data is 55 degrees, as compared to a minimum dip of 45 degrees used in the 2011 Shoreline Fault Zone Report. The steeper dip leads to a smaller fault area, and the magnitude is reduced from 6.8 to 6.7.

The AB 1632 studies did not provide new information for the San Luis Bay fault length or dip. Using the length and dip from the 2011 Shoreline Fault Zone Report leads to a magnitude of 6.4. The increase from the 2011 magnitude of 6.3 results from using the bounding length and dip rather than the full logic tree to define the rupture area.

Additional linking of the ruptures to fault segments outside the study region (such as linking the Hosgri–San Simeon rupture to a San Gregorio rupture) was not evaluated in the AB 1632 studies. Because this is best addressed with the probabilistic approach, the potential for linking of ruptures outside the AB 1632 study area is being characterized in the SSHAC seismic source characterization study.

2.0 DETERMINISTIC GROUND MOTIONS

2.1 Hazard Sensitivity for Updated Scenarios

For the scenarios listed in Table 1-1, the parameters required as inputs to GMPEs are listed in Tables 2-1 and 2-2. A reference site condition with shear-wave velocity in the upper 30 meters (V_{S30}) at 760 meters per second (m/s) and default values for depths to V_S=1.0 km/s and V_S =2.5 km/s (called Z_1 and $Z_{2.5}$) is used to compute the median ground motion and standard deviation for the four NGA-West2 GMPEs (Abrahamson et al., 2014; Boore et al., 2014; Campbell and Bozorgnia, 2014; Chiou and Youngs, 2014). The four models are given equal weight of 0.25. In addition to the source parameters, the distanes from the source to the DCPP site is also required. There are three distance metrics used in the GMPEs: the closest distance from the rupture plane to the site (R_{RUP}), the shortest horizontal distance from the vertical projection of the rupture plane to the site (R_{JB}), and the shortest horizontal distance from the vertical projection of the top of the rupture to the site measured perpendicular to strike (R_X). These distance metric are listed in Table 2-2 for each scenario.

Table 2-1. Source Input Parameters Required for the GMPEs

Fault	Mag	Dip	Downdip Width (km)	Sense of Slip[1]	Hypocentral Depth (km)	Depth to Top of Rupture (km)
Hosgri (linked to San Simeon)	7.3	75	12.4	SS	8	0
Los Osos	6.7	55	14.6	RV	8	0
San Luis Bay	6.4	50	15.7	RV	8	0
Shoreline	6.7	90	12	SS	8	0

[1] RV = reverse-slip; SS = strike-slip

Table 2-2. Distance and Site Input Parameters Required for the GMPEs

Fault	R_{RUP} (km)	R_{JB} (km)	R_X (km)	Hanging Wall or Footwall	V_{S30} (m/s)	Z_1 (km)	$Z_{2.5}$ (km)
Hosgri (linked to San Simeon)	4.7	1.7	4.9	HW	760	Default	Default
Los Osos	8.1	1.5	9.9	HW	760	Default	Default
San Luis Bay	1.9	0.0	2.5	HW	760	Default	Default
Shoreline	0.6	0.6	0.6	N/A	760	Default	Default

To account for the site-specific site response at the DCPP, the amplification factors given in Table 3-3 of CCCSIP Report Chapter 11 (PG&E, 2014) are applied to the reference site condition ground motion from the GMPEs. As described in GEO.DCPP.TR.14.06, the deterministic 84th percentile ground motion is computed by combining the epistemic uncertainty in the site term ($\sigma_{SiteAmp}(f)$) with the single-station sigma ($\sigma_{SS}(f)$). The 84th percentile ground motion is computed using Equation 2-1:

$$\ln\left(PSA_{84th}(f)\right) = \ln\left(NGA_{Med}(f)\right) + \ln\left(SiteAmp(f)\right) + \sqrt{\sigma_{SS}^2(f) + \sigma_{SiteAmp}^2(f)} \quad (2\text{-}1)$$

where $\left(NGA_{Med}(f)\right)$ is the weighted average of the medians from the five NGA-West2 models, $\ln\left(SiteAmp(f)\right)$ is the natural log of the DCPP site-specific site amplification (for either the power block or the turbine building, $\sigma_{SS}(f)$ is the single-station sigma, and $\sigma_{SiteAmp}(f)$ is the epistemic uncertainty in the DCPP site-specific site amplification in natural log units. The single-station sigma is computed by removing the within-event site variability, $\phi_{S2S}(f)$, from the ergodic standard deviation, $\sigma_{ERG}(f)$ given by the GMPEs:

$$\sigma_{SS}^2(f) = \sqrt{\sigma_{ERG}^2(f) - \phi_{S2S}^2(f)} \quad (2\text{-}2)$$

The values of $\phi_{S2S}(f)$ from the 2011 Shoreline Fault Zone Report (Table 6-7 in the 2011 report) are listed in Table 2-3. The values of $\ln\left(SiteAmp(f)\right)$ for the power-block and turbine-building foundation levels and the values of $\sigma_{SiteAmp}(f)$ are given in GEO.DCPP.TR.14.06 and are repeated here in Table 2-3.

Table 2-3. Total Site-Specific Amplification from the NGA-West2 GMPEs for a Reference Site with V_{S30}=760 m/s to the Power-Block and Turbine-Building Foundation Levels

Frequency (Hz)	$\phi^2_{S2S}(f)$	Amplification, $\ln(SiteAmp(f))$ (LN units)		Epistemic Uncertainty in Site Amplification, $\sigma_{SiteAmp}(f)$
		Power Block Foundation	Turbine Building Foundation	
100	0.080	-0.506	-0.416	0.200
50	0.079	-0.520	-0.433	0.199
34	0.081	-0.546	-0.465	0.201
20	0.084	-0.706	-0.625	0.205
13.5	0.087	-0.718	-0.631	0.209
10	0.089	-0.751	-0.650	0.211
6.7	0.090	-0.785	-0.660	0.212
5	0.092	-0.704	-0.562	0.214
4	0.092	-0.551	-0.415	0.214
3.3	0.093	-0.420	-0.293	0.216
2.5	0.094	-0.015	0.075	0.217
2	0.096	0.020	0.094	0.219
1.3	0.099	0.065	0.120	0.222
1	0.103	-0.049	-0.006	0.227
0.67	0.106	-0.010	0.016	0.230
0.5	0.109	0.004	0.024	0.233

Sources: Shoreline Fault Zone Report (Table 6-7 of PG&E, 2011) and GEO.DCPP.TR.14.06 (Table 3-3).

The median and standard deviations of the ground motions are computed for the reference site condition using the NGA-West2 GMPEs. The software used for this calculation is the PEER NGA-W2 spreadsheet (file name: NGAW2-GMPE_Spreadsheets_V5.5_060514_protected.xlsm). This spreadsheet was checked in GEO.DCPP.14.03, Rev0.

The resulting ground motions values are are listed in Tables 2-4 through 2-7 for the Hosgri, Los Osos, San Luis Bay, and Shoreline scenarios. The deterministic 84th percentile ground motions are computed using Equation 2-1. The deterministic response spectra for the power-block foundation level are listed in Table 2-8 and the deterministic response spectra for the turbine-building foundation level are listed in Table 2-9. The deterministic spectra for the power block and turbine building are compared to the 1977 Hosgri and 1991 LTSP spectra on Figures 2-1 and 2-2, respectively. The 1977 Hosgri spectrum is defined for frequencies greater than 1 hertz (Hz). The extension of the 1977 Hosgri spectrum to lower frequencies is shown by the dashed black lines on Figures 2-1 and 2-2. For all the scenarios and for both sites, the deterministic ground motions are bounded by the 1977 Hosgri spectrum.

Table 2-4. Deterministic Response Spectra (5% Damping) for the Hosgri Fault for the Reference Site Condition (V_{S30} = 760 m/s)

Frequency (Hz)	Average Median from 4 NGA Models $NGA_{Med}(f)$ (g)	Average $\sigma_{ERG}(f)$ from 4 NGA Models (LN units)	$\sigma_{SS}(f)$ (LN units)
100	0.475	0.588	0.516
50	0.489	0.590	0.519
34	0.542	0.601	0.529
20	0.688	0.618	0.546
13.5	0.863	0.637	0.564
10	0.972	0.643	0.570
6.7	1.095	0.638	0.563
5	1.069	0.630	0.553
4	0.980	0.625	0.546
3.3	0.889	0.630	0.551
2.5	0.749	0.638	0.560
2	0.636	0.652	0.573
1.3	0.451	0.679	0.602
1	0.337	0.691	0.612
0.67	0.210	0.698	0.617
0.5	0.148	0.699	0.616

Table 2-5. Deterministic Response Spectra (5% Damping) for the Los Osos Fault for the Reference Site Condition (V_{S30} = 760 m/s)

Frequency (Hz)	Average Median from 4 NGA Models $NGA_{Med}(f)$ (g)	Average $\sigma_{ERG}(f)$ from 4 NGA Models (LN units)	$\sigma_{SS}(f)$ (LN units)
100	0.434	0.591	0.518
50	0.446	0.593	0.522
34	0.494	0.603	0.532
20	0.633	0.621	0.549
13.5	0.807	0.640	0.568
10	0.922	0.646	0.573
6.7	1.029	0.641	0.566
5	1.000	0.633	0.555
4	0.902	0.627	0.549
3.3	0.811	0.633	0.554
2.5	0.664	0.641	0.563
2	0.545	0.654	0.576
1.3	0.365	0.682	0.605
1	0.256	0.694	0.615
0.67	0.146	0.700	0.620
0.5	0.096	0.701	0.618

Table 2-6. Deterministic Response Spectra (5% Damping) for the San Luis Bay Fault for the Reference Site Condition (V_{S30} = 760 m/s)

Frequency (Hz)	Average Median from 4 NGA Models $NGA_{Med}(f)$ (g)	Average $\sigma_{ERG}(f)$ from 4 NGA Models (LN units)	$\sigma_{SS}(f)$ (LN units)
100	0.540	0.596	0.525
50	0.558	0.598	0.528
34	0.620	0.608	0.537
20	0.790	0.624	0.553
13.5	0.999	0.642	0.571
10	1.137	0.649	0.576
6.7	1.267	0.645	0.571
5	1.221	0.638	0.561
4	1.109	0.633	0.555
3.3	1.000	0.638	0.560
2.5	0.810	0.646	0.569
2	0.661	0.659	0.582
1.3	0.443	0.686	0.610
1	0.307	0.698	0.620
0.67	0.170	0.704	0.624
0.5	0.109	0.704	0.622

Table 2-7. Deterministic Response Spectra (5% Damping) for the Shoreline Fault for the Reference Site Condition (V_{S30} = 760 m/s)

Frequency (Hz)	Average Median from 4 NGA Models $NGA_{Med}(f)$ (g)	Average $\sigma_{ERG}(f)$ from 4 NGA Models (LN units)	$\sigma_{SS}(f)$ (LN units)
100	0.495	0.591	0.518
50	0.511	0.593	0.522
34	0.569	0.603	0.532
20	0.725	0.620	0.549
13.5	0.910	0.639	0.566
10	1.022	0.645	0.572
6.7	1.148	0.641	0.566
5	1.108	0.633	0.555
4	1.015	0.627	0.549
3.3	0.913	0.633	0.554
2.5	0.753	0.641	0.562
2	0.629	0.654	0.576
1.3	0.440	0.682	0.605
1	0.323	0.694	0.615
0.67	0.191	0.700	0.620
0.5	0.130	0.701	0.618

Table 2-8. Deterministic 84th Percentile Site-Specific Ground Motions for the Power-Block Foundation Level

	5% Damped Spectral Acceleration (g)			
Frequency (Hz)	**Hosgri (M 7.3, Dip=75)**	**Los Osos (M=6.7, Dip=55)**	**San Luis Bay (M=6.4, Dip=50)**	**Shoreline (M=6.7, Dip=90)**
100	0.498	0.456	0.571	0.520
50	0.507	0.464	0.583	0.531
34	0.553	0.505	0.637	0.582
20	0.609	0.561	0.703	0.643
13.5	0.768	0.721	0.895	0.811
10	0.842	0.801	0.991	0.887
6.7	0.912	0.859	1.063	0.958
5	0.957	0.897	1.101	0.993
4	1.015	0.937	1.159	1.055
3.3	1.056	0.966	1.197	1.087
2.5	1.345	1.196	1.467	1.355
2	1.198	1.030	1.256	1.188
1.3	0.914	0.742	0.905	0.894
1	0.616	0.470	0.566	0.592
0.67	0.402	0.280	0.327	0.366
0.5	0.287	0.187	0.213	0.253

Table 2-9. Deterministic 84th Percentile Site-Specific Ground Motions for the Turbine-Building Foundation Level

	5% Damped Spectral Acceleration (g)			
Frequency (Hz)	**Hosgri (M 7.3, Dip=75)**	**Los Osos (M=6.7, Dip=55)**	**San Luis Bay (M=6.4, Dip=50)**	**Shoreline (M=6.7, Dip=90)**
100	0.545	0.499	0.625	0.569
50	0.553	0.506	0.636	0.579
34	0.600	0.548	0.691	0.631
20	0.660	0.609	0.763	0.697
13.5	0.838	0.786	0.976	0.885
10	0.932	0.886	1.096	0.982
6.7	1.033	0.973	1.204	1.086
5	1.103	1.033	1.269	1.145
4	1.163	1.074	1.327	1.208
3.3	1.199	1.097	1.360	1.234
2.5	1.472	1.309	1.605	1.483
2	1.290	1.109	1.352	1.280
1.3	0.966	0.784	0.956	0.945
1	0.643	0.490	0.591	0.618
0.67	0.412	0.287	0.336	0.376
0.5	0.293	0.190	0.217	0.258

2.2 Shoreline Rupture Sensitivity

In the evaluation of the Shoreline fault rupture developed in the Shoreline Fault Zone Report (PG&E, 2011), the Shoreline fault was assumed to intersect with the Hosgri fault, but a linked rupture involving the full Shoreline fault and the full Hosgri fault was not included because the geometry of the two faults was unfavorable to allow such a rupture. Dynamic rupture modeling (see Appendix J in the 2011 Shoreline Fault Zone Report) showed that if the rupture on the Hosgri stepped onto the Shoreline fault, the rupture would continue for only a few kilometers at most. Similarly, ruptures on the Shoreline fault stepping onto the Hosgri would continue for only a few kilometers. To impact the deterministic hazard, the rupture on the Shoreline fault must rupture the section of the fault within 5 km of the DCPP (e.g. the rupture would have to include the central segment of the Shoreline fault), otherwise the ground motion will be less than for the Hosgri rupture, which is at a distance of 4.9 km and has the same magnitude.

The new information collected on the geometry of the Shoreline and Hosgri faults shows that within a resolution of a few hundred meters, the two faults intersect. This new information indicates that the fault may rupture together, but it does not change the unfavorable geometries for a linked rupture discussed above.

As a sensitivity, the deterministic hazard is computed assuming that the full Shoreline fault rupture is linked to a rupture on the Hosgri fault, extending north to the end of the San Simeon fault. The rupture length for this scenario is computed using the part of the Hosgri/San Simeon fault that is north of the intersection of the Shoreline fault and the Hosgri fault (100 km) and the full length of the Shoreline fault (45 km) for a total length of 145 km. Using a fault width of 12 km, this linked rupture has a magnitude of 7.23 based on the Leonard (2010) magnitude-area scaling relation for strike-slip faults. For this sensitivity, the magnitude is rounded up to M7.3. For this scenario, the closest distance is 0.6 km (this is the shortest distance to the Shoreline fault).

The median and standard deviations of the ground motions computed for the reference site condition using the NGA-West2 GMPEs are listed in Table 2-10. The deterministic 84th percentile ground motions are listed in Table 2-11, and the spectra are compared to the 1977 Hosgri and 1991 LTSP spectra on Figure 2-3. The ground motion from this linked rupture case remains bounded by the 1977 Hosgri spectrum.

Table 2-10. Deterministic Response Spectra (5% Damping) for the Scenario with the Shoreline Fault Rupture Linked to the Hosgri Fault and for the Reference Site Condition (V_{S30}=760 m/s)

Frequency (Hz)	Average Median from 4 NGA Models $NGA_{Med}(f)$ (g)	Average $\sigma_{ERG}(f)$ from 4 NGA Models (LN units)	$\sigma_{SS}(f)$ (LN units)
100	0.521	0.588	0.516
50	0.536	0.590	0.519
34	0.595	0.600	0.529
20	0.754	0.618	0.546
13.5	0.941	0.636	0.564
10	1.057	0.643	0.569
6.7	1.193	0.638	0.563
5	1.161	0.630	0.552
4	1.074	0.625	0.546
3.3	0.977	0.630	0.551
2.5	0.827	0.638	0.560
2	0.706	0.652	0.573
1.3	0.509	0.679	0.602
1	0.386	0.691	0.612
0.67	0.243	0.698	0.617
0.5	0.172	0.699	0.616

Table 2-11. Deterministic 84th Percentile Site-Specific Ground Motions for the Scenario with the Shoreline Fault Rupture Linked to the Hosgri Fault

	5% Damped Spectral Acceleration (g)	
Frequency (Hz)	**Power Block**	**Turbine Building**
100	0.546	0.598
50	0.556	0.606
34	0.607	0.658
20	0.667	0.723
13.5	0.838	0.914
10	0.915	1.012
6.7	0.993	1.125
5	1.038	1.196
4	1.113	1.275
3.3	1.160	1.317
2.5	1.485	1.625
2	1.330	1.432
1.3	1.032	1.090
1	0.706	0.737
0.67	0.465	0.477
0.5	0.334	0.340

3.0 CONCLUSIONS AND LIMITATIONS

For all the cases considered in this sensitivity study, the 84th percentile ground motions for the power-block and turbine-building foundation levels are bounded by the 1977 Hosgri spectrum.

For this evaluation, the reference rock ground motion is computed using the five NGA-West2 GMPEs with equal weight. The Southwestern United States (SWUS) ground-motion project is the SSHAC evaluation that will develop a complete set of ground-motion models and weights for application to the DCPP. The SWUS models will be completed as part of the March 2015 report. In addition, analytical modeling of the three-dimensional site amplification is being conducted and evaluated as part of the March 2015 hazard study, and this may affect the DCPP site-specific factors. Therefore, the ground motions shown in this section are for an initial hazard sensitivity evaluation only.

4.0 REFERENCES

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VERIFICATION SUMMARY REPORT

Item	Parameter	Yes	No*	N/A*
1	Purpose is clearly stated and the report satisfies the Purpose.	✓		
2	Data to be interpreted and/or analyzed are included or referenced.	✓		
3	Methodology is appropriate and properly applied.	✓		
4	Assumptions are reasonable, adequately described, and based upon sound geotechnical principles and practices.	✓		
5	Software is identified and properly applied. Validation is referenced or included, and is acceptable. Input files are correct.	✓		
6	Interpretation and/or Analysis is complete, accurate, and leads logically to Results and Conclusions.	✓		
7	Results and Conclusions are accurate, acceptable, and reasonable compared to the Data, interpretation and/or analysis, and Assumptions.	✓		
8	The Limitation on the use of the Results has been addressed and is accurate and complete.	✓		
9	The Impact Evaluation has been included and is accurate and complete.	✓		
10	References are valid for intended use.	✓		
11	Appendices are complete, accurate, and support text.			N/A*

*No appendices or supporting documents are included.

Comments:

- Table 1-1 "2011 Shoreline Report" parameters are the maximum fault length, the minimum dip, and the 90th fractile magnitude. The minimum dip and 90th fractile parameters in this table are correctly transmitted from Table 6-8 of the 2011 Shoreline Fault report. The maximum length for each fault source is taken from the 2011 Shoreline Fault logic trees in Chapter 5 (Shoreline: Figure 5-2, Hosgri: Figure 5-9, Los Osos: Figure 5-10, San Luis Bay: Figure 5-11). The "Updated Parameters" in Table 1-1 also include the maximum fault length, the minimum dip, and the magnitude. Updated magnitudes are verified using Leonard 2010 (see "Chapter13check.xls"). Updated dip for the Hosgri and Los Osos faults are taken from the "Study Results" section of the CCCSIP Report Executive Summary (Hosgri Dip: Study Result #2, Los Osos Dip: Study Result #5). The updated maximum length for the Shoreline fault is taken from the Study Result #10 of the CCSIP Report Executive Summary, and the updated maximum length for the Hosgri fault consistent with the USGS value. The approach for computing the Hosgri length is verified and appropriate. All values in Table 1-1 are verified to be accurate.
- Table 2-1 magnitudes and dips are correctly transmitted from Table 1-1. The downdip widths are independently computed (see "Chapter13check.xls") and verified to be

correct. The sense of slip for each of the faults is verified to be appropriate based on Table 6-8 of the 2011 Shoreline Fault report. Hypocentral depth is an assumed parameter, and it is verified to be reasonable. Also, the depth to top of rupture is an assumed parameter, and it is reasonable based on the magnitudes of the ruptures assigned to each fault. All values in Table 2-1 are verified to be accurate.

- Because the Hosgri and Los Osos dips have been updated, the R_{RUP} and R_{JB} parameters in Table 2-2 are new values. These parameters were independently computed by hand and verified to be correct. All other distance metrics (R_{RUP}, R_{JB}, and R_X) in Table 2-2 are correctly transmitted from Table 6-8 of the 2011 Shoreline Fault report. DCPP is located on the HW side of each of these fault sources (with the exception of Shoreline because dip=90) and this parameter is verified to be correct. Vs30 is a default parameter based on the reference rock condition. It is a reasonable assumption and verified to be appropriate. Default values are used for Z1 and Z2.5 and this is a reasonable approach for the purposes of this calculation. All values in Table 2-2 are verified to be accurate.
- Table 2-3 was verified against Tables 6.5-1 and 10.1-1 in GEO.DCPP.14.03 rev0.
- Median SA values (the geometric mean over the 4 NGA-W2 models) for the deterministic fault sources in Tables 2-4, 2-5, 2-6, 2-7, and 2-10 were computed using the PEER spreadsheet (NGAW2_GMPE_Spreadsheets_v5.5_060514_Protected.xlsm). The spreadsheet was also used to compute the Median SA plus one standard deviation and from these two numbers, the average standard deviation model over the 4 NGA GMPEs was computed. Finally, σ_{SS} was computed using equation 2-2. Tables 2-4, 2-5, 2-6, 2-7, 2-10 are verified to be correct (see "Chapter13check.xls" for independent ITR computation).
- Using equation 2-1, the deterministic 84th percentile ground motions were independently computed using the median spectral acceleration (Tables 2-4, 2-5, 2-6, 2-7, and 2-10), the site amplification factors for the power block foundation and the turbine building foundation (Table 2-3) and the standard deviation. The values in Table 2-8, 2-9, and 2-11 are verified to be correct (see "Chapter13check.xls" for independent ITR computation).

All supporting documents for this ITR report are located on the Geosciences S:/ Drive.

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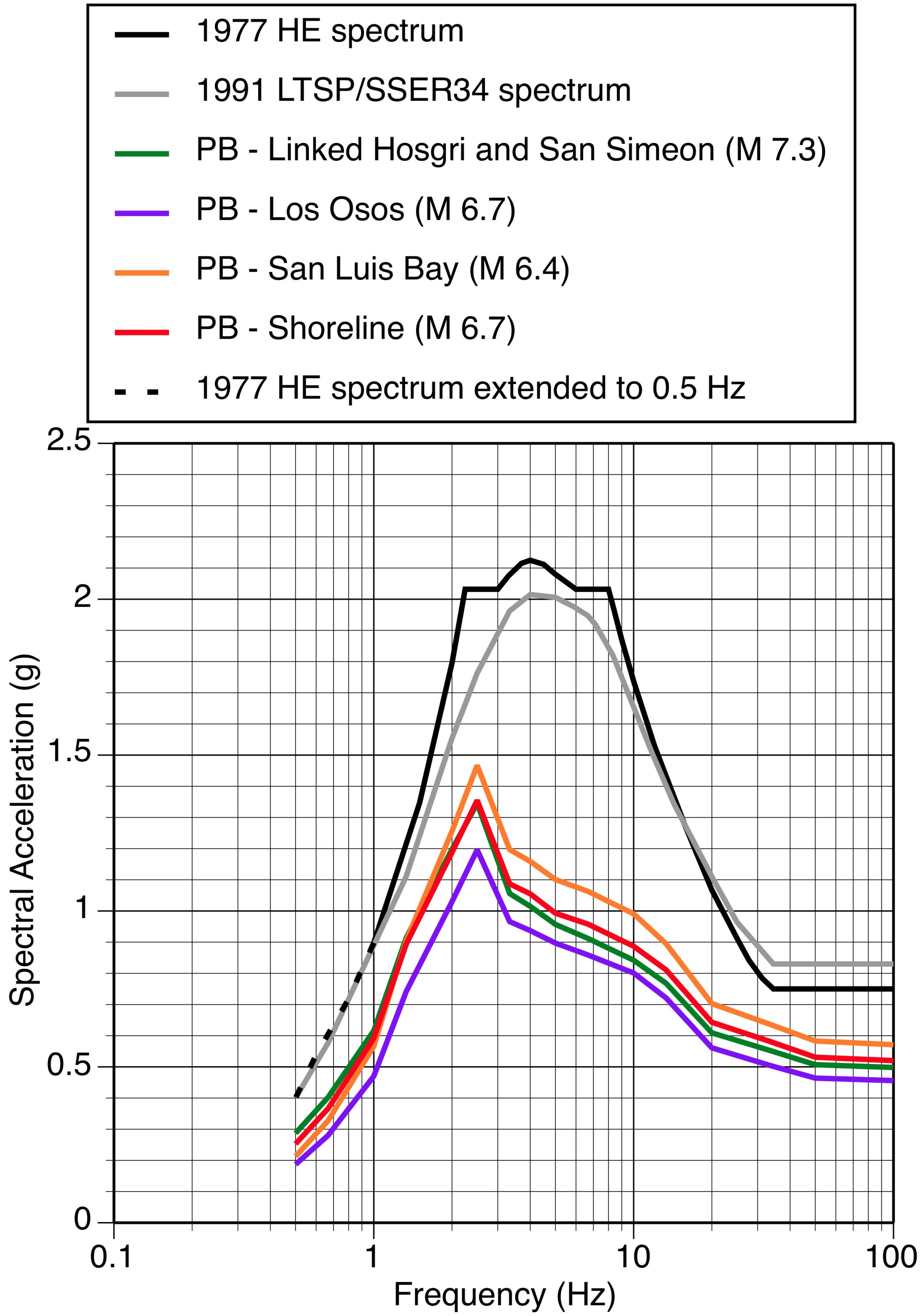

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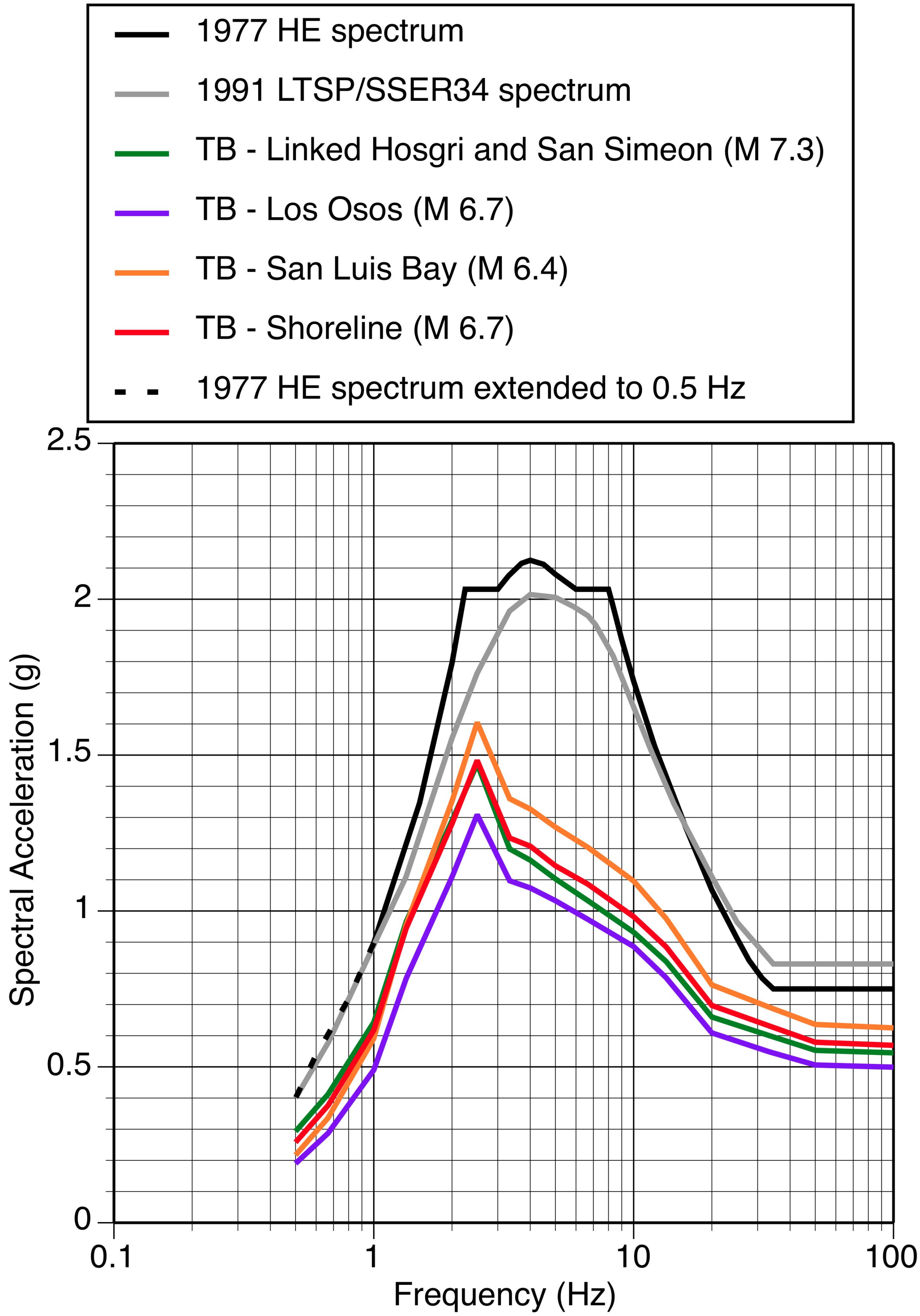
Deterministic Response Spectra (5% Damping) for the Power-Block Foundation Level

HAZARD SENSITIVITY AND IMPACT EVALUATION

Pacific Gas and Electric Company | Figure **2-1**



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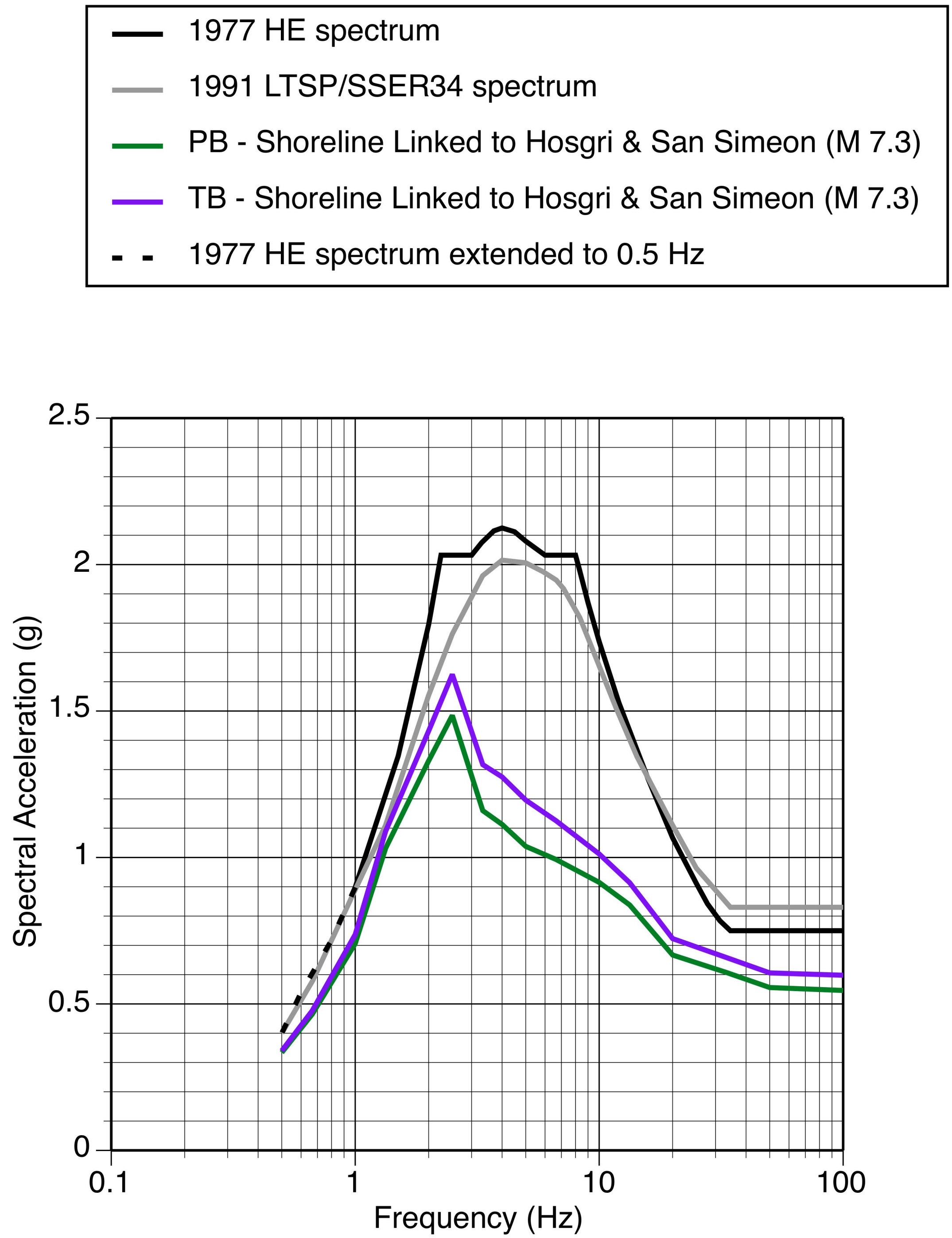
Deterministic Response Spectra (5% Damping) for the Turbine-Building Foundation Level

HAZARD SENSITIVITY AND IMPACT EVALUATION

Pacific Gas and Electric Company | Figure **2-2**



Deterministic Response Spectra (5% Damping) for the Power-Block and Turbine-Building Foundation Level for the Scenario with the Shoreline Fault Rupture Linked to the Hosgri Fault

HAZARD SENSITIVITY AND IMPACT EVALUATION

Pacific Gas and Electric Company | Figure **2-3**

14 Report Findings and Conclusions

14.1 Findings and Conclusions

Pacific Gas and Electric Company (PG&E) has completed its advanced seismic studies to further document the seismic characteristics of the fault zones in the region surrounding the Diablo Canyon Power Plant (DCPP) in San Luis Obispo County. These studies have given PG&E, as well as scientists and regulators, an unprecedented view into the earth's crust that significantly and fundamentally increases understanding of the seismic characteristics near the DCPP. These studies confirm previous analyses that the plant and its major components are designed to withstand—and perform their safety functions during and after—a major seismic event.

PG&E performed these studies following the recommendation of the California Energy Commission (CEC) in a report issued in response to state legislation (Assembly Bill 1632, or AB 1632). AB 1632 (Blakeslee, Chapter 722, Statutes of 2006) directed the CEC to assess the potential vulnerability of California's largest baseload power-generation facilities (1,700 megawatts or greater) to a major disruption due to a seismic event or plant aging. Upon completing that assessment, the CEC issued a report in 2008 "An Assessment of California's Nuclear Power Plants: AB 1632 Report" that contained findings and recommendations concerning the seismic vulnerability of the DCPP. These recommendations have been addressed in the Central Coastal California Seismic Imaging Project (CCCSIP) report (this report) as follows:

- *PG&E should use three-dimensional geophysical seismic reflection mapping and other advanced techniques to explore fault zones near Diablo Canyon.*

The AB 1632 Report specifically identified the use of seismic imaging to resolve questions about the tectonic style and geometry of the Hosgri fault zone, the subsurface structure at the DCPP, and the deep geometry, continuity and interaction of poorly expressed faults that comprise the structural boundaries of the San Luis – Pismo block to address the possibility of a 2003 San Simeon-type earthquake occurring beneath the plant.

Studies conducted as part of the CCCSIP have reduced a number of the parametric uncertainties associated with the key faults identified in both the Shoreline fault zone (PG&E, 2011) and AB 1632 reports. New information about the structural boundaries of the San Luis-Pismo block, including slip rates of the Hosgri and Shoreline faults, the overall length of the Shoreline fault, possible linkages between the San Simeon, Hosgri, Shoreline and Southwest Boundary fault zones, as well as the internal fault structure of the San Luis-Pismo block have been presented based on both high – and low-energy 2D and 3D seismic-reflection surveys and other geologic and geophysical studies.

The reduction of uncertainty due to the additional data collected by the CCCSIP study is shown in Figure 1-1. The probabilistic hazard sensitivity presented in

Chapter 1 (Figure 1-2) was repeated using the updated ranges of the source parameters developed in the CCCSIP study. The sensitivities to the new ranges are shown by the red points in Figure 1-1. The tighter range of the red points for the parameters near the top of the plot show the reduction of uncertainty. In particular, there is a significant reduction in uncertainty due to the improved constraints on the Hosgri slip rate, Hosgri dip, Shoreline slip rate, and Los Osos dip. The additional information on linking of ruptures (Hosgri with San Simeon and Shoreline with Hosgri) do not have a significant impact on the uncertainty for the probabilistic hazard. Also, the extension of the Shoreline fault to the south does not have a significant impact on the uncertainty for the probabilistic hazard. For other parameters (Los Osos slip rate, Los Osos sense of slip, and Shoreline segmentation), new models were not developed, so the change is not shown.

Long-term seismic and geodetic monitoring of the DCPP region using the PG&E Central Coast Seismic Network (CCSN, including the Point Buchon Ocean Bottom Seismometer (OBS) network), and the USGS Central California Coast Region (CCCR) geographic positioning system (GPS) arrays will continue as part of PG&E LTSP.

CCCSIP studies have also addressed the testimony of Dr. Douglas Hamilton concerning a previously recognized fault mapped under the DCPP turbine building and the Unit 1 containment (Diablo Cove fault), and a proposed fault named the San Luis Range/Infererd Offshore Fault (SLR/IOF). Through review of previously collected information about the Diablo Cove fault from the original siting and pre-construction activities supplemented with recently collected geologic map data and high-resolution 3D seismic –reflection data collected as part of the CCCSIP indicate that the Diablo Cove fault does not represent a seismic hazard (e.g. vibratory ground motion or surface faulting) to the DCPP. Analysis of high-resolution 2D and 3D seismic-reflection data, seismicity and potential field data does not support the SLR/IOF as proposed by Dr. Hamilton. The general aspects of Dr. Hamilton's SLR/IOF model will, however, be considered in a probabilistic seismic hazard analysis as part of the PG&E SSHAC Level 3 process.

- *As ground motion models are refined to account for a greater understanding of the motion near an earthquake rupture, it will be important for PG&E to consider whether the models indicate larger than expected seismic hazards at Diablo Canyon and if so, whether the plant was built with sufficient design margins to continue operating reliably after experiencing these large ground motions*.

Deterministic ground motions based on the new seismic source characterizations for the Shoreline and Hosgri faults developed by the CCCSIP (Executive Summary, Table 1-1) and new ground motion models developed as part of the PEER NGA program (PEER, 2014) are compared relative to the PG&E (2011) deterministic hazard model results. For the Shoreline fault, the length is extended farther to the south than in the Shoreline Fault Report (PG&E, 2011), increasing the magnitude from M 6.5 to M 6.7. For the Hosgri fault, the step over between the Hosgri and San Simeon faults is small enough that the two faults are assumed to rupture together rather then separately (PG&E, 1988; 2011), increasing the magnitude from M 7.1 to M 7.3. Source characterization for the Los Osos and San Luis Bay faults are modified slightly from PG&E (2011).

As seen in Chapter 13, Figures 2-1 and 2-2, the 84^{th} percentile deterministic ground motions for the Hosgri-San Simeon, Shoreline, Los Osos, and San Luis Bay faults are bounded by the 1977 Hosgri Earthquake (HE) and 1991 LTSP/SSER 34 spectrums for both the DCPP power block and turbine building.

A deterministic hazard sensitivity analysis for the case of a Shoreline fault rupture linked to the Hosgri/ San Simeon faults remains bounded by the 1977 HE and 1991 LTSP/SSER 34 spectrums in Chapter 13, Figure 3-1 for both the DCPP power block and the turbine building.

- *PG&E should assess the implications of a San Simeon-type earthquake beneath Diablo Canyon. This assessment should include expected ground motions and vulnerability assessments for safety-related and non-safety related plant systems and components that might be sensitive to long period motions in the near field of an earthquake rupture.*

The Shoreline Fault Report (2011) included a San Simeon-type earthquake beneath the Irish Hills and the DCPP where the San Luis Bay fault (dipping 50° -80° N) and the Los Osos fault (dipping 45° to 75° SW) intersect at depth. The SSC SSHAC logic trees will consider various fault models to explain the uplift of the Irish Hills, including a San Simeon-type earthquake model.

In conclusion, PG&E has addressed the recommendations in the AB 1632 Report and has confirmed previous analyses that the plant and its major components are designed to withstand—and perform their safety functions during and after—a major seismic event.

In addition, the Nuclear Regulatory Commission has instructed all U.S. nuclear power plants to perform site reevaluations using current NRC requirements and guidance for probabilistic seismic hazards analysis (PSHA) (NRC, 2012). All new information from the CCCSIP studies will be evaluated and integrated into the tectonic models being developed as part of the Senior Seismic Hazard Analysis Committee (SSHAC) process. The SSC model will be input into the PSHA that will be submitted to the NRC in March 2015.

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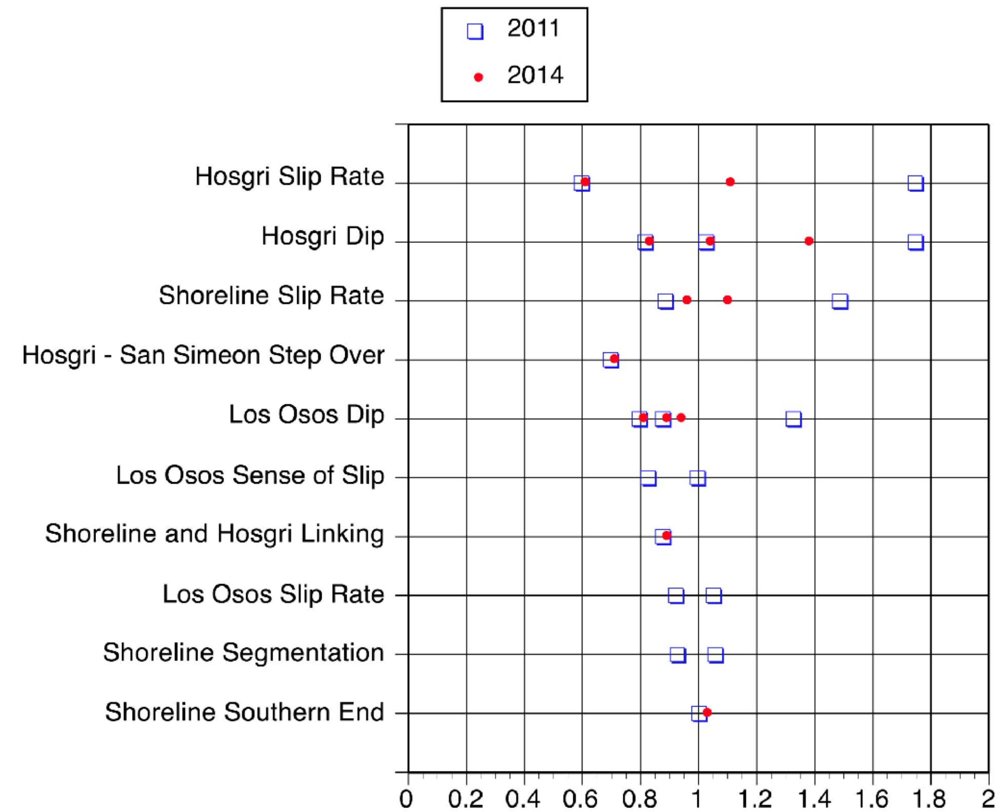

Tornado Diagram Comparison of 2011 and 2014 Hazard Significant Parameter Uncertainties

CCCSIP REPORT

Pacific Gas and Electric Company | Figure **1-1**