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March 11, 2015

PG&E Letter DCL-15-035

U.S. Nuclear Regulatory Commission
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10 CFR 50.54(f)

Docket No. 50-275, OL-DPR-80
Docket No. 50-323, OL-DPR-82
Diablo Canyon Units 1 and 2
Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident: Seismic Hazard and Screening Report

References:

1. NRC Letter, "Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3 of the Near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident," dated March 12, 2012

2. Electric Power Research Institute (EPRI) Report No. 1025287, "Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic," dated November 2012

3. PG&E Letter DCL-13-044, "Response to NRC Request for Information Pursuant to 10 CFR 50.54(F) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukuhsima Dai-ichi Accident," dated April 29, 2013

4. NRC Letter, "Supplemental Information Related to Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Seismic Hazards Reevaluations for Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident," dated February 20, 2014

Dear Commissioners and Staff:

On March 12, 2012, the Nuclear Regulatory Commission (NRC) issued Reference 1 to Pacific Gas and Electric Company (PG&E) directing PG&E to reevaluate the seismic hazards at Diablo Canyon Power Plant (DCPP) using present-day NRC requirements and guidance and to identify actions to address plant specific vulnerabilities associated with the updated seismic hazards. Specific requirements are outlined in Reference 1, Enclosure 1.

In response to Reference 1, and following the guidance provided in Reference 2, PG&E performed a seismic hazard reevaluation for DCPP and developed a DCPP-specific ground motion response spectrum (GMRS) for screening purposes. Enclosure 1 to this letter provides PG&E's Seismic Hazard and Screening Report. Consistent with Reference 4, the enclosed seismic hazard reevaluations are distinct from the current design and licensing bases of DCPP. Consequently, the results of these analyses - performed using present-day regulatory guidance, methodologies, and information - would not generally be expected to call into question the operability or functionality of structures, systems and components, and were not reportable pursuant to 10 CFR 50.72, "Immediate Notification Requirements for Operating Nuclear Power Reactors," and 10 CFR 50.73, "Licensee Event Report System."

The GMRS was developed through the performance of a Senior Seismic Hazards Analysis Committee (SSHAC) Level 3 seismic source characterization study and a SSHAC Level 3 ground motion characterization study, in accordance with NUREG 2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies," dated April 2012, followed by a site-specific amplification study. A copy of the participatory peer review panels (PPRP) closure letters for seismic source characterization and the ground motion characterization (GMC) is provided in Enclosure 1, Appendix C. The GMC closure letter found that the DCPP SSHAC meets the expectations for a SSHAC Level 3 study but requested that additional technical justification be provided regarding the application of the directivity component of the GMC model to the DCPP site. The SSHAC Technical Integration team provided a response to the PPRP request (see Enclosure 1, Appendix C). PG&E will submit the resolution of the PPRP identified request as soon as it is completed.

As discussed in NRC Letter, "Diablo Canyon Power Plant, Unit Nos. 1 and 2 – NRC Review of Shoreline Fault (TAC Nos. ME5306 and ME5307)," dated October 12, 2012, PG&E's reevaluation used the DCPP double design earthquake (DDE) as the safe shutdown earthquake for screening purposes. PG&E's screening evaluation of the GMRS indicates that the GMRS exceeds the DDE in the 1 to 10 hertz frequency range. Therefore, DCPP screens-in for a seismic risk evaluation

in accordance with Reference 2. PG&E will perform the seismic risk evaluation as required in Reference 2. In the interim, PG&E compared the GMRS to the design and licensing basis 1977 Hosgri earthquake spectrum and to the results of the long term seismic program seismic margins assessment. These comparisons demonstrate that there is reasonable assurance that the DCPP structures, systems, and components required for safe shutdown will continue to perform their intended safety function if subjected to the ground motions at the newly developed GMRS levels. PG&E will perform an update of the seismic probabilistic risk assessment (PRA), which will include high-frequency confirmation, and a spent fuel pool integrity evaluation in accordance with Reference 2.

PG&E is making a new regulatory commitment (as defined by NEI 99-04). PG&E is revising an existing regulatory commitment as shown in Enclosure 2. PG&E has determined that it is not necessary to perform an expedited seismic evaluation process as PG&E's interim evaluation provides reasonable assurance that it is safe to operate DCPP while the updated/upgraded seismic PRA is developed. Refer to Enclosure 2.

If you have any questions, or require additional information, please contact Mr. L. Jearl Strickland at (805) 781-9795.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on March 11, 2015.

Sincerely,

Barry S. Allen
Vice President, Nuclear Services

dmfn/50465913-3
Enclosures
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cc:/enc: Marc L. Dapas, NRC Region IV Administrator
Dan H. Dorman, NRC/NRR Director
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Pacific Gas and Electric Company

Seismic Hazard and Screening Report

Diablo Canyon Power Plant

Units 1 and 2

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1.0 Introduction

Following the accident at the Fukushima Daiichi nuclear power plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami, the Nuclear Regulatory Commission (NRC) established a Near Term Task Force (NTTF) to conduct a systematic review of NRC processes and regulations and to determine if the agency should make additional improvements to its regulatory system. The NTTF developed a set of recommendations intended to clarify and strengthen the regulatory framework for protection against natural phenomena. Subsequently, on March 12, 2014, the NRC issued a request for information letter under Title 10, "Energy," of the Code of Federal Regulations, Part 50, "Domestic Licensing of Production and Utilization Facilities," Section 50.54, "Conditions of Licenses," Subsection (f), "Request for Information," (March 12, 2012 10 CFR 50.54(f) letter), to assure that these recommendations are addressed by all United States nuclear power plants (NRC 2012). The March 12, 2012 10 CFR 50.54(f) letter requests that licensees and holders of construction permits under 10 CFR 50 reevaluate the seismic hazards at their sites against present-day NRC requirements. Depending on the comparison between the reevaluated seismic hazard and the current design/licensing basis, the result is either no further risk evaluation or the performance of a seismic risk assessment. Risk assessment approaches acceptable to the NRC staff include a seismic probabilistic risk assessment (SPRA), or a seismic margin assessment (SMA). Based upon the risk assessment results, the NRC staff will determine whether additional regulatory actions are necessary.

This report provides the information requested in items (1) through (7) of the "Requested Information" section and Attachment 1 of the 10 CFR 50.54(f) letter pertaining to NTTF Recommendation 2.1 (NRC 2012) for Diablo Canyon Power Plant (DCPP), located in San Luis Obispo County, California. In providing this information, Pacific Gas and Electric Company (PG&E) followed the guidance provided in Electric Power Research Institute (EPRI) Technical Report No. 1025287, "Seismic Evaluation Guidance: Screening, Prioritization, and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic" (EPRI 2013a).

The original geologic and seismic siting investigations for DCPP predate the issuance of Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR 100, "Reactor Site Criteria" (NRC 1973). The double design earthquake (DDE), which the NRC directed PG&E to use for the response to the March 12, 2012 10 CFR 50.54(f) letter[1], was originally developed using site-specific criteria and methods, and is used for the design of Design Class I structures, systems, and components, where Design Class I is DCPP's

[1] As stated in the NRC's letter to PG&E dated October 12, 2012 (NRC 2012c), "for the purposes of the response to the March 12, 2012 request for information, the NRC staff expects PG&E to use the DDE for comparison with the reevaluated seismic hazard GMRS."

equivalent to Seismic Category I, as defined in NRC Regulator Guide 1.29, "Seismic Design Classification" (NRC 1978). In addition, the seismic design of DCPP includes the 1977 Hosgri earthquake (HE). The 1977 HE, which has significantly larger ground motions than the DDE, is also used for design and evaluation of Design Class I structures, systems, and components. Finally, in response to License Condition 2.C.(7) of the DCPP Unit 1 operating license, the Long Term Seismic Program (LTSP) earthquake (LTSPE) was developed. The LTSPE was used for DCPP's prior SPRA and SMA (1988 LTSP Final Report, PG&E 1988).

In response to the NRC's March 12, 2012 10 CFR 50.54(f) letter, and following the guidance provided in the screening, prioritization, and implementation details (SPID)[2] (EPRI 2013a) and a Senior Seismic Hazard Analysis Committee (SSHAC) process established by the NRC for western United States plants, a seismic hazard reevaluation was performed for DCPP. This included development of DCPP-specific ground motion response spectrum (GMRS). Consistent with the NRC letter dated February 20, 2014, (NRC 2014) the seismic hazard reevaluations presented herein are being performed to beyond current design/licensing basis requirements for DCPP. Therefore, the results do not call into question the operability or functionality of structures, systems, and components and are not reportable pursuant to 10 CFR 50.72, "Immediate Notification Requirements for Operating Nuclear Power Reactors," or 10 CFR 50.73, "Licensee Event Report System."

The GMRS was developed through the performance of a SSHAC Level 3 seismic source characterization study and a SSHAC Level 3 ground motion characterization study, in accordance with NUREG-2117, "Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies," (NRC 2012b). In addition, a site-specific amplification study was performed. A copy of the participatory peer review panels (PPRP) closure letters for seismic source characterization and the ground motion characterization (GMC) is provided in Appendix C. The GMC closure letter found that the DCPP SSHAC meets the expectations for a SSHAC Level 3 study but requested that additional technical justification be provided regarding the application of the directivity component of the GMC model to the DCPP site. The SSHAC technical integration team provided a response to the PPRP request (see Appendix C). PG&E will submit the resolution of the PPRP identified request as soon as it is completed.

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2 Note: It has been recognized, and acknowledged by the NRC in public meetings (NRC 2014c and NRC 2014d), that the guidance provided in the SPID is more aligned with the seismic hazard studies associated with central and eastern United States plants, while SSHAC studies, performed in accordance with NUREG-2117 (NRC 2012b), and site-specific amplification studies, utilizing more up-to-date, modern day methodologies, are applicable to western United States plants.

DCPP's screening evaluation of the GMRS, performed in accordance with SPID Figure 1-1, indicates that the GMRS exceeds the DDE in the 1 to 10 Hz frequency range. Therefore, DCPP screens-in for a seismic risk evaluation per the requirements of the SPID. PG&E will perform a SPRA in accordance with the EPRI guidance (EPRI 2013a) and the schedule as defined in NEI's letter to the NRC, dated April 9, 2013 (NEI 2013) and confirmed in NRC's letter, dated May 7, 2013 (NRC 2013).

In accordance with the NRC's February 20, 2014 request for supplemental information from plant's that screen-in for a seismic risk evaluation (NRC 2014), PG&E has performed an interim evaluation to address the seismic safety of DCPP. This interim evaluation compared the GMRS to the design/licensing basis 1977 HE spectrum and to the results of the LTSP seismic margin evaluation. This comparison demonstrated that there is reasonable assurance that DCPP's safety related structures, systems, and components will continue to perform their intended safety function if subjected to the ground motions at the newly developed GMRS levels.

PG&E's letter to the NRC dated April 29, 2013 (PG&E 2013d), indicated that the expedited seismic evaluation process (ESEP) would be implemented for DCPP in accordance with EPRI Technical Report No. 3002000704, "Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic" (EPRI 2013b). However, as noted above, the interim evaluation already demonstrates DCPP's seismic safety while an updated/upgraded SPRA is being developed. No additional insights will be gained for DCPP from the implementation of the ESEP. PG&E concludes that only a SPRA will be performed, rather than the implementation of an ESEP, such that the critical skilled resources can be devoted towards an update/upgrade of the SPRA. The SPRA, which includes the high-frequency confirmation, will be performed in accordance with the EPRI guidance (EPRI 2013a) and the schedule as defined in NEI's letter to the NRC, dated April 9, 2013 (NEI 2013) and confirmed in NRC's letter, dated May 7, 2013 (NRC 2013).

PG&E's spent fuel pool (SFP) screening evaluation indicates that the GMRS exceeds the DCPP DDE in the 1 to 10 Hz frequency range. Therefore, DCPP screens-in for further review of the SFPs as required by the SPID. PG&E also performed an interim evaluation to address the seismic safety of the SFPs, which are located in the fuel handling area of the auxiliary building. Comparing the GMRS with the design/licensing basis 1977 HE spectrum and the LTSP seismic margin shows that the auxiliary building has a significant margin beyond the GMRS. Therefore, there is reasonable assurance that DCPP's SFPs will maintain their structural integrity if subjected to the ground motions at the newly developed GMRS levels. As indicated in PG&E's letter dated April 29, 2013 (PG&E 2013d), PG&E will perform additional evaluations of the SFPs in accordance with the EPRI guidance (EPRI 2013a) and the schedule as defined

by the NEI's letter to the NRC, dated April 9, 2013 (NEI 2013) and confirmed in the NRC's letter dated May 7, 2013 (NRC 2013).

2.0 Seismic Hazard Reevaluation

DCPP is located on the central California coast, approximately 19 kilometers (km) (12 miles (mi.)) west of San Luis Obispo, California (Figure 2.0-1). The plant is on the southwestern margin of the Irish Hills, an area of moderate relief bordered by Morro Bay on the north, San Luis Obispo Bay on the south, and Los Osos Valley on the east. The Irish Hills are the northwestern part of the San Luis Range, which trends approximately west-northwest/east-southeast and separates the Santa Maria River Valley to the south from the Los Osos and Edna valleys to the north.

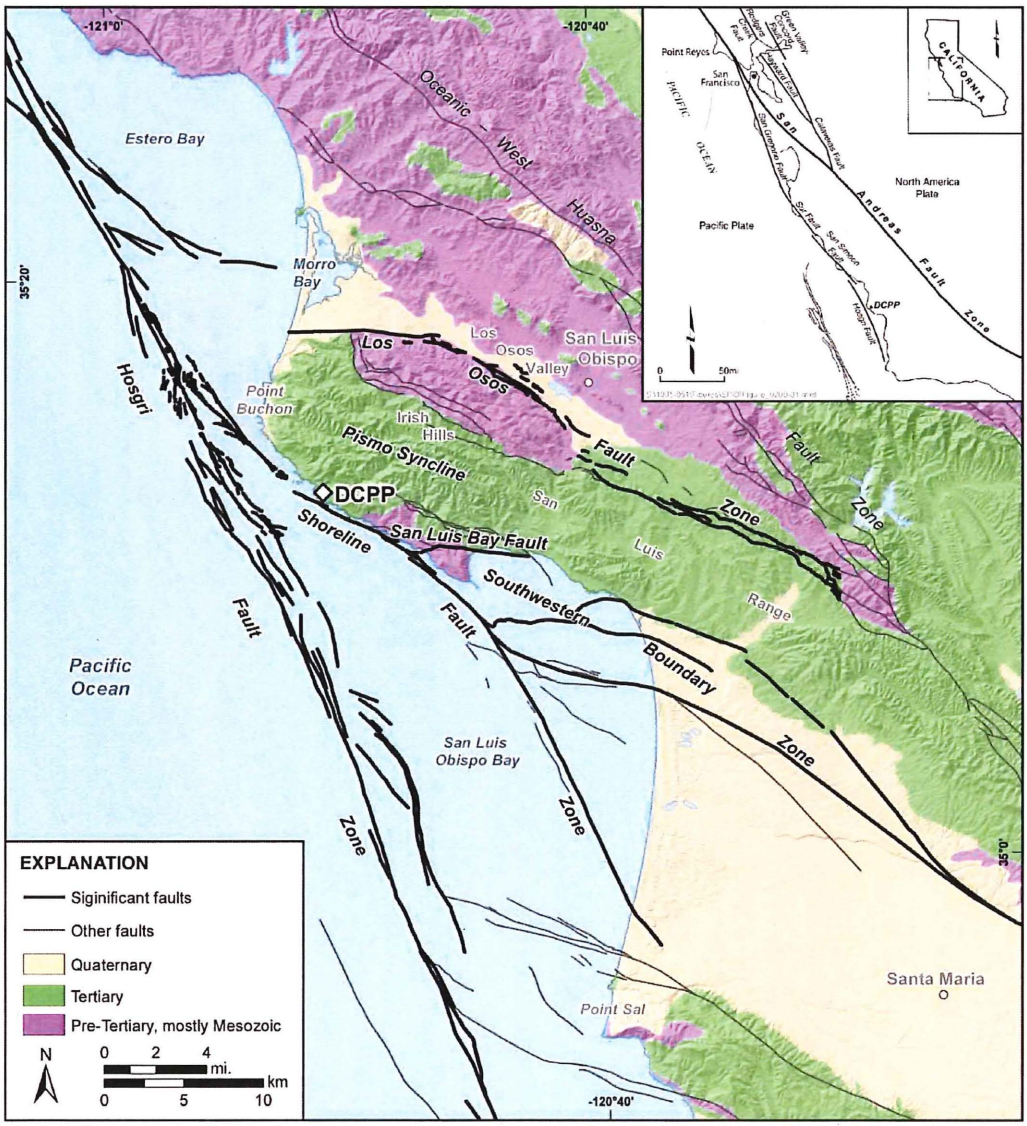

Figure 2.0-1: Simplified Geology and Faults in DCPP's Vicinity

DCPP's site region is within the broad boundary between the Pacific and North American tectonic plates. The majority of relative motion between the plates is accommodated by the right-lateral strike-slip San Andreas Fault Zone (SAFZ), located approximately 80 km (50 mi.) northeast of DCPP. Lesser rates of plate-boundary deformation are accommodated by faults and folds in the coastal and offshore areas around the site.

Historical earthquakes in the DCPP region have been moderate to large. The largest ground motion recorded at the site is a peak ground acceleration (PGA) (horizontal) of 0.042 g from the 2003 moment magnitude (**M**) 6.5 San Simeon earthquake. This ground motion is significantly lower than the ground motions from the design, licensing, and evaluation basis earthquakes (see Section 3.0 for definitions:

a) Design Earthquake (DE): An earthquake having a horizontal PGA of 0.20 g.

b) Double Design Earthquake (DDE): The DDE is defined as twice the DE and is an earthquake having a horizontal PGA of 0.40 g. The NRC staff requested that PG&E use the DDE for the GMRS comparison (NRC 2012c).

c) 1977 Hosgri Earthquake (HE): DCPP's highest-level design/licensing basis earthquake having a horizontal PGA of 0.75 g.

d) 1991 Long Term Seismic Program Earthquake (LTSPE): DCPP's review level earthquake associated with the SPRA and SMA, having a horizontal PGA of 0.83 g.

2.1 Regional and Local Geology

Bedrock in DCPP's vicinity includes highly deformed Mesozoic and Cenozoic sedimentary and volcanic rocks. Foundations of principal plant buildings are founded directly on volcaniclastic rocks of the Miocene Obispo Formation (Fm.).

2.1.1 Bedrock Stratigraphy

Basement rocks exposed in the central California coastal region generally consist of Jurassic to Cretaceous Franciscan Complex rocks (primarily mélange, metavolcanics, ophiolite, and serpentine) faulted against Cretaceous marine arkosic to lithic sandstone (Figure 2.0-1).

Overlying basement rocks in DCPP's vicinity are a sequence of Cenozoic sedimentary and volcanic rocks deposited in fault-bounded, marine to coastal sedimentary basins. Faulted and folded strata of the Pismo basin are located beneath the DCPP site and much of the San Luis Range in the Pismo syncline

(Figure 2.0-1). The base of the Pismo basin Cenozoic sequence consists of the Oligocene Rincon shale and Vaqueros sandstone, which unconformably overlie the Mesozoic basement rocks. Overlying the Oligocene strata are the Miocene Obispo and Monterey Formations and the Miocene to Pliocene Pismo Fm.. The Obispo Fm. consists of resistant zeolitized tuff, tuffaceous marine sandstone, and diabase, whereas the Monterey and Pismo Formations consist of nonvolcanic marine siltstone, chert, and porcelaneous shale.

2.1.2 Tectonic Setting

DCPP is located within a tectonic region of distributed transpressional dextral shear bordering the eastern margin of the Pacific Plate. The SAFZ, located approximately 80 km (50 mi.) northeast of DCPP, accommodates most of the relative motion between the Pacific Plate and the Sierra Nevada–Great Valley microplate. West of the SAFZ, an additional component of relative Pacific–Sierra Nevada plate motion is accommodated by slip on various Quaternary faults bounding crustal blocks and, to a lesser extent, by deformation within the blocks.

In DCPP's site vicinity, the San Luis Range and adjacent valleys and ranges are underlain by crustal blocks that together make up a larger tectonic element called the Los Osos domain (Lettis et al 2004). The Los Osos domain is a triangular structural region bounded by three Quaternary faults: the northwest-striking right-lateral oblique Oceanic–West Huasna fault zone on the east; the west-striking left-lateral oblique Santa Ynez River fault on the south; and the north-northwest-striking right-lateral Hosgri–San Simeon fault zone on the west (Figure 2.0-1).

Individual blocks within the Los Osos domain are bounded by northwest-striking reverse, oblique, and strike-slip fault zones. Crustal shortening within the Los Osos domain is accommodated primarily by reverse faulting along the block margins, producing alternating uplifted and down-dropped blocks (Lettis et al 1994, Lettis et al 2004). Additional crustal shortening and dextral shear is accommodated by a combination of reverse, oblique, and strike-slip faulting between and within blocks and by block rotation.

DCPP is located within the San Luis–Pismo block, which is topographically expressed by the San Luis Range. The San Luis–Pismo block is bounded by the Los Osos fault zone on the north, by the faults of the "southwestern boundary zone" (including the San Luis Bay, Wilmar Avenue, Los Berros, and Oceano fault zones) on the south, and by the Hosgri fault zone on the west (Figure 2.0-1).

2.1.3 Significant Faults

Faults that contribute significantly to the seismic hazard at DCPP include the Hosgri fault zone, the Los Osos fault zone, the San Luis Bay fault within the southwestern boundary zone, and the Shoreline fault (Figure 2.0-1).

2.1.3.1 Hosgri Fault Zone

The Hosgri fault zone is the southern part of the larger 410 km (255 mi.) long San Gregorio–San Simeon–Hosgri fault system (Figure 2.0-1). The location of the offshore Hosgri fault zone is known primarily from the interpretation of marine seismic-reflection data. The fault zone consists of multiple vertical to steeply dipping traces in a zone up to 2.5 km (1.6 mi.) wide directly offshore of DCPP and forms the western termination of the offshore bedrock platform associated with uplift of the San Luis–Pismo block (PG&E 1988, PG&E 1990, PG&E 2011; Willingham et al 2013). Focal mechanisms and the distribution of seismicity along the Hosgri fault zone document nearly pure strike slip on a near vertical to steeply east-dipping fault to a depth of 12 km (7.5 mi.) (McLaren and Savage 2001; Hardebeck 2010, Hardebeck 2013).

Slip rate studies provide an estimate of approximately 1 to 3 millimeters per year (mm/year) of right-lateral slip on the Hosgri fault near DCPP (Hanson and Lettis 1994; Johnson et al 2014; PG&E 2014, Chapter 3). These rates are consistent with regional geodetic data showing approximately 1 to 3 mm/year of plate-margin lateral shear in the region west of the West Huasna fault (DeMets et al 2014).

2.1.3.2 Los Osos Fault Zone

The Los Osos fault zone borders the northeastern margin of the San Luis Range (Figure 2.0-1). The south to southwest-dipping fault generally separates the uplifting San Luis–Pismo block from the subsiding or southwest-tilting Cambria block to the northeast (Lettis et al 1994). As described by Lettis and Hall (Lettis and Hall 1994), the fault zone is a 2 km (1.2 mi.) wide system of discontinuous, sub-parallel and en-echelon fault traces extending from an intersection with the Hosgri fault zone in Estero Bay on the north to an intersection with the West Huasna fault southeast of San Luis Obispo, for a distance of over 55 km (34 mi.). The slip rate of this reverse to reverse-oblique fault is estimated to be approximately 0.2 to 0.4 mm/year (PG&E 2015).

2.1.3.3 San Luis Bay Fault within the Southwestern Boundary Zone

The southwestern margin of the San Luis Range is bordered by a complex zone of late Quaternary reverse, oblique-slip and possibly strike-slip faults (Figure 2.0-1). These faults in aggregate separate the San Luis–Pismo block from the subsiding Santa Maria Valley block to the southwest (Lettis et al 1994). The zone of faults is collectively called the southwestern boundary zone, and is 4 to 10 km (2.5 to 6.2 mi.) wide and over 60 km (30 km) long (Lettis et al 1994; Lettis et al 2004). The faults generally strike west-northwest and dip moderately to steeply to the northeast. Principal structures within this fault zone include the San Luis Bay, Wilmar Avenue, Los Berros, Oceano, and Nipomo faults. The cumulative rate of vertical separation across the fault zone, based primarily on

deformation of the marine terrace sequence along the coast and southwest side of the range onshore, ranges from about 0.1 to 0.3 mm/year with each fault generally having a rate of 0.04 to 0.1 mm/year (Lettis et al 1994). Within the southwestern boundary zone, the north-dipping, reverse-slip San Luis Bay fault lies closest to DCPP. The fault has an estimated slip rate of approximately 0.1 to 0.3 mm/year (PG&E 2015).

2.1.3.4 Shoreline Fault Zone

The Shoreline fault was originally identified from a seismicity lineament trending approximately N60°W to N70°W offshore and parallel to the coast in the vicinity of DCPP (Hardebeck 2010) (Figure 2.0-1). Mapping of the Shoreline fault zone at and near the seafloor was performed by PG&E (PG&E 2011; PG&E 2014, Chapters 2 and 3). The hypocentral distribution of seismicity forms a nearly vertical alignment that extends to a depth of about 8 to 10 km, and focal mechanisms indicate the fault is right-lateral strike slip (Hardebeck 2013). Hardebeck (Hardebeck 2013) interprets that to the north the Shoreline fault zone likely connects with the Hosgri fault zone, a result that is consistent with PG&E (PG&E 2014, Chapter 2). Within San Luis Obispo Bay and south of the seismicity lineament, high-resolution 3D seismic data show that the Shoreline fault zone displaces sediments of late Quaternary age providing clear geologic evidence of late Quaternary fault activity (PG&E 2014, Chapter 3). The Shoreline fault zone has an estimated slip rate of approximately 0.03 to 0.15 mm/yr (PG&E 2015).

2.1.4 Site Geology

The geology of DCPP's site area consists of Tertiary Obispo Fm. resistant tuff, volcaniclastic strata, and later-stage Obispo Fm. diabase that intruded into the Obispo Fm. volcaniclastics, Quaternary surficial deposits, and engineered fill (Figures 2.1.4-1 and 2.1.4-2). Older Cretaceous sandstone and Franciscan basement rocks are mapped on the seafloor approximately 500 meters (m) southwest of DCPP (Figure 2.1.4-1), and onshore along the coastline several km to the southeast (Figure 2.0-1; PG&E 2014, Chapter 9).

Four map-scale Obispo Fm. sub-units, or lithofacies, are recognized within the DCPP site area. From oldest to youngest, these sub-units are as follows:

a) Resistant, bedded to massive tuffaceous rocks, including possible "peperite," a near-source intrusive tuff (Tmor)

b) Bedded, shaley siltstone with tuffaceous fine sandstone interbeds (Tmofc)

c) Bedded, tuffaceous and dolomitized fine sandstone and siltstone (Tmofb)

d) Massive to jointed diabase (Tmod).

The diabase sub-unit intrudes all the other lithologies, and thus is the youngest (PG&E 2014, Chapter 9).

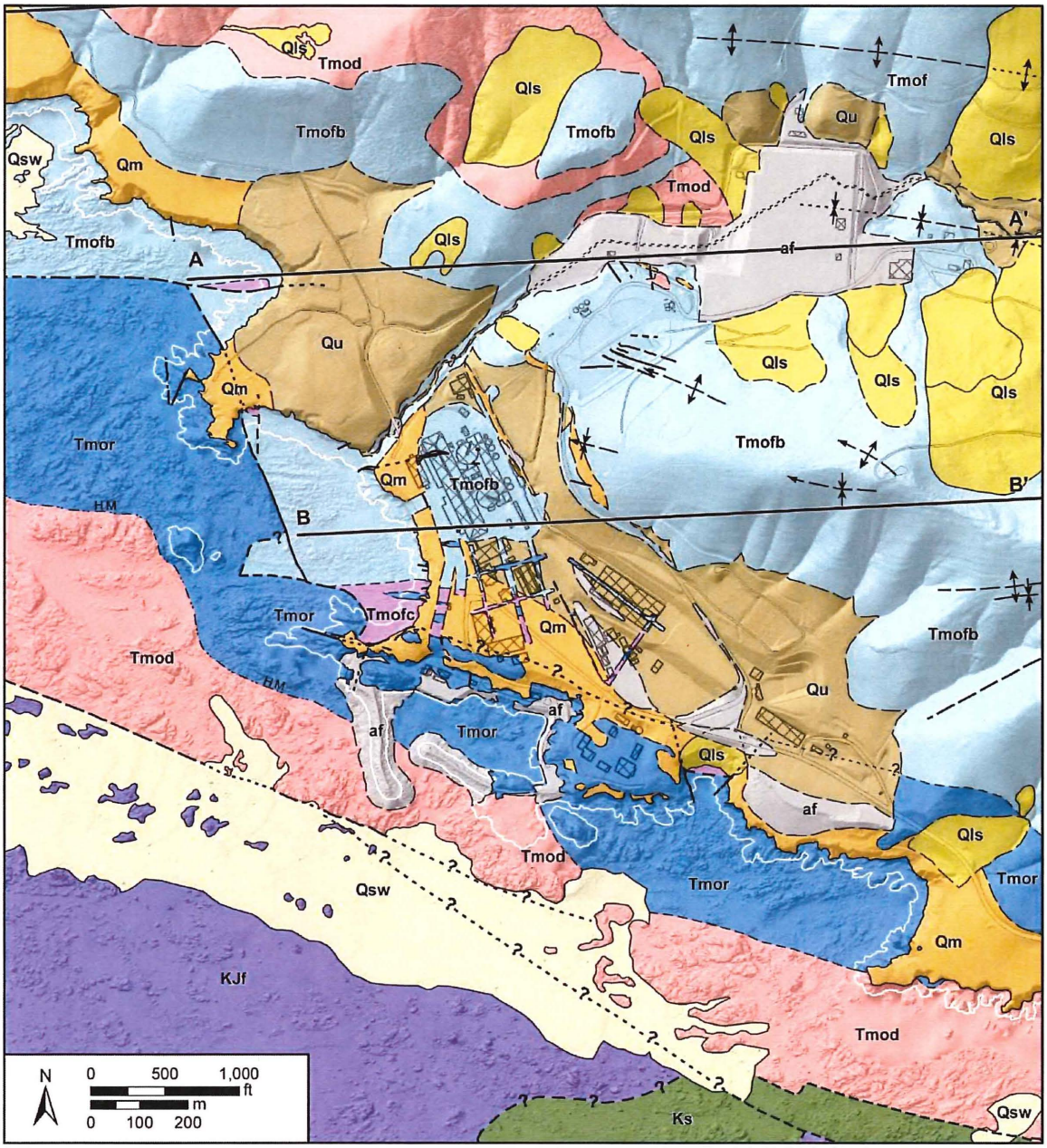

Figure 2.1.4-1: Geologic Map of DCPP's Site Area from (PG&E 2014, Chapter 9) (Explanation of geologic units and symbols are shown on Figure 2.1.4-2)

Geologic Units

Quaternary

- **af** — **Artificial fill:** fill material emplaced locally during construction and improvement activities. Shallow fills not shown; bedrock with trenches and excavation for power block shown; filled with af.
- **Qsw** — **Sand wave deposits, offshore:** unlithified sheets of sand that form migrating marine dunes.
- **Qls** — **Landslide deposits:** unlithified masses of displaced bedrock and/or soil; may be active or inactive.
- **Qm** — **Marine terrace deposits:** unlithified to weakly lithified marine sand and gravel deposited above wave-cut platforms in the Pleistocene and commonly overlain by alluvial fan and colluvial deposits.
- **Qu** — **Quaternary deposits, undifferentiated:** unlithified silt, sand, and/or gravel; consists of alluvial fan, fluvial terrace, alluvial and colluvial deposits.

Neogene — Miocene

- **Tmod** — **Obispo Formation, diabase:** brown, aphanitic to phaneritic, intrusive in dikes and sills.
- **Tmofb** — **Obispo Formation, fine-grained sub-member b:** Bedded tuffaceous, dolomitic, fine to medium-bedded siltstone and fine sandstone.
- **Tmofc** — **Obispo Formation, fine-grained sub-member c:** Bedded shale and siltstone, very fine bedded silty shale with medium bedded, dolomitic siltstone interbeds.
- **Tmor** — **Obispo Formation, resistant member:** Bedded to massive zeolitic tuff, tuff breccia, and tuffaceous sandstone.

Jurassic/Cretaceous

- **Ks** — **Cretaceous Sandstone:** arkosic to lithic sandstone, brown, bedded, well-lithified, fine- to course-grained, includes minor shale.
- **KJf** — **Franciscan Complex, undifferentiated**

Geologic Structures

From previous mapping and GMP

- **Contact:** solid where well located, long dash where approximate, short dash where inferred, dotted where concealed, queried where uncertain.
- H M — Boundary (contact) between Obispo diabase and tuffaceous rocks interpreted from helicopter magnetic survey (PG&E, 2011). Line may not follow exact contact of rock at surface.
- **Syncline:** dashed where approximate, dotted where concealed. Arrow points in direction of plunge.
- **Anticline:** dashed where approximate, dotted where concealed. Arrow points in direction of plunge.
- **Fault:** solid where well located, long dash where approximate, short dash where inferred, dotted where concealed, queried where uncertain.

Geographical Features

- Roads
- Buildings
- Coastline (white line) at mean lower low water (approximate sea level)
- A — A' Vp Cross sections (Figure 2.3.1-3)

Figure 2.1.4-2: Explanation of Geologic Units and Symbols for Figure 2.1.4-1

DCPP is underlain by gently to steeply dipping sub-unit Tmofb, the bedded, tuffaceous and dolomitized fine sandstone and siltstone (Figure 2.1.4-1). Directly adjacent to the foundation area, this volcaniclastic sub-unit is locally unconformably overlain by Quaternary surficial units including alluvial fan sediments (mapped as part of undifferentiated Quaternary deposits (Qu)) and marine terrace deposits (Qm) (Figure 2.4.1-1). Additionally, engineered fill (af) underlies portions of the roadways and infrastructure at the DCPP site.

2.2 Probabilistic Seismic Hazard Analysis

2.2.1 Probabilistic Seismic Hazard Analysis Results

In accordance with the March 12, 2012 50.54(f) letter (NRC 2012) a site-specific probabilistic seismic hazard assessment was completed for DCPP's site. The assessment used an updated seismic source characterization (SSC) model and an updated GMC model as basic inputs. The SSC and GMC studies were undertaken to fulfill the NRC requirement that PG&E conduct a probabilistic seismic hazard assessment using SSHAC Level 3 procedures for DCPP, as specified by the NRC (NRC 2012). Thus, the SSC and GMC models were developed using processes that are appropriate for a SSHAC Level 3 study, as described in NUREG/CR-6372 (NRC 1997), and the detailed implementation guidance provided in NUREG-2117 (NRC 2012b). Both the SSC and GMC models represent new or "replacement" models according to the definitions and instructions in NUREG-2117. The SSC model describes the future earthquake potential (e.g., magnitudes, locations, and rates) for the region surrounding the DCPP site, and the GMC model describes the distribution of the ground motion as a function of magnitude, style of faulting, source-to-site geometry and reference site condition.

The DCPP SSC model includes fault and areal seismic sources out to and beyond the 320 km (200 mi.) DCPP site region. The SSC model focuses on those sources that contribute most to hazard at DCPP: the Hosgri, Los Osos, San Luis Bay, and Shoreline fault sources, called the primary fault sources, and the local areal source zone, which accounts for earthquakes that occur near DCPP but off the recognized fault sources (PG&E 2015). Uncertainty and variability in earthquake ruptures that are modeled to occur on the primary and adjacent fault sources consider alternative fault geometries and fault slip rates, and include alternative connections of adjacent fault sections across which earthquake ruptures may occur. New elements in the SSC model compared to prior SSC models include fault magnitude probability density functions that allow a fault source to rupture during more common, characteristic earthquakes and rare but permissible multi-fault, maximum earthquakes. The largest earthquake considered in the SSC model is a magnitude **M** 8.5 on the Hosgri fault source, representing an extremely rare, but plausible, rupture between offshore Point Arguello south of DCPP and the Mendocino Triple Junction offshore Cape Mendocino in northern California. The postulated rupture would include the

entire 410 km (255 mi.) length of the Hosgri–San Simeon–San Gregorio fault zone and an additional 330 km (205 mi.) of the northern San Andreas fault north of San Francisco. More common characteristic earthquake magnitudes on the fault sources range between **M** 6 and **M** 7.3, with strike-slip, reverse, and reverse-oblique slip senses occurring between approximately 10 and 1 km (6 and 0.6 mi.) from DCPP at closest source-to-site distances. Another new element of the DCPP SSC model is the inclusion of uncertainty in the time-dependent nature of the earthquake occurrence rate. Instructions for implementing the SSC model are in the SSC hazard input document. Full documentation of the DCPP SSC model and the SSHAC Level 3 process is contained in the DCPP SSC Report (PG&E 2015) and is available online at www.pge.com/dcpp-ltsp.

The DCPP GMC model is derived as part of a regional study addressing the ground motion characterization for two sites located in the Southwestern United States (SWUS) (DCPP and Palo Verde Nuclear Generating Station in Arizona), for a common reference site condition with V_{S30}[3] of 760 meters per second (m/s) and kappa of 0.041 seconds (sec) (GeoPentech 2015). The DCPP GMC model for the median is derived from published ground motion prediction equations which are then reparameterized into models that use a common functional form. With a set of models based on a common functional form, the covariance structure of the model coefficients can be estimated and sampled to produce a large number of alternative ground motion prediction equations (GMPEs). This large space of ground motion models is then discretized into a smaller number of representative ground motion models. A key advantage of this approach is that the weights on the alternative models represent probabilities of the ground motion models based on the discretization of the ground motion model space. The ground motion models are optimized for large magnitudes (**M** 5.5 to **M** 7.5) strike slip and reverse events at short distances (< 10 km) that dominate the hazard at DCPP. The hanging-wall effects are captured from a suite of hanging-wall adjustment models derived from the hanging-wall scaling in the existing NGA-West2 R_{RUP}-based GMPEs.

In addition to the empirically-based models, finite fault simulations were used for three purposes: (1) to constrain the hanging-wall scaling; (2). to provide an alternative data set of large magnitude near-fault ground motions for use in the evaluation of the weights for the ground motion models; and (3) to constrain the scaling of ground motions for complex and splay ruptures that are not well constrained in the empirical data sets (complex rupture refers to a case with significant (i.e., > 15 degrees) changes in rake and dip along fault strike, and splay rupture refers to a case with two faults rupturing together). The GMC model for the standard deviation for DCPP uses the partially non-ergodic approach (Al Atik et al, 2010) in which the variability of the average site-specific amplification, not captured in the simple site scaling in the GMPEs, is removed from the within-event standard deviation. This approach provides a consistent

[3] V_{s30} is defined as the average shear-wave velocity in the first 30 m of subsoil/rock.

method for combining the uncertainty in the site-specific site amplification with the aleatory variability of the ground motion models.

Instructions for implementing the GMC model are in the GMC hazard input document. Full documentation of the DCPP GMC model and the SSHAC Level 3 process is contained in the southwestern United States GMC report (GeoPentech 2015) which is available online at www.pge.com/dcpp-ltsp.

2.2.2 Base Rock Seismic Hazard Curves

For the central and eastern United States (CEUS) sites, the base rock condition is a hard rock site condition (shear-wave velocity of 2800 m/s) (EPRI 2013c). For the western United States, the ground motion models are not well constrained for hard-rock conditions. Therefore, a reference rock condition for soft-rock (V_{S30} = 760 m/s) is used for the base rock hazard calculation.

The hazard is computed using a minimum moment magnitude of 5.0. All sources within 320 km (200 mi.) of DCPP are included in the hazard calculation, as required by Regulatory Guide 1.208 (NRC 2007). The aleatory variability is modeled using the single-station sigma approach (Al-Atik et al 2010), which removes the systematic site terms from the traditional total standard deviation. Using the single-station sigma approach requires that the epistemic uncertainty in the site-specific site terms be included. The epistemic uncertainty in the site term at each spectral frequency is included through the standard error of the empirical site term.

The hazard curves by seismic source are shown in Figures 2.2.2-1 and 2.2.2-2 for 1 and 10 Hz spectral acceleration, respectively. The digital data associated with these figures are listed in Appendix A. The sources that contribute at least 5 percent to the total hazard at 1×10^{-3} hazard level are shown individually. Only the sources that come within 15 km (9 mi.) of DCPP contribute significantly (at least 5 percent) to the total hazard at any spectral period for hazard levels of 1×10^{-3} or less. The total hazard for seven frequencies is shown in Figure 2.2.2-3.

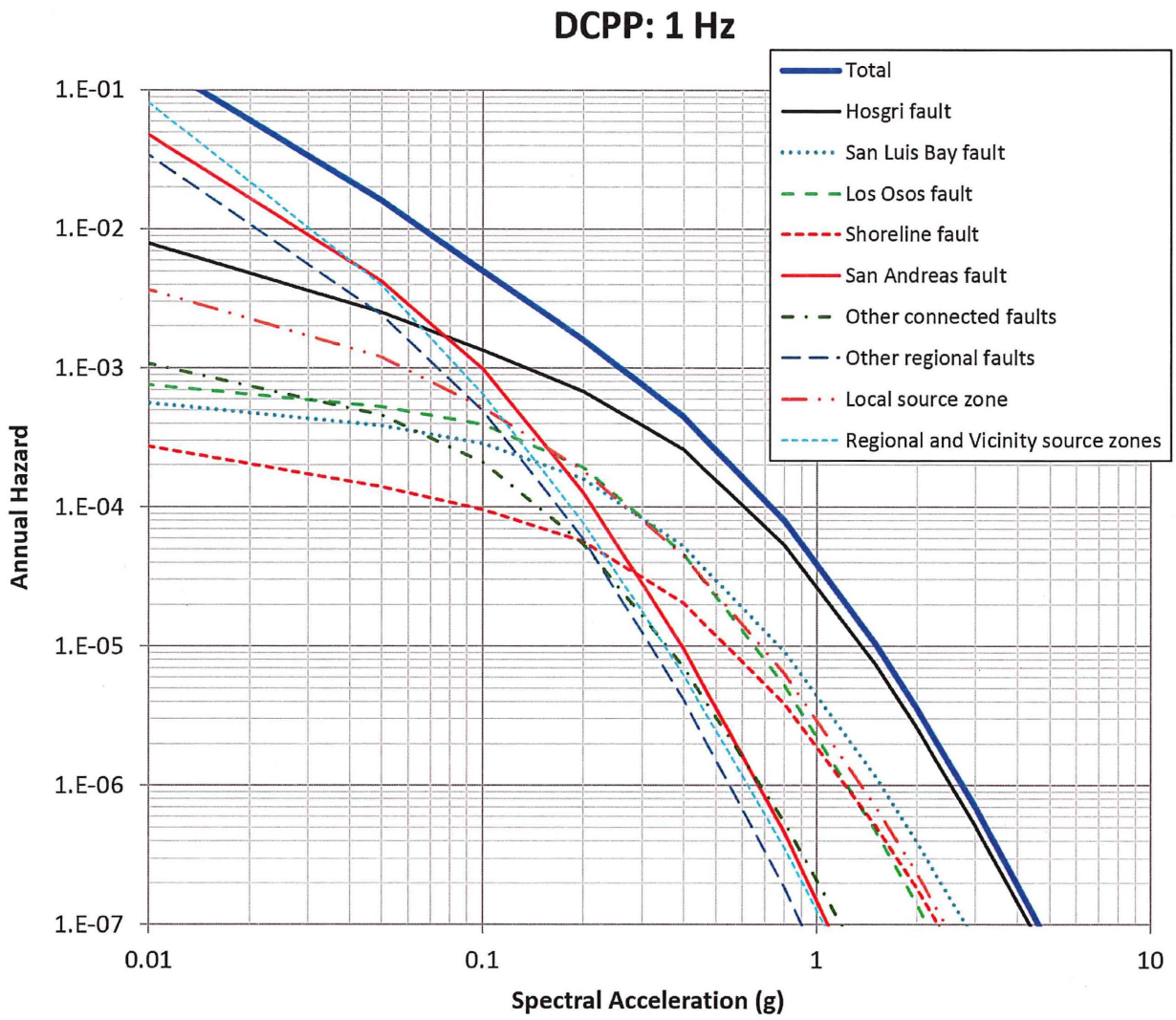

Figure 2.2.2-1: Reference Rock Hazard by Source for 1 Hz Spectral Acceleration

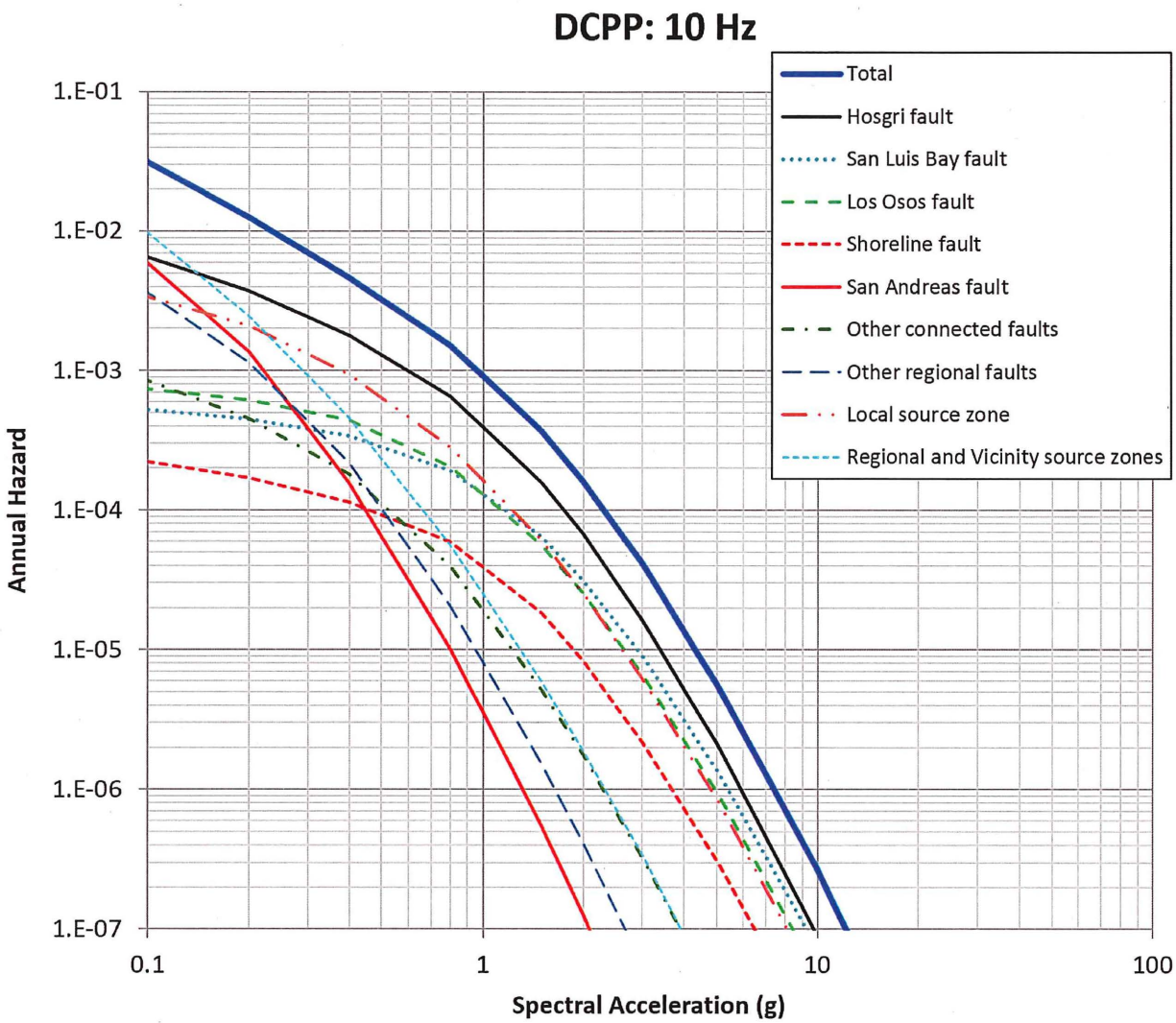

Figure 2.2.2-2: Reference Rock Hazard by Source for 10 Hz Spectral Acceleration

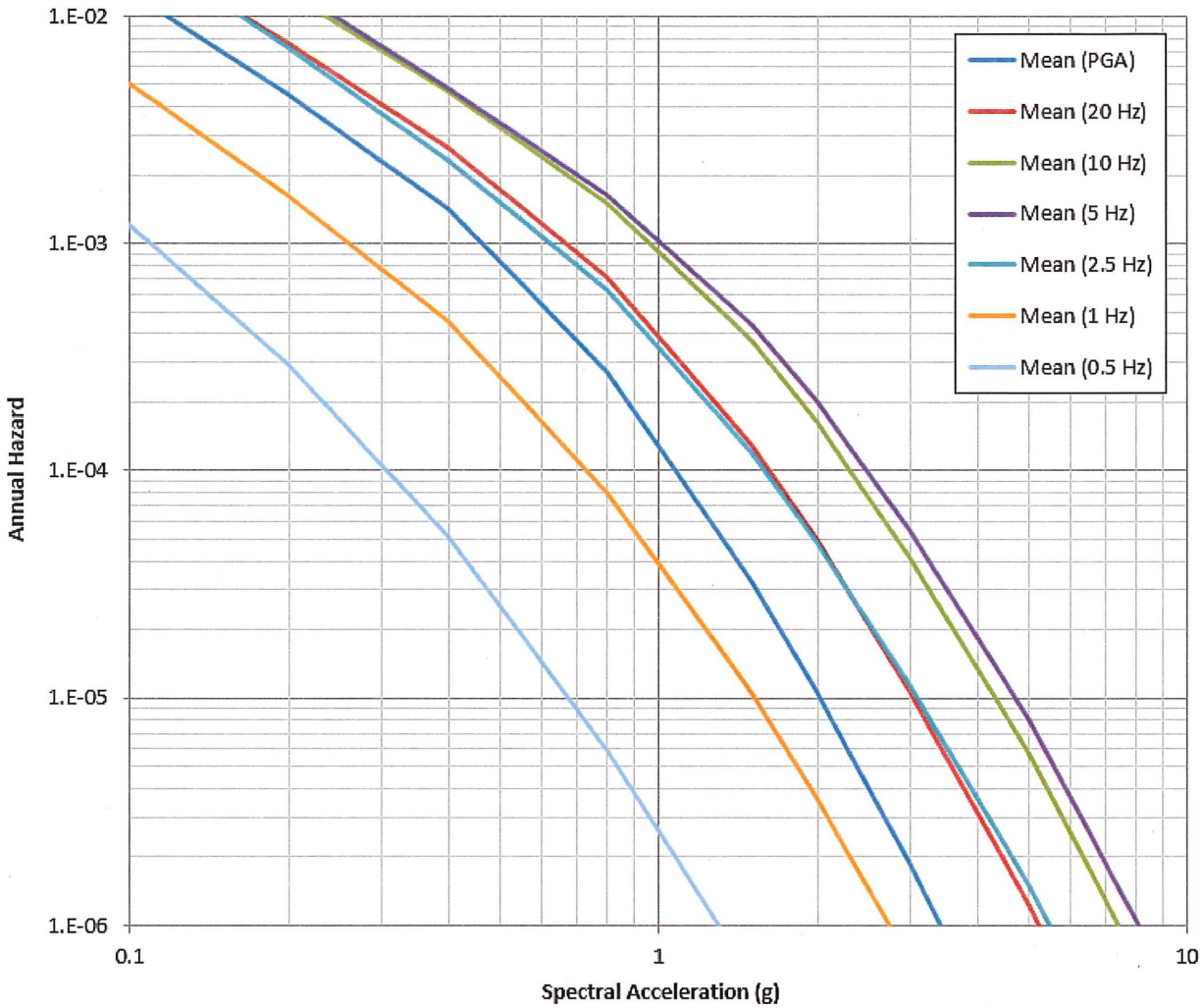

Figure 2.2.2-3: Reference Rock Mean Hazard for PGA and 20, 10, 5, 2.5, 1, and 0.5 Hz Spectral Acceleration

2.3 Site Response Evaluation

The traditional approach for site response is to develop analytical models for the site amplification relative to the reference rock site condition used for computing the hazard. An alternative empirical approach is used for DCPP to account for the recorded ground motion data at DCPP[4]. This approach relies on the observed ground motions at the site to constrain the site amplification rather than analytical models. When site specific data are available, the empirical approach is preferred over analytical modeling. The epistemic uncertainty due to the limited number of recordings is taken into account.

[4] DCPP's seismic instrumentation system, described in Section 3.7.4 of the DCPP UFSAR (PG&E 2013), includes several free-field recording instruments. Ground motion records from instrument nos. ESTA27 and ESTA28 (see Figure 2.3.2-4 for instrument locations) are used as input to the site response evaluation.

The empirical site term represents the difference from the site amplification expected for a reference V_{S30} of 760 m/s and the observed site amplification. It is estimated from recorded data after removing the average source and path terms from the observed ground motions at DCPP.

The control point for DCPP is set at one of the free-field recording instruments (ESTA28). This control point is at elevation 26 m (85 feet (ft)). The empirical site response approach estimates the site amplification at the control point. To estimate the ground motions at other locations as part of the soil-structure interaction analyses, a three-dimensional (3D) site response will be conducted in a separate study. The 3D site response will be used to compute the factors to scale the control point ground motions to other locations accounting for the lateral differences in the 3D velocity structure across the DCPP site. Equivalent one-dimensional (1D) profiles will be developed that capture the range of the amplification from the alternative 3D velocity models in order to define the inputs for the soil-structure interaction analyses.

2.3.1 Description of Subsurface Material

The volcaniclastic Tmofb subunit of the Tertiary Obispo Fm. is mapped to the bottom of the four deepest boreholes in the DCPP foundation area, as well as two deep boreholes located about 305 m (1000 ft) east-northeast of the northeastern corner of the DCPP foundation. Directly adjacent to the Tmofb subunit are other subunits of the Obispo Fm. as shown on Figure 2.1.4-1.

There is considerable rock velocity variability observed in the high-resolution 3D tomographic 5 km by 5 km (3 mi. by 3 mi.) area containing the DCPP structure foundations (PG&E, 2014, Chapter 10). A substantial portion of this variability appears to be related to volcanic intrusion and alteration of the diabase subunit. Characteristics of acoustic (Vp) seismic velocities estimated using 3D tomography from active-source seismic data collected in 2011 and 2012 (PG&E 2014, Chapter 10) are briefly discussed below and then related to first-order geology in the remainder of this section.

The 2011-2012 active seismic acoustic-wave (Vp) travel-time and 2013 gravity data were inverted to estimate 3D Vp in a large area containing DCPP (PG&E 2014, Chapter 10). Several additional 3D Vp inversions used successively finer grid spacing and progressively smaller maximum offset arrival time data to estimate more detailed 3D Vp in the 5 km by 5 km (3 mi. by 3 mi.) volume containing DCPP. The active seismic data were also processed to produce prestack depth-migrated 3D seismic velocity volumes containing DCPP.

There is a first-order correlation between 3D Vp and geologic units (Table 2.3.1-1). The lowest seismic velocities are associated with Quaternary surficial units and the shallowest weathered regions in Tertiary rocks beneath

surficial units. The highest seismic velocities are associated with massive diabase. Seismic velocities in the top 300 m vary by more than a factor of 13 in DCPP's site area. Less than half this velocity range is represented by about a factor of three range in velocities between the slowest Quaternary surficial units (Vp = 0.5 kilometers per second (km/s)) and the top of competent weathered rock (Vp = 1.5 km/s). The remaining velocity variability of about a factor of four occurs within Tertiary Obispo Fm. rocks that comprise the entire rock portion of the DCPP foundation to about 300 m below sea level or more.

Interpretation of 3D seismic-reflection data acquired in 2012 in a 3D depth-migrated volume containing the DCPP foundation indicates that there is an unconformity at elevations deeper than 300 m below sea level that separates shallow Obispo rocks from either deeper older Obispo rocks or Cretaceous sandstone (PG&E, 2014, Chapter 8). Thus the entire rock portion of the 3D DCPP foundation velocity model likely consists entirely of Tertiary Obispo Fm. rocks beneath surficial deposits.

Table 2.3.1-1: Generalized Irish Hills Vp-Geologic Unit Correlation

Bin Color (Figure 2.3.1-1)	Vp		Geologic Unit(s)
	(km/sec)	(ft/sec)	
Black	0.560	1,857	Dry soil
Dark Blue	1.120	3,675	Dry soil–weathered rock
Dark Green	1.676	5,512	Saturated soil–weathered rock
Medium Green	2.235	7,349	Typical Tertiary (all units except diabase), weathered Ks and KJf, and KJf of the northern Irish Hills
Light Green	2.794	9,186	Typical higher velocity Obispo Fm. except diabase, and KJf of the northern Irish Hills
Light Blue	3.353	11,024	Typical Ks, fast Obispo Fm. (except diabase), and KJf of the northern Irish Hills
Yellow	3.911	12,861	Typical near the top of KJf, zones around thin diabase, and KJf of the northern Irish Hills
Red	4.470	14,698	Near maximum for KJf, low diabase, and Monterey and Obispo Fm. in the hanging wall of the Edna fault
Dark Red	5.029	16,535	KJf near large-scale diabase intrusions, thin diabase, and Monterey and Obispo Fm. near the Edna fault
Purple	5.588	18,373	Exclusively diabase

Notes: Minimum velocity of the bin is listed.
Ks = Cretaceous sandstone
KJf = Franciscan complex

The 3D Vp values and their correlative geologic units shown in Table 2.3.1-1 were developed by comparing 3D Vp values to observed geologic units throughout the Irish Hills. The table illustrates that, while there probably are unique correlations between velocity and geologic unit for the fastest and slowest velocities in the DCPP foundation area, intermediate velocities can correspond to several different rock types and geologic units of various ages that exist beneath the greater Irish Hills. Thus, seismic velocity does not, in general, uniquely distinguish one rock type or formation from another. For instance, the velocity bin of ~2.2 to 2.8 km/s in Table 2.3.1-1 captures Tertiary Monterey and lower-velocity Obispo Fm. rocks as well as weathered Cretaceous sandstone (Ks) and Franciscan rocks (KJf). Unweathered, massive Obispo diabase is likely the only high-velocity rock unit that has a unique velocity signature over its maximum velocity range of 5.5–6+ km/s (Table 2.3.1-1).

Tabular and saucer-shaped high-velocity bodies are evident in east-west oriented Vp cross sections located beneath and to the north DCPP

(Figures 2.1.4-1 and 2.3.1-1) and within the high-resolution 5 km by 5 km (3 mi. by 3 mi.) tomographic model where dense seismic travel-time measurements where obtained (PG&E 2014, Chapter 10).

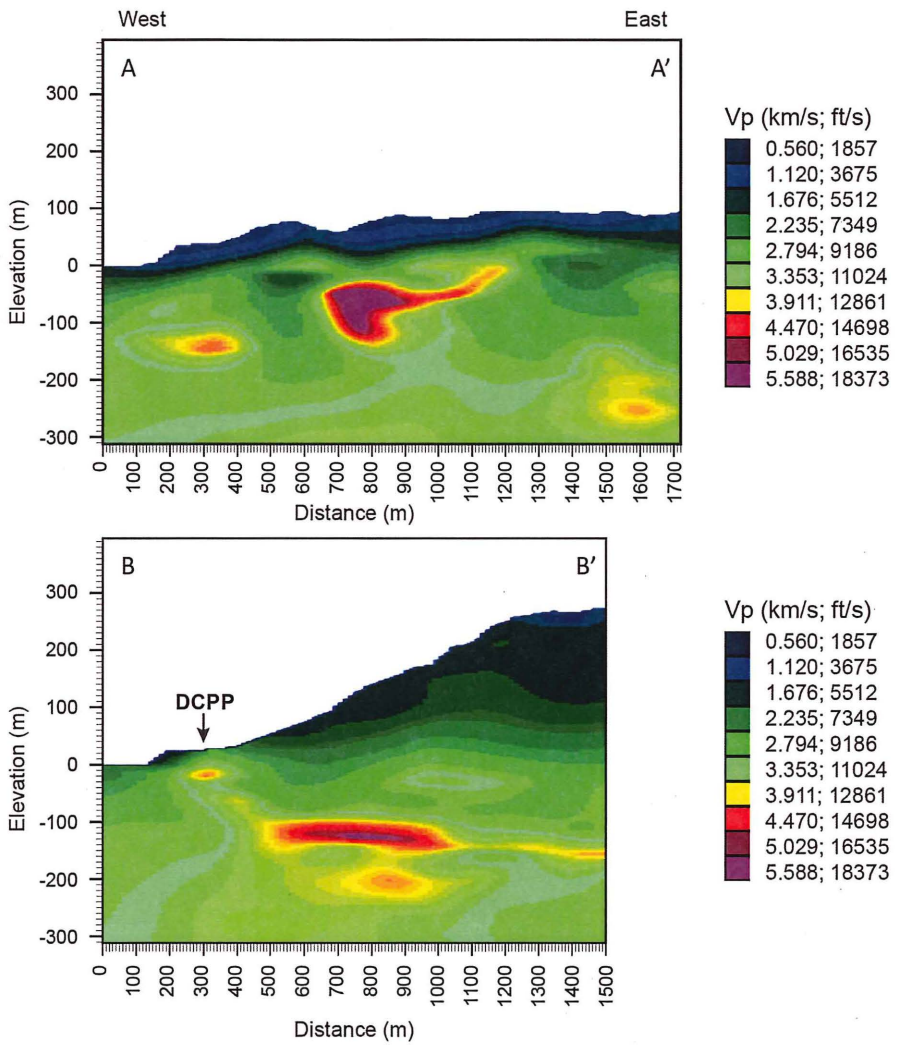

Figure 2.3.1-1: Vp Cross Sections Showing High-Velocity (yellow to magenta) Saucer-Shaped Bodies
(Vertical exaggeration is approximately 2:1. Velocities listed correspond to the top of each color bin. See Figure 2.1.4-1 for cross-section locations)

These high-velocity bodies have 3D shapes that are typically associated with saucer-shaped intrusive sills (PG&E 2014, Chapter 10). The shallow position of the saucer-shaped sills adjacent to, and beneath, some edges of DCPP's foundation area may in part explain observations of the diabase subunit exposed adjacent to the breakwater of intake cove (Figure 2.1.4-1), along the coastline southeast of DCPP, and offshore of DCPP (PG&E 2014, Chapter 9).

2.3.2 Development of Base Case Profiles and Nonlinear Material Properties

The traditional approach uses multiple base profiles and non-linear properties to capture the epistemic uncertainty in the site amplification. For the empirical site term approach used for DCPP, epistemic uncertainty is captured through the epistemic uncertainty of the empirical site terms rather than using uncertainty in the inputs to an analytical site response model.

For DCPP, we use alternative 3D models to capture the epistemic uncertainty in the lateral variation of the ground motion across the DCPP site region. The alternative 3D velocity models were selected from a large suite of alternative models such that they appropriately capture the range of the amplification at the key structures. The epistemic uncertainty in the amplification at the control point ground motion is included in the uncertainty of the empirical site factors. To avoid double counting uncertainty, only the uncertainty in the lateral variations of the site amplification due to the alternative 3D velocity is included in the 3D site response evaluation. As an example, three alternative 3D models of the shear-wave velocity are shown in Figures 2.3.2-1, 2.3.2-2, and 2.3.2-3. Figure 2.3.2-4 shows 1D profiles at the control points based on the 3D models.

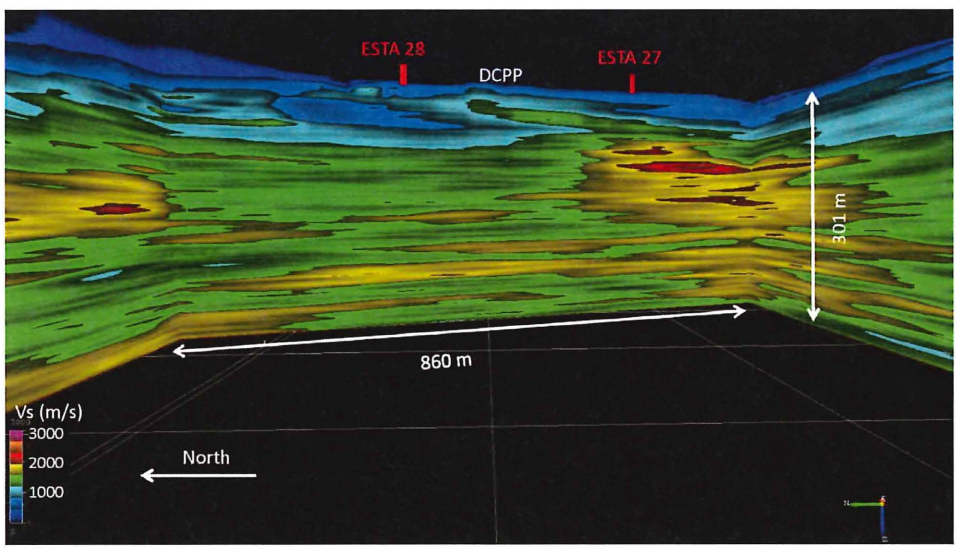

Figure 2.3.2-1: 3D Perspective of Vs-Depth Cross Section Slices through the Low-Amplification 3D Vs DCPP Site Model (Model 1). Location of Cross Section is Shown in Figure 2.3.2-4.

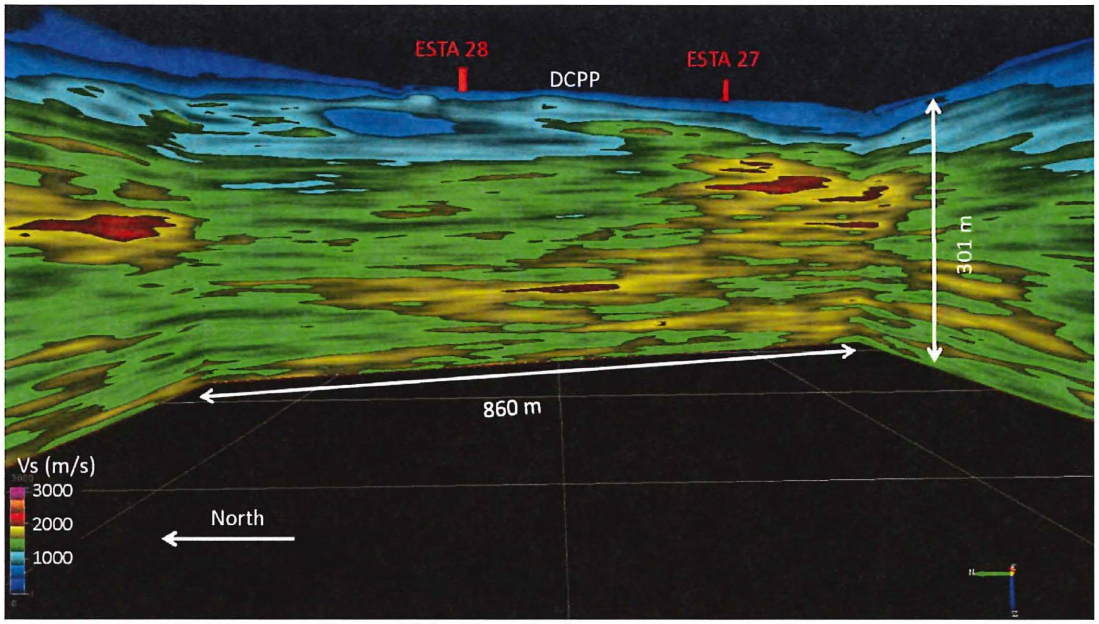

Figure 2.3.2-2: 3D Perspective of Vs-Depth Cross Section Slices through the Medium-Amplification 3D Vs DCPP Site Model (Model 2). Location of Cross Section is Shown in Figure 2.3.2-4.

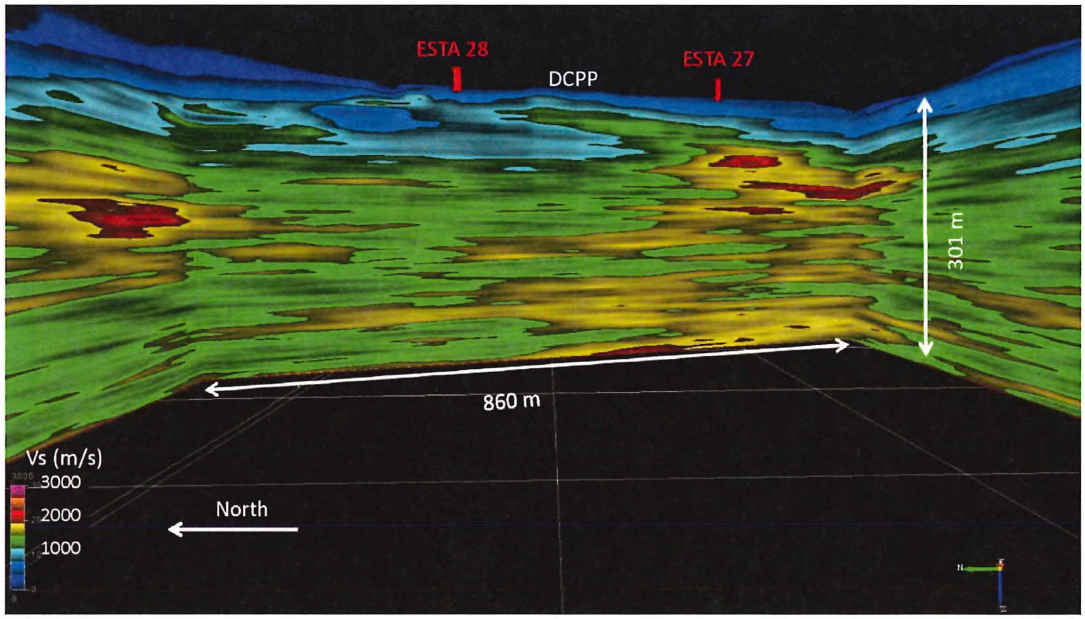

Figure 2.3.2-3: 3D Perspective of Vs-Depth Cross Section Slices through the High-Amplification 3D Vs DCPP Site Model (Model 3). Location of Cross Section is Shown in Figure 2.3.2-4.

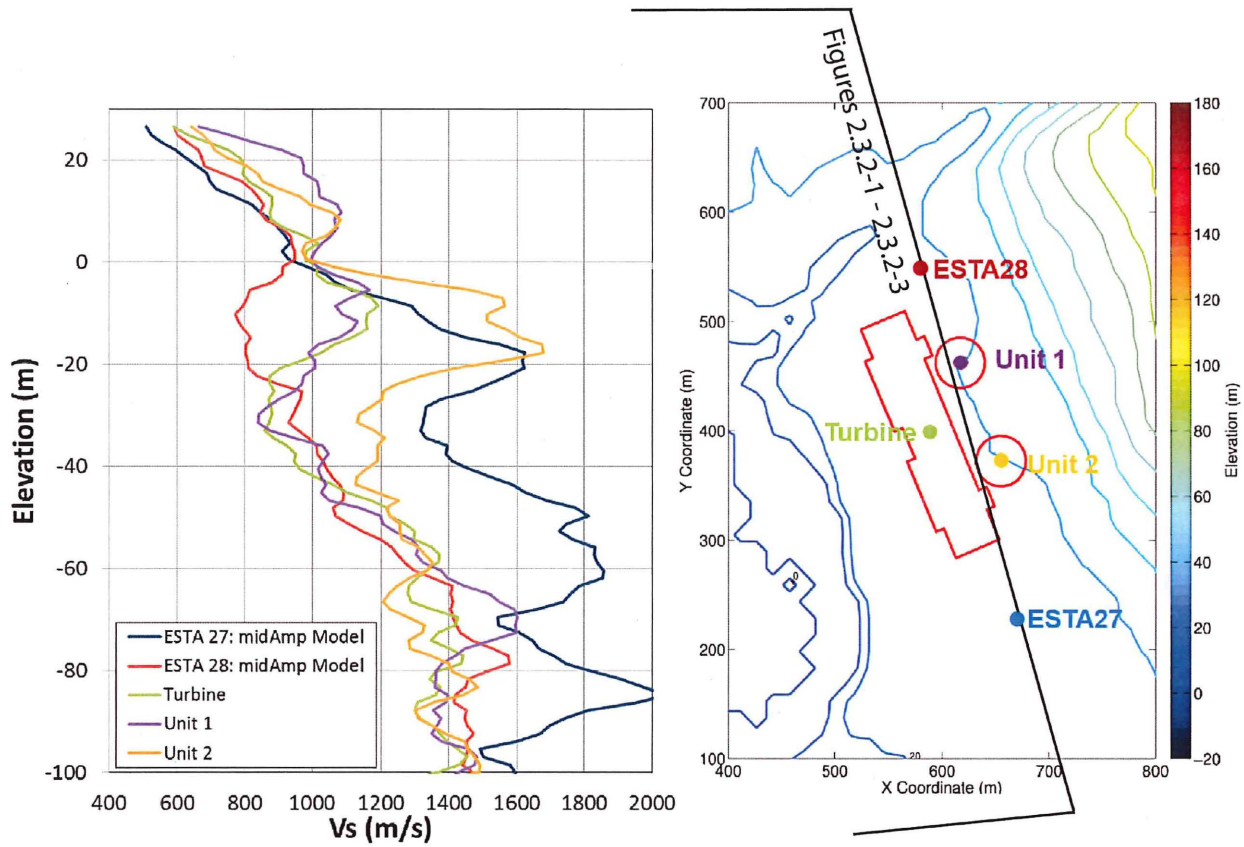

Figure 2.3.2-4: 1D Velocity Model for the Control Point (ESTA 28) and Other Locations in the Plant Area

2.3.2.1 Shear Modulus and Damping Curves

Shear-modulus curves and damping curves are not directly applicable to DCPP, since analytical modeling is not used. The non-linear site effects are implicitly included in the empirical GMPEs for V_{S30} = 760 m/s. The non-linearity in the NGA-West2 GMPEs is generally consistent with the EPRI Peninsular Range shear-modulus curves and damping curves (Kamai et al 2014). In the Kamai et al 2014 model, there is no dependence of the site amplification on the rock ground motion level (e.g. no non-linearity) for V_{S30} > 760 m/s. The NGA-West2 GMPEs also have very weak or no rock ground motion level dependence on the sites amplification for V_{S30} > 760 m/s. Therefore, the empirical site factors are applicable to high rock ground motion levels.

2.3.2.2 Kappa

The kappa values are implied in the empirical GMPEs used to develop the ground motion model and in the site-specific recordings. The GMPEs used to develop the ground motion model have average (host) kappa of 0.041 sec (Appendix M of GeoPentech 2015). The issue for DCPP's empirical approach is the applicability of this host kappa to DCPP's site. The kappa for DCPP was

evaluated using the spectral shape of the 2003 Deer Canyon earthquake (Appendix L of the 2011 Shoreline fault report (PG&E 2011)) and was found to be consistent with a kappa of 0.04 sec. Empirical evaluations of the kappa scale factors (Ktenidou and Abrahamson 2015) show that the dependence of the high-frequency ground motion residuals are not strongly correlated with kappa computed from the observed ground motions. They conclude that the estimated site kappa is correlated with other parameters, which limits the observed correlation of residuals and kappa. Therefore, the kappa from the empirical GMPEs used for the ground motion model is consistent with the DCPP site kappa and an adjustment for site-specific kappa or adding additional uncertainty for kappa is not warranted.

2.3.3 Randomization of Base Case Profiles

Randomization of the base case profiles is not needed since DCPP is using the empirical site term approach.

2.3.4 Input Spectra

An input spectrum is not required since DCPP is using the empirical site term approach.

2.3.5 Methodology

The empirical site-term approach is used because site-specific empirical ground-motion data are available at DCPP. These data provide the best information on the site response because they sample the actual conditions at DCPP. In particular, the data provide a better representation of the effects of the deeper structure (top 0.5–1 km) that are important to the kappa and to the low-frequency response, which may not be captured in the analytical modeling. A disadvantage of using site-specific empirical data is the limited number of recordings; however, this limitation is addressed by estimating the epistemic uncertainty in the site response factors based on the number of recordings and the global estimate of the standard deviation of site-specific site terms.

The free-field recordings at DCPP (available from the Pacific Earthquake Engineering Research ground motion database) are used to estimate the site-specific effects on the ground motions relative to the reference-rock GMPEs. The ground motions at a site from a given earthquake reflect the event-specific source and attenuation effects in addition to the site-specific site effects. To isolate the site effects, the differences in the event-specific source and event-specific attenuation effects from the average effects captured in the GMPEs are removed. This is done by computing the mean residual at each spectral frequency over a subset of recorded ground motions from a representative distance range and then developing a source-specific estimate of the ground motion at DCPP by adding the mean residual to the median ground motion from

each of the GMPEs. The mean residual for the selected data is different from the traditional event term used in developing GMPEs because it is for a limited distance range. This provides an estimate of not just the average source effect, but also the average path effect (difference from the distance scaling in the GMPEs). To avoid having the DCPP site effects influence the correction, the mean residual is computed without the DCPP data.

Ground motions from the 2003 San Simeon and 2004 Parkfield earthquakes were selected for use in this evaluation. The 2003 Deer Canyon earthquake did not have enough recordings to constrain the mean event term independent of DCPP's recordings. Therefore, the recording from the 2003 Deer Canyon earthquake is not used in this evaluation.

The mean residuals are computed for each of the five NGA-West2 GMPEs. Following the method used in the 2011 Shoreline fault report (PG&E 2011), the residuals are computed for eight recordings in the distance range of 0 to 100 km (62 mi.) for the San Simeon earthquake and for 16 recordings in the distance range of 40 to 170 km (25 to 106 mi.) for the Parkfield earthquake to capture the event term in the relevant distance ranges (35 km (22 mi.) for San Simeon and 85 km (53 mi.) for Parkfield). This mean residual is used to adjust the NGA-West2 GMPEs to the event and distance specific values (e.g. remove average source and path effects). The residuals of the free-field spectral accelerations recorded at DCPP are computed with respect to the event and distance specific spectral accelerations.

The 2003 San Simeon earthquake was recorded at one free-field instrument at DCPP (ESTA27). Following the San Simeon earthquake, additional seismic instrumentation was installed, including an additional free-field instrument (ESTA28). The 2004 Parkfield earthquake was recorded at both free-field instruments (ESTA27 and ESTA28).

The velocity profile at the location of instrument no. ESTA28 becomes similar to the power block[5] and turbine building profiles at depths of about 100 m (see Figure 2.3.2-4 above). The profile for free-field instrument no. ESTA27 shows a different gradient and does not merge with the power block and turbine building profiles at depth as seen with the profile for ESTA28. Since the profile at instrument no. ESTA28 is more consistent with the power block and turbine building profiles, this site is selected as the control point.

2.3.6 Amplification Functions

The residuals for the DCPP free-field recordings were computed (PG&E 2014, Chapter 11) for each of the five event-adjusted NGA-West2 models for a

[5] The term "power block" herein refers to the combination of the Unit 1 containment structure, the Unit 2 containment structures, and the common auxiliary building.

reference rock with V_{S30} = 760 m/s. The average residuals over the five GMPEs are shown on Figure 2.3-1. Overall, the frequency-dependent residuals are consistent between the two recordings over most of the frequency range, but there is a large difference at 0.5 hertz (Hz). In particular, the San Simeon residuals are much larger. The ESTA27 time histories from this earthquake show that the 0.5 Hz ground motion is coming from late-arriving surface waves, indicating different path effects for these two earthquakes. This is not seen in the Parkfield recordings at either ESTA27 or ESTA28. Since the low-frequency residual are not similar for both earthquakes, they are not consistent with a strong site effect. The variability of the low frequency amplification is included in the uncertainty of the site factor. The smoothed model is shown by the heavy black line and represents the DCPP site term relative to the reference free-field instrument no. ESTA28 with V_{S30} = 753 m/s.

If there was no ground motion data at a given site, then the mean site term would be zero and the epistemic uncertainty in the site term would have a standard deviation of phi_{S2S}, which is the standard deviation of the site terms from worldwide data sets. As data is recorded at the site of interest, then the mean site term can be estimated and the epistemic uncertainty reduced from the value of phi_{S2S} from global data. The source and path corrected residual at the site given an estimate of the site term. The standard error of the site terms is phi_{S2S} divided by $\sqrt{N}$, where *N* is the number of recordings. The uncertainty in the estimated of the source and path terms due to the limited number of recordings is added to the standard error of the site term. The standard error of the DCPP site term is listed in Table 2.3.6-1. The upper and lower ranges shown in the figure are based on ± 1.25 times the standard error and represent the 10th and 90th confidence limits.

The epistemic uncertainty in the site term has two components: the uncertainty in the estimated event-path terms for each earthquake and the variability in the single-path within-event residuals (phi0). The uncertainty in the event-path term is given by the standard error of the estimate of the mean residual of the selected subsets of recordings (8 recordings from San Simeon and 16 recordings from Parkfield). The observed ground motion at a site is a sample from a normal distribution with a standard deviation given by the single-path within-event standard deviation (called phi0). The standard deviation of the epistemic uncertainty in the site term is given by sqrt((SE1^2 + phi0^2)/4 + (SE2^2+Phi0^2)/4) where SE1 and SE2 are the standard errors of the event-path terms from San Simeon and Parkfield respectively. The value of phi0 is given by Lin et al 2011. The epistemic uncertainty is modeled using a three point distribution based on -1.64, 0, and 1.64 times the standard of the epistemic uncertainty with weights of 0.2, 0.6, and 0.0, respectively. The upper and lower ranges shown in Figure 2.3.6-1 and represent the 5th and 95th confidence limits. The central, upper, and lower ranges of DCPP's site-specific site term are listed in Table 2.3.6-1. The median amplification factors and epistemic uncertainty at

the control point, using the empirical site response approach, are listed in Appendix A.

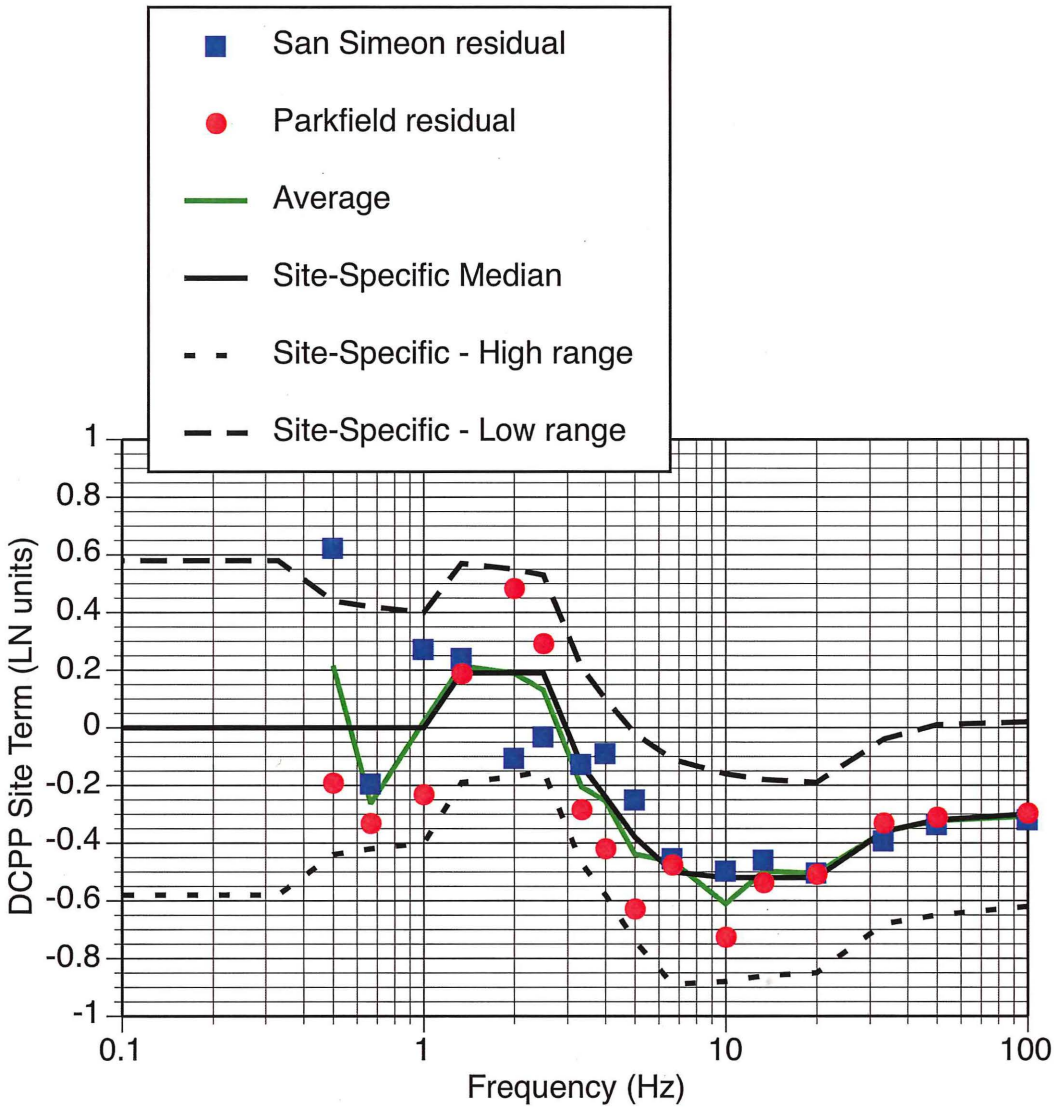

Figure 2.3.6-1: Mean Event-Specific Residuals for DCPP Relative to the ESTA28 Reference Rock Site Condition with V_{S30} = 750 m/s
Note: Epistemic uncertainty (10% and 90% confidence levels) is shown by the dashed lines

Table 2.3.6-1. DCPP Site-Specific Site Amplification Terms

Frequency (Hz)	DCPP Site Term for Control Point (ESTA28) (natural log units)			
	Standard Deviation of DCPP Site Term	Median	Upper Range	Lower Range
100	-0.20	-0.3	-0.62	0.02
50	-0.20	-0.32	-0.65	0.01
34	-0.20	-0.36	-0.68	-0.04
20	-0.20	-0.52	-0.85	-0.19
13.5	-0.21	-0.52	-0.86	-0.18
10	-0.22	-0.52	-0.88	-0.16
6.7	-0.24	-0.5	-0.89	-0.11
5	-0.22	-0.38	-0.74	-0.02
4	-0.21	-0.24	-0.58	0.1
3.3	-0.21	-0.13	-0.47	0.21
2.5	-0.21	0.19	-0.15	0.53
2	-0.22	0.19	-0.17	0.55
1.3	-0.23	0.19	-0.19	0.57
1	-0.24	0	-0.4	0.4
0.67	-0.26	0	-0.42	0.42
0.5	-0.27	0	-0.44	0.44
0.33	-0.35	0.00	0.58	-0.58
0.2	-0.35	0.00	0.58	-0.58
0.1	-0.35	0.00	0.58	-0.58

2.3.7 Control Point Seismic Hazard Curves

The mean hazard for the control point is computed using a method that is consistent with approach 3 of NUREG/CR-6728 (NRC 2001). The site term is added to the median from the ground motion models developed as part of the SSHAC ground motion characterization. Epistemic uncertainty is captured by using a logic tree for the range of the site terms. The mean hazard for the control point for seven frequencies is shown in Figure 2.3.7-1 and listed in Appendix A.

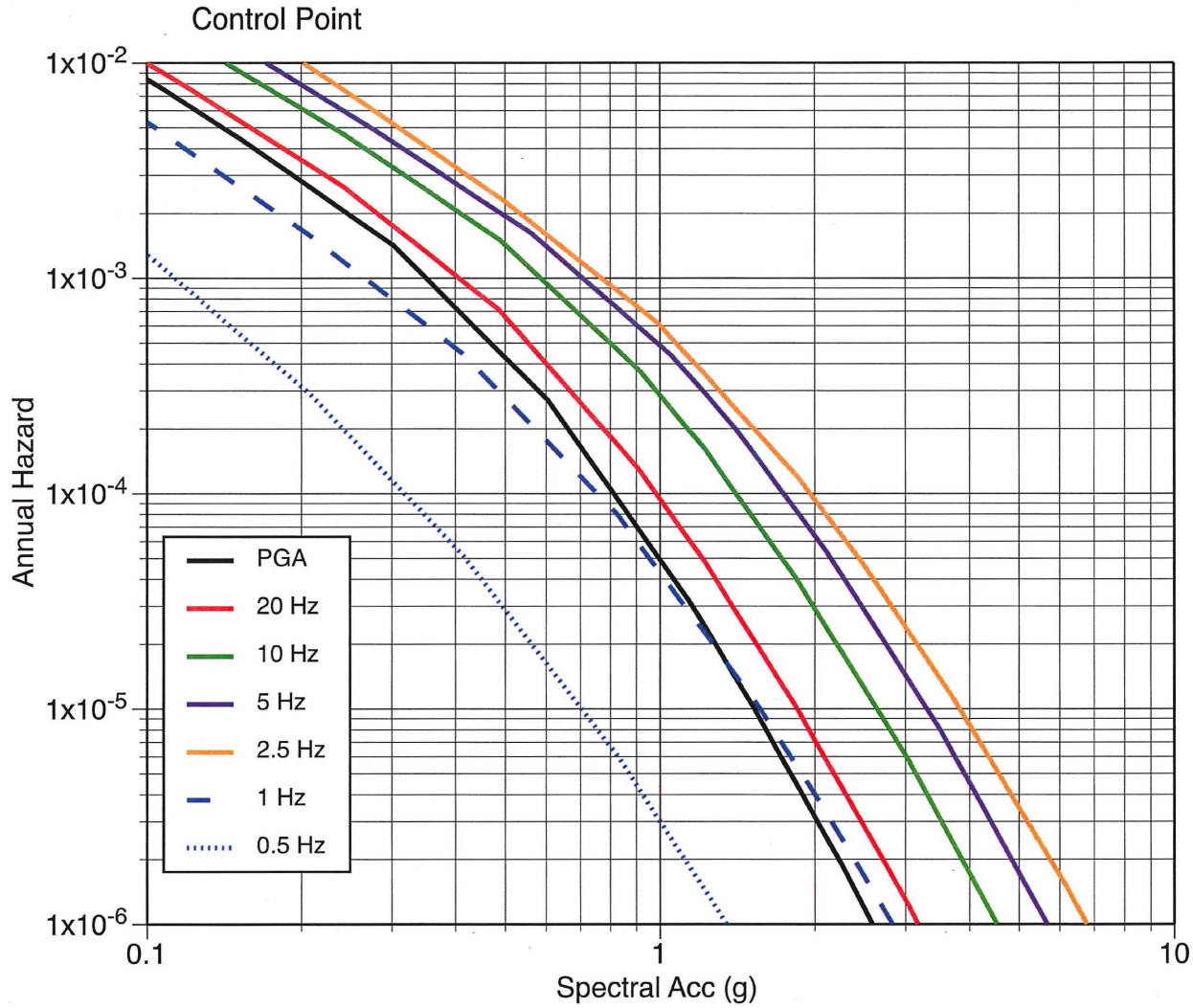

Figure 2.3.7-1 Control Point Mean Hazard Curves for PGA and 20, 10, 5, 2.5, 1, and 0.5 Hz Spectral Frequencies

2.4 Control Point Response Spectra

The uniform hazard response spectra (UHRS) for 1 x 10^{-4} and 1 x 10^{-5} hazard levels at the control point are computed from the mean hazard curves. The UHRS are plotted in Figure 2.4-1 and are listed in Table 2.4-1. The GMRS is computed following the requirements of Regulatory Guide 1.208 (NRC 2007). The GMRS is equal to the 1 x 10^{-4} UHRS at frequencies greater than or equal to 1 Hz. At lower frequencies, the GMRS is slightly greater than the 1 x 10^{-4} UHRS.

Table 2.4-1 UHRS for 1E-4 and 1E-5, and GMRS at Control Point for DCPP (5% damping)

Frequency (Hz)	Spectral Acceleration (g)		
	Control Point 1E-4 UHRS	Control Point 1E-5 UHRS	GMRS
100.00	0.812	1.525	0.812
50.00	0.832	1.564	0.832
33.33	0.882	1.659	0.882
20.00	0.983	1.849	0.983
13.33	1.236	2.295	1.236
10.00	1.405	2.640	1.405
6.67	1.613	3.054	1.613
5.00	1.740	3.305	1.744
4.00	1.785	3.373	1.785
3.33	1.714	3.236	1.714
2.50	1.960	3.830	2.010
2.00	1.634	3.186	1.672
1.33	1.200	2.469	1.282
1.00	0.755	1.566	0.812
0.67	0.478	1.017	0.525
0.50	0.318	0.703	0.360
0.33	0.188	0.408	0.210

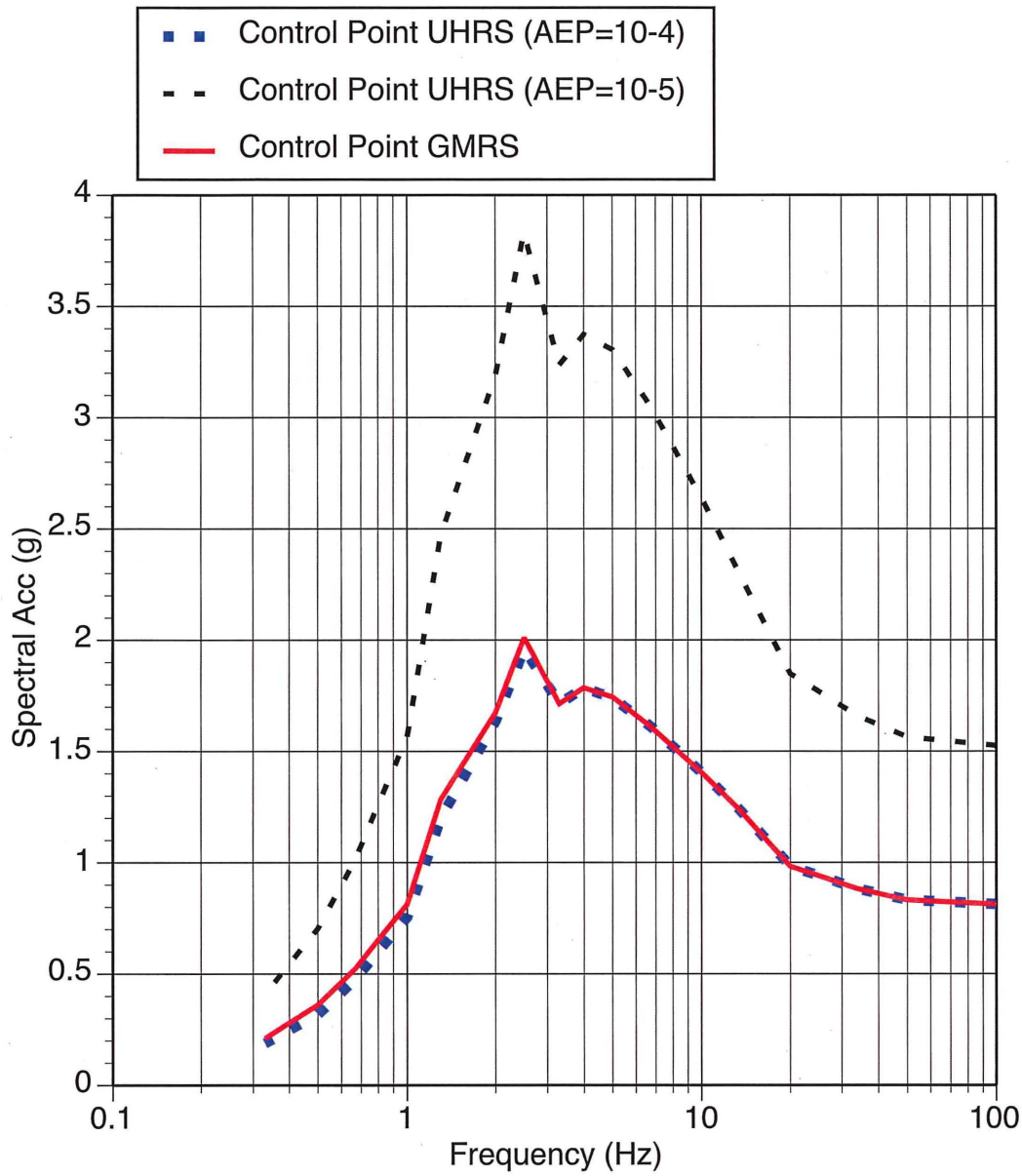

Figure 2.4-1 UHRS for 1E-4 and 1E-5, and GMRS at Control Point for DCPP

3.0 Plant Design, Licensing, and LTSP Evaluation Bases Ground Motions

The seismic design, licensing, and LTSP evaluation bases for DCPP are identified in Sections 2.5, 3.1, and 3.7 of the UFSAR, Revision 21 (PG&E 2013) the Hosgri Report (PG&E 1980), the 1988 LTSP Final Report (PG&E 1988), and the 1991 Addendum to the LTSP Final Report (PG&E 1991).

Since the development of the seismic design/licensing basis for DCPP predates the issuance of Appendix A to 10 CFR 100 (NRC 1973) site-specific criteria and methods were employed in the development of the design/licensing basis ground motions.

The seismic design, licensing, and LTSP evaluation of DCPP includes the following earthquakes:

1. Design Earthquake (0.20g PGA)

   The DE is defined in UFSAR Section 2.5.3.10.1 based on the maximum size earthquakes that can be expected to occur at DCPP during the life of the reactor. Four earthquakes of varying magnitudes and distances were postulated (described as Earthquake A, Earthquake B, Earthquake C, and Earthquake D in UFSAR Section 2.5.3.9.1). The postulated ground motions at DCPP for these four earthquakes were based on empirical data, with certain modifications based on input from the Atomic Energy Commission and their consultants. As described in UFSAR Section 2.5.3.10.1, Earthquakes B and D were found to be governing over Earthquakes A and C. In addition, based on meetings between PG&E, the Atomic Energy Commission, and the Atomic Energy Commission's consultants, the shape of the response spectra associated with Earthquake D was modified and the accelerations associated with Earthquake B were increased by 25 percent. After the incorporation of the modifications, the following two earthquake ground motions were selected to represent the DE for DCPP:

   (a) Earthquake D-modified, derived by modifying the S80°E component of the 1957 Golden Gate Park, San Francisco earthquake, and then normalizing to a maximum ground acceleration of 0.20 g. The smoothed response spectrum for this earthquake is shown in UFSAR Figure 2.5-21.

   (b) Earthquake B, derived by normalizing the N69°W component of the 1952 Taft earthquake to a maximum ground acceleration of 0.15 g. The smoothed response spectrum for Earthquake B is shown in UFSAR Figure 2.5-20.

Seismic design for the DE is based on the envelope of Earthquake B and Earthquake D-modified.

2. Double Design Earthquake (0.40g PGA)

The DDE is defined in UFSAR Section 2.5.3.10.2 as an earthquake having twice the maximum ground acceleration and response spectra as those associated with the DE.

3. 1977 Hosgri Earthquake (0.75g PGA)

The 1977 HE is defined in UFSAR Section 2.5.3.10.3 as the predicted ground motion at DCPP associated with a Richter magnitude 7.5 earthquake on the Hosgri fault at a point nearest to DCPP. There are two ground motion definitions associated with the HE:

(a) The Newmark HE, is an earthquake developed by Dr. N. M. Newmark, having an effective maximum horizontal ground acceleration of 0.75 g. The smoothed response spectrum for the Newmark HE is shown in UFSAR Figure 2.5-30.

(b) The Blume HE, is an earthquake developed by Dr. J. A. Blume based on empirical data associated with strong-motion time histories recorded on rock close to the epicenters, and normalized to a 0.75 g peak acceleration. The smoothed response spectrum for the Blume HE is shown in UFSAR Figure 2.5-29.

The seismic design for the HE is summarized in Supplement No. 5 to the NRC's Safety Evaluation Report (SER) for DCPP (NRC 1976) and is based on the envelope of the loadings associated with the Newmark HE and the Blume HE. The HE is the largest ground motion considered in the seismic design of DCPP.

4. Long Term Seismic Program Earthquake (0.83 g PGA)

The LTSPE is associated with license condition 2.C.(7) of the DCPP Unit 1 operating license, that required, in part: "PG&E shall develop and implement a program to reevaluate the seismic design bases used for the DCPP." PG&E's reevaluation effort in response to the license condition was titled the "Long Term Seismic Program."

The LTSPE is defined in UFSAR Section 2.5.3.10.4 as the predicted ground motion at DCPP associated with a moment magnitude 7.2 earthquake on the Hosgri fault approximately 4.5 km (3 mi.) from DCPP.

The LTSP included both a SPRA and a deterministic SMA. The results of the LTSP are described in the 1988 LTSP Final Report (PG&E 1988) and the 1991 Addendum to the LTSP Final Report (PG&E 1991). The LTSP evaluation concluded that the structures, systems, and components previously qualified for the DE, DDE, and 1977 HE seismic loads remained qualified for the LTSPE. The NRC's review and acceptance of the LTSP evaluations are documented in Supplement No. 34 of the SER for DCPP (NRC 1991).

3.1 Description of Response Spectra Shapes

3.1.1 Double Design Earthquake Response Spectrum

The DDE response spectrum, which corresponds to an envelope of the 5 percent damped horizontal Earthquake B (UFSAR Figure 2.5-20) response spectrum and the 5 percent damped Earthquake D-modified response spectrum (UFSAR Figure 2.5-21), multiplied by a factor of two, is tabulated in Table 3.1.1-1 and illustrated in Figure 3.1.1-1.

Table 3.1.1-1: DDE Response Spectrum for DCPP
(5% Damping)

Period (sec)	Frequency (Hz)	Spectral Acceleration (g)
0.010	100.000	0.400
0.050	20.000	0.400
0.060	16.667	0.432
0.070	14.286	0.498
0.080	12.500	0.666
0.090	11.111	0.930
0.100	10.000	1.266
0.110	9.091	1.386
0.120	8.333	1.434
0.130	7.692	1.464
0.140	7.143	1.476
0.150	6.667	1.473
0.160	6.250	1.467
0.170	5.882	1.443
0.180	5.556	1.413
0.200	5.000	1.338
0.250	4.000	1.182
0.290	3.448	1.047
0.300	3.333	1.005
0.320	3.125	1.009
0.330	3.030	1.005
0.350	2.857	0.993
0.380	2.632	0.963
0.500	2.000	0.786
0.580	1.724	0.705
0.660	1.515	0.639
0.740	1.351	0.609
0.880	1.136	0.595
1.000	1.000	0.594

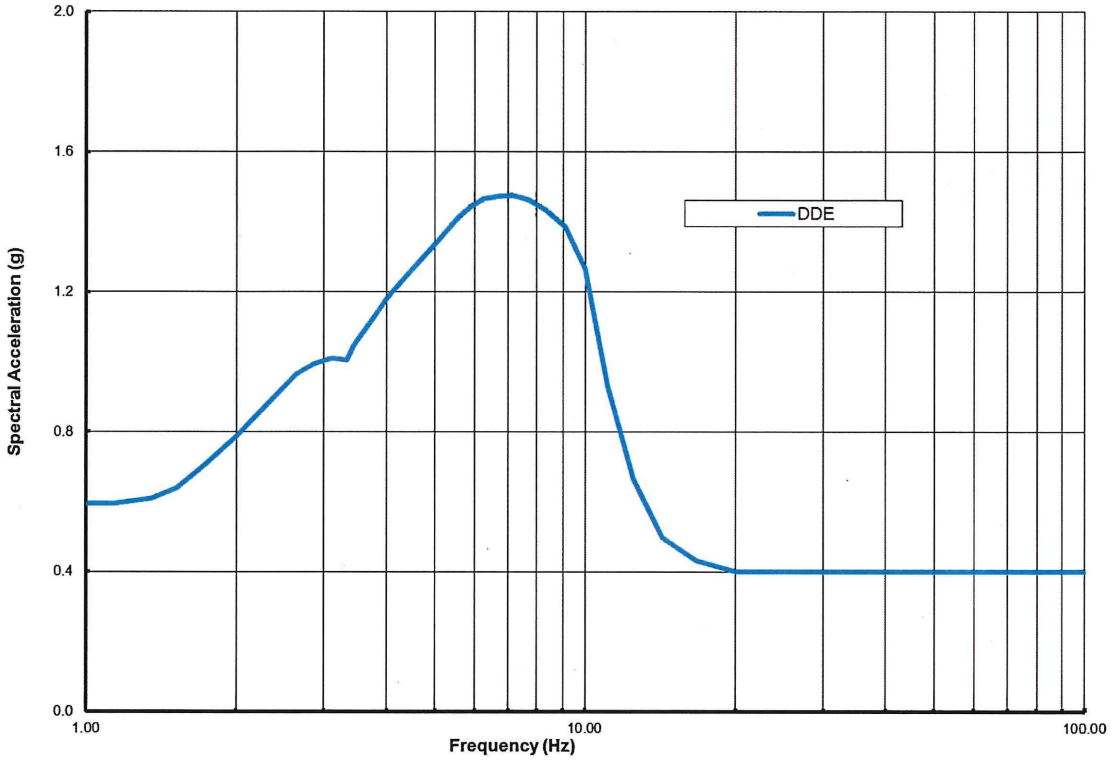

Figure 3.1.1-1: DDE Response Spectrum for DCPP
(5% Damping)

3.1.2 1977 Hosgri Earthquake Response Spectrum

The 1977 HE response spectrum, which corresponds to an envelope of the 5 percent damped horizontal Newmark HE response spectrum (UFSAR Figure 2.5-30) and the 5 percent damped horizontal Blume HE response spectrum (UFSAR Figure 2.5-29), is tabulated in Table 3.1.2-1 and illustrated in Figure 3.1.2-1.

Table 3.1.2-1: 1977 HE Response Spectrum[6] for DCPP
(5% Damping)

Period (sec)	Frequency (Hz)	Spectral Acceleration (g)
0.010	100.000	0.750
0.029	34.000	0.750
0.032	31.000	0.784
0.040	25.000	0.912
0.050	20.000	1.067
0.063	16.000	1.248
0.071	14.000	1.371
0.083	12.000	1.528
0.100	10.000	1.737
0.111	9.000	1.870
0.125	8.000	2.032
0.174	5.750	2.032
0.182	5.500	2.044
0.190	5.250	2.061
0.200	5.000	2.080
0.217	4.600	2.106
0.238	4.200	2.128
0.250	4.000	2.125
0.263	3.800	2.118
0.278	3.600	2.111
0.303	3.300	2.075
0.333	3.000	2.032
0.435	2.300	2.032
0.455	2.200	1.975
0.500	2.000	1.795
0.556	1.800	1.616
0.625	1.600	1.436
0.714	1.400	1.257
0.800	1.250	1.124
1.000	1.000	0.898
1.538	0.650	0.586
2.000	0.500	0.411

[6] The spectral acceleration values represent the envelope of the Newmark HE (UFSAR Figure 2.5-30) and the Blume HE (UFSAR Figure 2.5-29). Note that the HE response spectra have been extrapolated to a minimum frequency of 0.50 Hz for this application.

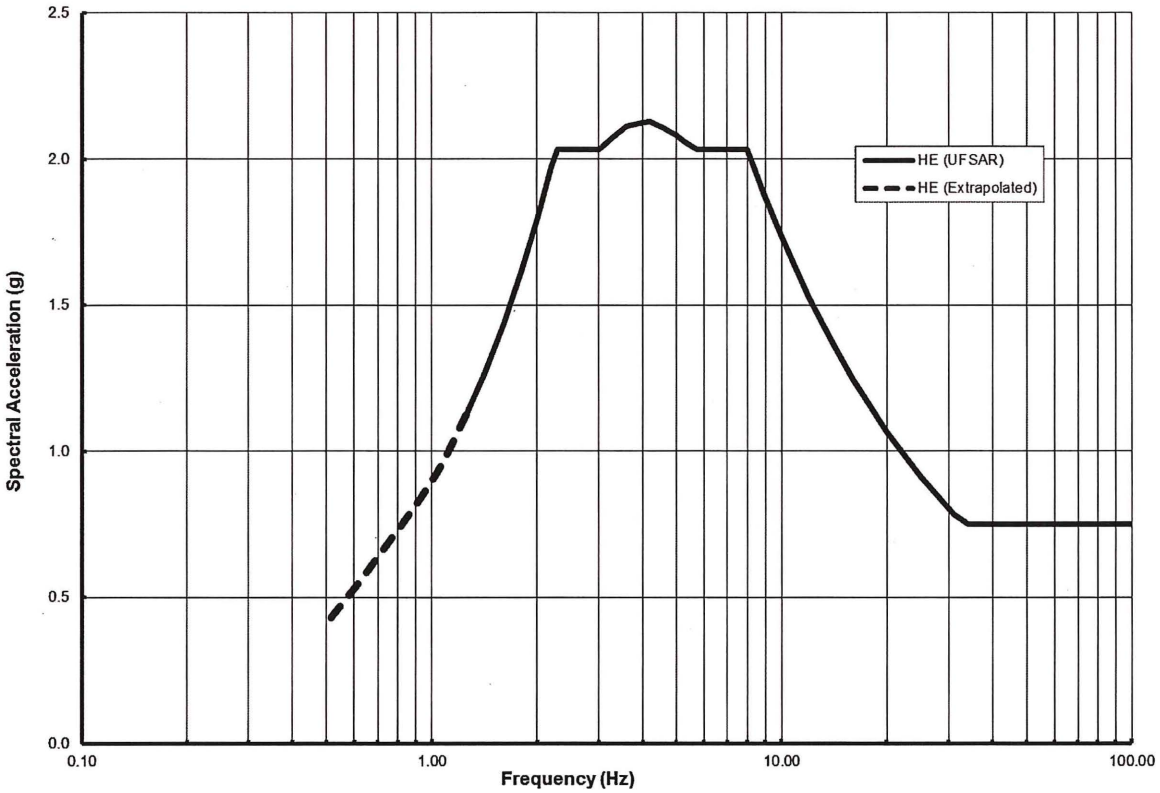

Figure 3.1.2-1: 1977 HE Response Spectrum for DCPP
(5% Damping)

3.1.3 Long Term Seismic Program Earthquake Spectrum

The 5 percent damped horizontal 84th percentile of non-exceedance 1991 LTSPE response spectrum (UFSAR Figure 2.5-33), is tabulated in Table 3.1.3-1 and illustrated in Figure 3.1.3-1.

Table 3.1.3-1: 1991 LTSPE 84th Percentile Response Spectrum for DCPP (5% Damping)

Period (sec)	Frequency (Hz)	Spectral Acceleration (g)
0.010	100.000	0.830
0.025	40.000	0.830
0.030	33.000	0.830
0.040	25.000	0.964
0.050	20.000	1.110
0.070	14.286	1.344
0.085	11.765	1.508
0.100	10.000	1.654
0.120	8.333	1.819
0.140	7.143	1.918
0.150	6.667	1.947
0.170	5.882	1.976
0.200	5.000	2.006
0.250	4.000	2.015
0.300	3.333	1.962
0.400	2.500	1.763
0.500	2.000	1.554
0.750	1.333	1.109
1.000	1.000	0.831
1.500	0.667	0.524
2.000	0.500	0.356

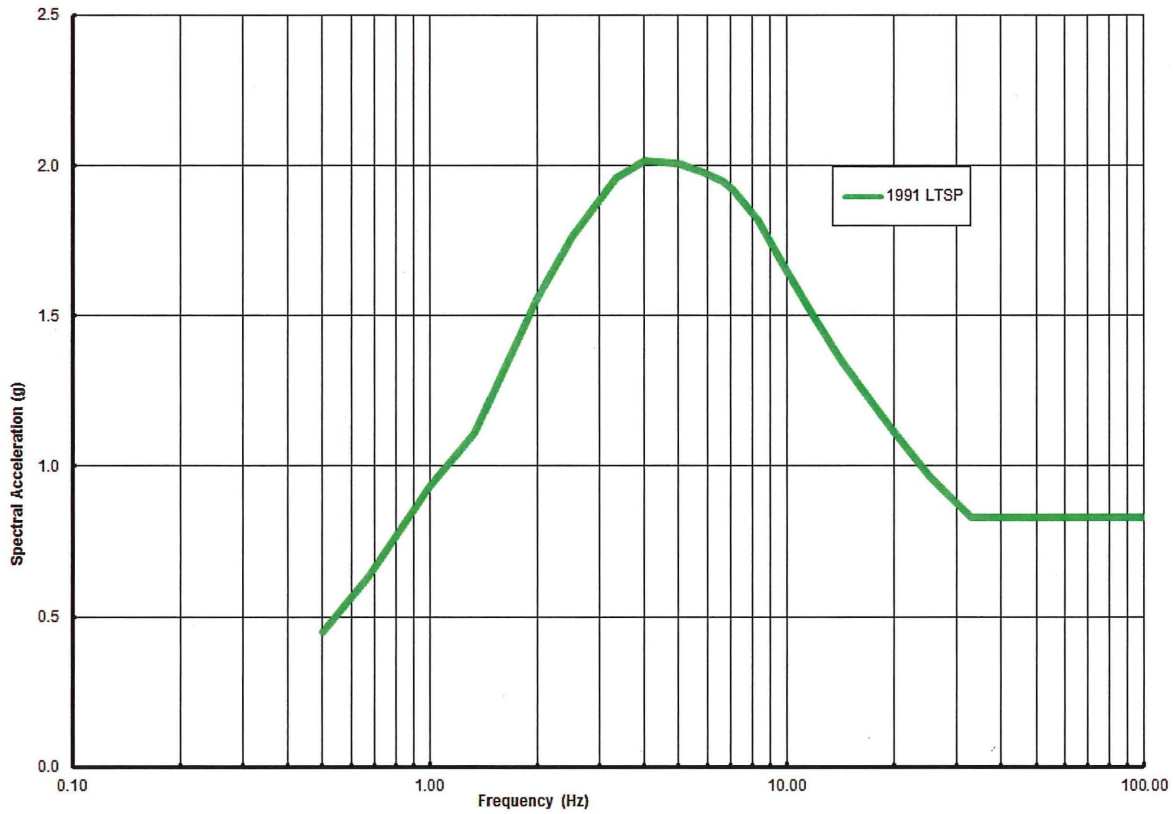

Figure 3.1.3-1: 1991 LTSPE 84th Percentile Response Spectrum for DCPP (5% Damping)

3.2 Control Point Elevation

The control point elevation for DCPP's DDE is defined based on the criteria provided in Section 2.4.2 of the SPID (EPRI 2013a).

As shown on UFSAR Figures 2.5-15, 2.5-16, and 2.5-17, all original surface materials (soil and rock) were removed from the locations of the major structures[7] and their foundations were excavated into the bedrock. Therefore, the major structures are rock-founded.

The free-field ground motions, associated with the DDE (described in Section 3.1.1) and the 1977 HE (described in Section 3.1.2), are used as input to all structures at DCPP. The UFSAR does not explicitly define a control point for the ground motions, but it can be derived from the seismic analyses of structures described in UFSAR Section 3.7. Based on a review of the seismic analyses of the major structures, as described in UFSAR Section 3.7.2.1.7, the control point for the seismic analyses is the finished grade level, which corresponds to

7 Major structures at DCPP include the containment structures, the auxiliary building, and the turbine building.

26 m (85 ft) mean sea level at the location of the major structures (see UFSAR Figure 2.5-18). This is consistent with the control point elevation associated with the site response evaluation, as described in Section 2.3.

Since the site-amplification studies associated with the GMRS (Section 2.4) are developed based on the free-field recordings of historical earthquakes affecting DCPP, the control point is specifically at the location of free-field seismic instrument no. ESTA28 (located in the yard area at elevation 26 m (85 ft), approximately 96 m (316 ft) north of the centerline of the Unit 1 containment structure and 2.4 m (8 ft) east of a north-south line passing through the centerlines of the Unit 1 and Unit 2 containment structures - see Figure 2.3.2-4). See Section 2.3.5 for additional information on the selection of the control point.

4.0 Screening Evaluation

In accordance with Section 3 of the SPID, a screening evaluation was performed, as described in the following subsections. As stated in the NRC's letter to PG&E dated October 12, 2012 (NRC 2012c), "for the purposes of the response to the March 12, 2012 request for information, the NRC staff expects PG&E to use the DDE for comparison with the reevaluated seismic hazard GMRS." Therefore, the following screening evaluations are based on the DDE.

4.1 Risk Evaluation Screening (1 to 10 Hz)

The GMRS exceeds the DDE in the 1 to 10 Hz frequency range, as shown in Figure 4.1-1. Therefore DCPP screens-in for a risk evaluation.

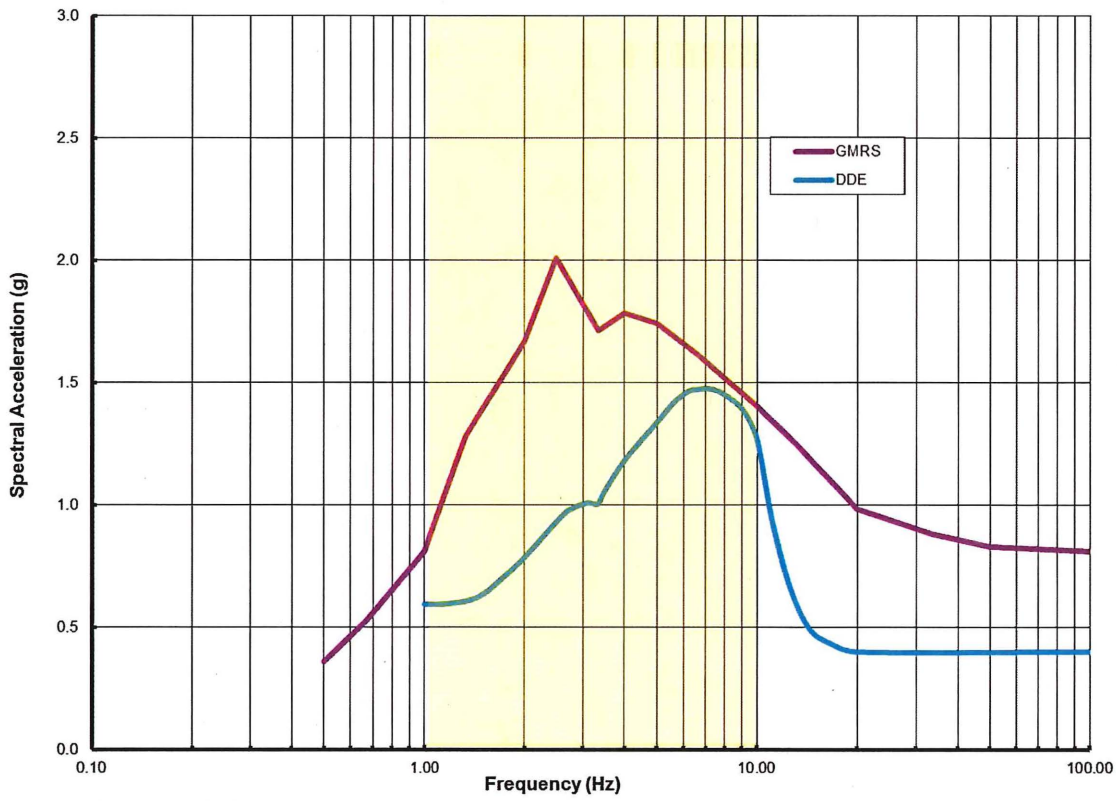

Figure 4.1-1: Comparison of GMRS and DDE Spectrum for DCPP (5% Damping)

4.2 High Frequency Screening (> 10 Hz)

The GMRS exceeds the DDE for frequencies greater than 10 Hz, as shown in Figure 4.1-1. This exceedance will be addressed in the required risk evaluation.

4.3 Spent Fuel Pool Evaluation Screening (1 to 10 Hz)

The GMRS exceeds the DDE in the 1 to 10 Hz frequency range, as shown in Figure 4.1-1. Therefore DCPP screens-in for a SFP evaluation. Note that at DCPP the SFPs are located in the fuel handling area of the auxiliary building.

5.0 Interim Evaluation

Consistent with the NRC letter dated February 20, 2014, (NRC 2014) the seismic hazard reevaluations presented herein are distinct from the current design and licensing bases of DCPP. Consequently, the results of these analyses performed using present-day regulatory guidance, methodologies, and information would not generally be expected to call into question the operability or functionality of structures, systems, and components, and are not reportable pursuant to 10 CFR 50.72 or 10 CFR 50.73.

The NRC's March 12, 2012 10 CFR 50.54(f) letter (NRC 2012) and February 20, 2014 supplemental letter (NRC 2014) request that Licensees submit an interim evaluation or actions taken or planned to address the reevaluated hazard where it exceeds the current design basis, if necessary prior to completion of the risk evaluation. PG&E's interim evaluation is based on comparisons of the beyond design basis GMRS to the design/licensing basis 1977 HE and the 1988 LTSP evaluations:

(a) <u>1977 HE Evaluation</u>

All Design Class I structures, systems, and components at DCPP, including the SFPs[8], have been designed/evaluated for the design/licensing basis 1977 HE spectrum and found to meet the HE acceptance criteria (PG&E 1980 and NRC 1978b).

A comparison of the GMRS with the design/licensing basis 1977 HE spectrum is shown in Figure 5.0-1. This comparison indicates that, with the exception of an exceedance of approximately 0.09 g (7 percent) at 1.33 Hz, the GMRS is bounded by the design/licensing basis 1977 HE spectrum at all frequencies in the 1 to 10 Hz frequency range (frequency range associated with the risk evaluation screening). The exceedance is insignificant because no structure, system, or component required for safe shutdown is susceptible to the 1.33 Hz frequency (Tables 6-24 and 6-25 of PG&E 1988).

The GMRS also exceeds the design/licensing basis 1977 HE spectrum for frequencies > 24 Hz. As stated in Section 3.4 of the SPID (EPRI 2013a):

> "high-frequency vibratory motions above about 10 Hz are not damaging to the large majority of [nuclear power plant] structures, components, and equipment. An exception to this is the functional performance of vibration sensitive components, such as relays and

[8] As indicated in Section 4.3, the SFPs are located in the fuel handling area of the auxiliary building, which is a Design Class I structure.

other electrical and instrumentation devices whose output signals could be affected by high-frequency excitations."

Therefore, in accordance with Section 3.4 of the SPID (EPRI 2013a), the results of the design/licensing basis 1977 HE evaluation demonstrate that all Design Class I structures, systems, and components are capable of resisting the ground motions associated with the GMRS with exception of the high-frequency sensitive equipment. The impact of the high-frequency exceedance is addressed as part of the LTSP evaluation, discussed below.

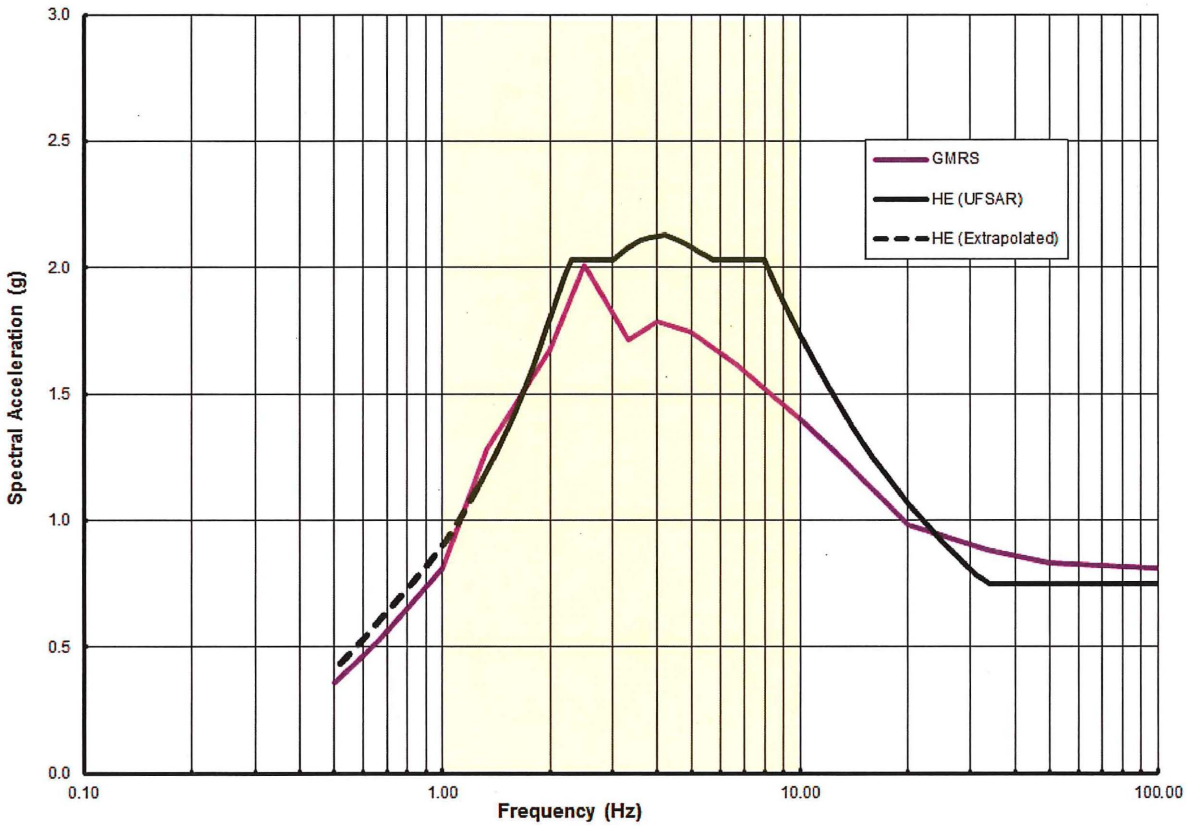

Figure 5.0-1: Comparison of GMRS and 1977 HE Design Spectrum for DCPP (5% Damping)

(b) <u>1988 LTSP Evaluation</u>

All structures[9], systems, and components required for safe shutdown[10] have been evaluated for the 1988 LTSP spectrum and found to have

[9] The auxiliary building, which contains the SFPs, is included in the scope of the LTSP evaluation.
[10] The safe shutdown-related structures, systems, and components addressed in the 1988 LTSP are listed in Tables 7-1 and 7-2 of the 1988 LTSP Final Report (PG&E 1988)