Independent Peer Review Panel

A multi-agency panel of seismic hazard specialists
established by the California Public Utilities Commission

CALIFORNIA GEOLOGICAL SURVEY, CALIFORNIA COASTAL COMMISSION, CALIFORNIA PUBLIC UTILITIES COMMISSION, CALIFORNIA ENERGY COMMISSION, CALIFORNIA SEISMIC SAFETY COMMISSION, COUNTY OF SAN LUIS OBISPO

IPRP Report No. 9, March 6, 2015

Comments on PG&E's Central Coastal California Seismic Imaging Project Report part 3: onshore seismic studies intended to reduce the uncertainty in seismic hazard at Diablo Canyon Power Plant

BACKGROUND

In 2006, the California Legislature enacted Assembly Bill (AB) 1632, which was codified as Public Resources Code Section 25303. AB 1632 directed the California Energy Commission (CEC) to assess the potential vulnerability of California's largest baseload power plants, which includes Diablo Canyon Power Plant (DCPP), to a major disruption due to a major seismic event and other issues. In response to AB 1632, in November 2008 the CEC issued its findings and recommendations in its AB 1632 Report, which was part of its 2008 Integrated Energy Policy Report Update. As noted in the CEC's AB 1632 Report, a major disruption because of an earthquake or plant aging could result in a shutdown of several months or even cause the retirement of one or more of the plants' reactors. A long-term plant shutdown would have economic, environmental and reliability implications for California ratepayers.

In Pacific Gas and Electric Company's (PG&E) 2007 General Rate Case decision D.07-03-044, the California Public Utilities Commission (CPUC) directed PG&E to address and incorporate the recommendations from the AB 1632 Report into its feasibility study to extend the operating licenses of its Diablo Canyon Units 1 and 2 for an additional 20 years.

In November 2009, PG&E submitted its formal application with the Nuclear Regulatory Commission (NRC) to extend the licenses of DCPP Units 1 and 2. In 2010 PG&E filed for cost recovery with the CPUC for expenditures associated with the enhanced seismic studies recommended by the CEC's AB 1632 Report. The motions for cost recovery were subsequently approved in 2010 and 2011. CPUC Decision D.10-08-003, issued on August 16, 2010, established that the CPUC would convene its own Independent Peer Review Panel (IPRP) and invite the CEC, the California Geological Survey, the California Coastal Commission, and the California Seismic Safety Commission to participate on the panel. Under the auspices of the CPUC, the IPRP is conducting an independent review of PG&E's seismic studies including independently reviewing and commenting on PG&E's study plans and the findings of the studies. The comprehensiveness, completeness, and timeliness of these studies will be critical to the CPUC's ability to assess the cost-effectiveness of Diablo Canyon's proposed license renewal.

IPRP reports 7, 8 and this report respond to studies released by PG&E on September 10, 2014. Those studies are referred to collectively as the Central Coastal California Seismic Imaging Project (CCCSIP) report. The CCCSIP report is divided into 14 chapters focused on individual studies intended to help constrain factors that are important to seismic hazard analysis. Due to the large volume of information presented in the CCCSIP report, IPRP's review of the document was divided into three sections. IPRP Report No. 7, issued November 21, 2014, reviewed offshore seismic surveys as presented in chapters 2 and 3 of the CCCSIP report. IPRP Report No. 8, issued December 17, 2014, reviewed onshore seismic surveys and analysis as presented in chapters 7,8,9 and 12 of the CCCSIP report.

This IPRP report is the third part of IPRP's review of the CCCSIP report. It includes onshore seismic studies in the immediate area of the DCPP and the hazard parameters that they are designed to study. These studies, Chapters 10, 11, and 13 of the CCCSIP report, were the subject of a public meeting on January 8, 2015. The focus of chapter 10 is on the shear-wave velocity (V_S) of the geologic material beneath DCPP. Following the public meeting on January 8, 2015, the IPRP had a number of additional questions regarding the velocity model described in Chapter 10 and requested an additional meeting with PG&E. PG&E declined to meet again with IPRP. As a result, this report only covers aspects of those models described in the CCCSIP report and the public meeting. Chapter 11 describes PG&E's evaluation of such "site conditions" and methods to consider "site response amplification" in seismic hazard calculations. Chapter 13 describes hazard sensitivity by comparing response spectra for selected scenario earthquakes with response spectra previously used for DCPP.

SUMMARY OF PREVIOUS RECOMMENDATIONS

The IPRP previously reviewed DCPP site conditions and PG&E site amplification approaches documented in the Shoreline Fault Report (PG&E, 2011) and documented its findings and recommendations in IPRP Report No. 6. Important findings and recommendations from that report and PG&E responses are summarized briefly in this section to facilitate discussion.

In the 2011 Shoreline Fault Report, PG&E estimated the average shear-wave velocity in the upper 30 m (V_{S30}), commonly used to represent "site conditions", to be 1200 m/s. IPRP Report No. 6 noted that "V_S data at the DCPP site indicate significant variability /uncertainty" and that PG&E's estimates "appear to include unconservative assumptions of velocity in boreholes". IPRP recommended additional studies to determine the V_S beneath DCPP and the variability of V_S.

While the IPRP found the empirical approach used by PG&E to incorporate site-specific amplification reasonable and intuitive, the panel concluded that further justifications/clarifications are necessary. Specifically, IPRP Report No. 6 recommended that PG&E "demonstrate that the low site amplification seen at the DCPP site is due to site effects, not specific to the azimuths and distances traveled by the recorded ground motions at the site from the two earthquakes used" and "justify the adequacy of using only two earthquakes to characterize site amplification".

In response, PG&E confirmed in a letter to CPUC (PG&E, 2013) that it would conduct further studies to improve the quantification of site conditions and amplification. These studies would: (1) use new data from on-land exploration geophysics surveys to develop a 3D model of shear wave velocity beneath the plant site; (2) analyze broad band ground motion data and ground motions from small earthquakes to better quantify site-specific amplification terms; and (3) evaluate site amplification using analytical approaches in which seismic waves are propagated through a velocity model. The CCCSIP report addressed the first study as discussed in detail in the remainder of this IPRP report, but not the second and third studies.

DCPP SITE SHEAR WAVE VELOCITY AND SITE CONDITIONS

Chapter 10 of the CCCSIP report presents the "CCCSIP DCPP P- and S-Wave Foundation Velocity Report". Background, methods and conclusions of this study were presented at the IPRP meeting on January 8, 2015 by Dr. Daniel O'Connell of Fugro Consultants. The CCCSIP study consisted of new 3D tomographic imaging of the geologic material beneath DCPP to a depth of about 3000 ft. The tomographic imaging used the same seismic survey sources and receivers as the reflection seismic surveys discussed in IPRP Report No. 8 and used the resulting data, combined with gravity data, to estimate p-wave and s-wave velocities in 3-dimensional cells. Velocity estimates were made for 200x200x200 ft cells underneath the Irish Hills and higher resolution 50x50x10 ft cells in the area around DCPP.

The presentation by Dr. O'Connell showed some images of the tomographic model of the Irish Hills. These images show some of the same large-scale features of the geology of the Irish Hills as the seismic reflection studies and geologic mapping described in other chapters of the CCCSIP report, including higher-velocity material consistent with uplifted Franciscan Complex bedrock in the northern Irish Hills, lower-velocity material in the central to southern Irish Hills consistent with the Pismo Syncline, and higher-velocity material along the south edge of the Irish Hills consistent with areas where diabase is mapped at the surface or projected into the subsurface.

The high-resolution tomographic model of the area near DCPP presented in the CCCSIP report shows details of the variation in interpreted velocity. Important elements of this detailed model include: relatively low near-surface velocities in areas with remaining natural soil; relatively high near-surface velocities underlying much of the plant itself; highly variable estimates of V_{S30}; and irregularly shaped subsurface regions interpreted to have high velocity.

While each of these features of the tomographic model may represent improved understanding of the "site conditions" at DCPP and may lead to decreased uncertainty in seismic hazard estimates, PG&E has not confirmed the uncertainties in these velocity estimates. Moreover, the CCCSIP report has an extensive discussion of the difficulty of gaining accurate tomographic results at shallow depths, given the constrained source-receiver locations.

Estimates of seismic shaking are commonly calculated for a "firm rock" site condition with a V_{S30} of 760 m/s, then adjusted for the V_{S30} of the site. In previous evaluations, PG&E estimated a V_{S30} of 1200 m/s for DCPP. IPRP Report No. 6 noted that this value did not reflect the values or variability of V_S measured in 1978. The CCCSIP report presents Vs profiles and estimates of V_{S30} of 570 m/s and 750 m/s for two sites adjacent to DCPP. For additional context, the CCCSIP report provides V_{S30} estimates ranging from 429 to 479 m/s for five sites in the DCPP area. The CCCSIP report estimates V_{S30} of 980 m/s at the basement elevation of the turbine building and 1260 m/s at the basement elevation of the power block.

The variation in V_{S30} estimated from the tomographic model support the IPRP interpretation of "overall lower velocity of the rock underlying the plant and greater variability in velocity across the plant footprint" relative to PG&E's previous interpretation. Much of this variation in V_S is expected on a site that has been graded. Low velocities are modeled in soil and deeply-weathered rock. Removal of soil and weathered rock in preparing excavations for construction results in higher V_{S30}.

The tomographic model depicts the expected variability in shear wave velocity. V_{S30} of 750 at seismic station ESTA 28 adjacent to the south side of the turbine building and 570 m/s at seismic station ESTA 27 north of the turbine building are consistent with removal of soil and weathered rock from these sites. Simply considering the amount of grading, V_{S30} values at DCPP can be expected to be lower than 760 m/s at the ground surface around the south, west, and north sides of the turbine building and higher on the east and around the power block. Higher values would be expected at foundation levels, where more weathered rock has been removed and higher-velocity rock is at the surface.

The IPRP understands that the purpose of the detailed 3-dimensional velocity model is to replace the simple V_{S30} index with detailed amplification estimates that take into account of the velocity structure of the rock underlying the plant. For comparison of ground motion estimates below, the IPRP is using 760 m/s, the approximate value at the ground surface adjacent to the south side of DCPP, in estimating ground motion at DCPP.

In addition to the variation in V_S at the surface due to grading, the CCCSIP report suggests that irregularly shaped diabase bodies in the subsurface lead to large variations in seismic velocity. The centers of some regions interpreted to be diabase bodies are estimated to have p-wave velocities of over 5000 m/s, nearly double the velocity of the surrounding sedimentary rock. The presentation by Dr. O'Connell showed that the detailed tomographic model includes modeled diabase bodies to a depth of about 1000 feet below DCPP.

The high-resolution tomographic model of the DCPP region is dependent on details of seismic data acquisition and processing. Also, as noted above, PG&E has not provided estimates of the uncertainty in velocity estimates included in the model. One way to check the accuracy of the model is to compare it with other measurements of p- and s-wave velocity in the same area and with expected velocities in similar materials statewide. Chapter 10 of the CCCSIP report provides profiles of modeled V_S with depth at numerous locations. These can be compared with profiles measured at the DCPP in 1978. Previous V_S measurements were provided to the IPRP as described in IPRP Report No. 6.

Comparison of V_S profiles from the tomographic model with profiles measured in 1978 shows broadly similar ranges of V_S and variation of V_S with depth. In detail, however, V_S profiles from the tomographic model do not appear to reproduce the variation in V_s with depth in nearby measured profiles. The most prominent feature in previous profiles is the high-velocity zone centered at approximately 50' elevation in profile DDH-C (Figure 1). The tomographic model includes a high-velocity zone near this elevation, but not in any of the profiles near the site of profile DDH-C presented on transects B-B' or D-D'. Below the high-velocity zone, profile DDH-C shows lower velocity (731 m/s) but all nearby profiles from the tomographic model show increasing velocity through this zone, reaching velocities of over 1600 m/s in the profile at 1000 ft on transect B-B' (the closest profile to DDH-C presented in the CCCSIP report). Downhole profile DDH-D shows much less variation of V_S with depth than the nearest profile shown in the CCCSIP report.

Differences between V_S profiles measured in 1978 and profiles derived from the tomographic model may reflect poor data or poor resolution in the 1978 profiles. If the 1978 downhole velocity surveys represent "ground truth", however, it appears that the tomographic model does not show some shallow high velocity layers up to 50' thick or low velocity layers up to 100' thick. The lack of correspondence between measured V_S profiles and V_S profiles estimated from the tomographic model suggests significant uncertainty remains in estimates of "site conditions" at DCPP. The IPRP cannot determine if these differences reflect poor data or analysis in one or both measurements of V_S or if both surveys are essentially correct, but have differing levels of spatial resolution. Certainly, the differences between V_S profiles from the tomographic model and previously measured V_S profiles should have been addressed in the CCCSIP report.

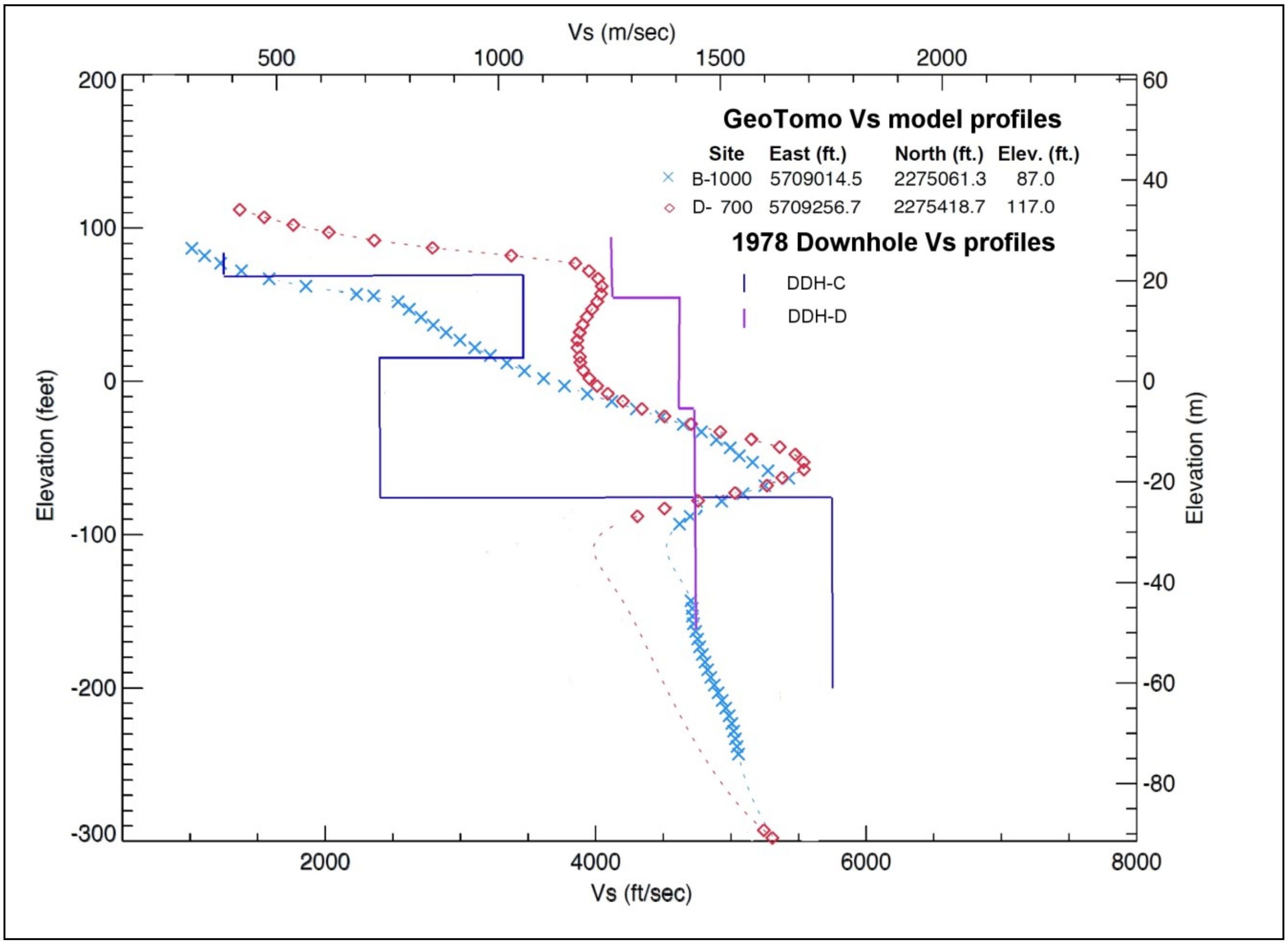


Figure 1. Comparison of measured V_S profiles from 1978 with the nearest profile from the 3D tomographic survey presented in the CCCSIP report. Site B-1000 is closest to downhole profile DDH-C. Site D-700 is closest to profile DDH-D. Profiles from 3D model from CCCSIP report, Chapter 11, Figures B-2 and B-4.

PG&E SITE RESPONSE METHODOLOGY AND SITE AMPLIFICATION CALCULATION

The PG&E methodology to account for site response in its CCCSIP report is essentially the same as the methodology documented in the Shoreline Fault Report. However, the CCCSIP methodology incorporated two new developments: (1) the new V_{S30} values at the two free field ground motion recording stations and at the foundation levels of the power block and the turbine building, and (2) four new ground motion prediction equations (GMPEs) developed as part of the 2014 updates of the Next Generation Attenuations for Western United States (NGA West2). The new V_{S30} values were developed based on the new shear wave velocity data interpreted from the high-resolution tomographic model. IPRP review of the new V_{S30} values is documented in the previous section of this report. Evaluation of NGA West2 GMPEs is beyond the scope of this review. However, we note PG&E indicated in its CCCSIP report that it would conduct a complete evaluation of the NGA West2 GMPEs as part of the Southwestern United States (SWUS) Senior Seismic Hazard Analysis Committee (SSHAC) ground motion studies required by the NRC. We also note the NGA West2 GMPEs were developed via a multidisciplinary, multi-year research program coordinated by the Pacific Earthquake Engineering Research Center (PEER) (Bozorgnia et al., 2014) and have been adopted in the 2014 updates of the National Seismic Hazard Maps (Petersen et al., 2014).

The incorporation of these new developments necessitated recalculation of site amplification parameters. The PG&E methodology consists of two components: (1) an empirical site-specific site term that accounts for differences in observed ground motions at the DCPP site and an average site depicted by the GMPEs for a reference site condition, and (2) a site amplification term that accounts for differences between sites with different V_{S30} values reflecting differences in shallow V_S profiles. We refer to these two terms as site-specific term and V_{S30} scaling term, respectively.

In the CCCSIP report, recording station ESTA28 (V_{S30} = 753 m/s, approximated as 750 m/s) was selected to be the reference free field site. Ground motions recorded at station ESTA27 (V_{S30} = 570 m/s) were adjusted to the reference site condition. Following the procedure described in the Shoreline Fault Report, a site-specific term at each frequency is determined as the mean residuals from the two available earthquakes (averaged period by period and smoothed over a period range) and uncertainty is estimated based on station-to-station variability from a worldwide dataset and number of available earthquakes recorded at the DCPP (2 earthquakes). The values of the smoothed mean residuals (i.e., site specific term for reference V_{S30} of 760 m/s) and uncertainty range are listed in Table 3-1 and illustrated in Figure 3-4, Chapter 11 of the CCCSIP report.

In the Shoreline Fault Report, scaling of ground motions for sites with different V_{S30} values was based on the site response analysis results of Silva (2008). In the CCCSIP report, PG&E scaled ground motions at the reference site (V_{S30} = 760 m/s) to the power block foundation (V_{S30} = 1260 m/s, approximated as 1200 m/s) using scaling factors derived from site response analysis carried out by the NRC (2012) using a DCPP shear wave velocity profile with V_{S30} of 1200 m/s. In applying the NRC scaling factors, PG&E made additional corrections to account for difference in basin depth according to the studies of Kamai et al. (2013). Scaling factors from the reference site to the turbine building were interpolated from scaling factors from the reference site to the power block. Amplification factors for V_{S30} scaling (i.e., V_{S30} scaling term) are listed in Table 3-2 for the foundations at the power block and turbine building and are illustrated in Figure 3-5 (for power block foundation) in Chapter 11 of the CCCSIP report.

The total site-specific amplification factor (in natural log scale) for each site with respect to the NGA West2 predictions for a reference rock site of V_{S30} = 760 m/s is the sum of the site specific term (Table 3-1 in Chapter 11 of the CCCSIP report) and the V_{S30} scaling term for that site (Table 3-2 in Chapter 11 of the CCCSIP report). The total

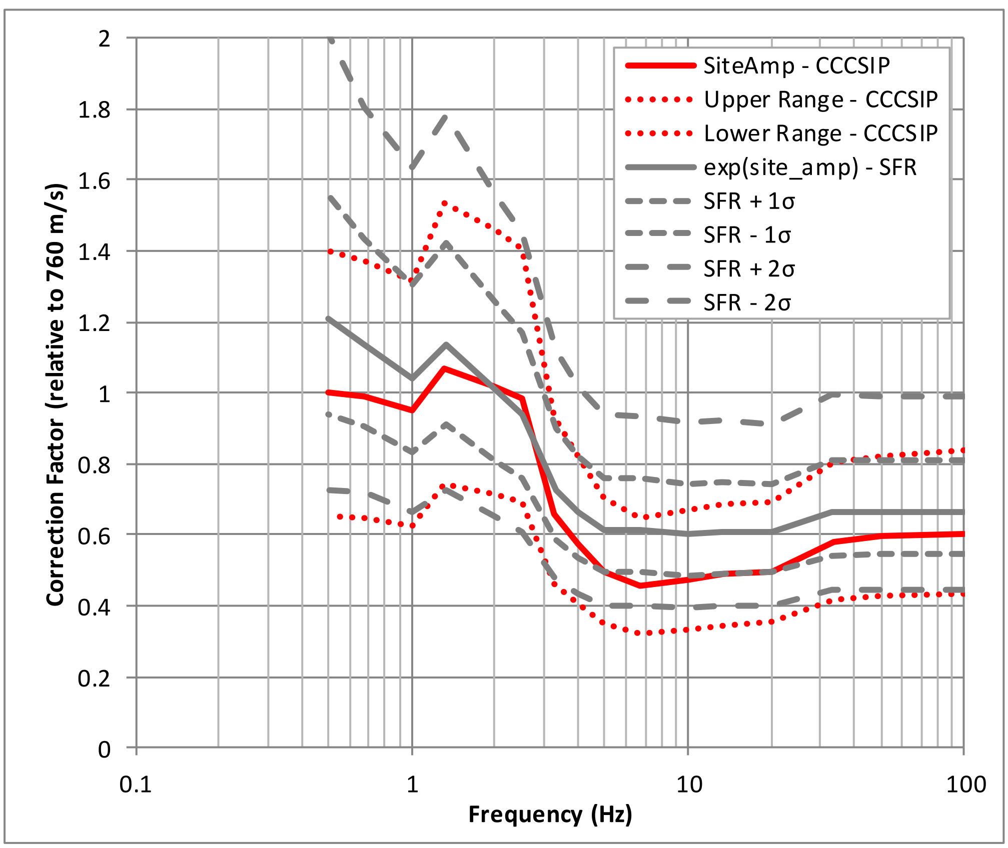


Figure 2. Comparison of site-specific amplification factors (in linear units) and associated uncertainty in the CCCSIP report and the Shoreline Fault Report (SFR) (plotted according data presented in the CCCSIP report, SFR, and presentation by Norm Abrahamson on June 6, 2013, σ is standard deviation).

amplification factors for the foundation levels at the power block and the turbine building are listed in Table 3-3, Chapter 11 of the CCCSIP report. Figure 2 compares updated site amplification factors and associated uncertainties in the CCCSIP report with those used in the Shoreline Fault Report. In general, the new factors are slightly lower. However, given large uncertainty in site amplification, the difference should be considered insignificant.

HAZARD SENSITIVITY AND IMPACT

Impact of the updated fault source and site amplification parameters on ground motion hazards at the DCPP site was evaluated using a simple, deterministic approach in Chapter 13 of the CCCSIP report. Changes in source parameters that have potential impact in estimated ground motion hazards include: increase in Shoreline Fault length (from 23 km to 45 km); coseismic rupture of the Shoreline, Hosgri, and San Simeon Faults with a potential magnitude of 7.3; the longer trace, shallower dip for the Hosgri Fault; coseismic rupture of the Hosgri and San Simeon Faults with a potential magnitude of 7.3; and increase in the minimum dip angle for the Los Osos Fault (by 10 degrees). There is no change to the San Luis Bay Fault.

Figure 3 compares deterministic ground motion spectra presented in the CCCSIP report (for the turbine building foundation level, V_{S30} = 980 m/s, solid curves) and the Shoreline Fault Report (for the DCPP site with V_{S30} = 1200 m/s, dashed curves) for the four most important fault sources affecting the DCPP site. The PG&E 1991 LTSP/SSER 34, the 1977 HE (Hosgri Earthquake) design spectrum, and the frequency range important to DCPP structures (marked by vertical dark grey lines) are plotted for reference. Although the CCCSIP updates resulted in different ground motions for individual scenarios, there is little difference in estimated ground motion portrayed by the four scenarios as a group. Ground motion is higher for the linked Hosgri and San Simeon M7.3 scenario compared to the SFR Hosgri M7.1 scenario, except at frequency lower than 1 Hz. The updated Los Osos M6.7 scenario resulted in lower ground motions across the spectrum due to combined effects of the new GMPEs, slightly lower site amplification factors, and steeper minimum dip angle. For the Shoreline and San Luis Bay Fault scenarios, slightly lower ground motions were predicted by the CCCSIP updates for frequency range of 3 to 10 Hz. All scenario spectra fall below the 1991 LTSP and the 1977 HE design spectra. For each earthquake scenario, the CCCSIP deterministic spectrum for the power block foundation level (V_{S30} = 1200 m/s) is slightly lower than the CCCSIP spectra for the turbine building foundation level shown in Figure 3 due to higher V_{S30} value at the power block foundation level.

To illustrate important aspects of seismic hazard evaluation at the DCPP site, Norm Abrahamson presented an updated “tornado plot” at the January 8, 2015 IPRP meeting. The updated tornado plot is re-produced as Figure 4 in this report to facilitate

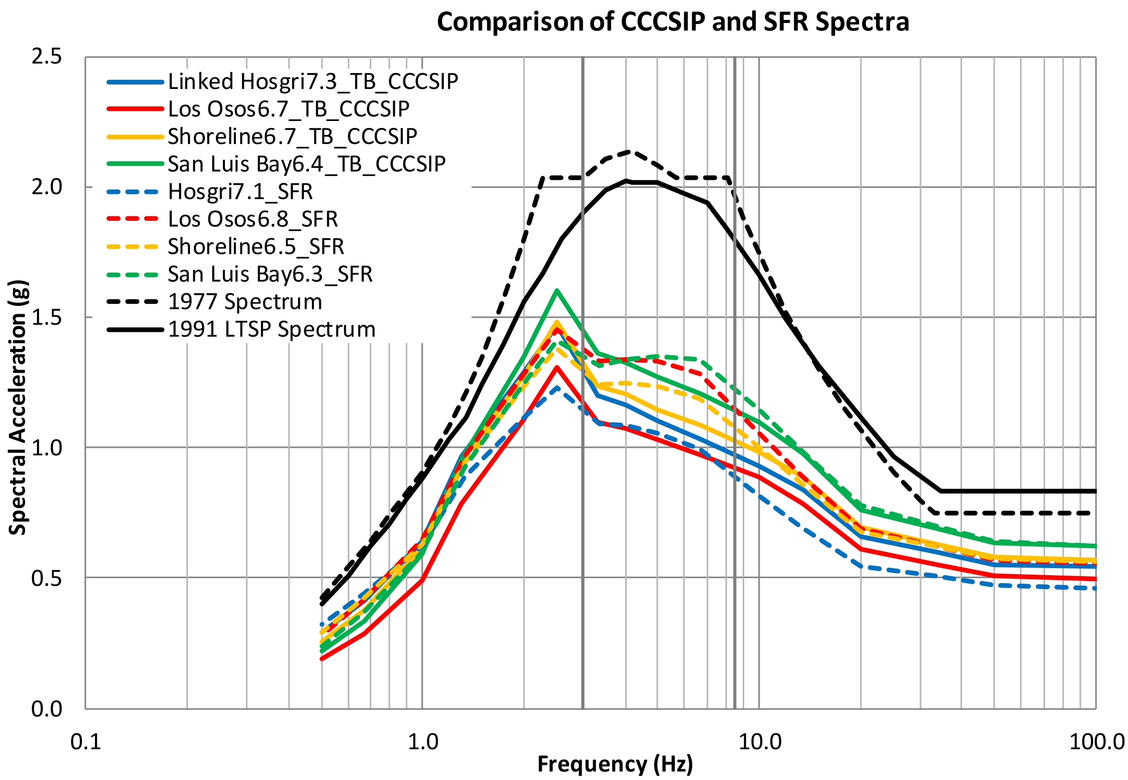


Figure 3. Comparison of deterministic ground motion spectra from the CCCSIP update for the turbine building foundation level (V_{S30} = 980 m/s, solid curves) and from the Shoreline Fault Report for the DCPP site (V_{S30} = 1,200 m/s, dashed curves). The PG&E 1991 LTSP/SSER 34, the 1977 HE (Hosgri Earthquake) design spectrum, and the frequency range important to DCPP (bracketed by vertical dark grey lines) are also plotted for reference.

discussion. The horizontal axis is the ratio of 5 Hz hazard at 2 g spectral acceleration to the reference hazard of 10^{-4} annual rate of exceedance (i.e., the approximate base case hazard for 5 Hz at 2 g spectral acceleration at the DCPP site). The vertical axis ranks sensitivity of ground motion hazard to various input parameters.

The updated tornado plot illustrates the reduction of uncertainties in some source parameters based on information developed by the AB1632 studies as reported in the CCCSIP. We note that uncertainty reductions shown in the updated tornado plot is based on PG&E's updated PSHA analyses as part of the SSHAC process. IPRP has not reviewed these new calculations and cannot comment on whether the reductions seen on the updated tornado plot are reasonable.

The most striking feature of this updated tornado plot is the 6 items related to ground motion calculation on the top of the tornado that have considerably greater uncertainty and hazard sensitivity compared to the source parameters (lower part of the tornado starting from Hosgri slip rate). The IPRP previously recognized the importance of ground motion calculation parameters (including site specific amplification and ground

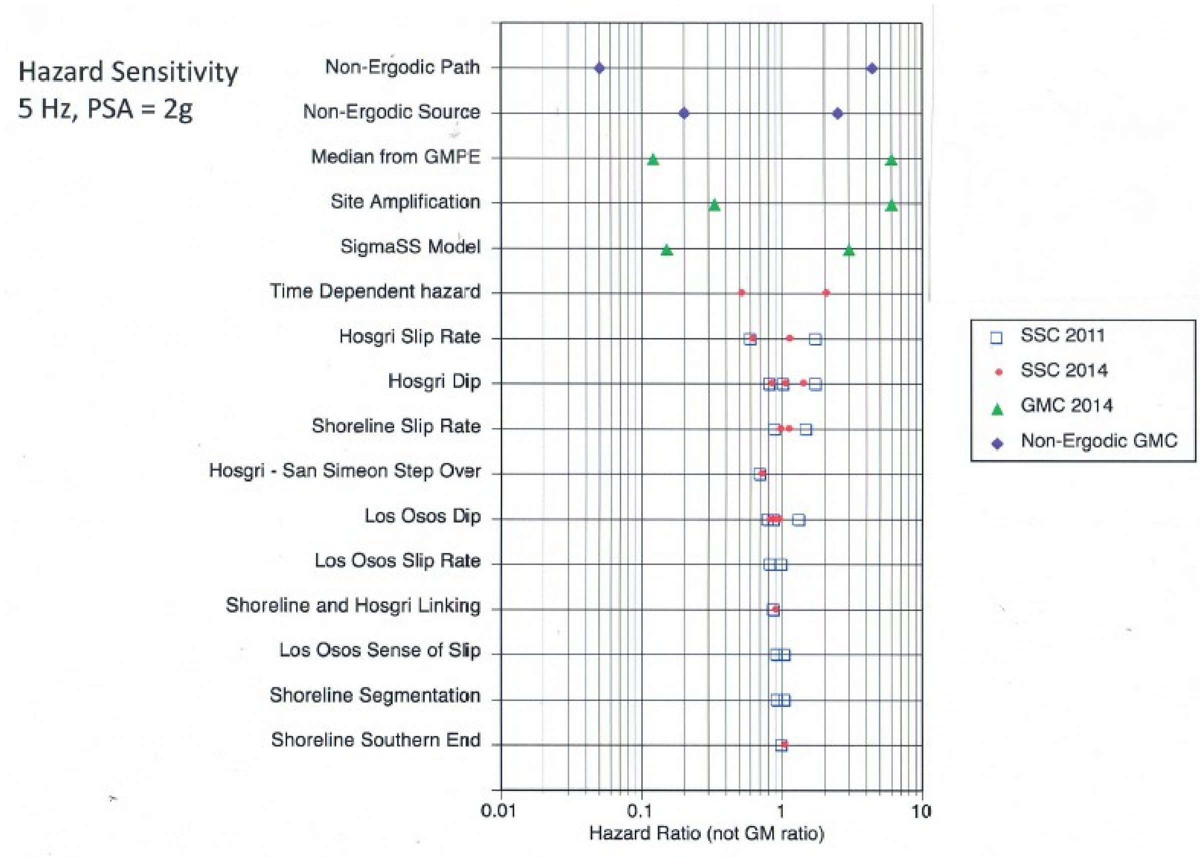


Figure 4. "Tornado Plot" ranking sensitivity of ground motion hazards to uncertainty in input parameters (presented by Norm Abrahamson at the January 8, 2015 IPRP public meeting).

motion uncertainty or sigma model) and illustrated their importance in ground motion estimation using a "half tornado plot" in IPRP Report No. 6 (Figure 10).

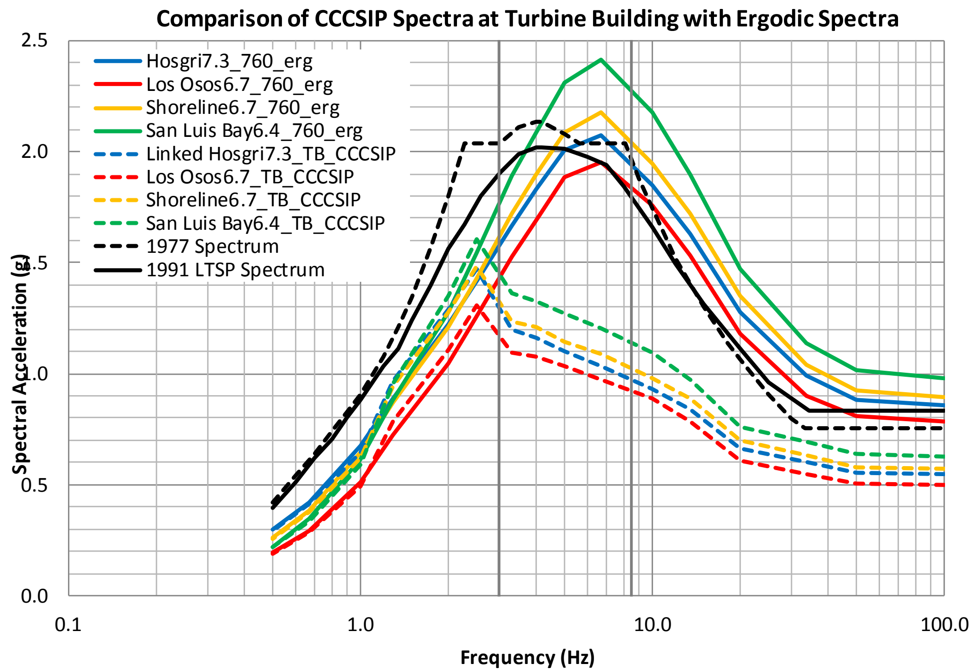
Figure 5 further illustrates the significant impact of ground motion sigma model and site amplification on estimated ground motions. The sensitivity cases illustrated in Figure 5 are based on earthquake scenarios and site amplification parameters developed in the CCCSIP report and the NGA West2 GMPEs. The two components of the overall site amplification (i.e., site-specific term and V_{S30} scaling) are separated to illustrate their relative importance.

Figure 5 compares the CCCSIP deterministic spectra for the turbine building foundation (calculated using the single station sigma assumption, site-specific term, its uncertainty, and scaling from V_{S30} of 760 m/s to 980 m/s) with two sensitivity cases: (a) an average site with V_{S30} of 760 m/s using the ergodic assumption (i.e., 84th percentile ground motion calculated directly using GMPEs); and (b) a DCPP site with V_{S30} of 760 m/s using the single station sigma assumption, the site-specific term and its uncertainty (i.e., eliminating the scaling from V_{S30} of 760 m/s to 980 m/s compared to the CCCSIP spectra).

Figure 5a shows that the deterministic spectra calculated based on the ergodic assumption exceed the 1977 HE and the 1991 LTSP spectra for all but one scenarios in the period range important to DCPP, which re-illustrates observations made in the IPRP Report No. 6 and depicted in Figure 7c of that report. Scaling of V_{S30} from 760 m/s to 980 m/s decreases deterministic ground motion across the spectrum, except for frequencies less than 1 Hz (Figure 5b). Differences between the V_{S30} of 760 m/s cases (solid curves) shown in Figures 5a and 5b reflect differences when ergodic assumption is used (Figure 5a) versus when single station sigma with site specific term is used (Figure 5b). For the DCPP site, the use of single station sigma with site-specific term appears to be the key factor that brings the deterministic spectra below the original design spectra.

While the single station sigma assumption and especially the site term have a significant effect on hazard, the site term is based on the observations of only two earthquakes. As described in IPRP Report No. 6, the IPRP is not convinced that the "site term" reflects some property of the site that would affect all earthquakes recorded at DCPP. The alternative hypothesis that additional factors related to the particular source or paths of those two earthquakes remains at least as plausible. The CCCSIP report does not include any additional studies to address this issue. The 3D site response analyses proposed by PG&E will not address whether single station sigma model is more reasonable than the ergodic assumption, nor will it reduce uncertainty in the site specific term that is calculated based on two recorded earthquakes. The proposed 3D site response model will address V_{S30} scaling and the effect of large variability in V_{S30} values at the DCPP site.

Figure 6 compares deterministic spectra for the CCCSIP sensitivity scenario assuming linked co-seismic rupture of the Shoreline, Hosgri, and San Simeon Faults (M7.3). It shows that deterministic ground motion increases across the spectrum as magnitude for the Shoreline Fault rupture increases from 6.7 to 7.3. This figure also shows increased ground motion as V_{S30} decreases from 1200 m/s [at the power block foundation level] to 760 m/s. More significantly, the figure shows, once again, that the most influential factor affecting deterministic ground motion estimates is the single station sigma assumption and the site term.



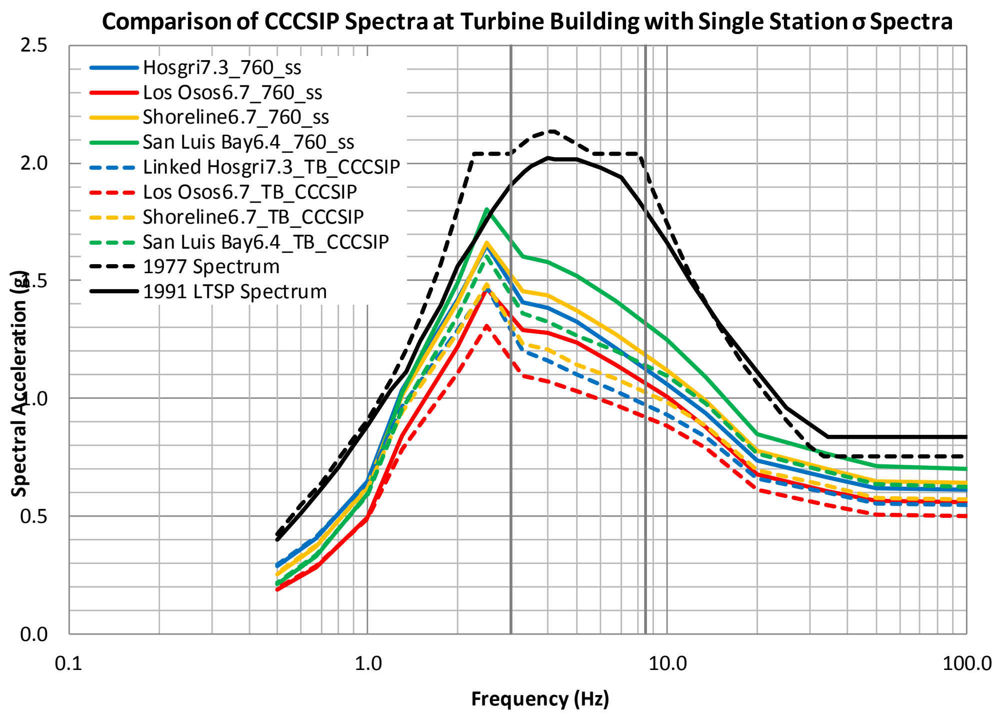


Figure 5. Comparison of deterministic ground motion spectra from the CCCSIP update for the turbine building foundation level (dashed curves; using single station sigma, site term, site term uncertainty, and scaling from V_{S30} of 760 m/s to 980 m/s) with deterministic spectra of two sensitivity cases: (a) an average site with V_{S30} of 760 m/s using the ergodic assumption (i.e., calculated from GMPEs directly); and (b) A DCPP site with V_{S30} of 760 m/s using single station sigma assumption, and site-specific term and its uncertainty. The PG&E 1991 LTSP/SSER 34, the 1977 HE (Hosgri Earthquake) design spectrum, and the frequency range important to DCPP (bracketed by vertical dark grey lines) are also plotted for reference.

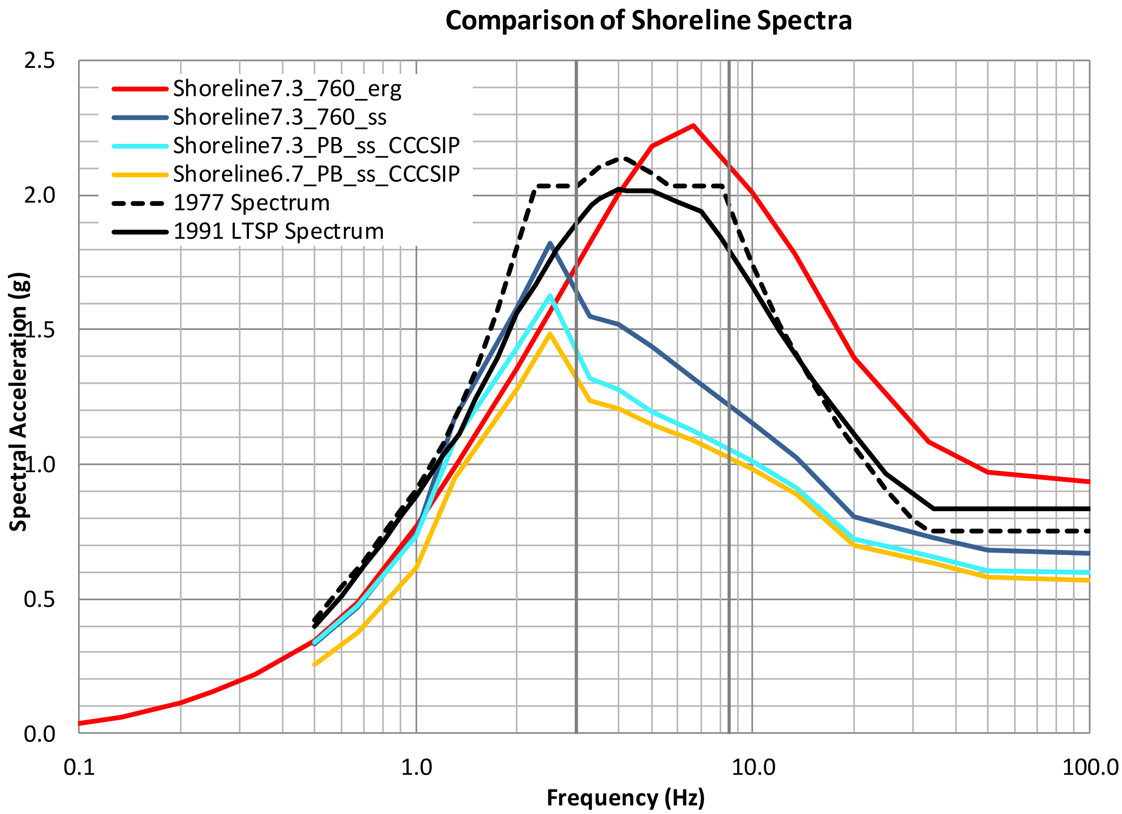


Figure 6. Comparison of deterministic ground motion spectra for the Shoreline Fault rupture linked with the Hosgri and San Simeon Faults.

CONCLUSIONS

The CCCSIP report, chapter 10, presents a new high-resolution tomographic model intended to be used to model how seismic waves are modified as they pass through the rocks immediately beneath DCPP. That model shows overall lower V_S and greater variability of V_S than used in the Shoreline Fault Report, as the IPRP anticipated in Report No. 6. Estimates of V_S near the surface approximately reflect the amount of soil and weathered rock removed from the site during grading, as expected. Estimates of V_{S30} are 570 m/s and 750 m/s at ground level on opposite ends of the turbine building, within the range expected for the type of rock at these locations. Estimates of V_{S30} for foundation levels are higher, reflecting removal of more weathered rock. While the estimated V_S values in the tomographic model correspond to expected relationships of V_S with depth, with removal of low-V_S material by grading, and general range of V_S for different geologic units these values do not correspond well to values previously measured in boreholes. PG&E has not reconciled these differences, nor have they provided estimates of uncertainty in the velocity values in the tomographic model.

The PG&E methodology to account for site amplification in the CCCSIP report is essentially the same as in the Shoreline Fault Report. Nevertheless, site amplification factors were updated to incorporate two new developments: the new NGA West2 GMPEs and the updated V_{S30} values for the two free field recording stations. The updated site amplification factors are generally lower than those in the Shoreline Fault Report. However, the difference is insignificant given large uncertainty in site amplification.

The CCCSIP report states that the new 3D velocity model is to be used in 3D response analysis as part of the SSHAC process. The 3D response analysis may improve the estimate of site amplification from the reference site with V_{S30} of 760 m/s to the foundation levels of the power block and the turbine building. It could also account for the effect of highly variable V_{S30} values at the DCPP site on estimated ground motion.

The 3D response analysis cannot, however, address issues associated with the site-specific term. IPRP previously expressed its concern regarding the adequacy of using only two earthquakes in estimating the site-specific term and made recommendations to gain confidence in the PG&E site-specific approach, including analyzing broad band ground motion data and ground motions from small earthquakes to better quantify the site-specific term. PG&E has not addressed these recommendations.

SUMMARY

- The CCCSIP report presents a detailed 3D velocity model that reproduces several expected variations in shear-wave velocity in subsurface, however:
    - Uncertainties of velocities are not clearly described.
    - Correspondence with previously measured velocities is poor.
- The single-station sigma approach has significant effects on calculated earthquake shaking.
    - Calculated ground motions using the 3D tomographic model should reflect uncertainties in that model, which have not been described.
    - The “site term” based on two recorded earthquakes may represent other factors, rather than site conditions. IPRP is not convinced that this factor is adequately constrained for use in ground motion calculations.

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