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. 10, December 4, 2015

Preliminary Comments on PG&E's May 2015 Update of the Three-Dimensional Velocity Model for the Diablo Canyon Power Plant Foundation Area and Site Amplification Using Analytical Approach

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 9 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). 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. IPRP Report No. 9, issued March 6, 2015 reviewed onshore seismic studies in the immediate area of the DCPP, PG&E's evaluation of site conditions and hazard sensitivity as described in chapters 10, 11, and 13 of the CCCSIP report.

PG&E (2015a) issued a response to the IPRP Report Nos 7, 8, and 9 on April 22, 2015, acknowledging that the IPRP process has provided valuable insight and guidance on the CCCSIP, and that PG&E will use the IPRP comments as guidance for planning future seismic studies as part of the DCPP Long Term Seismic Program. With regard to site velocity model, site amplification, and associated uncertainties (subject of IPRP Report No. 9 as well as this report), PG&E noted that additional work is ongoing which would address the comments raised by the IPRP.

Subsequently, PG&E completed a report summarizing the methodology and results of an update to the three-dimensional (3D) velocity model, associated model uncertainties, and model validation (Fugro, 2015a). PG&E (2015b) performed one dimensional (1D) site response analysis in response to a request from the NRC, following NRC required procedure. These two new studies were the subject of a public meeting on September 9, 2015.

This report summarizes IPRP's preliminary review of these new studies by PG&E based on documents available to the IPRP. We note that in-depth review is not yet practical because some essential documents are not available to the IPRP and because PG&E is still in the process of finalizing its site velocity model and conducting 3D site response analysis.

THREE-DIMENTIONAL VELOCITY MODEL

The 3D velocity model was developed previously as part of the CCCSIP (PG&E, 2013) using seismic tomographic data. By adding constraints from surface wave dispersion and vibrator time history data, PG&E developed a revised 3D velocity model and quantified model uncertainty (Fugro, 2015a). Sufficient surface dispersion data were obtained at about 90 locations in the northwest, west, and southeast vicinities of the plant area to enable development of shear wave velocity (Vs) profiles at these locations with good constraints to the shallow parts of the profiles. The new data also allowed development of uncertainty ranges in the Vs profiles based on inversion analyses that satisfy previous tomographic data as well as the new surface dispersion data.

These newly developed Vs profiles as well as the Vs profiles from the 1978 downhole measurements in three boreholes were used to develop adjustment factors to revise the 3D Vs model. The revised 3D Vs model is further adjusted by waveform analyses based on the tomographic data so that the final 3D Vs model satisfies the constraints of both surface dispersion and tomographic data. The revised 3D Vs model is also verified via numerical analyses using the finite difference approach of a commercial software package, $FLAC^{3D}$.

As a verification of the revised 3D Vs model, seismic waves were propagated through the velocity model and synthetic shear wave travel times within 30 m of a borehole location were compared with the arrival time picks from the shear wave velocity measurements for each of the three deep boreholes (DDH-A2, C, and D) as shown in Figure 4.1-1 in Fugro (2015a).

For borehole DDH-A2, measured travel times are consistently lower than the lower bound of the ranges of synthetic travel times. The comparison shows reasonably good agreement between synthetic and measured travel times for depth less than 40 m in DDH-C and for depth less than 55 m in DDH-D. Near these depths in DDH-C and DDH-D, measured shear-wave travel times show large scale scattering over approximately 0.02 seconds based on Figure 4.1-1 in Fugro (2015a). In DDH-C, measured arrival times are longer than the upper bound of the synthetic arrival time uncertainty ranges below 40 m. In DDH-D, measured shear wave travel times are close to the upper bound of the synthetic arrival time uncertainty ranges below 55 m.

Fugro (2015a) states that the narrow depth ranges with large scattering in measured shear wave travel times in DDH-C and DDH-D correspond to the low Vs zones in the profiles extracted from the revised 3D Vs model near these two locations (Figure 4.1-2 of Fugro, 2015a). The report speculates that the large shear wave impedances at the top of these low-velocity zones make it difficult or impossible to consistently pick the first arrival times. The report, however, doesn’t state clear reasons for the inconsistencies between the measured and synthetic travel times noted above, nor does it compare shear wave velocities from downhole measurements with those obtained from the revised 3D Vs model.

To facilitate direct comparison, we made Figure 1 by superimposing velocity profiles from the 1978 downhole measurements on velocity profile ranges (Figure 4.1-2 of Fugro, 2015a) derived from the 3D Vs model. We note that the comparison between Vs profiles obtained from downhole measurements and those obtained based on the revised 3D Vs model (Figure 1 in this report) is remarkably similar to the comparison shown in Figure 1 of the IPRP Report No. 9. In that figure, downhole velocity profiles are compared with the nearest profile from the 3D tomographic survey presented in the CCCSIP report. In IPRP Report No.9, we stated that Vs profiles from the tomographic model do not appear to reproduce the variation in Vs with depth in nearby measured profiles.

Figure 1 of this report shows similar results: the ranges of Vs profiles from the updated 3D Vs model do not reproduce the variation in Vs with depth from the downhole measurements. In other words, the updated 3D model does not provide better consistency with the 1978 downhole measurements. Measured Vs values in DDH-C are all outside the range of Vs values from the 3D Vs model. This observation also applies to large portions of the Vs profiles in DDH-A2 and DDH-D.

Fugro (2015a) noted that the updated 3D Vs model was used in a 3D dynamic site response analyses. The work is documented in a progress report (Fugro 2015b, citation is based on information given in Fugro, 2015a) and is reviewed by another peer review panel [not IPRP]. We would like to request that the progress report (Fugro 2015b), other relevant documents, and any updates to these documents be provided for IPRP review.

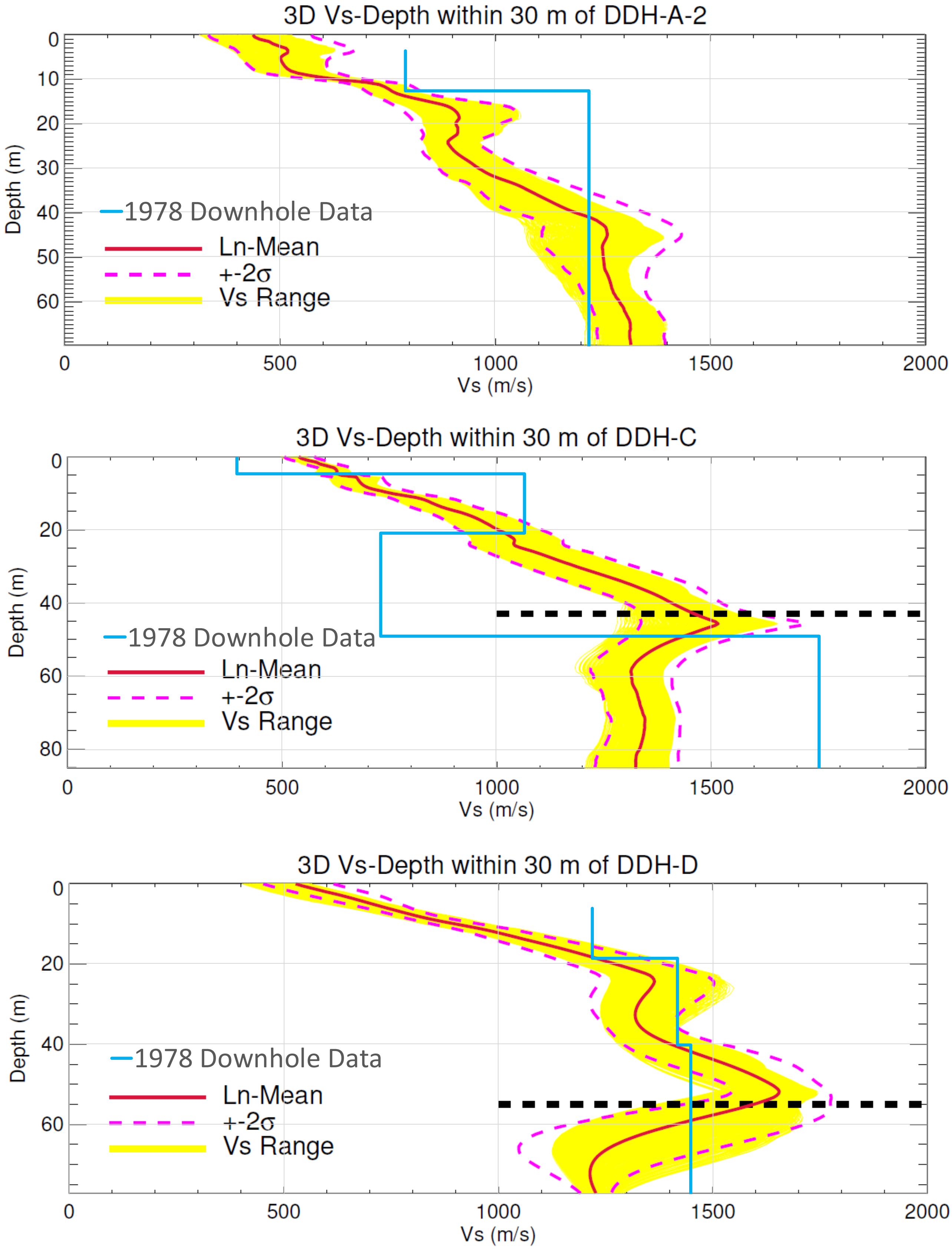

Figure 1. Comparison of measured Vs profiles from 1978 with profiles in the revised 3D Vs model within 30 m of borehole locations shown as Figure 4.1-2 in Fugro (2015a). As noted in Fugro (2015a), black dashed lines delineate depths where travel time uncertainties become large.

ANALYTICAL SITE RESPONSE APPROACH AND SITE AMPLIFICATION FACTORS

As discussed in IPRP Reports Nos. 6 and 9, PG&E used an empirical approach to evaluate potential amplification/de-amplification of earthquake ground motions by local site conditions. This approach was used in the Shoreline Fault Report (PG&E, 2011), the CCCSIP report (PG&E, 2014), and the SHACC report (PG&E, 2015c).

To address a request from the NRC, PG&E (2015b) derived two different site amplification factors using a 1D site response analysis procedure required by the NRC following its guidance document "The Screening Prioritization and Implementation Details" (SPID) (Electric Power Research Institute, 2013). These new analytical factors were derived for two shaking intensity levels: peak acceleration values of 0.1 g and 1.0 g. PG&E noted that 0.1 g represents the level of shaking from the empirical data used to compute the empirical site terms, and 1.0 g is the approximate shaking level at the DCPP corresponding to the hazard level (10^{-4} annual exceedance rate) required by the NRC for design and evaluation of nuclear power plants.

Uncertainty in analytical site terms was evaluated using multiple shear wave velocity profiles, kappa values, and nonlinear material models. PG&E noted that ground motions were developed previously for the foundation levels at the containment and turbine buildings. New ground motions, starting from those in the SSHAC reports for the NRC, are for a reference or control point at the free-field recording station ESTA 28 (Vs30 of 760 m/s). Ground motions at other structures, including containment, turbine, and auxiliary buildings will be computed as part of soil structure interaction analysis (PG&E, 2015b).

The new analytical site factors are compared to the empirical factors in Figures 1 and 2 in PG&E's response to the NRC (PG&E, 2015b). Analytical factors show de-amplification over the entire spectrum with the greatest de-amplification occurring around 8 and 11 Hz. There is greater de-amplification for more intense shaking due to nonlinear effects. In contrast, the empirical factors show no amplification or de-amplification for frequencies less than 1 Hz, slight amplification for 1 to 3 Hz, and de-amplification for frequencies greater than 3 Hz with the greatest de-amplification from about 6.5 Hz to 11 Hz.

PG&E noted that the analytical site terms are generally similar to the empirical site terms for high frequencies (specifically for frequencies greater than about 4 Hz based on Figures 1 and 2 of PG&E, 2015b). PG&E further noted that the uncertainty range for analytical site terms is broader than empirical site terms because large uncertainties were included in the inputs to the analytical modeling and because nonlinear effects captured by analytical modeling at high shaking levels are not captured by the empirical approach.

The broader uncertainty range is largely the consequence of the range of uncertainty in the site kappa value, which PG&E believes is well defined by the shape of response spectra in the high frequency range from the three earthquakes recorded at the DCPP (2003 M6.5 San Simeon, 2004 M6.0 Parkfield, and 2003 M3.4 Deer Canyon). In PG&E's analytical site response analyses, profiles with damping levels equivalent to kappa values of 0.07, 0.04 and 0.024 were developed by adjusting damping of deeper layers where material properties are not well constrained. The resulting analytical site factors show great sensitivity to kappa values, with an equivalent kappa value of 0.07 resulting in the greatest de-amplification and 0.024 slight amplification.

New hazard curves and ground motion response spectra at the control point were developed using the new analytical amplification factors and a logic tree approach to incorporate uncertainties. PG&E concludes that the ground motion response spectrum [GMRS, the basis for hazard screening and risk assessment for the DCPP (PG&E, 2015d)] based on empirical factors is not altered by additional studies using the analytical approach for site factors.

IPRP requests more convincing justifications for precluding kappa values other than 0.04 at the DCPP site. It is unsatisfactory that material properties, particularly damping, for deeper layers beneath the DCPP site are largely unknown and have to be calibrated by the kappa value estimate from limited empirical data. Because damping properties of these deeper layers have such profound effects on the analytical site factors and because they are calibrated by empirical data, it is not surprising that analytical factors show de-amplification that is similar to the empirical factors.

Deep 1D response analyses may be appropriate for sites located on near horizontal subsurface layers of soil and rocks that show little lateral variation in material property and structural geologic conditions, such as sites in central and eastern US. We doubt that 7-km deep 1D profiles would be appropriate for the DCPP site because of complex structural geological characteristics that vary significantly in all three spatial dimensions below the DCPP site.

Although key results from analytical response analyses are presented in PG&E (2015b, which IPRP reviewed), detailed information regarding methodology, input parameters and assumptions are documented in a report by Pacific Engineering and Analysis (2015), which IPRP currently does not have. IPRP requested a copy of that report to review during the September 9, 2015 public meeting, but have not received the report as of this writing.

SUMMARY

It is encouraging that PG&E is utilizing shear wave velocity profiles developed from surface wave dispersion data to update the 3D velocity model to be consistent with both surface wave dispersion and previous tomographic data. The 3D velocity model is yet to be finalized to include the full plant region. Also, 1D velocity profiles and associated uncertainty ranges are yet to be developed under the plant foundation area for soil structural interaction analysis and risk assessment.

IPRP would like to see better agreement between velocity profiles from the updated 3D model and from 1978 downhole measurements or reasonable explanations for inconsistencies. However, we realize adjustments are still being made to the 3D model. If the fit to the 1978 downhole measurements does not improve in the final 3D Vs model, sufficient explanations should be provided.

IPRP is not confident that the 7-km deep 1D site response analysis would be applicable to the DCPP site because of complicated 3D geological conditions beneath the site. It is unsatisfactory that material damping is so poorly understood in deep layers that damping had to be calibrated by kappa values derived from empirical data, even though damping has profound effects on analytical site factors. For these reasons, we do not put much faith in the relatively good agreement between empirical and analytical site factors at high frequencies. We are pleased that PG&E is conducting 3D site response analysis using the updated 3D velocity and request to review that work.

IPRP will continue to review site response and related issues and requests the following be provided:

1. Pacific Engineering and Analysis, 2015, *Development of Amplification Factors for the Diablo Canyon Nuclear Power Plant, Revision 1* or a newer revision if there is one.
2. Fugro Consultants, Inc., 2015b, *3-D Site Response Analyses for Diablo Canyon Power Plant (DCPP),* Report prepared for Pacific Gas and Electric, Fugro Job No. 04.761140022, February.
3. Final report and progress reports on continued updates of the 3D shear wave velocity model for the DCPP.
4. Final report and progress reports on the on-going 3D analytical site response analyses.
5. Electronic files of 3D velocity model described in Appendix H of Fugro Consultants, Inc., 2015, *Update of the Three-Dimensional Velocity Model for the Diablo Canyon Power Plant (DCPP) Foundation Area*, Fugro Job No. 04.76140022, May. Currently, only a description of electronic files is available on PG&E website where the report is (http://www.pge.com/en/safety/systemworks/dcpp/sshac/index.page). The electronic files are not available.

REFERENCES

Fugro Consultants, Inc., 2015a, *Update of the Three-Dimensional Velocity Model for the Diablo Canyon Power Plant (DCPP) Foundation Area*, Fugro Job No. 04.76140022, May.

Fugro Consultants, Inc., 2015b, *3-D Site Response Analyses for Diablo Canyon Power Plant (DCPP),* Report prepared for Pacific Gas and Electric, Fugro Job No. 04.761140022, February.

Electric Power Research Institute, 2013, *Seismic Evaluation Guidance: Screening, Prioritization, and Implementation Details (SPID) for Resolution of Fukushima Near-term Task Force Recommendation 2.1 – Seismic,* 1025287.

Pacific Engineering and Analysis, 2015, *Development of Amplification Factors for the Diablo Canyon Nuclear Power Plant*, Revision 1.

Pacific Gas and Electric Company (PG&E), 2011, *Report on the Analysis of the Shoreline Fault Zone, Central Coastal California*, Report to the U.S. Nuclear Regulatory Commission, January.

Pacific Gas and Electric Company (PG&E), 2014, *Central Coastal California Seismic Imaging Project*, Report to the California Public Utilities Commission, 3 volumes, 13 chapters, September 2014.

Pacific Gas and Electric Company (PG&E), 2015a, Pacific Gas and Electric Company's *Response to CPUC Independent Peer Review Panel Report Nos. 7, 8, and 9*, Letter to California Public Utilities Commission, April.

Pacific Gas and Electric Company (PG&E), 2015b, *Response to NRC Request for Additional Information Regarding Recommendation 2.1 of the Near-Term Task Force Seismic Hazard and Screening Report*, Letter to U.S. Nuclear Regulatory Commission, August. PG&E Letter DCL-15-095.

Pacific Gas and Electric Company (PG&E), 2015c, *Seismic Source Characterization for Probabilistic Seismic Hazard Analysis for the Diablo Canyon Power Plant, San Luis Obispo County, California,* Report on the Results of the SSHAC Level 3 Study in Partial Compliance with NRC Letter 50.54(f), March.

Pacific Gas and Electric Company (PG&E), 2015d, *Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Task Force Review of Insights from the Fukushima Dai-ichi Accident: Seismic Hazard and Screening Report,* PG&E Letter DCL-15-035, March.