From: Youssef Hashash, Boris Jeremic and Ellen Rathje
To: Dr. Norman Abrahamson, Pacific Gas & Electric

Subject: **"Update of the three-dimensional velocity model for the Diablo Canyon Power Plant (DCPP) foundation Area, by Fugro Consultants Inc, May 2015.**

August 4, 2011

Dear Dr. Abrahamson,

At your request the review panel consisting of Ellen Rathje, Boris Jeremic and Youssef Hashash reviewed the above referenced report. This report is an update of an earlier report developed by Fugro Consultant that we have reviewed as well.

General Comments:

The update of the 3-D velocity model by FUGRO Consultants Inc, represents an important step for performing high fidelity modeling and simulation of seismic wave propagation for the Diablo Canyon Nuclear Power Plant (DCNPP). The updated model is responsive to many of the comments made by this review team. A wealth of high-quality geologic and geophysics data makes this unique endeavor an example of what will future design and licensing simulations efforts look like. It is particularly important to note the systematic verification and validation effort that FUGRO undertook in characterizing, modeling and simulating free field behavior at DCNPP location.

Comments provided below are provided in hope to improve modeling and simulation process.

Velocity Profiles from Surface Wave Dispersion and impacting ESTA 28

Each of the inversions of the surface wave dispersion data shown in Section 2.0 of the report includes multiple velocity profiles, each of which has a very similar dispersion curve. However, the dispersion curves do not extend fully across the error bars in phase velocity, particularly at low frequencies. Please provide some justification for not capturing the uncertainty represented by the error bars in the dispersion curves.

The variability among the velocity profiles for each inversion is between 0.1 and 0.2 (ln units) across the depths considered (e.g., Figs 2.2-1 to 2.2-7). Additionally, the variability among the median profiles from the different locations considered is between 0.1 and 0.2 (e.g., Fig 2.3-2). It appears that only the variability between the median profiles was used to develop the final variability estimates (Table 3.4-1). Please explain why the variability within each inversion was not incorporated in the final variability estimate.

Velocity Profiles in other areas including under the plant

It is understood that all surface wave measurements were done at locations that are some distance from the main DCNPP buildings and were used to update the Vs model. To what extent does the absence of such information in the immediate vicinity of the buildings affect the fidelity of the Vs model in that zone and the epistemic uncertainty of the free field motion modeling?

Comparisons with Other Velocity Data

The revised 3D velocity model is compared with the downhole data from boreholes DDH-A-2, DDH-C, and DDH-D using travel times. It would be useful to also see these comparisons in terms of Vs profiles.

For DHH-A-2, the velocity model and downhole data do not agree. Please explain this discrepancy and why you did not adjust your 3D velocity data to better match the downhole velocity model.

For DDH-C and DDH-D there is a lot of discussion about the effect of the low velocity layer at depth on the downhole travel time estimate. It is not clear whether this means that the downhole Vs estimates are in error. Please comment further on this issue.

Please provide an estimate of the velocity profiles from your 3D model at the locations of the ISFSI boreholes that have Vs profiles from PS suspension logging.

Section 3.4: Alternative Velocity Models

Please provide some details regarding the procedures that will be used to develop the alternative 3D velocity models using the information from Section 3.4. After these alternative models have been developed, please provide comparison between the three models in terms of Vs profiles at different locations.

Issues related to three-dimensional simulations:

On page 3.1 it is noted that FUGRO aimed to verify numerical model using Lamb problems and used axisymmetric finite difference mesh. However, for the DCNPP problem that was later analyzed, a cubic finite difference mesh was used. Hence, provided verification applies to axisymmetric problems (and finite difference implementation) and not to the one that was used for actual modeling.

Is it possible that the 2% difference in "measured" Vp and Vr might be due to an artificial, hidden/numerical damping used in FLAC or issues of numerical accuracy. If no damping is used then there should not be any difference! These 2% difference might become important as for the most part, ratios of updated Vs versus original Vs, at DCNPP locations, are small (differences are on order of few percent, as per plots in Appendix F) and 2% might actually be on the order of updated values. It is of course important to realize that difference of 2% is probably not important for updated Vs values, however it might be important to investigate where such 2% difference comes from for a clean, verification example using Lamb solution. Is it the mesh size, time step size, hidden damping...

In addition, being an explicit finite difference code, time step size is of importance for FLAC results, and it would be worth noting what time steps are used!

Comments on SECTION 3.2

In section 3.2.1, last paragraph on page 3-3: The text starts by saying that the Vs Dependent Rayleigh damping is used and then indicated at the end of the paragraph that no damping was used. Please clarify.

Please check consistency with units used, and that all the numerical values have appropriate units (for example on section 3.2.3 it is noted that the size of the model is 100 by 30m and it is assumed that the 100 means 100m. What is the maximum frequency that can be propagated through the recommended grid size?

It is noted that for bondary conditions (BC), a quiet boundary was used. There is no such thing as a quiet boundary, so the question is how quiet is this boundary conditions and what is returned into the system? Perhaps a simple example with a simple shock load on top would suffice to show BC damping effectiveness

Miscellaneous Issues

There are some inherent limitations in the use of FLAC for this wave propagation problem due to the unique way in which it employs the finite difference method.

FLAC is a finite difference code, hence in principle we should talk about 3D polyhedra cells, rather than elements. We recognize that FLAC uses the term elements and uses overlapping triangles. These are non-standard approximations that are employed in the numerical implementation.

As for the following of surface topography using finite difference code, it is not clear how much error this change of rectangular finite difference grid introduces in wave results. Is that an issue when using FLAC? This change from a rectangular grid might need to be investigated in using a simple example, particularly since all results that are shown are produced in the surface region, where such grid changes are occurring.

Given the above two issues, it would be worthwhile to explore the use of finite element based methods for wave propagation. Possible software platforms to use include LS-DYNA, ABAQUS and a Real ESSI Simulator.

Sincerely,

Youssef Hashash *Boris Jeremic* *Ellen Rathje*

August 10, 2015

Response to Peer Review on "Update of the three-dimensional velocity model for the Diablo Canyon Power Plant (DCPP) foundation Area, by Fugro Consultants Inc, May 2015, dated August 5, 2011

Prepared by: Norman Abrahamson

Velocity Profiles from Surface Wave Dispersion and impacting ESTA 28

The peer review identifies two issues related to the size of the uncertainty in the velocity profile at ESTA28, which is used as the control point for the DCPP GMRS. As explained below, the two issues identified by the peer review do not represent an underestimation of the uncertainty for the profile at ESTA28.

1. Uncertainty from dispersion curves

The peer review notes that the range of the velocity profiles does not span the full range of allowable velocity models given the dispersion curves. If the dispersion curves were the only information used to constrain the velocity profiles, then the full range allowed by the dispersion curves should be considered; however, there is other data, such as travel times, used to constrain the velocity. The uncertainty in the final velocity profiles is intended to represent the uncertainty given all of the data, not just the dispersion data. In this case, the main check from the dispersion curves is that the derived profiles are not inconsistent with the dispersion curves. The report shows that the range of velocity profiles remains consistent with the dispersion data.

2. Multiple Uncertainty Terms

The peer review also noted that there are two estimates of uncertainty of the velocity profiles shown in the report, but that the final uncertainty is based on only one estimate. The two methods are (1) uncertainty of the profile at a point due to different inversions and (2) variability of the profiles over a short lateral separation (25 m). The two estimates give similar uncertainties. The reason for not combining these two estimates is that they are correlated. If the velocity profile at a point is changed, then the velocity of the nearby locations will adjust so that the model fits the observed travel times. Therefore, simply combining these two uncertainty estimates is not appropriate.

As a sensitivity study, the effect of including additional uncertainty is evaluated in the DCPP site response evaluation. In the site response calculation, there is randomization of the soil velocity profile using the SPID "footprint" correlation model that represents the variability of the velocity profile under the footprint of the structure. The uncertainty in the soil randomization is greater than the uncertainty estimated for the site given in the Fugro report. The sensitivity study showed that the effect of including this additional uncertainty on the estimation of the GMRS is addressed in the DCPP site response evaluation. The sensitivity shows that ignoring the correlation and including the full uncertainty from both terms leads to a very small change in the GMRS.

Velocity Profiles in other areas including under the plant

1. Effect Of Absence Of Shallow Data In The Immediate Vicinity Of The Buildings.

The absence of shallow data leads to larger epistemic uncertainty for the shallow velocity profile in regions that were not accessible for the surface wave measurements. This increases uncertainty will be included in the range of velocity models used for the soil structure interaction (SSI) studies. We note that the main buildings of interest are embedded so the shallow soil have been removed. At the foundation depth for the containment structures and turbine building, the low shallow velocities will be much less of an issue.

2. Comparisons with Other Velocity Data.

An important topic for the 3-D velocity model is the testing of the model against the available borehole data. The Fugro report uses the travel time data for the comparisons rather than interpreted velocities. The reason for making the comparison using the travel time data is that it is the raw data. In particular, there are not clear arrival times for some of the data. Using the range of the travel times better represents the uncertainty in the measurements.

The peer review comments noted that it would be useful to see the comparisons of the interpreted velocity profiles with the 3-D model and not just use the travel time for comparison. These comparison will be provided to the peer review before finalizing the 3-D velocity model for the full plant region. We note that these comments apply mainly to the sites toward the coast and do not affect the evaluation of the velocity profile used for ESTA28.

The additional comparisons of the 3-D profile and the measured profiles will be made using all of the available boreholes.

3. Alternative Velocity Models.

To date, only the uncertainty for a 1-D profile has been provided. The alternative 3-D profiles that will be used for developing the equivalent 1-D models for use in the SSI have not been developed yet. Once developed, they will be provided to the peer review panel for review.

Issues related to three-dimensional simulations:

The peer review comments on the three-dimensional simulations provide several useful suggestions for improvements to the 3-D modeling calibration and methods used. These will be addressed and discussed with the peer review panel before proceeding to implement the 3-D simulations.