BOARD OF SUPERVISORS

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BRUCE GIBSON
SUPERVISOR DISTRICT TWO

June 20, 2012

Mr. L. Jearl Strickland
Director, Nuclear Projects
Diablo Canyon Power Plant
PO Box 56
Avila Beach, CA 93424

RE: Central Coastal California Seismic Imaging Project (CCCSIP) -- High-energy 3D seismic reflection survey near Diablo Canyon Power Plant (DCPP)

Dear Mr. Strickland:

The Independent Peer Review Panel (IPRP, convened by the California Public Utilities Commission under Decision 10-08-003, 2010) has met several times and has commented on the design of the 3-D seismic survey referenced above. The IPRP has commented that, with certain adjustments, the overall survey coverage of geologic targets relevant to the seismic hazard analysis appears adequate. The IPRP, however, has also suggested more detailed review of the seismic acquisition and processing techniques proposed to be used within the overall survey footprint.

With this letter, I am requesting that PG&E provide public responses regarding the data acquisition and processing issues described below. Please note that I am writing here as an elected official representing the residents of San Luis Obispo County (and not officially on behalf of the IPRP). The basis for these questions is my previous experience as a seismic exploration research geophysicist (CV attached) and consultation with current experts in seismic acquisition and data processing.

Discussion of these issues is warranted because PG&E has proposed to use a survey vessel owned by the National Science Foundation and operated by Lamont-Doherty Earth Observatory of Columbia University (LDEO). While LDEO is an outstanding research institution, the seismic imaging capabilities of the academic world have historically lagged those available from seismic exploration contractors ("the industry"). This difference is attributable to superior acquisition technology, enhanced data processing techniques, and a comprehensive integration of acquisition and processing decisions.

The fundamental question then is whether PG&E's proposed survey is consistent with state-of-the-art seismic reflection imaging practice. As noted below, the proposed survey vessel has less acquisition capability than most industrial vessels, and since no data processing approach has been specified, no acquisition/processing coordination has been detailed. Given the importance of the seismic hazard analysis of the area surrounding DCPP, PG&E should publically explain why industrial-level current technology has not been proposed for these studies.

Sections below include a summary comparison of PG&E's proposed survey with the current industrial state-of-the-art. Sections following that contain expanded discussions of the relevant technical issues of 3-D seismic reflection practice.

PG&E's proposed survey

The following summary specifications of PG&E's proposed survey are taken from the Project Description section of the Draft Environmental Impact Report prepared for the California State Lands Commission:

- One survey vessel towing 4 hydrophone streamers of 6 km length each, with a cross-line separation of 100 to 150 m.
- Two air-gun source sub-arrays towed by the survey vessel, fired alternately, cross-line separation 75 m.
- Offshore survey conducted over four defined areas. Within each area, air-gun shots taken along parallel track lines. Compass heading of track lines is constant in each area, resulting in a narrow range of source-receiver azimuths.
- Shallow water, near-shore (transition zone) data acquired by 5 lines of cabled geophones placed on the seafloor. Seismic sources located offshore (air-gun shots from the offshore survey) and onshore (vibrator trucks).

PG&E has indicated that design of the offshore and transition zone surveys was tested in an "illumination study" based on 2D and 3D ray-tracing calculations. No specific data processing for the acquired data or specific interpretation products have been specified.

Current industrial survey practice

The current industrial state-of-the-art for complex geologic areas with deep imaging targets is as follows:

- One survey vessel towing 10 or more streamers of 7 to 8 km in length, with cross-line separations of 75 to 125 m.
- One air-gun source array located on the streamer boat and at least one additional and identical source array on a source-only boat. The two or more sources fire alternately (or sequentially, if more than 2). The purpose of the additional source(s) is to provide a wider source-receiver azimuth range to the recorded wavefield.
- Adjacent traverses of the seismic vessel through the survey area are offset laterally such that there is a partial overlap of the streamer spreads. This provides a finer cross-line spatial sampling of the reflected wavefield.
- Major steps in current 2D and 3D data processing include: data conditioning (ambient noise attenuation, estimation and equalization of source wavelets from one shot to the next), 3D surface related multiple elimination (SRME), several passes of migration/tomography (velocity) analysis to determine subsurface velocities, 3D pre-stack reverse time migration (RTM) and post-image signal enhancements.
- Transition zone surveys include seafloor hydrophones, as well as geophones. Extensive data processing is especially directed at static timing corrections, source wavelet equalization and suppression of water column reverberations.
- In designing both offshore and transition zone surveys, iterative finite-difference wave equation modeling of expected targets is used to develop acquisition parameters (source-receiver type, spacing and location) and integrated data processing techniques.

- Required interpretation products are considered during survey design, and usually include time and depth maps of key reflectors, maps of faults with discernible travel time offset, horizon-based and volumetric attributes, several of which assist in small fault detection.
- Interpretation products also include interval velocity maps (including azimuthal variations) for the characterization of azimuthal velocity anisotropy and the horizontal stress field.

Attachment 1 includes an expanded discussion of these technical issues, beginning with a description of the process of modern survey design.

Summary request for response

Comparison of the information summarized above clearly shows areas where PG&E's proposed survey design and execution is not consistent with current industry standards. Assurance of the quality of seismic images produced by the offshore and transition zone surveys is foundational to understanding the seismo-tectonic setting and the quantitative analysis of seismic hazard.

Given long-standing concerns regarding the seismic threat posed by the geologic setting near Diablo Canyon – concerns heightened by the Fukushima disaster – the public deserves to know that the best possible seismic survey technology is applied to the studies that PG&E is undertaking. Taking care to document now that data are to be acquired and processed at the highest standards is fundamentally important to the future interpretation of the results.

For these reasons, I request that PG&E provide justification for their proposed choice of survey parameters and approach, given the current industrial standards summarized above. I ask that, at a minimum, PG&E provide a thorough discussion of the specific issues listed below:

- The overall design approach for both the offshore and transition zone surveys should be described. The survey design discussion should explain how survey acquisition parameters, data processing sequence, and interpretation products were chosen and how these three elements are integrated.
- The offshore and transition zone survey design process should analyze results of recently-conducted land surveys to confirm the adequacy of acquisition parameters and processing flow.
- The choice of basic parameters such as spatial sampling interval and maximum source-receiver offset should be discussed relative to the spatial resolution required to image expected target structures at depth. For instance, what spatial resolution is required to evaluate geologic markers that might provide a measure of fault slip rate?
- The choice of towing only 4 streamers in the offshore survey should be evaluated. Typical industrial surveys deploy 10 or more streamers to improve survey efficiency (i.e., reduced acquisition time). This should be a significant issue for the proposed survey, which has been analyzed to have significant impacts to marine life, based on time exposure to the seismic source.
- The potential benefit of data acquisition over a wide (in contrast to the proposed narrow) source-receiver azimuth range should be evaluated for both image quality improvement and the ability to evaluate the orientation of maximum horizontal stress.
- The proposed seismic data processing flow, data processing contractor and experience should be specified.
- The potential benefit of evaluating vertical fracture alignment, maximum horizontal stress, and directional stress inequality should be discussed. While this information is not typically used in traditional seismic hazard analysis, it does relate to the physical state of the overall seismo-tectonic setting.

- The specific acquisition parameters and processing sequence of the transition zone survey should be discussed. Of particular importance would be the processing proposed to assure a high-quality seismic image after merging the transition zone data with the onshore and offshore survey data.

Conclusion

I appreciate the effort required to design and execute a high-quality seismic survey of the geologic setting surrounding this important facility, and I thank you in advance for your responsiveness to this request. I believe it vitally important that the public is assured that we are all making best efforts to develop a more robust understanding of risks to the safety of the Diablo Canyon power plant, a critical feature of our county's environmental and economic landscape.

If I can answer any questions or provide any further information, please don't hesitate to contact me. Thank you.

Sincerely yours,

Bruce Gibson, Ph.D.

Attachment 1. Discussion of survey design, acquisition, processing and interpretation
Attachment 2. B. Gibson's curriculum vitae

Distribution
Stuart Nishenko, PG&E
Tom Jones, PG&E
Eric Greene, CPUC
Sup. Adam Hill, SLO County
Jennifer DeLeon, State Lands Commission
Cy R. Oggins, State Lands Commission

ATTACHMENT 1
DISCUSSION OF SURVEY DESIGN, ACQUISITION, PROCESSING AND INTERPRETATION
June 20, 2012

Seismic survey design

The design of a modern industrial seismic survey begins with the question "What are the imaging goals of the survey?" The answer to that question involves specification of parameters such as imaging target depth and the desired vertical and horizontal resolution. The main objective of the seismic imaging project, as stated in IPRP Report No. 3 (dated April 6, 2012), is to "explore fault zones in the vicinity of the DCPP, especially the intersection between the Hosgri and Shoreline faults." Targets to be imaged might range in depth from the seafloor (top of the sedimentary section) to as deep as 15 km (maximum seismogenic depth). In general, a seismic survey of targets over this depth range will require long source-receiver offsets, densely spaced sources and receivers, and small common midpoint (CMP) bins.

Once these basic parameters are set, the next question is "Given the survey goals and desired parameters, our knowledge of the geology of the area, and all environmental issues, what data acquisition and processing specifications are sufficient to meet the goals in an environmentally sound and economical fashion?" Consideration of the geology is important because the complexity of an area has a large impact on the detailed design of the survey. Challenges such as those related to large subsurface dips, velocity-field complexity and high acoustic attenuation zones must be recognized and planned for. Environmental considerations encompass many aspects, including: weather, ocean currents, obstructions to navigation, shipping lanes, ambient noise, and the regional fauna and flora that could be affected by the survey activity.

As discussed below, the specifics of data acquisition parameters are typically determined by iterative modeling of the expected seismic response of the survey targets for a variety of source and receiver combinations. The modeled seismic response is then processed to confirm both the survey acquisition geometry and the necessary data processing flow. This integration of acquisition and processing, which has not been discussed by PG&E, is fundamental to modern reflection survey design to assure the expected effectiveness of the survey, as constrained by the environmental factors listed above.

The current industry state-of-the-art for survey design is to create synthetic acoustic seismic data using finite-difference wave-equation calculations for a specific geology and a range of acquisition parameters. Each model data set is then processed using appropriate techniques such as 3D surface related multiple elimination (SRME) and 3D reverse time migration (RTM). This allows the best of the acquisition designs to be selected based on the evaluation of the final image. If details of the geology are unknown, an informed guess can be used. For example, a survey designer can pose and answer a question such as "If a high-dip fault existed in this area, could it be imaged using this acquisition and processing scheme?"

In the complete design of a survey, the interpretation goals, methods, and products should be specified as well. At the minimum, the interpretation output would include: time and depth maps of all key reflectors, showing faults with discernible offset in time or depth; horizon-based and volumetric attributes for subtle fault detection, and interval velocity maps between key reflectors (including information on the azimuthal variation of interval velocity). The azimuthal interval velocity maps (co-rendering of the local fast, slow and azimuth of fast interval velocity) can be used to discern the azimuth of local maximum horizontal stress and the inequality of the horizontal stresses.

Marine acquisition parameters

Spatial sampling. In typical marine surveys, the spatial sampling is most dense along the streamer direction and thus most survey tracks are generally oriented in the targets' dip direction. In the CCCSIP, shooting tracks (which in some areas parallel the fault's strike) should be carefully assessed for the ability for direct fault imaging. However, shooting parallel to fault strike will enhance the spatial resolution of information that may be helpful in estimating past slip movement. The tradeoffs presented by shooting direction can be assessed with survey design modeling, described above.

Maximum source-receiver offset. From a pure imaging standpoint, longer offsets allow imaging of deeper structure. A 6-km maximum offset provides acceptable imaging down to a depth below sea level (BSL) of about 6 km. From an interpretation standpoint, longer offsets provide valuable amplitude versus offset (AVO) information for inversion of rock properties.

Number of towed streamers. Typical industrial survey vessels tow 10 or more streamers with nominal cross-line separations of 100 m. In general, a greater number of streamers towed reduces the number of required shooting passes. This improved data acquisition efficiency results in economic -- and potentially environmental -- benefits. An additional important advantage is that a wider streamer spread samples more of the reflected wavefield, which can enhance image quality relative to narrow-spread streamers.

While more streamers are potentially better, survey design decisions involving the number of streamers must consider both the capability of the survey vessel (streamer storage and handling capacity, towing horsepower) and environmental constraints (ocean currents and obstructions).

Position accuracy. Position accuracy of the source and receivers directly affects the overall fidelity of the seismic image. For example, in marine surveys, accurate source and receiver depths lead to consistent and better deghosting from one trace to the next. In the land case, vertical accuracy is required for application of elevation statics. Lateral accuracy is related to the fidelity of both data conditioning (interpolation and 3D SRME in particular) and imaging processing steps. These algorithms depend on knowledge of the locations of the source and receivers; if those data are poor quality, then the algorithm results will be likewise. The end result of poor positioning accuracy is a decrease in the resolution of the final image. Typical vertical and lateral accuracy are about ± 0.5 m and ± 3 m or better, respectively. For wide-azimuth surveys the cable steering is generally used to keep the streamers parallel to one another. Active steering fins on streamer cables can change the cable feathering by as much as ± 4°. Knowledge of expected ocean currents is important to assessing streamer positioning accuracy.

Wide-azimuth seismic reflection surveys – acquisition and processing

For areas with complex geology, wide-azimuth data can contribute significantly to better quality of the subsurface image[1]. Additionally, wide-azimuth data analysis has become commonplace in mapping the in-situ horizontal stress field (azimuth of local maximum horizontal stress, and inequality of the horizontal stresses), and the dominant vertical aligned fracture set (its azimuth and relative fracture density)[2]. Differences in the horizontal stress field in and around the known (and unknown) faults may prove valuable to the tectono-physicists in understanding potential fault ruptures.

Marine wide-azimuth seismic acquisition was originally developed to improve the imaging of reflecting horizons lying below complex structures such as salt domes. The method is also valuable, however, for any regime that includes high dips and significant structure in the cross-line direction. For the geologic situations just mentioned, a narrow-azimuth seismic survey can produce sub-optimal imaging results. The basic problem is that with complex geology the subsurface can scatter the incident wavefield in all directions. If the orientation of an acquisition program favors only a specific source-receiver orientation (narrow-azimuth), then it is likely that portions of the scattered wavefield are not recorded. As a result, those portions of the scattered wavefield cannot contribute their information to the final seismic image, thereby creating zones in which the image is misleading or even entirely missing[3].

The acquisition of wide-azimuth marine data generally requires more than one shooting boat, although creative vessel navigation has been used to accomplish similar results[4]. The lateral offset of a second source boat (offset typically 1 – 2 km cross-line to the receiver array) is the most efficient means of widening the range of source-receiver azimuth. Since image quality is sensitive to source timing and location, sophisticated control systems are required to coordinate shot initiation and positioning of multiple vessels.

Among the first data processing issues of marine surveys, suppression of multiple reflections is particularly important. State-of-the-art processing includes a 3D SRME algorithm that is capable of predicting multiples for data that are irregularly sampled (because of cable feathering, for example). Failure to suppress multiples causes artifacts to appear in migrated images. Such artifacts can obscure primary reflections or might even be misinterpreted as primary reflections. Successful multiple suppression requires significant computing resources and experienced technical staff.

Processing software must also account for and estimate the azimuthal variation in travel times (velocity). Not only can this information be used in interpretation, it is essential to include the azimuthal variations in velocity to obtain the best image possible. Otherwise, the stacked image after pre-stack migration will lose bandwidth due to improper event alignment.

Data processing that reveals the azimuthal variation in the AVO (amplitude variation with offset) is the state-of-the-art for vertical aligned fracture detection and characterization. Azimuthal variations in interval velocities, after pre-stack time migration that preserves azimuth and offset, are used to characterize the in-situ horizontal stress field.

Transition zone surveys – acquisition and processing

Seismic surveys in areas covered by shallow water (transition zones) are particularly challenging because the physical characteristics of each transition zone are unique. Transition zone survey design must consider water depth, wave action, tides, water bottom characteristics, type of onshore terrain, and other factors. In general, the survey designer tries to create a well-sampled distribution of receivers and shots that will provide a data set that can be processed successfully using standard algorithms.

Most transition zone surveys include deployment of water-bottom and onshore recording sensors with air-gun arrays for offshore shots and vibrators for onshore shots. A dual-sensor (hydrophone/vertical component geophone) is the minimum industry standard for ocean-bottom recording in transition zones. Vertical geophones are particularly valuable for helping to eliminate water-column reverberations during processing. Four-component (3 components of geophone and one hydrophone) sensors are used when shear-wave information is acquired.[2] Four-component recording is indicated when knowledge of the in-situ stress field and vertical aligned fractures is desired. The P-S (mode-converted shear wave reflections) data are sensitive to the presence of unequal horizontal stresses and vertical aligned fractures; these P-S data can be compared to the azimuthal P-P reflections to learn of lithology, porosity, pore fill, stress state, and fractures.

A key challenge in processing transition zone data is that the individual portions of the survey have to be matched for the various combinations of sources and receivers. For a standard dual sensor, there are four data subsets: air gun/hydrophone, air gun/geophone, vibrator/hydrophone, and vibrator/geophone. Each source/receiver combination has a unique "wavelet" response to the initiation of a shot. Extensive data processing by experienced personnel is required to covert the individual wavelets to a common form. This conversion is necessary before the entire volume of recorded data can be merged to produce a unified image.

Other data processing challenges within the transition zone survey include 1) static time corrections that must be applied to the data subsets (each subset requiring a different set of statics, 2) water-column reverberations which can be extreme and might require specialized processing in order to reveal the subsurface reflections of interest, and 3) estimation and correction of the variability of geophone-seafloor coupling.

If the transition zone data are to be merged with the deep-water 3-D survey, additional data processing, including wavelet correction and ghost reflection corrections, must be applied. In any case, transition zone imaging requires extraordinary documentation (e.g., water depths, tidal variations) and seamless coordination of acquisition and processing.

General data processing issues

Major steps in current 2D and 3D data processing include: data conditioning (ambient noise attenuation, estimation and equalization of source wavelets from one shot to the next), 3D surface related multiple elimination (SRME), several passes of migration/tomography (velocity) analysis to determine subsurface velocities, 3D pre-stack reverse time migration (RTM) and post-image signal enhancements.

In marine surveys, successful data processing depends on good onboard quality control during acquisition. The survey vessel should have adequate computing capability to assure that noise and other possible processing issues can be successfully dealt with in the final processing flow.

While the data processing sequence will be evaluated in the survey design phase described above, it is also important to review the processing flow and image results of previously recorded data. For instance, in the CCCSIP, the images produced from the land-based data recorded in 2011 (vibrator and accelerated weight drop sources with nodal recording) should be reviewed to inform future processing decisions.

References

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Chris Corcoran, Colin Perkins, David Lee, Paul Cattermole, Richard Cook, and Nick Moldoveanu
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2. **The Winds of Change,** *Heloise Lynn,* The Leading Edge, v. 23, 1156-1162.

3. **Breakthrough acquisition and technologies for subsalt imaging** (see Figure 1)
Denis Vigh, Jerry Kapoor, Nick Moldoveanu, and Hongyan Li
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4. **A single-vessel method for wide-azimuth towed-streamer acquisition**
Nick Moldoveanu, Jerry Kapoor, and Mark Egan
SEG Expanded Abstracts **27**, 65-69 (2008)

Attachment 2

CURRICULUM VITAE

BRUCE GIBSON
San Luis Obispo County, California

CURRENT POSITION:
San Luis Obispo County Supervisor (District 2); reelected in June, 2010 to second term through 2014. As Supervisor, I also serve on the following local Boards and Commissions, and am active in the California State Association of Counties.

LOCAL BOARDS:
Local Agency Formation Commission (LAFCO)
San Luis Obispo Council of Governments (SLOCOG) (Chair)
San Luis Obispo Regional Transit Authority (SLORTA)
Air Pollution Control District (APCD) (Chair)
Integrated Waste Management Authority (IWMA)
San Luis Obispo First 5 Commission

CALIFORNIA STATE ASSOCIATION OF COUNTIES (CSAC):
Member, Board of Directors
Chairman, Government Finance and Operations Committee
Member, Coastal Counties Regional Association

PREVIOUS GOVERNMENTAL SERVICE:

2005 - 2006	Commissioner, San Luis Obispo County Planning Commission;
2000 - 2003	Member, Ag Preserve Review Committee, San Luis Obispo County Advisory Committee for Williamson Act contract applications;
1998 - 1999	Member, Facilities Advisory/Oversight Committee, Coast Union School District, Cambria, CA;

PREVIOUS CONSERVATION/ENVIRONMENTAL ACTIVITIES:

2001- 2006	Member, Board of Directors, Cayucos Land Conservancy (a private non-profit land trust);
1998 - 2006	Member, Board of Trustees, The Land Conservancy of San Luis Obispo County, (a private, non-profit land trust). President, 1999-2001 and 2002-2004.

PREVIOUS EMPLOYMENT:

1990 - present	Self-employed rancher/farmer, Cayucos
1984 - 1989	Research Scientist, Rice University, Houston, TX, Director of Data Processing for the Department of Geology and Geophysics. Responsible for data processing of crustal-scale seismic reflection data and teaching of seismic reflection data processing techniques. Conducted research on seismic reflection response and imaging issues of randomly heterogeneous crustal materials.
1976 - 1984	Senior Research Geophysicist, Western Geophysical Co., Houston, TX. Conducted research and development of seismic reflection imaging techniques. Published research on signal processing (deconvolution), and 2-D and 3-D time and depth migration imaging techniques.
1973 - 1976	Research Assistant, University of Hawaii, Honolulu, HI

EDUCATION:

B.A., Physics, 1973	Pomona College, Claremont, CA
M.S., Geophysics, 1975	University of Hawaii, Honolulu, HI
Ph.D., Geophysics, 1989	Rice University, Houston, TX

TECHNICAL PUBLICATIONS

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SCIENTIFIC ORGANIZATION MEMBERSHIPS

American Geophysical Union
Society of Exploration Geophysicists