United States Department of the Interior

GEOLOGICAL SURVEY
BOX 25046 M.S. 966
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

March 6, 1989

Robert Rothman
U.S. Nuclear Regulatory Commission
Mail Stop 8D22
Washington, D.C. 20555

Dear Bob:

Enclosed are my comments on PG&E's written responses to questions 1, 4-18, 20, 23 and 40, and their discussion of these responses during the recent LTSP meeting of February 28 through March 3, 1989 held in San Francisco.

PG&E's responses, while answering many of the original questions, raised several more questions. Some of my current questions require a considerable amount of work by PG&E. You should decide whether it is reasonable to expect PG&E to engage in this additional work. In my view, the work is required in order to independently assess the appropriateness of the ground-motions used in the LTSP.

Since many of my concerns have been accommodated in my own analyses, some of this additional work would not be necessary if you were to decide to use my computed spectra or an envelope of my computed spectra and PG&E's computed spectra in place of their site-specific spectra. However, until that time I see no recourse but to request these additional analyses in order to better understand the bases for their site-specific spectra.

On another matter, the discussion of my work at the recent LTSP meeting in San Francisco identified an error in Table 1 of my report entitled *Preliminary Report on Empirical Studies of Horizontal Strong Ground Motion for the Diablo Canyon Site, California*. I inadvertently omitted coefficients g_1 and g_2 for PHV. Enclosed is a revised copy of this table that should be distributed to all recipients of my report. I will independently send a revised copy of

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the table to LLoyd Cluff of PG&E so that PG&E can correct their copies of the report immediately.

Sincerely,

Ken

Kenneth W. Campbell
Research Civil Engineer

TABLE 1

Results of Regression Analyses on PHA, PHV, and PSRVH

Parameter, Y	Period (sec)	a	b	c_1	c_2	d	e	f_1	f_2	f_3	g_1	g_2	no. of records	no. of events	σ
PHA, g	--	-2.470	1.08	0.311	0.597	-1.81	0.382	--	--	--	--	--	200	25	0.421
PHV, cm/sec	--	-1.974	1.34	0.00935	1.01	-1.32	0.327	--	--	--	1.16	0.0776	152	21	0.395
PSRVH, cm/sec	0.04	-0.648	1.08	0.311	0.597	-1.81	0.382	--	--	--	--	--	86	15	0.42
	0.05	-0.379	1.08	0.311	0.597	-1.81	0.382	--	--	--	--	--	142	20	0.44
	0.075	0.251	1.08	0.311	0.597	-1.81	0.382	--	--	--	--	--	144	21	0.46
	0.10	0.754	1.08	0.311	0.597	-1.81	0.382	--	--	--	--	--	144	21	0.48
	0.15	1.424	1.08	0.311	0.597	-1.81	0.382	--	--	--	--	--	144	21	0.50
	0.20	1.788	1.08	0.311	0.597	-1.81	0.382	--	--	--	--	--	144	21	0.50
	0.30	2.170	1.08	0.311	0.597	-1.81	0.382	--	--	--	--	--	144	21	0.50
	0.40	2.009	1.08	0.311	0.597	-1.81	0.382	0.425	0.570	-4.7	--	--	144	21	0.50
	0.50	1.930	1.08	0.311	0.597	-1.81	0.382	0.685	0.570	-4.7	--	--	144	21	0.50
	0.75	1.612	1.08	0.311	0.597	-1.81	0.382	1.266	0.570	-4.7	--	--	144	21	0.50
	1.0	1.268	1.08	0.311	0.597	-1.81	0.382	1.743	0.570	-4.7	--	--	144	21	0.50
	1.5	0.487	1.08	0.311	0.597	-1.81	0.382	2.425	0.570	-4.7	0.344	0.553	144	21	0.50
	2.0	0.040	1.08	0.311	0.597	-1.81	0.382	2.827	0.570	-4.7	0.469	0.553	144	21	0.50
	3.0	-0.576	1.08	0.311	0.597	-1.81	0.382	3.166	0.570	-4.7	0.623	0.553	144	21	0.50
	4.0	-0.766	1.08	0.311	0.597	-1.81	0.382	3.079	0.570	-4.7	0.857	0.553	127	20	0.50

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COMMENTS ON PG&E RESPONSES TO
QUESTIONS 1, 4-18, 20, 23 AND 40

Kenneth W. Campbell
U.S. Geological Survey

QUESTION 4

(1) I seriously question the validity of using modified soil recordings as a representation of rock recordings in the development of either the fragility data bases or the site-specific data bases. The modification is extremely generalized, whereas we know that site response is highly site specific. If it is crucial that soil sites be used, than a site-specific modification would be more appropriate. If this is not possible, then I would remove the soil sites from the analyses. In lieu of excluding soil recordings or performing site-specific site response analyses, PG&E should demonstrate that the inclusion of modified soil recordings has not resulted in lower ground motions than if they were excluded.

(2) In the fragility data base (Table Q4-2), only the Imperial Valley recordings were corrected for site conditions. The Pleasant Valley Pump Plant recording of the 1983 Coalinga earthquake was also sited on soil, but was not modified for site response. Also, my data indicate that the Tabas and Karakyr Point recordings are sited on soil not rock. However, I believe that including these latter two recordings as rock sites is conservative. The Pleasant Valley Pump Plant recording should be modified for site response before being used in the response to (1).

(3) The criteria used to select a set of ground motions for the fragility analyses was to choose ground motions representative of recordings obtained at a rock site within 10 km of the rupture surface of shallow crustal earthquakes having moment magnitudes between 6.5 and 7.5, and having strike-slip, oblique, or thrust fault mechanisms. The selection criteria used to choose the set of recordings used in the fragility analyses does not insure that these criteria are met. If all magnitudes and distances within the specified ranges are considered equally likely, and if a specific mix of fault types is desired (e.g., 60-35-5 percent weighting of strike-slip/oblique/thrust faulting), then the recordings have not been properly scaled to meet these criteria. Two questions come to mind. First, why wasn't the time series modified to represent a target spectrum (e.g., the site-specific spectrum) as in the SSI analyses? Such a modification bypasses the need for scaling and would insure consistent and proper spectral shapes. PG&E should show that their approach has produced ground motions and spectral shapes that adequately represent the range of distances, magnitudes, and fault types specified above.

(4) Provide a summary similar to Table Q4-2 for the 25 time series used in the nonlinear analysis of the turbine building. Compare the mean and 84 percentile spectra with the spectra used in the other fragility analyses. Show that these ground motions and spectral shapes also adequately represent the range of distances, magnitudes, and fault types specified in the selection criteria.

(5) Compare the mean and 84 percentile empirical fragility spectra with the mean and 84 percentile numerical fragility spectra for each of the two fragility data sets referred to in (3) and (4).

(6) The large number of adjustments and weights applied to the statistical analysis of near-source recordings as part of the site-specific analyses is somewhat disconcerting. In order to assess the impact of these modifications, recompute the spectra using the following guidelines: (a) reduce the lower magnitude threshold for selecting ground motions to a moment magnitude of 6.0, (b) exclude soil sites (i.e., the Imperial Valley recordings), (c) do not use any weighting factors (i.e., assign each recording an equal weight of 1.0, (d) do not include adjustments for topography (e.g., the Pacoima Dam Recording), and (e) compare the mean and 84 percentile spectra developed using (a) through (d) with existing site-specific spectra (e.g., figs. Q4-1 and Q4-2).

QUESTION 6

(1) Provide tables similar to Tables Q6-1 through Q6-3 and figures similar to Fig. Q6-1 for each subset of the LTSP data base used to develop attenuation relationships and those parameters that were constrained in the regression analyses. These subsets should include those used in Steps (1) through (3) and in the analyses of ln Sa/a described in Question 8.

QUESTION 8

(1) Some critical close-in recordings used in the regression analyses were down-weighted according to weights described in the discussion of the fragility analyses. Repeat all regression analyses setting these weights to 1.0 and compare the results with those obtained previously. Were weights also used to give each earthquake equal weight in each of a number of distance intervals as has been done in the past? If so, explain the procedure for weighting. If not, why was this practice abandoned?

(2) Show plots of the relationships and the data used for all analyses described in Step (1). How were these results used to constrain C(M)? How was the C=18.5 value established from the analysis of M=6.5 data used to constrain C(M) in Steps (2) and (3)?

(3) I seriously question the validity of using so few data to establish the attenuation relationship for earthquakes of M=6.5 and greater in Step (2). The selection of data recorded on rock from M=6.5 and larger earthquakes having thrust-faulting mechanisms seems overly restrictive. Final judgement, however, will have to await review of the actual data used to develop the relationship. In the meantime, PG&E should demonstrate why they believe the restricted data set used to develop the attenuation relationship for M=6.5 and larger earthquakes is statistically adequate.

(4) The regression analysis used to develop the attenuation relationship for M < 6.5 earthquakes in Step (3) is based on data whose distance measure is primarily based on hypocentral distance. This difference

in distance measure from that used in the M = 6.5 and greater analyses is probably responsible for the abrupt change in the magnitude-scaling properties of PGA at close distances below M = 6.5. Although the attenuation relationship for M < 6.5 earthquakes, because of its independence, will not effect the estimation of ground motions for M > 6.5 earthquakes, it is important to recognize that this change in distance measure must be taken into account when using these attenuation relationships (e.g., in the seismic hazard analyses). It is extremely important that the seismic hazard analysis used point sources and hypocentral distances when estimating ground motions for M < 6.5 earthquakes. If not, probabilistic ground motions will tend to be underestimated. This point will have to await the review of the seismic hazard analyses.

(5) Document the basis for the magnitude-dependent standard error developed in Step (3).

(6) Show and describe all analyses (including the data bases) used to determine the style of faulting factors derived from both the empirical and numerical LTSP studies referred to in Table Q8-1.

(7) Show and describe all analyses (including the data bases) used to develop the term $(8.5\text{-}M)^{2.5}$ used in the analysis of ln Sa/a.

(8) Show results of smoothing (similar to Fig. Q8-12) for predictions of Sa for M = 7.2 and R = 4.5.

(9) I question the validity of a positive value for the coefficient C_2' (Table Q8-2 and Fig. Q8-14). Discuss why such a trend is justified both empirically and theoretically. Show plots similar to Fig. Q8-14 for all 14 periods.

(10) It appears that all fault types were used in the analysis of ln Sa/a without including a coefficient for fault type. Show that there is a statistical justification for neglecting fault type in these analyses (e.g., through hypothesis testing).

(11) How were potential embedment and SSI effects taken into account? Statistically show (e.g., through hypothesis testing) that the use of recordings from building basements and other embedded instruments and the use of recordings from large structures has not systematically biased the prediction of free-field ground motions.

(12) Statistically show (e.g., through hypothesis testing) that the use of recordings from hard-rock sites (i.e., crystalline rock, old sedimentary rock, and shallow soils over hard rock) has not biased the prediction of ground motions at soft-rock sites similar to Diablo Canyon.

QUESTION 9

(1) The basis for down-weighting certain recordings is extremely weak, in my opinion. Other investigators would have no doubt applied a totally different weighting scheme to these recordings. For example, I would have given recordings from the same earthquake equal weight with recordings from

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other earthquakes, and would have down-weighted recordings from soil sites because of the large uncertainty involved in correcting for site response. This concern has been addressed in my discussion of Question 4.

(2) Show a comparison of distance-scaling properties of PGA for the attenuation relationships listed in Fig. Q9-1 for magnitudes of 6.0, 6.25, 6.5, 7.0, 7.2 and 7.5. Update these relationships to include my 1988 attenuation relationships. Be sure to correct for any differences in the definitions of magnitude and distance.

(3) Repeat (2) for Sa at all 14 periods used to develop attenuation relationships. Use attenuation relationships for Sa or PSRV (which can be converted to Sa) available in the literature, including my 1988 relationships.

(4) It is my opinion that the form of the correction factor used to modify soil recordings (Fig. Q9-3) is highly influenced by hard-rock sites. This contributes to my uneasiness in using such a generalized correction factor to model what we know to be highly site-specific site response characteristics. My questions concerning the use of this correction factor is addressed elsewhere.

(5) The differences in the Nahanni and California spectra shown in Figs. Q9-4 and Q9-5 can be explained in part by simple differences between hard-rock ground motions (e.g., Nahanni) and soft-rock ground motions (e.g., California). This, of course, is closely related to differences in f_{max}. Such differences are generally thought to be due to differences in attenuation in the crust beneath the recording site. Therefore, I find it hard to accept a justification for down-weighting the Nahanni recordings because of their apparent enrichment in high frequencies when similar hard-rock sites from California have been used in all phases of the empirical analyses without consideration as to whether they have similar properties.

QUESTION 11

(1) The data base used to develop the attenuation relationship for earthquakes of M = 6.5 and larger is extremely small for such empirical analyses. Therefore, I question the statistical significance of the saturation properties of this relationship. My own analyses show that such properties exist, but they are based on a much larger data base. Would the property of saturation remain if the data base were expanded to include smaller earthquakes (e.g., down to M = 5.0 as used in my own analyses)?

QUESTION 12

(1) PG&E admits that their numerical spectra are deficient for frequencies less than about 3 Hz for a variety of reasons. However, I question the appropriateness of the numerical spectra at high frequencies as well. For example, the recordings of the Coalinga and Imperial Valley aftershocks used as empirical source functions have been recorded in highly attenuative regions; Kappa in these regions are some of the highest determined for California and are certainly higher than those for rock sites as determined by Anderson and Hough (1984). My concern is that this has resulted

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in empirical source functions that are deficient in high-frequency energy, resulting in a deficiency in the high-frequency ground motions computed at Diablo Canyon. Show that the highly attenuative recordings used as source functions is appropriate for Diablo Canyon and that they have not resulted in an underestimation of high-frequency ground motions.

QUESTION 13g

(1) Some investigators believe that stress drops are higher for oblique and thrust faulting earthquakes than for strike-slip earthquakes, yet PG&E used a constant stress drop of 50 bars for all fault types. Had they used higher stress drops for their oblique and thrust faulting scenarios, they would have obtained higher ground motions for these two scenarios. Review the literature on potential differences in stress drop due to region, stress regime, and fault type and justify why a constant stress drop of 50 bars is appropriate for all three styles of faulting.

QUESTION 17a

(1) I am concerned about the lack of directivity in PGA demonstrated by Fig. Q17a-3. My concern is that the randomness in rupture times imposed in the numerical simulations has removed the potential effects of directivity. However, since PGA is not as sensitive to directivity as are longer-period components of ground motion, the presence or lack of directivity is better determined by inspection of response spectra. Produce figures similar to Fig. Q17a-3 for PGA, PGV, and Sa for all 14 periods used to develop the site-specific spectra for (a) each style of faulting, and (b) each empirical source function.

QUESTION 17c

(1) I question whether the selected horizontal to vertical spectral ratio (Fig. Q17c-1) used to develop vertical response spectra (Fig. Q17c-2) is appropriate for M = 7.2 and R = 4.5. Repeat the empirical analyses of ground motions used to develop horizontal spectra for PGA and vertical response spectra and compare the results to the vertical site-specific spectra developed using Fig. Q17c-1.

QUESTION 18

(1) In comparing the response spectra from the unilateral and bilateral rupture configurations, I do not see any significant differences due to directivity. This concern has been raised with respect to Question 17a and can best be addressed there.