Lettis Consultants International, Inc.
EARTH SCIENCE CONSULTANTS

CE&G
CAL ENGINEERING & GEOLOGY

April 9, 2015

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RE: Revised Landslide Displacement Estimated for the Penitencia Delivery Main and Penitencia Force Main Seismic Retrofit Project, San Jose, California: Technical Memorandum

Dear Mr. Baune:

Lettis Consultants International, Inc. (LCI) and Cal Engineering & Geology, Inc. (CE&G) are pleased to submit this technical memorandum that provides revised landslide displacement estimates for the design phase of the Santa Clara Valley Water District's (District) Penitencia Delivery Main and Penitencia Force Main Seismic Retrofit Project (the “Project”). The scope of work for this activity is based on our correspondence with you, the District, and DWR; and on our understanding of the changes to the recently updated national seismic hazard map (NSHM) (Petersen et al., 2014). This scope of work is a collaborative effort between LCI and CE&G and thus, we have developed this joint draft technical memorandum.

1.0 INTRODUCTION AND PURPOSE

The purpose of this recent effort is to update LCI/CE&G’s (2014) previously reported estimates of seismically-induced landslide displacements by incorporating new information from the 2014 national seismic hazard map (NSHM) developed by the U.S. Geological Survey (USGS) (Petersen et al., 2014). Based on a review of Peterson et al. (2014), the estimated hazard at the Penitencia Water Treatment Plan (PWTP) and in the Project region has increased in comparison to the earlier 2008 USGS PSHA (Petersen et al., 2008) that was used as input to the analysis presented in the LCI/CE&G (2014) technical memorandum. As a result of the potential increase in strong ground shaking hazard, LCI and CE&G recommended that the project team conduct an additional phase of work to evaluate the impact of these larger ground motions on seismically-induced landslide displacement estimates previously presented in the LCI/CE&G (2014) technical memorandum. The latest evaluation summarizes the results of LCI/CE&G (2014) and provides supplemental (updated) information on the revised seismically-induced landslide displacements developed from Peterson et al. (2014).

1.1 SCOPE OF WORK

The scope of work for the supplemental evaluation of potentially increased ground motions for the project site included four tasks:

- Task 1 - Review the 2014 USGS National Seismic Hazard Map and engage in discussions with the USGS, the Carollo design team, the District, and California Department of Water Resources (DWR) technical representatives;
- Task 2 - Select and scale additional earthquake acceleration time histories based on the results of Task 1;
- Task 3 - Re-evaluate the Newmark landslide deformation analysis by incorporating the updated time histories; and
- Task 4 - Prepare a technical memorandum to summarize the results of the updated evaluation.

- A more detailed description of each of these tasks is discussed below.

Task 1 – Review of the 2014 National Seismic Hazard Map (NSHM) and Discussions with Project and Government Representatives

Task 1 included further review and analysis of the 2014 national seismic hazard map (Petersen et al., 2014), coupled with discussions with the U.S. Geological Survey (USGS). As part of this task, LCI and DWR staff (Don Hoirup) contacted USGS personnel (Dr. Peter Powers) and requested site-specific PSHA results for the Project site. The USGS provided the team site-specific results including horizontal uniform hazard response spectra (UHRS) and deaggregation information at a probability of exceedance of 5% in 50 yrs (975 yr return period) (email correspondence with Dr. Powers, dated December 5, 2014). These results are summarized in Section 2.0 and are provided as part of Appendix A (digital appendix).

Task 2 – Selection and Scaling of Earthquake Time Histories

Based on the 2014 NSHM results provided by the USGS, LCI developed parameters for the selection and scaling of earthquake time histories to be incorporated into the LCI/GE&G (2014) landslide seismic displacement model. A suite of 15 time history pairs (30 records total) were selected from the PEER Strong Motion Database (http://peer.berkeley.edu/peer_ground_motion_database/). The time histories were scaled to closely match the 5% in 50 years UHRS provided by the USGS (Task 1). The time history selection approach and results are discussed further in Section 2.0.

Task 3 – Landslide Displacement Analysis

Using the NSHM (2014) scaled time histories, CE&G re-evaluated the landslide displacement model developed previously by LCI/CE&G (2014) to develop revised estimates for the magnitude of seismically induced landslide movement. CE&G also plotted a mesh of displacement to characterize the relative displacement along the ground surface. The results of these analyses are discussed in Section 3.0.

Task 4 – Preparation of a Technical Memorandum

Based on the results of Tasks 1 through 3, LCI and CE&G developed this technical memorandum to summarize the results of this latest effort. The memorandum includes: (1) a summary of the 2014 NSHM of Petersen et al. (2014) and the UCERF 3.0 model (Field et al., 2013), (2) rationale for selecting and scaling the time-histories, and (3) a summary of the results of the updated seismically-induced landslide displacements (including a revised estimate of the magnitude of displacement based on the updated USGS ground motions). This technical memorandum is focused on discussion of the national and state PSHA update, time history selection/scaling, and the landslide deformation analysis only. We have not revisited or updated other topics discussed in the LCI/CE&G (2014) technical memorandum that are not impacted by this study. This final technical memorandum includes responses to review comments provided by the Carollo, Degenkolb Engineers (Dr. Mahmoud Hachem), and the District.

2.0 UPDATED 2014 USGS GROUND MOTIONS

The following section discusses the changes between the previous (2008) and latest (Petersen et al., 2014) NHSM, results of the hazard deaggregation provided by the USGS, and the process of time history selection and scaling.

2.1 OVERVIEW OF THE 2014 NATIONAL SEISMIC HAZARD MAP AND UCERF 3.0

The USGS's release of the latest national seismic hazard map (Petersen et al., 2014) post-dated the analysis and completion of LCI/CE&G (2014), and represents an update to the 2008 national seismic hazard map that was used to calculate seismically induced displacements of the Penitencia Creek Landslide (referred to here after as the "Landslide") by LCI/CEG (2014). In particular, the Petersen et al. (2014) NSHM includes two key updates that contribute to a higher estimate of seismic hazard at the Project site: (1) a revised seismic source model for California; and (2) new ground motion prediction equations (GMPEs).

The latest 2014 NSHM includes a revised seismic source model for California (called the Uniform California Earthquake Rupture Forecast or UCERF 3.0) that was developed by the Working Group on California Earthquake Probabilities (WGCEP; Field et al., 2013). This revised seismic source model is significantly different than the previous UCERF 2.0 model developed by the 2008 WGCEP (Field et al. 2007). For example, the UCERF 3.0 model relaxed the fault-segmentation assumptions and as a result includes multi-fault ruptures (both of these were deemed limitations of the previous model [UCERF2]). The incorporation of multi-segment and multi-fault ruptures allows for larger earthquake magnitudes than previously considered in UCERF 2. Field et al. (2013) implemented these changes to eliminate "*the apparent UCERF2 overprediction of Mw6.5–Mw7 earthquake rates"* and to permit the *"inclusion of multifault ruptures similar to those recently observed in nature (for example, the 2002 Mw7.9 Denali, Alaska earthquake rupture, Schwartz and others, 2012)"* (p. 103).

The second major difference in the 2014 NSHM is the incorporation of the new ground motion prediction equations (GMPEs), called the Next Generation West 2 (NGA-West 2) (Abrahamson et al., 2014; Boore et al., 2014; Campbell and Bozorgnia, 2014; Idris, 2014). The new GMPEs include a larger earthquake database, changes in the median and standard deviations of each model, lower median motions for small magnitude events, and changes to the hanging wall terms.

In summary, the new UCERF 3.0 model imposes a direct impact on hazard at the Project site by: (1) the addition of the Southern Extension of the Hayward Fault (a seismic source which is within two kilometers of the Project site; the fault increased in length and comes closer to the project site than the UCERF 2 model), and (2) an increase in earthquake magnitude (up to **M** 8.25) for the Central Calaveras fault (Field et al., 2013), located 4.5 km to the northeast of the Project site. The larger event on the Calaveras fault represents a multi-segmented rupture.

2.2 2014 NSHM RESULTS FOR THE PENITENCIA WATER TREATMENT PLANT

As discussed above, Dr. Peter Powers at the USGS provided the project team with site-specific PSHA results including uniform horizontal response spectra (UHRS) and deaggregation information at a probability of exceedance of 5% in 50 yrs (975 yr return period) (Appendix A). These data include a series of deaggregation plots that illustrate the percent contribution of seismic sources based on magnitude and distance from the Project site (-121.834° W, 37.399° N) assuming a Vs30 value of 518 m/s (based on WWC [1993]; see LCI/CE&G, 2014 for further description). These results are summarized in Table 1. It is important to note, the project team was provided two sets of deaggregation results (named FM3-1 and FM 3-2) for 14 spectral periods (PGA to 5 sec). These two deaggregation results represent the hazard estimates from two separate fault models (FM3-1 and FM3-2). The UCERF 3.0 seismic source model uses two fault models with the intent to capture the uncertainty in UCERF-3.0's fault system location and geometry. According to Dr. Powers, due to the complexity of UCERF-3.0, the USGS is unable to summarize the deaggregated hazard results of the two fault models into one deaggregation summary at this time. Regardless, the overall results for each fault model are very similar, so an average deaggregated hazard was developed for the Project (Table 1). The deaggregation results indicate the controlling seismic source for the Project at a 5% in 50 yrs probability of exceedance is located approximately 4 km from the site and has dominant earthquake magnitudes ranging between 6.8 to 7.3 (Table 1; Appendix A). Based on the deaggregated distance of 4 km, the controlling seismic source is the Central Calaveras fault, which is located approximately 4.5 kilometers northeast of the Project site. The southern extension of the Hayward fault extension at 2 km is also a significant contributor to hazard at the Project site (Appendix A).

Using the results shown in Table 1, LCI developed a Uniform Horizontal Response Spectrum (UHRS) for the 2014 results. Figure 1 illustrates the new 2014 UHRS results with respect to the 2008 UHRS results on a log-log plot. In general, the strong ground shaking hazard increased at the site uniformly by 30 to 40% at most spectral periods. For example, peak ground acceleration (PGA) increased from 0.84 g to 1.15-1.17 g. The increase in hazard is likely due to one or more of the following: the addition of the Southern Extension of the Hayward fault, the increase in earthquake magnitude on the Central Calaveras fault, and the use of the revised NGA-West 2 GMPEs.

2.3 TIME HISTORY SELECTION AND SCALING TO THE 2014 UHRS

Based on the 2014 NSHM results (Table 1 and Figure 1), LCI developed parameters for the selection and scaling of earthquake time histories used for input into the landslide seismic displacement model developed during the planning study phase by CE&G. The resulting suite of records was selected to reflect the intensity of shaking represented by the updated UHRS over a range of periods, as well as generally agree with seismological characteristics obtained from the deaggregated hazard.

All time histories were downloaded from the PEER NGAWest2 earthquake time history database. Specific records were selected based primarily on magnitude, distance, and spectral shape over the period range of interest. The UHRS was used to match the overall spectral shape of the candidate time histories, as well as the deaggregated magnitude and distance (~M 7 at 4 km) at intervals of half magnitude ranging from M 6.75 to 7.25. The spectral period range of interest for time history selection was based on an estimated period of the slide of 0.75 second (developed following procedures recommended in Blake et al. [2002]). To account for uncertainty in landslide period, a range of 0.2 to 1.5 times the landslide period was considered. This period range was rounded off to cover a factor of 10 from 0.12 to 1.2 seconds. All other seismological parameters of the time histories were considered secondary, as the combination of energy in the ground motion coupled with site effects, duration, directivity, and other characteristics is largely reflected in the response spectrum.

Based on discussions with the project team (including LCI, CE&G, Degenkolb, and Carollo), it was decided that 15 time history pairs of horizontal components with common scale factors would be sufficient to characterize the range of potential landslide displacements (Table 2). Due to the low mean deaggregated distance and proximity to the Calaveras fault, pulse-like characteristics were also considered following guidance from Hayden et al. (2014). Time history selection was split into two parts: pulse-like records and non-pulse-like records. The number of pulse-like records (11 of the 15 pairs, 72%) was determined from the deaggregated distance and acceleration epsilon at 0.75 second at the 5% in 50 year hazard level using the empirical equation from Hayden et al. (2014). Because this empirical relationship requires so many of the records to be pulse records, the pool of ground motions reflecting all seismological characteristics is quite limited. Three times as many records were obtained from the PEER database as were needed, and the selection was refined afterward. Refinement included rotating pulse-like records to fault normal (FN) and fault parallel (FP) if not already done, rescaling the records such that they had a good fit on average to the target spectrum with the least possible spectral variability (considering the geometric mean spectra, not the individual components, since scale factors were equal for each component), limiting (to the extent possible) multiple records from common events, and ensuring representation of a range of pulse periods. In the case of the pulse-like records, the magnitude bands had to be widened to a range from M 6.5 to 7.5 to achieve satisfactory spectral shapes. Similarly, more non-pulse-like records were obtained than were needed and refined afterward. However, no rotation was performed for these records.

The target spectrum for selection is a UHRS, not a scenario spectrum corresponding to a given magnitude, distance, site conditions, etc. Therefore, some seismological characteristics of the records must be relaxed, since it is not possible to satisfy the deaggregated scenario and site-specific characteristics as well as have spectra that agree with the UHRS shape over a broad range of periods. To find a suite of time histories that match the overall spectral shape of the UHRS (and containing pulses), it was necessary to broaden the acceptable range of site classification (i.e., shear wave velocity) and earthquake mechanism (strike slip and reverse). As a first pass, records were filtered based on site seismic velocity (i.e. Vs30 or the average shear wave velocity in the first 30 m of subsoil) with the intention to best match the site characteristics beneath the Landslide (approximately 518 m/s based on WWC, 1993). However, the resulting records with similar site velocities had a poor fit to the target spectrum. Thus, the site seismic velocity criterion was relaxed because the response spectrum is considered of primary importance in the time history selection process. Similarly, the earthquake mechanism parameter was relaxed to increase the pool of time histories that match the target spectrum.

The resulting suite of 15 time histories is provided in Table 2. The selected time histories include a range of earthquake magnitudes of 6.53 to 7.35 with durations of shaking that range between 6 and 38.2 seconds

(5-95%). The group of selected time histories includes both strike-slip and reverse mechanism earthquake records from the 1971 San Fernando, 1978 Tabas, 1940 and 1979 Imperial Valley, 1989 Loma Prieta, 1994 Northridge, 1999 Duzce, 2010 Darfield, and 2010 El Mayor-Cucapah earthquakes. For the pulse records, a range of pulse periods that include a few < 1 second (e.g., near the estimated period of the slide) were considered. The group of selected time histories includes a wide range of site seismic velocities between 211 to 2016 meters per second.

Figures 2 and 3 illustrate the scaled time histories and the variability about the target UHRS spectrum. The geometric mean of the suite of time histories (labeled as "Suite geomean") matches the target spectrum well. In Figure 2, the individual lines are the geometric mean spectra of each pair, given that it was desired to use pairs of time histories with a common scale factor. Figure 3 illustrates the spectral variability represented by individual components about the target spectrum, which is larger than shown on Figure 2 due to averaging of the components and the polarity of some of the motions after rotating pulse-like records to fault-normal and fault-parallel directions.

3.0 LANDSLIDE DISPLACEMENTS

Based on the selected scaled time history pairs (Table 2), CE&G input the 15 time history pairs (30 records total) into the existing Landslide Newmark model (LCI/CE&G, 2014) to develop revised landslide displacement estimates. The results are summarized in Table 3. Appendix B contains plots of each scaled time history and deformation versus time diagrams. The overall range of displacements is between 0.18 and 24.6 m (0.6 to 81 ft) as shown graphically in the histogram of Figure 4. This plot indicates that the bulk (83%) of the calculated displacements are less than 5 meters (16.4 ft) (25 total) and the peak of the distribution is less than 1 meter (<3.2 ft). Figure 5 shows record duration (5-95%) vs. displacement and in general suggests a strong relationship between these variables. Figure 6 illustrates the correlation between log responses and log spectral acceleration over a range of periods. High correlation for longer periods indicates that although the time histories have been scaled to agree well with the target UHRS over the range of periods indicated in Section 2, long period energy has a strong influence over displacement. Figure 7 shows this relationship directly for a period of 5 seconds. Due to this relationship, it is important that the long period energy also agree well with the target spectrum, on average, to avoid a bias in displacement. Figures 2 and 3 confirm that long period spectral accelerations of the selected suite are representative of target intensity levels, on average.

The displacements are approximately lognormally distributed (Figure 4); therefore, it was considered appropriate to approximate the average Newmark displacement using the geometric mean of the 30 displacement estimates (as opposed to the arithmetic mean). This yields a median displacement of 2.05 meters (6.7 ft) (note that the geometric mean of a lognormally distributed variable is equivalent to the median). It is important to emphasize that this design displacement value was estimated using a statistical approach and professional judgement. Therefore, the geometric mean of 2.05 m (6.7 ft) should not be thought of as an upper bound that cannot be surpassed.

Despite matching the target spectrum rather well in an average sense, there is still a good deal of response variability (coefficient of variation is ~1+). This is due to the relatively large variability of response spectra at longer periods, as observed in Figure 3, and their strong relationship with displacement, as observed in Figure 7. However, because the median response spectrum of the selected suite at longer periods is consistent with the target response spectrum, it is reasonable to conclude that the resulting median displacement is also consistent with the target spectrum.

As described above, each of the earthquake time histories used for analysis is comprised of two orthogonal horizontal components, and each of the pulse-like records is oriented to FN/FP. The FN orientation coincides more directly with the orientation of the landslide model. The geometric mean of the estimated displacements increases or decreases by less than 10% if only the FN or FP components from the eleven pulse-like records are used (in addition to a single component of the four non-pulse-like records). However, the intensities of the FN and FP components (as represented by the geometric mean response spectra) are very similar to the target UHRS when considered separately (Figures 8 and 9), making it possible that these increases/decreases are at least in part due to the large variability and smaller sample size. Thus, we believe that both the FN and FP components represent reasonable records for input into the existing Landslide Newmark Model, and that the calculated median displacement of 2.05 meters using all components of motion is a reasonable, hazard-consistent estimate of the response of the landslide at the 5% in 50 year level. This results in a Newmark displacement roughly 50% higher than previously calculated.

Following completion of the revised Newmark displacement analysis, CE&G also completed a more detailed evaluation of the resulting finite element results to improve the interpretation of the distribution of the estimated Newmark displacement along the length of the landslide. The evaluation consisted of estimating the relative displacement of finite element nodes along the ground surface and along the failure plane. As previously noted in our 24 June 2014 report, the occurrence of less displacement at the toe is consistent with distribution of displacement typically observed for landslides that exhibit large deformation at the crown due to extensional forces and significantly less deformation at the toe area where compressional forces dominate. However, the evaluation also indicates that there is a substantial increase in displacement at the toe relative to the Finished Water Meter Vault ("Meter Vault"). As a result of this additional evaluation, CE&G has determined that the relative displacement at the toe should be considered to be approximately 115% of the calculated Newmark displacement (i.e. 115% of 2.05 m or 6.7 ft) rather than the 130% recommended previously in LCI/CE&G (2014). Additionally, the evaluation of relative displacement suggests that differential movement between the Meter Vault and the Penvault would result in extension of the pipe and that the amount of extension could be as high as two-thirds of the calculated Newmark displacement.

As a result of the revised displacement analysis and displacement distribution evaluation, it is now recommended that a seismically induced displacement of 2.35 m (7.7 feet = 6.7 ft x 115%) be used for the toe area of the Landslide and approximately 0.78 m (2.2 feet = 6.7 ft x 33%) be used for the Meter Vault area. The displacements between the overflow bypass structure and the Meter Vault can be linearly interpolated.

3.1 ESTIMATED TOTAL DISPLACEMENT OVER 50 YEARS

The estimated total displacement over a 50 year period can be determined by summing the estimated creep-related displacements from our 24 June 2014 report with the estimated displacement resulting from the design ground motions. At the toe of the landslide, the new revised total displacement is 9.4 feet (7.7 ft seismic + 1.7 ft creep). This displacement estimate represent an approximate 22% increase from the previously estimated 7.4 ft of total displacement derived from the NSHM (2008; UCERF 2 Model) and referenced in LCI/CE&G (2014). A total displacement of approximately 3.1 feet (9.4 x 33%) should be used for the Meter Vault location, which results in approximately 6.3 ft of distributed extension between the Meter Vault and the Landslide toe.

4.0 SUMMARY OF FINDINGS

The findings of this effort to update LCI/CE&G's (2014) previously reported estimates of seismically-induced Landslide displacements include the following:

(1) The 2014 USGS hazard results suggest that the estimate of strong ground shaking hazard at the Project site has increased 30 to 40% at most spectral periods (Figure 1);
(2) The total range of estimated landslide Newmark displacements is between 0.18 and 24.6 m (0.6 to 81 feet) based on the 15 time history pairs (Table 3);
(3) The peak of the overall displacement distribution is less than 1 meter (Figure 4);
(4) The estimated geometric mean displacement is 2.05 meters (6.7 feet);
(5) Displacements at the Landslide toe estimated from our interpretation of the Newmark displacement analyses is 2.35 m (7.7 feet);
(6) The total average displacement deformation at the Landslide toe is estimated to be about 9.4 feet (7.7 feet from seismic displacement and 1.7 feet from creep over a 50 yrs period);
(7) The design displacement may occur over a small distance (i.e. <5 ft or up to 150ft wide) at the toe of the Landslide; and
(8) Differential movement of the landside will also result in extension between the Meter Vault and the Penvault (up to 6.3 ft).

The new revised total displacement(s) represent an increase of about 22% over that estimated from the NSHM (2008; UCERF 2 Model) and referenced in LCI/CE&G (2014).

In conclusion, the findings of this memorandum and the revised displacement estimates contained herein should be considered in the design of the Penitencia Delivery Main and Force Main Retrofit project over the LCI/CE&G (2014) findings, which were developed using now outdated GMPE's and seismic source model.

5.0 LIMITATIONS AND CONSIDERATIONS

There are several limitations and consideration that should be noted. First, the analysis contained herein estimated a range of seismically induced displacements for a single moderate to large magnitude earthquake on nearby active faults based on the USGS deaggregation results for UCERF 3.0. Additional landslide displacements may be triggered by multiple earthquakes, foreshocks and/or aftershocks during the design life of the project. These events could precede or follow a mainshock event by hours, days, or weeks. Second, it is important to reiterate that the design displacement value was estimated using a statistical approach and professional judgement. Thus, this median value (6.7 ft) does not necessarily represent an upper bound. Third, seismic hazard and earthquake engineering is a dynamic and rapidly evolving field and thus, the District and/or their consultants (e.g. LCI and CE&G) should review new information (e.g. inclinometer data) or new studies as it becomes available to evaluate whether this new information impacts the design and/or operation of Project pipelines as currently planned. For example, after an earthquake occurs the resulting landslide displacement measurements from inclinometers could be compared to the Newmark model results, discussed herein, to evaluate the performance of the Project pipelines.

6.0 CLOSING

Lettis Consultants International, Inc. and Cal Engineering & Geology, Inc. appreciate the opportunity to work on this exciting project. Should you have any questions or like to discuss this technical memorandum, please contact us at your convenience.

Sincerely,

Lettis Consultants International, Inc.

and

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Table 1. 2014 USGS Deaggregation Results for the Penitencia Water Treatment Plant

FM 3-1 Deaggregation					
T (sec)	RP	Sa(g)	M	R	E
0	975	1.16	6.9	3.91	1.53
0.05	975	1.54	6.86	3.99	1.54
0.1	975	2.26	6.82	4.17	1.58
0.2	975	2.8	6.89	4.03	1.54
0.3	975	2.59	6.92	3.99	1.47
0.4	975	2.27	6.95	3.96	1.44
0.5	975	1.98	6.97	4	1.42
0.75	975	1.44	6.99	4.09	1.4
1	975	1.11	7.02	4.11	1.39
1.5	975	0.684	7.08	4.46	1.36
2	975	0.482	7.12	4.79	1.35
3	975	0.302	7.2	5.46	1.31
4	975	0.208	7.28	6.73	1.31
5	975	0.162	7.35	8.17	1.34

FM 3-2 Deaggregation					
T (sec)	RP	Sa(g)	M	R	E
0	975	1.1546	6.9052	3.9265	1.5125
0.05	975	1.5281	6.8644	4.0037	1.5269
0.1	975	2.2476	6.8303	4.1928	1.5681
0.2	975	2.7796	6.8953	4.0503	1.5222
0.3	975	2.5666	6.9263	4.0148	1.4616
0.4	975	2.2553	6.9538	3.978	1.4308
0.5	975	1.9694	6.9753	4.0288	1.4089
0.75	975	1.4269	7.0031	4.1181	1.3912
1	975	1.0986	7.0303	4.1426	1.3806
1.5	975	0.6798	7.0874	4.5029	1.3516
2	975	0.4792	7.1282	4.8417	1.3453
3	975	0.3004	7.2013	5.5162	1.3045
4	975	0.2077	7.2844	6.7873	1.3039
5	975	0.1612	7.3506	8.2417	1.3348

Average of each hazard and deaggregation from USGS					
T (sec)	RP	Sa(g)	M	R	E
0	975	1.1573	6.9026	3.91825	1.52125
0.05	975	1.5341	6.8622	3.99685	1.53345
0.1	975	2.2538	6.82515	4.1814	1.57405
0.2	975	2.7898	6.89265	4.04015	1.5311
0.3	975	2.5783	6.92315	4.0024	1.4658
0.4	975	2.2627	6.9519	3.969	1.4354
0.5	975	1.9747	6.97265	4.0144	1.41445
0.75	975	1.4335	6.99655	4.10405	1.3956
1	975	1.1043	7.02515	4.1263	1.3853
1.5	975	0.6819	7.0837	4.48145	1.3558
2	975	0.4806	7.1241	4.81585	1.34765
3	975	0.3012	7.20065	5.4881	1.30725
4	975	0.2079	7.2822	6.75865	1.30695
5	975	0.1616	7.3503	8.20585	1.3374

Target spectrum for selection:	
T (sec)	Sa(g)
0.01	1.157
0.05	1.534
0.1	2.254
0.2	2.790
0.3	2.578
0.4	2.263
0.5	1.975
0.75	1.433
1	1.104
1.5	0.682
2	0.481
3	0.301
4	0.208
5	0.162

RP - Rupture Probability or return period; Sa (g) - Spectral Acceleration in gravity;
M - magnitude; R - Distance in km to source; E – epsilon

Table 2. Selected time history pairs from the Peer NGA 2 West Database.

	Record Sequence Number from PEER database	Scale Factor	Strike Azimuth (deg)	H1 Azimuth (deg)	Rotation (deg)	Tp-Pulse Period (sec)	5-75% Duration (sec)	5-95% Duration (sec)	Arias Intensity (m/sec)	Earthquake Name	Year	Station Name	Magnitude	Mechanism	Rjb (km)	Rrup (km)	Vs30 (m/sec)	Lowest Useable Frequency (Hz)	Horizontal-1 Acc. Filename	Horizontal-2 Acc. Filename
Pulse-like																				
1	77	1.451	288	164	-214	1.638	5.8	7.3	8.9	"San Fernando"	1971	"Pacoima Dam (upper left abut)"	6.61	Reverse	0	1.81	2016.13	0.0875	SFERN_PUL164.AT2	SFERN_PUL254.AT2
2	143	1.158	330	74	-346	6.188	8.3	16.5	11.8	"Tabas	1978	"Tabas"	7.35	Reverse	1.79	2.05	766.77	0.125	TABAS_TAB-L1.AT2	TABAS_TAB-T1.AT2
3	178	4.175	323	140	-273	4.501	5.1	14.1	1.2	"Imperial Valley-06"	1979	"El Centro Array #3"	6.53	strike slip	10.79	12.85	162.94	0.0625	IMPVALL.H_H-E03140.AT2	IMPVALL.H_H-E03230.AT2
4	184	2.350	323	270	-143	6.265	3.7	7	2.1	"Imperial Valley-06"	1979	"El Centro Differential Array"	6.53	strike slip	5.09	5.09	202.26	0.02875	IMPVALL.H_H-EDA270.AT2	IMPVALL.H_H-EDA360.AT2
5	802	3.067	128	0	-218	4.571	4.1	9.4	1.5	"Loma Prieta"	1989	"Saratoga - Aloha Ave"	6.93	Reverse Oblique	7.58	8.5	380.89	0.125	LOMAP_STG000.AT2	LOMAP_STG090.AT2
6	1004	1.404	122	270	58	0.931	4.7	8.5	7	"Northridge-01"	1994	"LA - Sepulveda VA Hospital"	6.69	Reverse	0	8.44	380.06	0.182	NORTHR_SPV270.AT2	NORTHR_SPV360.AT2
7	1051	1.039	122	104	-108	0.84	3.8	6	8.7	"Northridge-01"	1994	"Pacoima Dam (upper left)"	6.69	Reverse	4.92	7.01	2016.13	0.16	NORTHR_PUL104.AT2	NORTHR_PUL194.AT2
8	1602	1.676	270	0	-360	0.882	2.6	9	3.7	"Duzce	1999	"Bolu"	7.14	strike slip	12.02	12.04	293.57	0.0625	DUZCE_BOL000.AT2	DUZCE_BOL090.AT2
9	6942	5.463	85.1	167	-8.1	8.043	11.3	29.3	0.8	"Darfield	2010	"NNBS North New Brighton School "	7	strike slip	26.76	26.76	211	0.05	DARFIELD_NNBSS13E.AT2	DARFIELD_NNBSS77W.AT2
10	6969	5.637	85.1	272	96.9	9.352	14.2	38.2	0.9	"Darfield	2010	"Styx Mill Transfer Station "	7	strike slip	20.86	20.86	247.5	0.05	DARFIELD_SMTCN88W.AT2	DARFIELD_SMTCS02W.AT2
11	8606	3.475	236	0	-326	7.084	10.1	25.3	1.9	"El Mayor-Cucapah	2010	"Westside Elementary School"	7.2	strike slip	10.31	11.44	242	0.05	SIERRA.MEX_CIWESHNN.AT2	SIERRA.MEX_CIWESHNE.AT2
Non-pulse-like																				
1	6	3.870	-	-	-	-	17.7	24.2	1.6	"Imperial Valley-02"	1940	"El Centro Array #9"	6.95	strike slip	6.09	6.09	213.44	0.25	IMPVALL.I_I-ELC180.AT2	IMPVALL.I_I-ELC270.AT2
2	1615	6.862	-	-	-	-	13.6	16.1	1	"Duzce	1999	"Lamont 1062"	7.14	strike slip	9.14	9.14	338	0.0625	DUZCE_1062-N.AT2	DUZCE_1062-E.AT2
3	5829	2.257	-	-	-	-	15.6	26.2	4.7	"El Mayor-Cucapah	2010	"RIITO"	7.2	strike slip	13.7	13.71	242.05	0.05	SIERRA.MEX_RII000.AT2	SIERRA.MEX_RII090.AT2
4	6961	7.366	-	-	-	-	13.2	20.3	0.5	"Darfield	2010	"RKAC"	7	strike slip	13.37	16.47	295.74	0.15	DARFIELD_RKACN14E.AT2	DARFIELD_RKACS76E.AT2

Table 3. Average Landslide movement calculated from individual time history records

Ground Motion Record	Deformation (m)
DARFIELD_NNBSS13E	8.81
DARFIELD_NNBSS77W	5.77
DARFIELD_RKACN14E	2.53
DARFIELD_RKACS76E	4.23
DARFIELD_SMTCN88W	24.6
DARFIELD_SMTCS02W	11.8
DUZCE_1062-E	0.86
DUZCE_1062-N	0.85
DUZCE_BOL000	1.06
DUZCE_BOL090	0.56
IMPVALL.H_H-E03140	3.46
IMPVALL.H_H-E03230	2.45
IMPVALL.H_H-EDA270	1.92
IMPVALL.H_H-EDA360	2.90
IMPVALL.I_I-ELC180	1.52
IMPVALL.I_I-ELC270	2.82
LOMAP_STG000	1.38
LOMAP_STG090	2.76
NORTHR_PUL104	0.33
NORTHR_PUL194	0.18
NORTHR_SPV270	0.75
NORTHR_SPV360	0.79
SFERN_PUL164	1.20
SFERN_PUL254	0.71
SIERRA.MEX_CIWESHNE	11.1
SIERRA.MEX_CIWESHNN	3.61
SIERRA.MEX_RII000	3.16
SIERRA.MEX_RII090	1.18
TABAS_TAB-L1	2.59
TABAS_TAB-T1	3.85

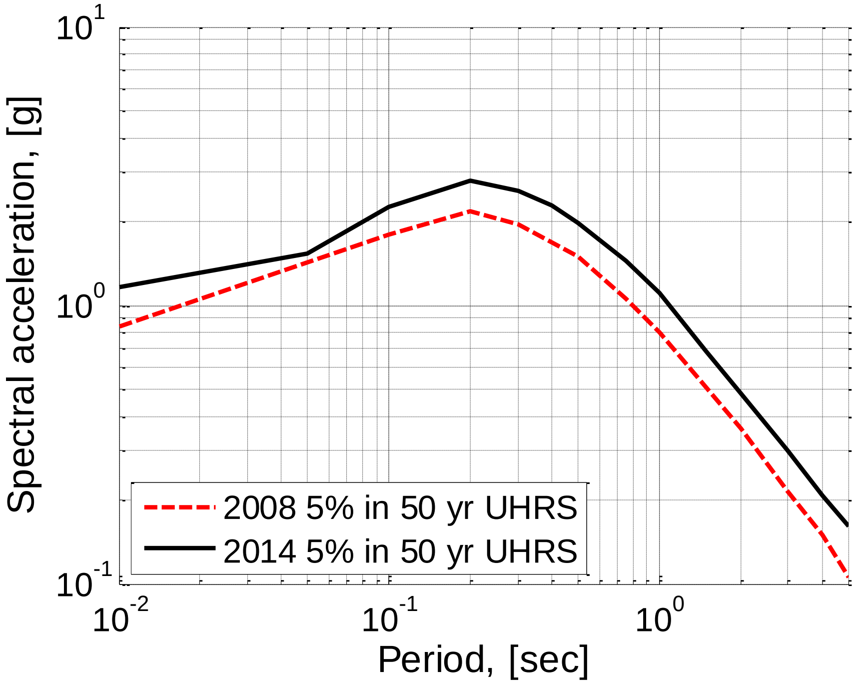

Figure 1: Response spectra for the Penitencia Water Treatment Plant from the USGS 2008 and 2014 seismic hazard models at a 5% in 50 year probability of exceedance(975 year return period).

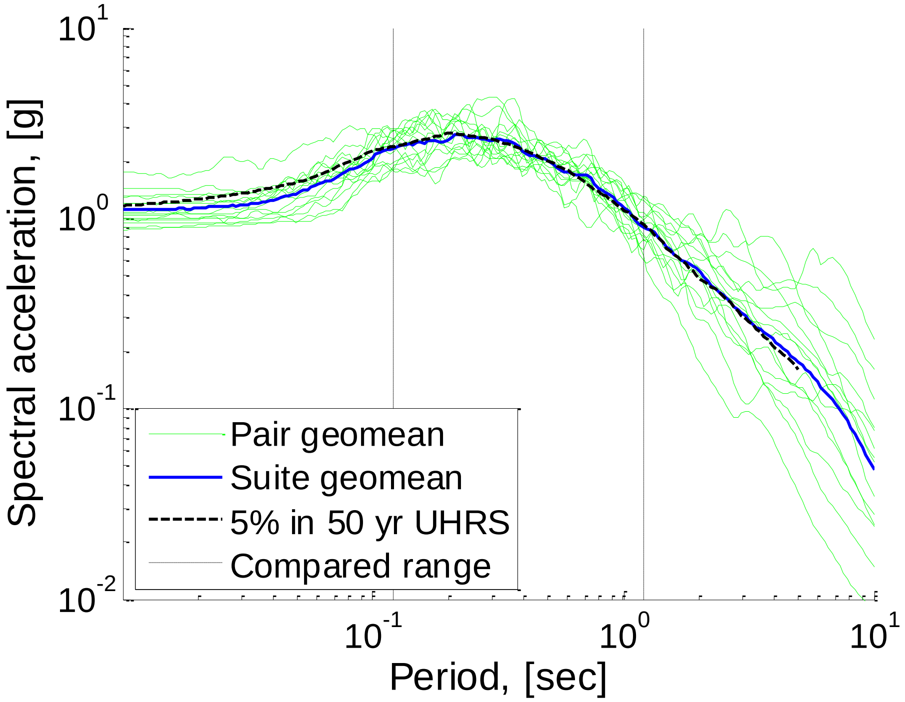

Figure 2: Scaled geometric mean spectra for each of the 15 records.

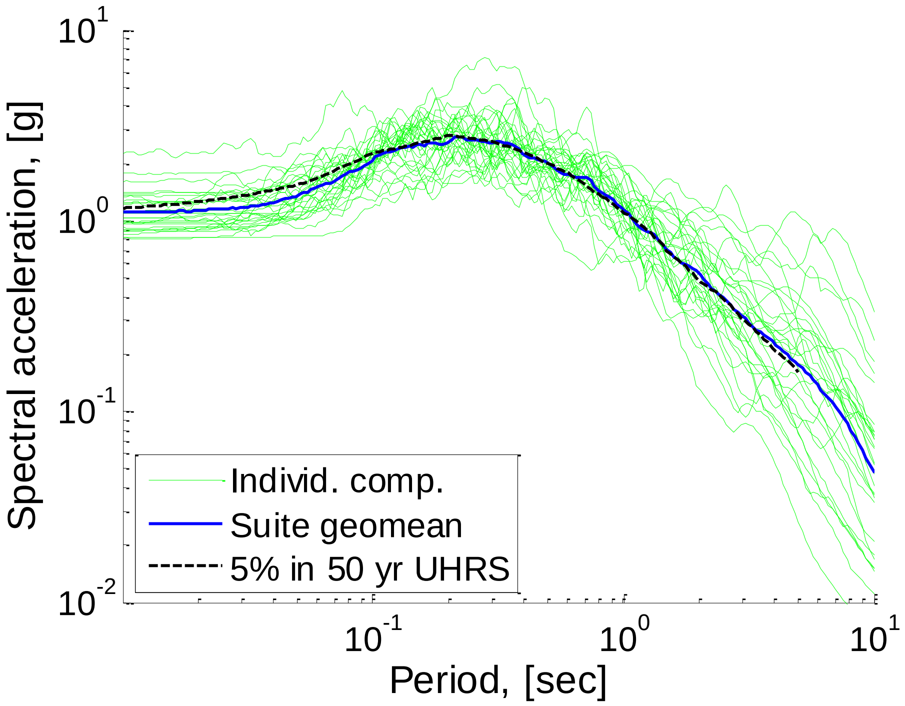

Figure 3: Scaled individual horizontal components of the 15 records.

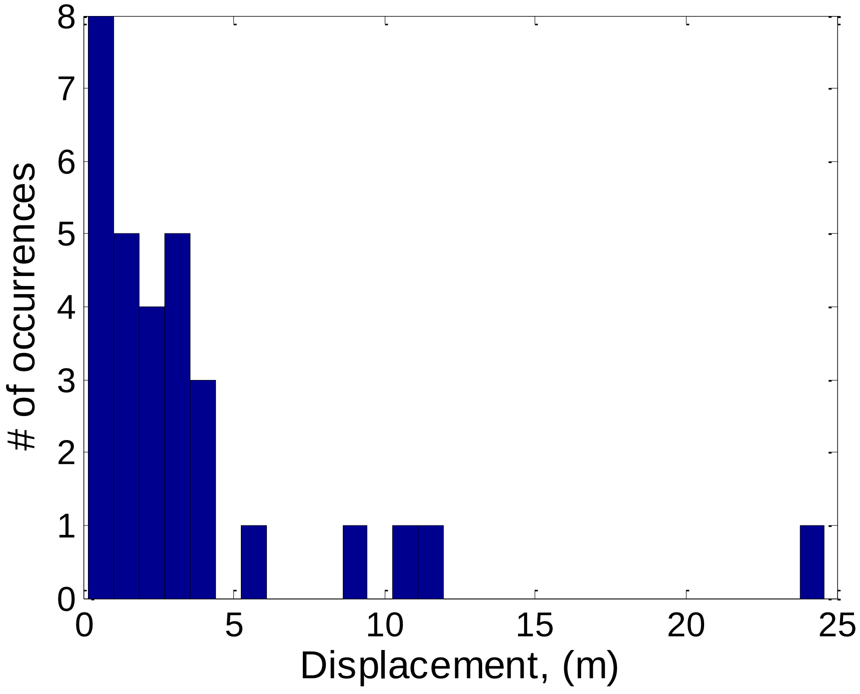

Figure 4. Histogram of estimated landslide displacements based on 30 input time histories.

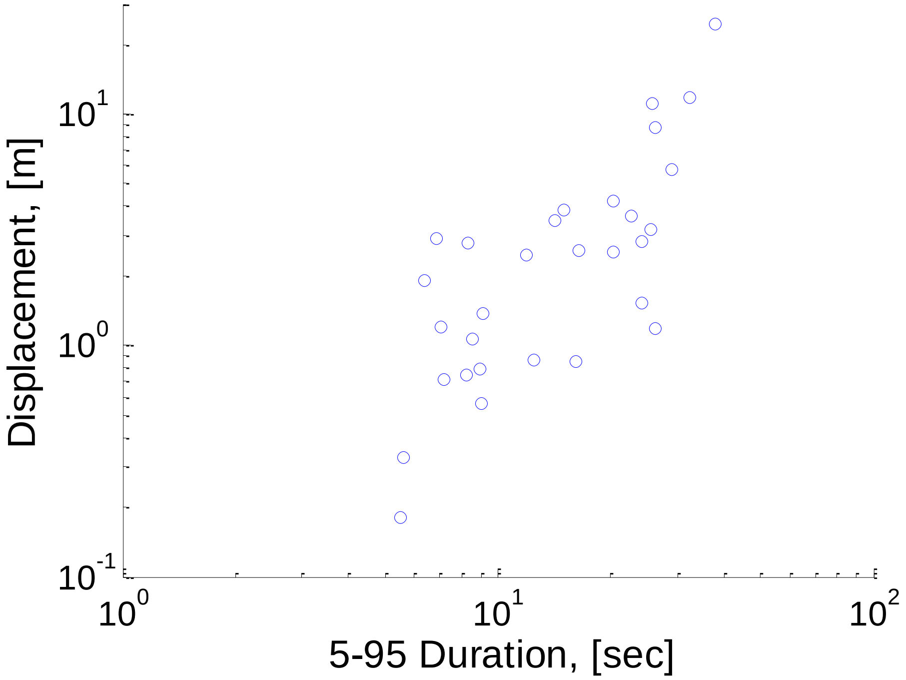

Figure 5. Response versus record duration (5-95%).

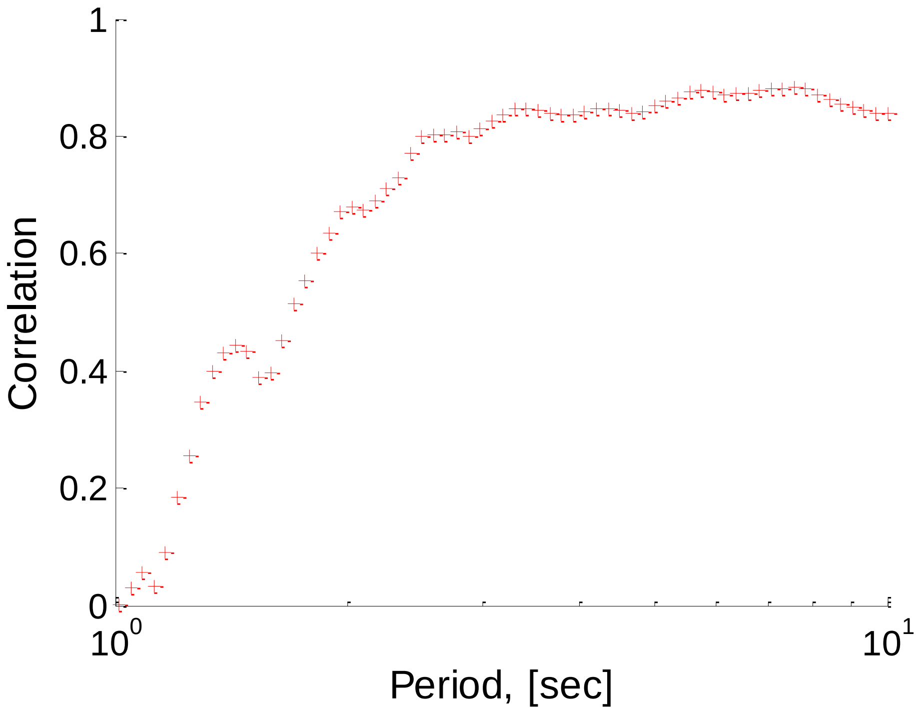

Figure 6: Correlation between log responses and log spectral acceleration over a range of periods.

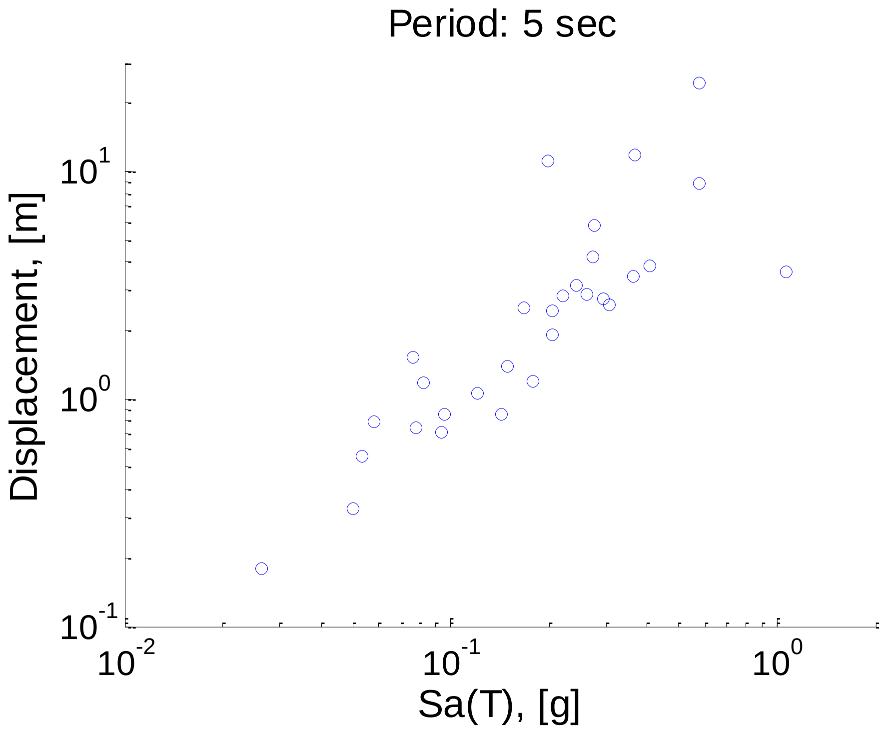

Figure 7: Response versus spectral acceleration at 5 seconds.

s

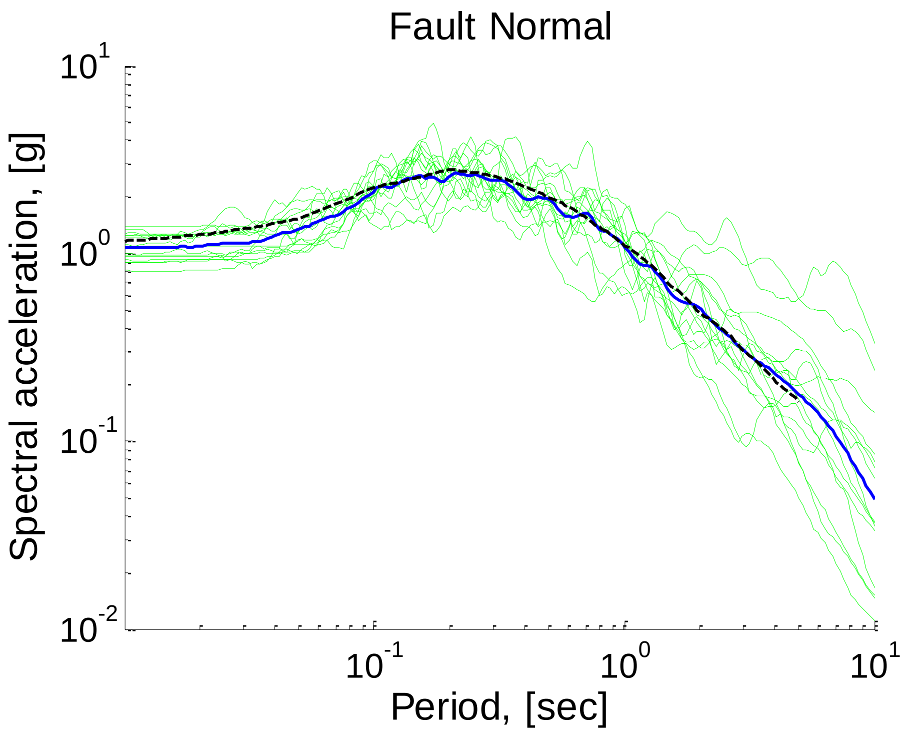

Figure 8: Response spectra of 11 fault-normal components from pulse-like records with 4 components from randomly oriented non-pulse-like records.

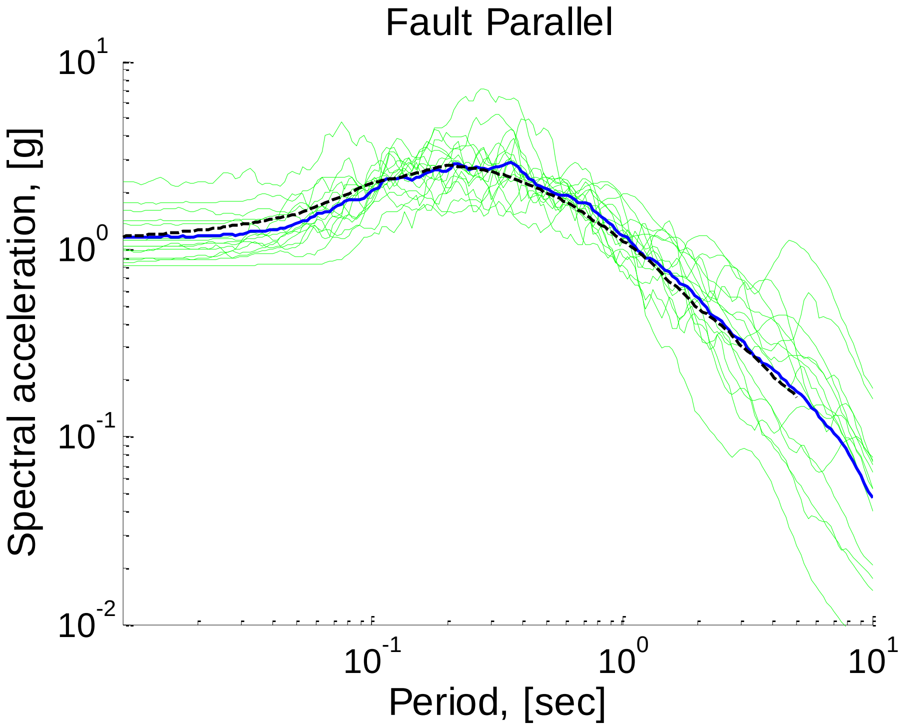

Figure 9: Response spectra of 11 fault-parallel components from pulse-like records with 4 components from randomly oriented non-pulse-like records.