Evaluation of SCEC Broadband Platform Phase 1 Ground Motion Simulation Results

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1. Executive Summary

The first validation phase of the SCEC Broadband Platform (BBP) was evaluated for the suitability of simulated pseudo-spectral acceleration (PSA) for use in engineering applications. The focus at this stage investigates the centering of the simulation methods by comparing the mean ground motion estimates. Future phases will address the dispersion of estimates or in terms of standard deviations (often referred to as "sigmas"). Five simulation methods were evaluated, and there were two parts to the validation.

In the first, Part A, the methods were studied using the bias of simulation results with respect to observations for seven specific events. Bias is defined as the natural logarithm of the ratio of the observed PSA to that for each simulation method. The term goodness-of-fit (GOF) is used interchangeably to represent this bias in the current project. A suite of 63 periods were used to define the PSA from 0.01 to 10s. For each event 40 stations providing good azimuthal coverage of the source and providing coverage within 200 km (1 to 193 km) of closest rupture distance range were used in the validation. Part A examined the mean bias for the events, individually and collectively. Assessment criteria included (1) performance relative to thresholds of 0.5 and 0.35 natural log units, (2) a measure of distance-period dependence of the bias, and (3) performance of the methods compared to published ground motion prediction equations (GMPEs). The results of this analysis show that three methods, EXSIM, G&P and SDSU, are suitable for broadband simulation of PSA from 0.01 to 3 seconds period over the entire distance range.

The second validation test, Part B, considered a comparison with published GMPEs of simulated PSA at two distances, 20 and 50 km for M_W6.2 and 6.6 strike-slip, and reverse-slip scenarios. The Part B acceptance criterion permits simulation means to deviate only up to a preset amount from the mean of the NGS-West 2 GMPEs (the permissible deviation being scaled by the maximum positive and negative deviations of the GMPEs from their mean). While all methods satisfied the evaluation criteria for at least one of the cases, only EXSIM, G&P and SDSU satisfy the acceptance criteria for all of the cases.

Based on the Part A and Part B validation tests the EXSIM, G&P and SDSU methods are considered suitable for broadband simulation of median PSA from 0.01 to 3 seconds period within the validation magnitude range; they are suitable up to M_W8 for the purposes of assessing relative effects of changes in source geometry, rupture direction, presence of secondary slip on splays, hanging wall effects, etc. We note that for periods above 1 second there is increased bias relative to recordings, and above 3 seconds period there are significant deviations from GMPEs. Further analysis will be required to understand the source of this additional bias, but possible contributors include the specifics of the moment-area scaling relationships used in source generation for the simulations and possible over excitation of surface waves from the employed 1D velocity models. In addition, above 3 seconds period the uncertainties in the GMPE estimates themselves may be comparable to the differences between the simulations and GMPEs. Future work should investigate systematic differences in simulated motions from 1D vs. 3D velocity structures.

It should be recognized that when the simulations are applied at magnitudes beyond the validation range, the results have additional epistemic uncertainty that has not been formally investigated. While formal validations of the methods are not currently possible for magnitudes greater than 8, their use at higher magnitude will require better understanding of epistemic uncertainties related to various model inputs including e.g., scaling and effects of stress parameters, subfault stress drop, parameterization of slip velocity function, and the degree of occurrence of super shear rupture velocity.

The concept and implementation of the BBP was to have well defined, version controlled methodologies and common post-processing and analysis tools. This approach successfully provides a framework for the evaluation of simulated ground motions for engineering applications that use PSA. All of the five methods currently implemented on the BBP should continue to be refined and improved to provide a variety of options for users, and to help to characterize epistemic uncertainty. Future development of the BBP should also evaluate the ability of simulations to represent observed PSA sigma values, and should include additional metrics to evaluate the suitability of simulated time histories for engineering applications.

2. Introduction

A panel was convened to evaluate the capabilities of participating simulation methods in the SCEC Broadband Platform (BBP). The panel members include; Douglas S. Dreger (Panel Chair, UCB), Gregory Beroza (Stanford), Steven M. Day (SDSU), Christine A. Goulet (UCB), Thomas Jordan (USC), Paul Spudich (USGS), and Jonathan P. Stewart (UCLA).

The concept of a numerical development platform to test and develop multiple, complex simulation methods has been successful in this first phase. Having codes run by a third party, using locked-in versions, and a common suite of post-processing algorithms for the generation of statistics and plots has resulted in a stable platform of fully-transparent simulation results for review. The BBP enables investigation of behaviors of single methods in terms of frequency dependence, distance, and source mechanism dependence, but importantly enables the direct comparison of results between difference simulation methods and also with ground motion prediction equations (GMPE).

This report focuses on the evaluation results from the panel. The more detailed aspects of the validation exercise design and products developed since the beginning of the project are provided in Appendix A. ("Validation Guidelines for Numerical Simulations of Ground Motions – Broadband Platform Validation Exercise for Pseudo-Spectral Acceleration" by C. A. Goulet). As outlined in Appendix A, the primary motivation of this stage of the BBP exercise is to verify the centering of the ground motion simulation methods with respect to recorded ground motions, and published ground motion prediction equations (GMPEs), and to validate the simulated results against Pseudo-Spectral Accelerations (PSA) from recordings spanning a range of magnitudes, focal mechanisms, and site-to-source distances. The oscillator period range considered in these analyses is 0.01 to 10 sec.

The participating methods being reviewed at this time are summarized in Table 2.1.1.

Table 2.1.1 Participating Methods

Method identifier	Responsible developers (affiliations)	Key references*
CSM: Composite Source Model	John Anderson (UNR)	Zeng et al. (1994)
UCSB Method	Ralph Archuleta, Jorge Crempien (UCSB)	Liu et al. (2006), Schmedes et al. (2010), and Schmedes et al. (2012)
EXSIM	Gail Atksinson, Karen Assatourians (UWO)	Motozedian and Atkinson (2005), Atkinson et al. (2009), and Boore (2009)
G&P: Graves and Pitarka	Robert Graves (USGS), Arben Pitarka (LLNL)	Graves and Pitarka (2010)
SDSU Method	Kim Olsen, Rumi Takedatsu (SDSU)	Mai et al. (2010), and Mena et al. (2010)

* References listed here are the latest published documentation of the methods. Some methods have been modified since publication. The documents on the current status of each method are provided in Appendices E.

The documentation provided to the panel for each method including the modelers' presented (panel review June 26, 2013 at Cal. State Pomona) self-assessments are included in Appendix E.

Although not being evaluated as a model, results for the widely used SMSIM stochastic point source model of Boore (2005) are also presented as a benchmark for comparison.

The Validation Guidelines for Numerical Simulations of Ground Motions – Broadband Platform Validation Exercise for Pseudo-Spectral Acceleration (Appendix A) provides two validation targets for use, Part A and Part B.

Part A validation involves the comparison of ln(PSA) RotD50 for discrete periods with actual recorded ground motions. For each recorded event, the method bias is computed as residuals (data minus simulations) computed in natural logarithm units. The bias, also referred to as goodness-of-fit (GOF) is therefore the ratio of the observed to simulated motions (ln(obs/syn)). The bias is computed independently for each spectral period and for a single realization of the source and for up to 40 selected stations. The method of station selection is described in Appendix A. The bias metric discussed in this report is a "combined" bias computed by first averaging the 50 realizations PSA at each station and period and then computing the bias for each period. Detailed GOF plots showing the average bias over stations for each period together with the standard deviation and the 95% confidence of the mean were provided (see examples in Appendix A). At this initial stage of the validation effort, focus is placed on the mean combined bias (or GOF) as defined above. Standard deviation (e.g. sigma) will be evaluated in a future phase of the BBP effort. To facilitate the panel review a spreadsheet summarizing the mean bias measure for specific events, distance ranges, period ranges, and mechanism types was provided.

Part B validation involved the comparison of mean ln(PSA) for M_w 6.2 and 6.6 events at distances of 20 km and 50 km over the period range with respect to published GMPEs. Southern California and Northern California cases were considered separately. For each of the three events (two strike-slip and one reverse-slip) the target was taken as the mean of published GMPEs as a function of period. An acceptance criterion was defined with lower and upper bounds taken as 1.15 times the maximum deviation of the upper envelope of the GMPEs from their mean, and similarly 0.85 times the minimum deviation of lower GMPE envelope from the mean. The effective range is ± 1.42 or ±0.35 in natural log units. The mean of 50 source realizations is considered and passing requires that the mean lies within the upper and lower bounds over the period range from 0.01 to 3 s. Periods longer than 3 s are not considered because of the lack of sufficient observations to constrain the GMPEs with sufficient reliability at longer periods.

3. Part A Validation Results

Part A validation involved comparing simulated ground motions from 50 source realizations against recorded PSAs for seven active tectonic region (ATR) earthquakes (Whittier Narrows, Northridge, Landers, Loma Prieta, Tottori, and Niigata). PSA was compared over a period range from 0.01 to 3 s period. The mean of the natural logarithm of the ratio of observed PSA to simulated PSA was provided in a series of plots for each event and method. In such plots, deviation from zero is referred to as bias. Examples of bias (GOF) plots are provided in appendix A. The mean absolute bias was also provided for distance bins (0-5 km, 5-20 km, 20-70 km, and 70-200 km), period bins (0.01 to 0.1 s, 0.1 to 1.0 s, 1 to 3 s, and more than 3 s), and mechanism type (strike-slip, reverse, and reverse-oblique).

The mean bias in each bin is simply computed as the average of the bias values contained within the bin. The mean absolute bias is the mean of the absolute value of the bias in each case. The inclusion of mean absolute bias is to evaluate whether there might be trends in the bias plots such that low mean bias results from cancelation of large positive and negative residuals within the trends.

The panel identified three ways of interpreting the mean bias results:

1. Apply relatively simple pass thresholds to each combination of simulation method, period band, and earthquake. The 'pass' or 'fail' of a simulation method would be judged through subjective interpretation of relative numbers of pass or fail realizations (i.e., if a method passes beyond a certain percentage of event and period combinations, it is judged to pass).
2. Plot an aggregate of all mean biases (using all events) against distance for a given simulation method and period range. Judge the performance of the method based on the statistics of a fit line through the results and provide confidence intervals.
3. Apply a criterion based on combined measures of mean bias, and mean absolute bias, and normalize this measure to the corresponding values obtained from application of GMPE relations. This procedure gives a measure

of performance of the simulation method relative to an objective standard (the misfit from conventional empirical formulas); in particular, it provides an allowance for un-modeled event terms in the validation data set (which could potentially have an appreciable non-zero average).

The three approaches are applied in the sub-sections that follow.

3.1 Pass Thresholds for Distance and Period Ranges

In this sub-section we use simple misfit metrics to obtain an initial overview of the performance of the methods. Mean bias exceeding a factor of 2 (0.69 natural logarithm units) is considered a fail condition, and we present results for two different pass criteria, ±0.5 and ±0.35 natural log units, respectively. To give some perspective to these choices, note that a 0.5 natural log unit amplitude shift (at long period and large distance) corresponds to an event magnitude shift of 0.14 units (and the 0.35 shift corresponds to a magnitude shift of 0.1 units). Also note that the predefined acceptance criterion for Part B validation (see Appendix A) corresponds to a ± 0.35 in natural logarithm units.

In Table 3.1.1 cases with mean bias less than ± 0.5 are shaded in green. Red indicates bias exceeding a factor of two in ground motion amplitude. Those cases larger than the acceptance or pass threshold but less than the factor of two threshold are white. Cases that were not investigated are shown by a stippled pattern.

In the 0-5 km distance range there are few observations and not all of the cases were considered but some trends may be observed. If the overall average is considered the CSM, EXSIM, G&P and SDSU methods satisfy the passing threshold over the entire period range. At short period (0.01 to 0.1 s) EXSIM, G&P and SDSU have issues fitting the Landers earthquake, which at this distance consists of only the Lucerne station. In the 0.1 to 1 passband all methods perform well, although UCSB exceeds the failure threshold for the North Palm Springs event. At long periods the UCSB method exceeds the failure threshold for all events, and EXSIM, G&P and SDSU each have a single case that exceeds the failure threshold. The point-source stochastic method SMSIM performs worse than all the tested methods except UCSB at all periods in the 0-5 km range

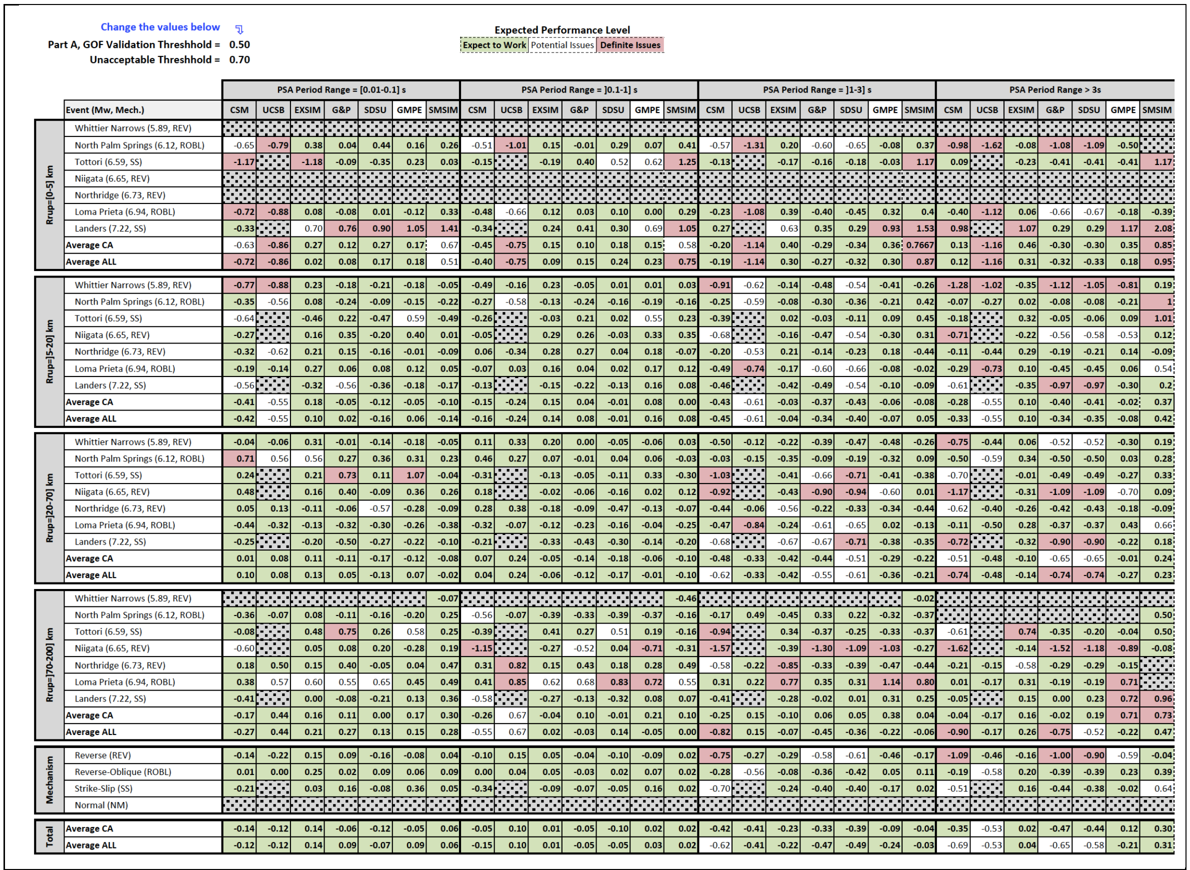
In the 5-20 and 20-70 km distance ranges all five tested methods perform well in the 0.01 to 3 s passband on average. The two Japanese cases start to show problems at periods longer than 1 s at distances greater than 70 km, which is likely due to problems with the velocity structure employed and the strength of surface waves produced by the simplified and uncalibrated velocity model that was used

At distances larger than 70 km on average all methods satisfy the pass threshold of 0.5 for periods from 0.01 to 0.1 s. UCSB fails for 0.1 to 1 s, and CSM fails for 1 to 3 s. For periods longer than 3 s the Niigata event results in failure for CSM, G&P and SDSU. The Tottori event results in failure for EXSIM. The two Japanese cases were not run for UCSB. The point source method SMSIM performs comparably or better than almost all tested methods for all periods and distances greater than 20 km.

On average there does not appear to be any systematic bias due to mechanism type with strike-slip, reverse and reverse-oblique all meeting the pass threshold for periods from 0.01 to 3 s. At periods greater than 1 s there are more instances of marginal cases, and at periods exceeding 3 s there do appear to be problems with reverse mechanisms for the CSM, G&P and SDSU methods.

Table 3.1.2 shows the same table utilizing a pass threshold of 0.35 natural log units. The results are essentially the same as in Table 3.1.1 however there are more potentially problematic cases shown by the unshaded (white) cells, particularly for periods between 1 to 3 s, and larger than 3 s.

One important point to mention for Part A bias results is the loss of reliability for periods larger than about 3 s. This is due to the limited usable bandwidth of recorded data, attributable to old or poor quality instrumentation and is also magnitude dependent (reduced signal-to-noise ratio of low frequencies at small magnitude). At large periods, we are effectively losing data due to the usable bandwidth of the records. This effect is visible in bias plots (e.g. Appendix A) where the confidence interval increases at large periods. For Landers, Northridge and Loma Prieta, this effect becomes important beyond 5s while for Whittier Narrows and North Palm Springs, data starts dropping just above 2 s with no data at all beyond 5s. The Japanese events do not show this trend.



Change the values below ↲

Part A, GOF Validation Threshhold = 0.50

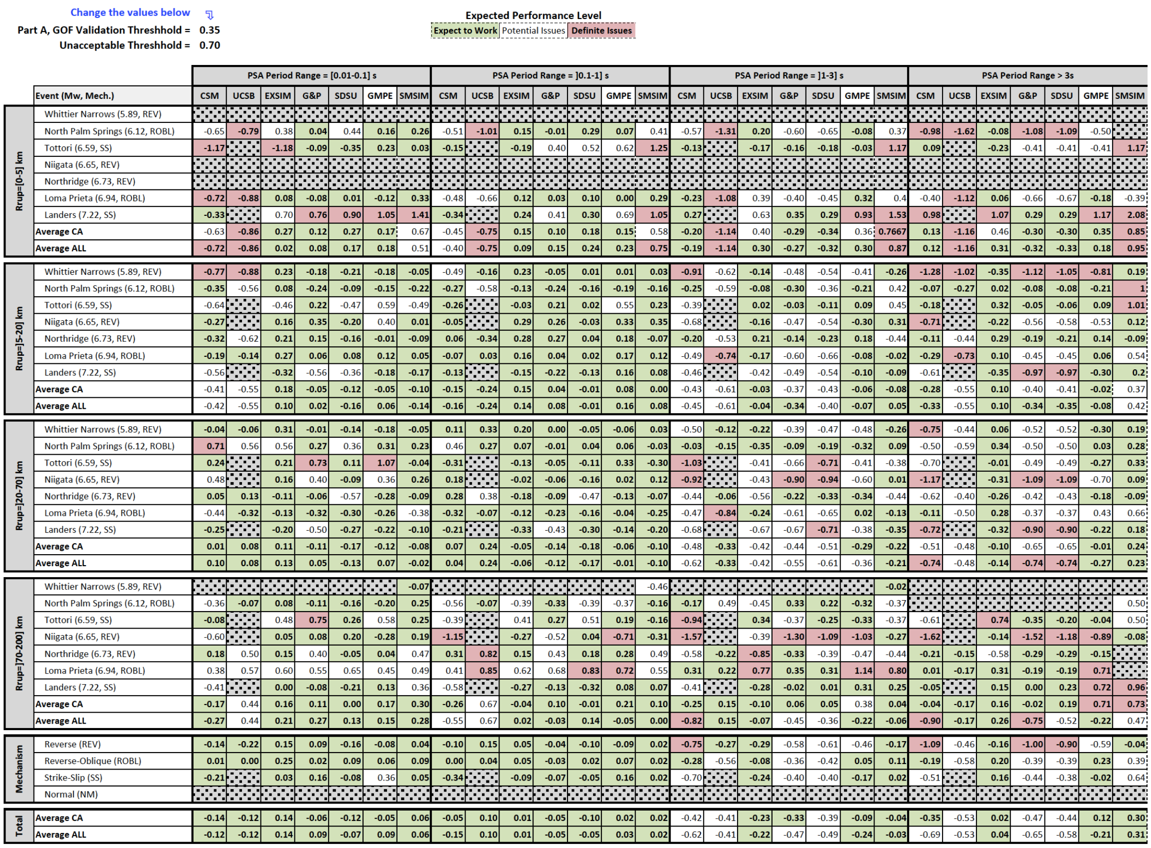
Unacceptable Threshhold = 0.70

Expected Performance Level

Expect to Work | Potential Issues | Definite Issues

		PSA Period Range = [0.01-0.1] s							PSA Period Range =]0.1-1] s							PSA Period Range =]1-3] s							PSA Period Range > 3s						
	Event (Mw, Mech.)	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM
Rrup=[0-5] km	Whittier Narrows (5.89, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	North Palm Springs (6.12, ROBL)	-0.65	-0.79	0.38	0.04	0.44	0.16	0.26	-0.51	-1.01	0.15	-0.01	0.29	0.07	0.41	-0.57	-1.31	0.20	-0.60	-0.65	-0.08	0.37	-0.98	-1.62	-0.08	-1.08	-1.09	-0.50	▨
	Tottori (6.59, SS)	-1.17	▨	-1.18	-0.09	-0.35	0.23	0.03	-0.15	▨	-0.19	0.40	0.52	0.62	1.25	-0.13	▨	-0.17	-0.16	-0.18	-0.03	1.17	0.09	▨	-0.23	-0.41	-0.41	-0.41	1.17
	Niigata (6.65, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Northridge (6.73, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Loma Prieta (6.94, ROBL)	-0.72	-0.88	0.08	-0.08	0.01	-0.12	0.33	-0.48	-0.66	0.12	0.03	0.10	0.00	0.29	-0.23	-1.08	0.39	-0.40	-0.45	0.32	0.4	-0.40	-1.12	0.06	-0.66	-0.67	-0.18	-0.39
	Landers (7.22, SS)	-0.33	▨	0.70	0.76	0.90	1.05	1.41	-0.34	▨	0.24	0.41	0.30	0.69	1.05	0.27	▨	0.63	0.35	0.29	0.93	1.53	0.98	▨	1.07	0.29	0.29	1.17	2.08
	Average CA	-0.63	-0.86	0.27	0.12	0.27	0.17	0.67	-0.45	-0.75	0.15	0.10	0.18	0.15	0.58	-0.20	-1.14	0.40	-0.29	-0.34	0.36	0.7667	0.13	-1.16	0.46	-0.30	-0.30	0.35	0.85
	Average ALL	-0.72	-0.86	0.02	0.08	0.17	0.18	0.51	-0.40	-0.75	0.09	0.15	0.24	0.23	0.75	-0.19	-1.14	0.30	-0.27	-0.32	0.30	0.87	0.12	-1.16	0.31	-0.32	-0.33	0.18	0.95
Rrup=]5-20] km	Whittier Narrows (5.89, REV)	-0.77	-0.88	0.23	-0.18	-0.21	-0.18	-0.05	-0.49	-0.16	0.23	-0.05	0.01	0.01	0.03	-0.91	-0.62	-0.14	-0.48	-0.54	-0.41	-0.26	-1.28	-1.02	-0.35	-1.12	-1.05	-0.81	0.19
	North Palm Springs (6.12, ROBL)	-0.35	-0.56	0.08	-0.24	-0.09	-0.15	-0.22	-0.27	-0.58	-0.13	-0.24	-0.16	-0.19	-0.16	-0.25	-0.59	-0.08	-0.30	-0.36	-0.21	0.42	-0.07	-0.27	0.02	-0.08	-0.08	-0.21	1
	Tottori (6.59, SS)	-0.64	▨	-0.46	0.22	-0.47	0.59	-0.49	-0.26	▨	-0.03	0.21	0.02	0.55	0.23	-0.39	▨	0.02	-0.03	-0.11	0.09	0.45	-0.18	▨	0.32	-0.05	-0.06	0.09	1.01
	Niigata (6.65, REV)	-0.27	▨	0.16	0.35	-0.20	0.40	0.01	-0.05	▨	0.29	0.26	-0.03	0.33	0.35	-0.68	▨	-0.16	-0.47	-0.54	-0.30	0.31	-0.71	▨	-0.22	-0.56	-0.58	-0.53	0.12
	Northridge (6.73, REV)	-0.32	-0.62	0.21	0.15	-0.16	-0.01	-0.09	0.06	-0.34	0.28	0.27	0.04	0.18	-0.07	-0.20	-0.53	0.21	-0.14	-0.23	0.18	-0.44	-0.11	-0.44	0.29	-0.19	-0.21	0.14	-0.09
	Loma Prieta (6.94, ROBL)	-0.19	-0.14	0.27	0.06	0.08	0.12	0.05	-0.07	0.03	0.16	0.04	0.02	0.17	0.12	-0.49	-0.74	-0.17	-0.60	-0.66	-0.08	-0.02	-0.29	-0.73	0.10	-0.45	-0.45	0.06	0.54
	Landers (7.22, SS)	-0.56	▨	-0.32	-0.56	-0.36	-0.18	-0.17	-0.13	▨	-0.15	-0.22	-0.13	0.16	0.08	-0.46	▨	-0.42	-0.49	-0.54	-0.10	-0.09	-0.61	▨	-0.35	-0.97	-0.97	-0.30	0.2
	Average CA	-0.41	-0.55	0.18	-0.05	-0.12	-0.05	-0.10	-0.15	-0.24	0.15	0.04	-0.01	0.08	0.00	-0.43	-0.61	-0.03	-0.37	-0.43	-0.06	-0.08	-0.28	-0.55	0.10	-0.40	-0.41	-0.02	0.37
	Average ALL	-0.42	-0.55	0.10	0.02	-0.16	0.06	-0.14	-0.16	-0.24	0.14	0.08	-0.01	0.16	0.08	-0.45	-0.61	-0.04	-0.34	-0.40	-0.07	0.05	-0.33	-0.55	0.10	-0.34	-0.35	-0.08	0.42
Rrup=]20-70] km	Whittier Narrows (5.89, REV)	-0.04	-0.06	0.31	-0.01	-0.14	-0.18	-0.05	0.11	0.33	0.20	0.00	-0.05	-0.06	0.03	-0.50	-0.12	-0.22	-0.39	-0.47	-0.48	-0.26	-0.75	-0.44	0.06	-0.52	-0.52	-0.30	0.19
	North Palm Springs (6.12, ROBL)	0.71	0.56	0.56	0.27	0.36	0.31	0.23	0.46	0.27	0.07	-0.01	0.04	0.06	-0.03	-0.03	-0.15	-0.35	-0.09	-0.19	-0.32	0.09	-0.50	-0.59	0.34	-0.50	-0.50	0.03	0.28
	Tottori (6.59, SS)	0.24	▨	0.21	0.73	0.11	1.07	-0.04	-0.31	▨	-0.13	-0.05	-0.11	0.33	-0.30	-1.03	▨	-0.41	-0.66	-0.71	-0.41	-0.38	-0.70	▨	-0.01	-0.49	-0.49	-0.27	0.33
	Niigata (6.65, REV)	0.48	▨	0.16	0.40	-0.09	0.36	0.26	0.18	▨	-0.02	-0.06	-0.16	0.02	0.12	-0.92	▨	-0.43	-0.90	-0.94	-0.60	0.01	-1.17	▨	-0.31	-1.09	-1.09	-0.70	0.09
	Northridge (6.73, REV)	0.05	0.13	-0.11	-0.06	-0.57	-0.28	-0.09	0.28	0.38	-0.18	-0.09	-0.47	-0.13	-0.07	-0.44	-0.06	-0.56	-0.22	-0.33	-0.34	-0.44	-0.62	-0.40	-0.26	-0.42	-0.43	-0.18	-0.09
	Loma Prieta (6.94, ROBL)	-0.44	-0.32	-0.13	-0.32	-0.30	-0.26	-0.38	-0.32	-0.07	-0.12	-0.23	-0.16	-0.04	-0.25	-0.47	-0.84	-0.24	-0.61	-0.65	0.02	-0.13	-0.11	-0.50	0.28	-0.37	-0.37	0.43	0.66
	Landers (7.22, SS)	-0.25	▨	-0.20	-0.50	-0.27	-0.22	-0.10	-0.21	▨	-0.33	-0.43	-0.30	-0.14	-0.20	-0.68	▨	-0.67	-0.67	-0.71	-0.38	-0.35	-0.72	▨	-0.32	-0.90	-0.90	-0.22	0.18
	Average CA	0.01	0.08	0.11	-0.11	-0.17	-0.12	-0.08	0.07	0.24	-0.05	-0.14	-0.18	-0.06	-0.10	-0.48	-0.33	-0.42	-0.44	-0.51	-0.29	-0.22	-0.51	-0.48	-0.10	-0.65	-0.65	-0.01	0.24
	Average ALL	0.10	0.08	0.13	0.05	-0.13	0.07	-0.02	0.04	0.24	-0.06	-0.12	-0.17	-0.01	-0.10	-0.62	-0.33	-0.42	-0.55	-0.61	-0.36	-0.21	-0.74	-0.48	-0.14	-0.74	-0.74	-0.27	0.23
Rrup=]70-200] km	Whittier Narrows (5.89, REV)	▨	▨	▨	▨	▨	▨	-0.07	▨	▨	▨	▨	▨	▨	-0.46	▨	▨	▨	▨	▨	▨	-0.02	▨	▨	▨	▨	▨	▨	▨
	North Palm Springs (6.12, ROBL)	-0.36	-0.07	0.08	-0.11	-0.16	-0.20	0.25	-0.56	-0.07	-0.39	-0.33	-0.39	-0.37	-0.16	-0.17	0.49	-0.45	0.33	0.22	-0.32	-0.37	▨	▨	▨	▨	▨	▨	0.50
	Tottori (6.59, SS)	-0.08	▨	0.48	0.75	0.26	0.58	0.25	-0.39	▨	0.41	0.27	0.51	0.19	-0.16	-0.94	▨	0.34	-0.37	-0.25	-0.33	-0.37	-0.61	▨	0.74	-0.35	-0.20	-0.04	0.50
	Niigata (6.65, REV)	-0.60	▨	0.05	0.08	0.20	-0.28	0.19	-1.15	▨	-0.27	-0.52	0.04	-0.71	-0.31	-1.57	▨	-0.39	-1.30	-1.09	-1.03	-0.27	-1.62	▨	-0.14	-1.52	-1.18	-0.89	-0.08
	Northridge (6.73, REV)	0.18	0.50	0.15	0.40	-0.05	0.04	0.47	0.31	0.82	0.15	0.43	0.18	0.28	0.49	-0.58	-0.22	-0.85	-0.33	-0.39	-0.47	-0.44	-0.21	-0.15	-0.58	-0.29	-0.29	-0.15	▨
	Loma Prieta (6.94, ROBL)	0.38	0.57	0.60	0.55	0.65	0.45	0.49	0.41	0.85	0.62	0.68	0.83	0.72	0.55	0.31	0.22	0.77	0.35	0.31	1.14	0.80	0.01	-0.17	0.31	-0.19	-0.19	0.71	▨
	Landers (7.22, SS)	-0.41	▨	0.00	-0.08	-0.21	0.13	0.36	-0.58	▨	-0.27	-0.13	-0.32	0.08	0.07	-0.41	▨	-0.28	-0.02	0.01	0.31	0.25	-0.05	▨	0.15	0.00	0.23	0.72	0.96
	Average CA	-0.17	0.44	0.16	0.11	0.00	0.17	0.30	-0.26	0.67	-0.04	0.10	-0.01	0.21	0.10	-0.25	0.15	-0.10	0.06	0.05	0.38	0.04	-0.04	-0.17	0.16	-0.02	0.19	0.71	0.73
	Average ALL	-0.27	0.44	0.21	0.27	0.13	0.15	0.28	-0.55	0.67	0.02	-0.03	0.14	-0.05	0.00	-0.82	0.15	-0.07	-0.45	-0.36	-0.22	-0.06	-0.90	-0.17	0.26	-0.75	-0.52	-0.22	0.47
Mechanism	Reverse (REV)	-0.14	-0.22	0.15	0.09	-0.16	-0.08	0.04	-0.10	0.15	0.05	-0.04	-0.10	-0.09	0.02	-0.75	-0.27	-0.29	-0.58	-0.61	-0.46	-0.17	-1.09	-0.46	-0.16	-1.00	-0.90	-0.59	-0.04
	Reverse-Oblique (ROBL)	0.01	0.00	0.25	0.02	0.09	0.06	0.09	0.00	0.04	0.05	-0.03	0.02	0.07	0.02	-0.28	-0.56	-0.08	-0.36	-0.42	0.05	0.11	-0.19	-0.58	0.20	-0.39	-0.39	0.23	0.39
	Strike-Slip (SS)	-0.21	▨	0.03	0.16	-0.08	0.36	0.05	-0.34	▨	-0.09	-0.07	-0.05	0.16	0.02	-0.70	▨	-0.24	-0.40	-0.40	-0.17	0.02	-0.51	▨	0.16	-0.44	-0.38	-0.02	0.64
	Normal (NM)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Total	**Average CA**	-0.14	-0.12	0.14	-0.06	-0.12	-0.05	0.06	-0.05	0.10	0.01	-0.05	-0.10	0.02	0.02	-0.42	-0.41	-0.23	-0.33	-0.39	-0.09	-0.04	-0.35	-0.53	0.02	-0.47	-0.44	0.12	0.30
	Average ALL	-0.12	-0.12	0.14	0.09	-0.07	0.09	0.06	-0.15	0.10	0.01	-0.05	-0.05	0.03	0.02	-0.62	-0.41	-0.22	-0.47	-0.49	-0.24	-0.03	-0.69	-0.53	0.04	-0.65	-0.58	-0.21	0.31

Table 3.1.1. Mean bias for the various cases. Green indicates bias is less than ±0.5. Red indicates bias is greater than ±0.69. White are marginal cases. Stippled indicates cases that were not examined.



Change the values below ↴

Part A, GOF Validation Threshhold = 0.35

Unacceptable Threshhold = 0.70

Expected Performance Level

Expect to Work	Potential Issues	Definite Issues

		PSA Period Range = [0.01-0.1] s							PSA Period Range =]0.1-1] s							PSA Period Range =]1-3] s							PSA Period Range > 3s						
	Event (Mw, Mech.)	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM
Rrup=[0-5] km	Whittier Narrows (5.89, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	North Palm Springs (6.12, ROBL)	-0.65	-0.79	0.38	0.04	0.44	0.16	0.26	-0.51	-1.01	0.15	-0.01	0.29	0.07	0.41	-0.57	-1.31	0.20	-0.60	-0.65	-0.08	0.37	-0.98	-1.62	-0.08	-1.08	-1.09	-0.50	▨
	Tottori (6.59, SS)	-1.17	▨	-1.18	-0.09	-0.35	0.23	0.03	-0.15	▨	-0.19	0.40	0.52	0.62	1.25	-0.13	▨	-0.17	-0.16	-0.18	-0.03	1.17	0.09	▨	-0.23	-0.41	-0.41	-0.41	1.17
	Niigata (6.65, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Northridge (6.73, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Loma Prieta (6.94, ROBL)	-0.72	-0.88	0.08	-0.08	0.01	-0.12	0.33	-0.48	-0.66	0.12	0.03	0.10	0.00	0.29	-0.23	-1.08	0.39	-0.40	-0.45	0.32	0.4	-0.40	-1.12	0.06	-0.66	-0.67	-0.18	-0.39
	Landers (7.22, SS)	-0.33	▨	0.70	0.76	0.90	1.05	1.41	-0.34	▨	0.24	0.41	0.30	0.69	1.05	0.27	▨	0.63	0.35	0.29	0.93	1.53	0.98	▨	1.07	0.29	0.29	1.17	2.08
	Average CA	-0.63	-0.86	0.27	0.12	0.27	0.17	0.67	-0.45	-0.75	0.15	0.10	0.18	0.15	0.58	-0.20	-1.14	0.40	-0.29	-0.34	0.36	0.7667	0.13	-1.16	0.46	-0.30	-0.30	0.35	0.85
	Average ALL	-0.72	-0.86	0.02	0.08	0.17	0.18	0.51	-0.40	-0.75	0.09	0.15	0.24	0.23	0.75	-0.19	-1.14	0.30	-0.27	-0.32	0.30	0.87	0.12	-1.16	0.31	-0.32	-0.33	0.18	0.95
Rrup=]5-20] km	Whittier Narrows (5.89, REV)	-0.77	-0.88	0.23	-0.18	-0.21	-0.18	-0.05	-0.49	-0.16	0.23	-0.05	0.01	0.01	0.03	-0.91	-0.62	-0.14	-0.48	-0.54	-0.41	-0.26	-1.28	-1.02	-0.35	-1.12	-1.05	-0.81	0.19
	North Palm Springs (6.12, ROBL)	-0.35	-0.56	0.08	-0.24	-0.09	-0.15	-0.22	-0.27	-0.58	-0.13	-0.24	-0.16	-0.19	-0.16	-0.25	-0.59	-0.08	-0.30	-0.36	-0.21	0.42	-0.07	-0.27	0.02	-0.08	-0.08	-0.21	1
	Tottori (6.59, SS)	-0.64	▨	-0.46	0.22	-0.47	0.59	-0.49	-0.26	▨	-0.03	0.21	0.02	0.55	0.23	-0.39	▨	0.02	-0.03	-0.11	0.09	0.45	-0.18	▨	0.32	-0.05	-0.06	0.09	1.01
	Niigata (6.65, REV)	-0.27	▨	0.16	0.35	-0.20	0.40	0.01	-0.05	▨	0.29	0.26	-0.03	0.33	0.35	-0.68	▨	-0.16	-0.47	-0.54	-0.30	0.31	-0.71	▨	-0.22	-0.56	-0.58	-0.53	0.12
	Northridge (6.73, REV)	-0.32	-0.62	0.21	0.15	-0.16	-0.01	-0.09	0.06	-0.34	0.28	0.27	0.04	0.18	-0.07	-0.20	-0.53	0.21	-0.14	-0.23	0.18	-0.44	-0.11	-0.44	0.29	-0.19	-0.21	0.14	-0.09
	Loma Prieta (6.94, ROBL)	-0.19	-0.14	0.27	0.06	0.08	0.12	0.05	-0.07	0.03	0.16	0.04	0.02	0.17	0.12	-0.49	-0.74	-0.17	-0.60	-0.66	-0.08	-0.02	-0.29	-0.73	0.10	-0.45	-0.45	0.06	0.54
	Landers (7.22, SS)	-0.56	▨	-0.32	-0.56	-0.36	-0.18	-0.17	-0.13	▨	-0.15	-0.22	-0.13	0.16	0.08	-0.46	▨	-0.42	-0.49	-0.54	-0.10	-0.09	-0.61	▨	-0.35	-0.97	-0.97	-0.30	0.2
	Average CA	-0.41	-0.55	0.18	-0.05	-0.12	-0.05	-0.10	-0.15	-0.24	0.15	0.04	-0.01	0.08	0.00	-0.43	-0.61	-0.03	-0.37	-0.43	-0.06	-0.08	-0.28	-0.55	0.10	-0.40	-0.41	-0.02	0.37
	Average ALL	-0.42	-0.55	0.10	0.02	-0.16	0.06	-0.14	-0.16	-0.24	0.14	0.08	-0.01	0.16	0.08	-0.45	-0.61	-0.04	-0.34	-0.40	-0.07	0.05	-0.33	-0.55	0.10	-0.34	-0.35	-0.08	0.42
Rrup=]20-70] km	Whittier Narrows (5.89, REV)	-0.04	-0.06	0.31	-0.01	-0.14	-0.18	-0.05	0.11	0.33	0.20	0.00	-0.05	-0.06	0.03	-0.50	-0.12	-0.22	-0.39	-0.47	-0.48	-0.26	-0.75	-0.44	0.06	-0.52	-0.52	-0.30	0.19
	North Palm Springs (6.12, ROBL)	0.71	0.56	0.56	0.27	0.36	0.31	0.23	0.46	0.27	0.07	-0.01	0.04	0.06	-0.03	-0.03	-0.15	-0.35	-0.09	-0.19	-0.32	0.09	-0.50	-0.59	0.34	-0.50	-0.50	0.03	0.28
	Tottori (6.59, SS)	0.24	▨	0.21	0.73	0.11	1.07	-0.04	-0.31	▨	-0.13	-0.05	-0.11	0.33	-0.30	-1.03	▨	-0.41	-0.66	-0.71	-0.41	-0.38	-0.70	▨	-0.01	-0.49	-0.49	-0.27	0.33
	Niigata (6.65, REV)	0.48	▨	0.16	0.40	-0.09	0.36	0.26	0.18	▨	-0.02	-0.06	-0.16	0.02	0.12	-0.92	▨	-0.43	-0.90	-0.94	-0.60	0.01	-1.17	▨	-0.31	-1.09	-1.09	-0.70	0.09
	Northridge (6.73, REV)	0.05	0.13	-0.11	-0.06	-0.57	-0.28	-0.09	0.28	0.38	-0.18	-0.09	-0.47	-0.13	-0.07	-0.44	-0.06	-0.56	-0.22	-0.33	-0.34	-0.44	-0.62	-0.40	-0.26	-0.42	-0.43	-0.18	-0.09
	Loma Prieta (6.94, ROBL)	-0.44	-0.32	-0.13	-0.32	-0.30	-0.26	-0.38	-0.32	-0.07	-0.12	-0.23	-0.16	-0.04	-0.25	-0.47	-0.84	-0.24	-0.61	-0.65	0.02	-0.13	-0.11	-0.50	0.28	-0.37	-0.37	0.43	0.66
	Landers (7.22, SS)	-0.25	▨	-0.20	-0.50	-0.27	-0.22	-0.10	-0.21	▨	-0.33	-0.43	-0.30	-0.14	-0.20	-0.68	▨	-0.67	-0.67	-0.71	-0.38	-0.35	-0.72	▨	-0.32	-0.90	-0.90	-0.22	0.18
	Average CA	0.01	0.08	0.11	-0.11	-0.17	-0.12	-0.08	0.07	0.24	-0.05	-0.14	-0.18	-0.06	-0.10	-0.48	-0.33	-0.42	-0.44	-0.51	-0.29	-0.22	-0.51	-0.48	-0.10	-0.65	-0.65	-0.01	0.24
	Average ALL	0.10	0.08	0.13	0.05	-0.13	0.07	-0.02	0.04	0.24	-0.06	-0.12	-0.17	-0.01	-0.10	-0.62	-0.33	-0.42	-0.55	-0.61	-0.36	-0.21	-0.74	-0.48	-0.14	-0.74	-0.74	-0.27	0.23
Rrup=]70-200] km	Whittier Narrows (5.89, REV)	▨	▨	▨	▨	▨	▨	-0.07	▨	▨	▨	▨	▨	▨	-0.46	▨	▨	▨	▨	▨	▨	-0.02	▨	▨	▨	▨	▨	▨	▨
	North Palm Springs (6.12, ROBL)	-0.36	-0.07	0.08	-0.11	-0.16	-0.20	0.25	-0.56	-0.07	-0.39	-0.33	-0.39	-0.37	-0.16	-0.17	0.49	-0.45	0.33	0.22	-0.32	-0.37	▨	▨	▨	▨	▨	▨	0.50
	Tottori (6.59, SS)	-0.08	▨	0.48	0.75	0.26	0.58	0.25	-0.39	▨	0.41	0.27	0.51	0.19	-0.16	-0.94	▨	0.34	-0.37	-0.25	-0.33	-0.37	-0.61	▨	0.74	-0.35	-0.20	-0.04	0.50
	Niigata (6.65, REV)	-0.60	▨	0.05	0.08	0.20	-0.28	0.19	-1.15	▨	-0.27	-0.52	0.04	-0.71	-0.31	-1.57	▨	-0.39	-1.30	-1.09	-1.03	-0.27	-1.62	▨	-0.14	-1.52	-1.18	-0.89	-0.08
	Northridge (6.73, REV)	0.18	0.50	0.15	0.40	-0.05	0.04	0.47	0.31	0.82	0.15	0.43	0.18	0.28	0.49	-0.58	-0.22	-0.85	-0.33	-0.39	-0.47	-0.44	-0.21	-0.15	-0.58	-0.29	-0.29	-0.15	▨
	Loma Prieta (6.94, ROBL)	0.38	0.57	0.60	0.55	0.65	0.45	0.49	0.41	0.85	0.62	0.68	0.83	0.72	0.55	0.31	0.22	0.77	0.35	0.31	1.14	0.80	0.01	-0.17	0.31	-0.19	-0.19	0.71	▨
	Landers (7.22, SS)	-0.41	▨	0.00	-0.08	-0.21	0.13	0.36	-0.58	▨	-0.27	-0.13	-0.32	0.08	0.07	-0.41	▨	-0.28	-0.02	0.01	0.31	0.25	-0.05	▨	0.15	0.00	0.23	0.72	0.96
	Average CA	-0.17	0.44	0.16	0.11	0.00	0.17	0.30	-0.26	0.67	-0.04	0.10	-0.01	0.21	0.10	-0.25	0.15	-0.10	0.06	0.05	0.38	0.04	-0.04	-0.17	0.16	-0.02	0.19	0.71	0.73
	Average ALL	-0.27	0.44	0.21	0.27	0.13	0.15	0.28	-0.55	0.67	0.02	-0.03	0.14	-0.05	0.00	-0.82	0.15	-0.07	-0.45	-0.36	-0.22	-0.06	-0.90	-0.17	0.26	-0.75	-0.52	-0.22	0.47
Mechanism	Reverse (REV)	-0.14	-0.22	0.15	0.09	-0.16	-0.08	0.04	-0.10	0.15	0.05	-0.04	-0.10	-0.09	0.02	-0.75	-0.27	-0.29	-0.58	-0.61	-0.46	-0.17	-1.09	-0.46	-0.16	-1.00	-0.90	-0.59	-0.04
	Reverse-Oblique (ROBL)	0.01	0.00	0.25	0.02	0.09	0.06	0.09	0.00	0.04	0.05	-0.03	0.02	0.07	0.02	-0.28	-0.56	-0.08	-0.36	-0.42	0.05	0.11	-0.19	-0.58	0.20	-0.39	-0.39	0.23	0.39
	Strike-Slip (SS)	-0.21	▨	0.03	0.16	-0.08	0.36	0.05	-0.34	▨	-0.09	-0.07	-0.05	0.16	0.02	-0.70	▨	-0.24	-0.40	-0.40	-0.17	0.02	-0.51	▨	0.16	-0.44	-0.38	-0.02	0.64
	Normal (NM)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Total	**Average CA**	-0.14	-0.12	0.14	-0.06	-0.12	-0.05	0.06	-0.05	0.10	0.01	-0.05	-0.10	0.02	0.02	-0.42	-0.41	-0.23	-0.33	-0.39	-0.09	-0.04	-0.35	-0.53	0.02	-0.47	-0.44	0.12	0.30
	Average ALL	-0.12	-0.12	0.14	0.09	-0.07	0.09	0.06	-0.15	0.10	0.01	-0.05	-0.05	0.03	0.02	-0.62	-0.41	-0.22	-0.47	-0.49	-0.24	-0.03	-0.69	-0.53	0.04	-0.65	-0.58	-0.21	0.31

Table 3.1.2. Mean bias for the various cases. Acceptance tolerance is lower than Table 3.1.1. Green indicates bias is less than ±0.35. Red indicates bias is greater than ±0.69. White are marginal cases. Stippled indicates cases that were not examined.

In summary the EXSIM, G&P and SDSU methods appear to be applicable to all distances ranges over a period range between 0.01 to 1 sec for a pass threshold of 0.5 natural log units. The more stringent 0.35 natural log unit metric shows many marginal cases that don't satisfy the pass threshold, but which also do not exceed the failure threshold at periods larger than 1 s. It is noted that at short distances the Landers earthquake is problematic for all of the methods in one or more of the period bins. SDSU shows problems in the 1-3 s passband in the 20-70 km distance bin. CSM and UCSB also pass over the 5-70 km distance range from 0.01 to 1 s period, however beyond 70 km these methods demonstrate GOF issues in different period bands. Considering the 'Total Average All' statistic in Table 3.1.1, SMSIM has comparable or lower biases than the other methods. However, it failed significantly in the 0-5 km range and thus cannot be accepted for short distance predictions.

3.2 Pass Threshold based on Aggregated Residuals and Distance Trend

In this subsection we assess the ability of the methods to correctly capture the distance dependence of PSA in the Part A data set. For a given simulation method, we plotted the mean bias vs. distance (log axis) using the information in the tables. Since there are seven earthquakes, there are generally seven values of mean bias to plot for each of four distance bins. We then fit a log-linear expression through the data points as follows:

$$X = a + b\ln\left(R_{rup}\right)$$

where R_{rup} is site-source rupture distance (average of the bin range), a and b are regression coefficients, and X is the average of the mean residuals for distance R_{rup}. A weighted least squares fit is determined where each data point is weighted by the number of periods and stations in each bin for each event. Confidence intervals (95%) on the mean trend line are computed. Examples of these plots for each simulation method and the GMPE predictions in the 0.1-1.0 sec period band are shown in Figure 1. The GMPE predictions are computed as the average of four NGA-West1 models: Abrahamson and Silva (2008), Boore and Atkinson (2008), Campbell and Bozorgnia (2008) and Chiou and Youngs (2008).

A general characteristic of all methods examined in this way is that the dispersion of mean bias increases with increasing distance. This is likely due to increasing effects of lateral heterogeneity for the longer paths, and the persistence of stratification to large distances in the 1D velocity models, which would result in unrealistically efficient surface wave excitation.

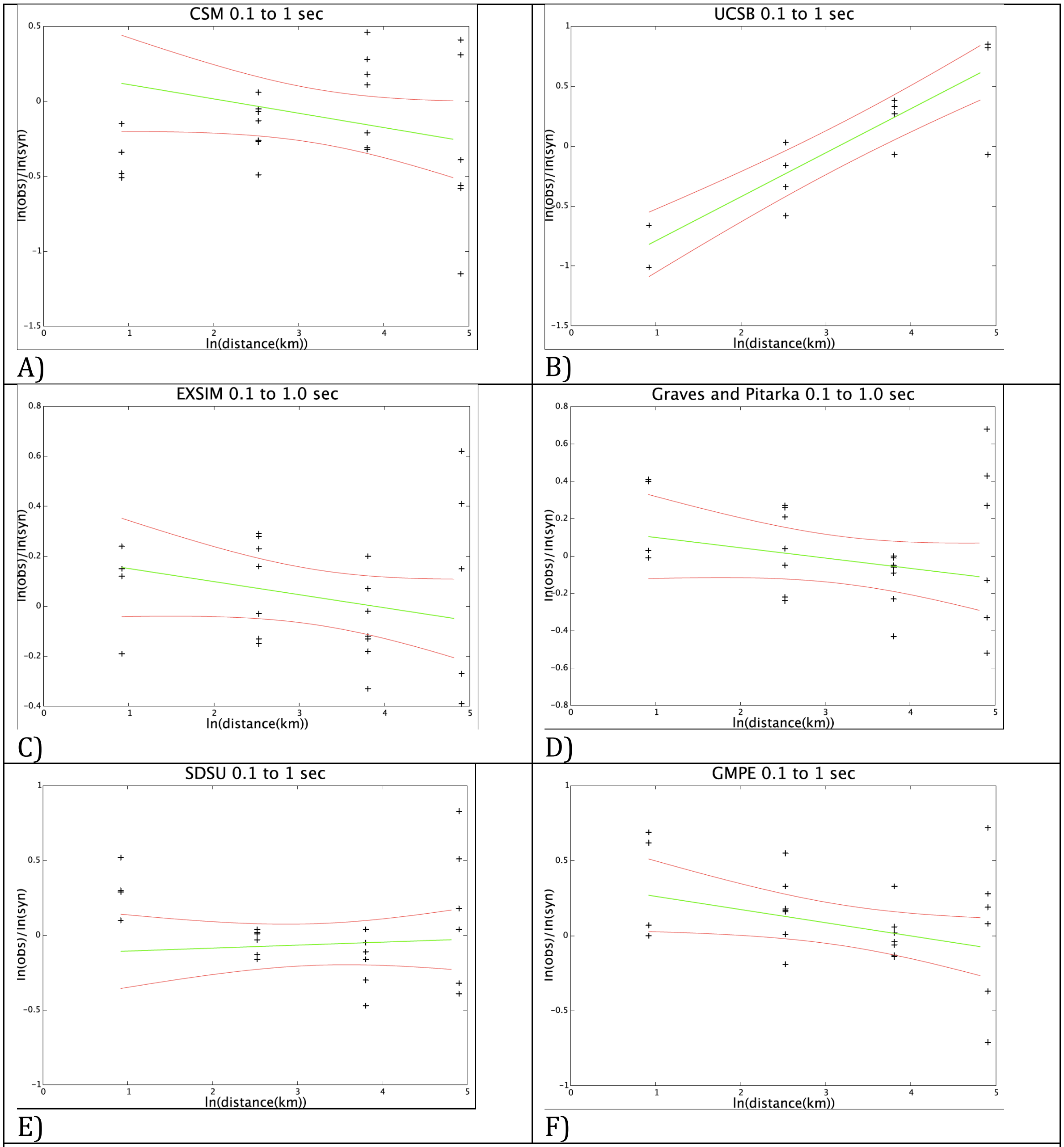
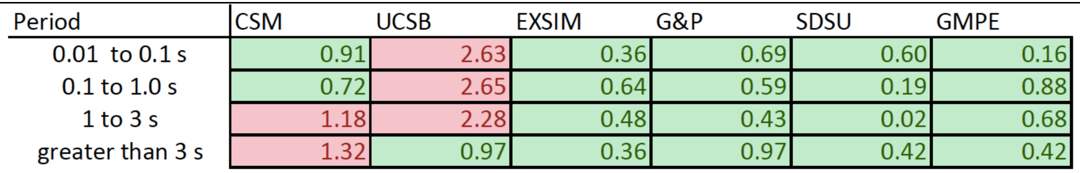


Figure 1. Best fit line (green), and 95% confidence regions (red-dashed) for the 0.1 to 1 s period bin. GOF values from Table 3.1.2 are shown for event and distance bin. A) CSM; B) UCSB; C) EXSIM, D) G&P, E) SDSU, and F) GMPE. Y-axis is mean bias in natural log units. Values are for each distance bin plotted with respect to the natural log of the central distance of each bin. Data are weighted by the number of stations and discrete periods in each distance bin.

The panel was interested in two particular aspects of the plots shown in Figure 1:

1. Overall bias: The plots provide a visual representation of bias in aggregate across the multiple distance ranges, along with a quantitative indicator of the significance of bias. For example, the SDSU results in Figure 1 show that the trend line is near zero (X=0) for close distance, and that it is zero within the confidence interval of the mean over the full distance range considered. This is suggestive of a lack of bias for the totality of considered events and distances.
2. Distance trend: One of the first-order effects that a simulation method should capture is the trend of ground motion with distance. Significant misfits in this behavior suggest further calibration of the model for the effects of geometric spreading and anelastic attenuation may be required. The performance of the simulation methods with respect to distance can be judged from the slope of the trend lines in Figure 1 (i.e., parameter *b*). We consider a method as passing this criterion if the values of slope parameter *b* are zero within the 95% confidence interval on b. Table 3.2.1 shows the resulting abs(*b)* values divided by the standard error in *b*. Values less than 1 indicate that zero slope (b=0) lies within the 95% confidence, and constitutes a passing condition shaded green. The failure threshold is set for ratios above 1 and corresponding cells are shaded red.

Table 3.2.1 Distance Dependence of Mean Bias



Period	CSM	UCSB	EXSIM	G&P	SDSU	GMPE
0.01 to 0.1 s	0.91	2.63	0.36	0.69	0.60	0.16
0.1 to 1.0 s	0.72	2.65	0.64	0.59	0.19	0.88
1 to 3 s	1.18	2.28	0.48	0.43	0.02	0.68
greater than 3 s	1.32	0.97	0.36	0.97	0.42	0.42

The ratio of the absolute value of slope of a best fit line between data from 4 distance bins (see Figure 1), and the 95% estimate of the slope. The weighted least squares fit for the best line used the number of discrete periods and stations in each period bin to weight each data point.

A complete inventory of plots similar to those in Figure 1 is provided for each simulation method and period range in Appendix C.

Our synthesis of the results is as follows:

- CSM: Problematic with respect to slope in 2 of 4 period bands. Overall assessment: does not pass.
- UCSB: Problematic with respect to slope in 3 of 4 period bands. The strong distance trend makes judgment of overall bias difficult to judge. Overall assessment: does not pass.

- EXSIM, G&P and SDSU: Good performance with respect to slope in all period bands. Unbiased at short periods but negative bias (overprediction) at long periods. Overall assessment: pass. It is also notable that, over the 0.1-1 s and 1-3 s period bins, these three methods performed better than the GMPEs by this measure.

On the basis of these analyses, the panel recommends the use of EXSIM, G&P, and SDSU simulation methods, but with the understanding that long period ground motion are biased for the latter two methods. It is likely that this bias is related to the use of 1D as opposed to 3D modeling.

The distance bias analysis above has proved very helpful; however future efforts should utilize the station-distance information directly rather than using lumped data from relatively wide distance bins. Analyzing the data in this way would obviate the need for weighting data.

3.3 Comparison of Results with GMPE for the same event, station combinations

In this subsection, we examine misfit metrics normalized to the corresponding misfits obtained by application of the GMPEs to the Part A data set. That procedure provides an objective standard for assessing the magnitude of the misfits, while implicitly providing an allowance for possible systematic event terms (since the latter would affect simulation- and GMPE-derived misfits similarly). The mean bias (Tables 3.1.2), and the mean absolute-bias were both considered in this measure. If there is a significant period dependent trend in the bias estimate it could still have a low mean bias, which would not be captured by the summary plots discussed in Section 3.1. Therefore we combined the two metrics using the following relationship,

$y_{\mathrm{mod}el} = w \cdot \left|\langle x \rangle\right| + (1-w) \cdot \langle |x| \rangle$, where

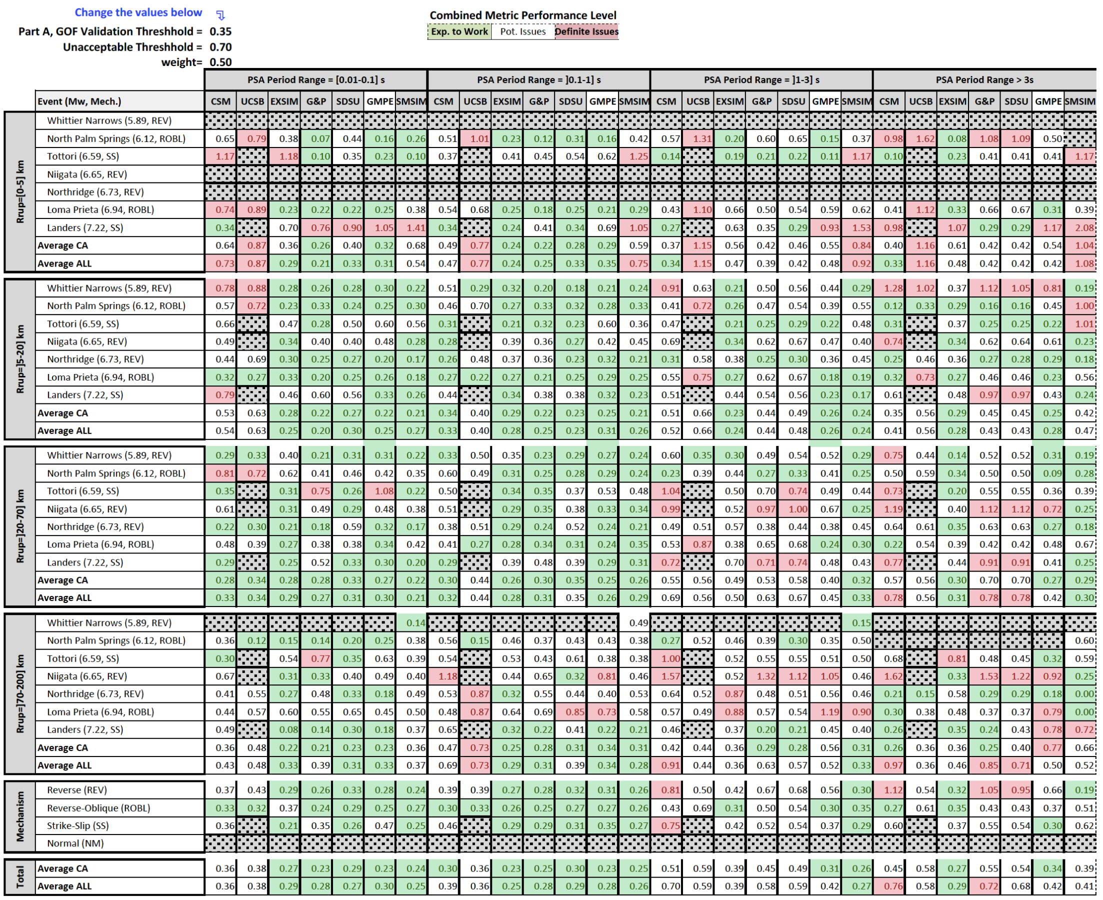
w is a weight (set to 0.5), $|\,|$ denotes absolute value, and $\langle\ \rangle$ denotes computation of the mean. x is the GOF parameter, ln(obs/sim).

Before normalizing y_{model} to the corresponding metric y_{GMPE} obtained using GMPE estimates for the Part A spectra, we show the raw y_{model} values in Table 3.3.1, with shading assuming pass and fail thresholds of 0.35 and 0.70 in natural logarithm units, respectively. This method confirms the observations made in Section 3.1.

Table 3.3.2 shows the ratio, $y_{\mathrm{mod}el} / y_{GMPE}$ where values less than 1 indicate superior performance of the simulations with respect to GMPEs. The results show that EXSIM, G&P and SDSU perform well with respect to the GMPEs with numerous cases in which they outperform them. The exception is for periods greater than 1 s, where as already reported the simulation methods collectively over-predict ground motion.

These finite-source simulation methods are also shown to perform better than the point-source simulation method (SMSIM) in the near-fault distance range.

CSM and UCSB are problematic in numerous cases for the combined metric, with both systematically underperforming compared to GMPEs.



Change the values below ↲

Part A, GOF Validation Threshhold = 0.35

Unacceptable Threshhold = 0.70

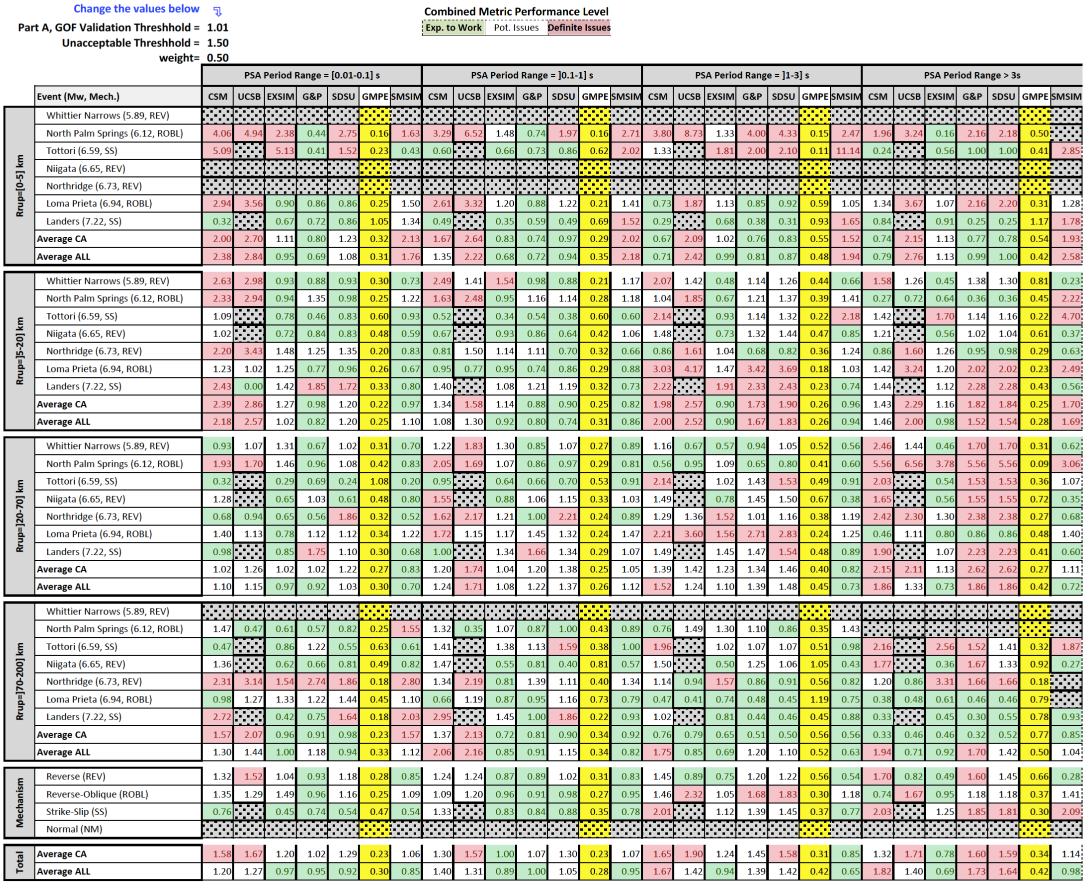
weight= 0.50

Combined Metric Performance Level

🟩 Exp. to Work | Pot. Issues | 🟥 Definite Issues

		PSA Period Range = [0.01-0.1] s							PSA Period Range =]0.1-1] s							PSA Period Range =]1-3] s							PSA Period Range > 3s						
	Event (Mw, Mech.)	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM
Rrup=[0-5] km	Whittier Narrows (5.89, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	North Palm Springs (6.12, ROBL)	0.65	0.79	0.38	0.07	0.44	0.16	0.26	0.51	1.01	0.23	0.12	0.31	0.16	0.42	0.57	1.31	0.20	0.60	0.65	0.15	0.37	0.98	1.62	0.08	1.08	1.09	0.50	▨
	Tottori (6.59, SS)	1.17	▨	1.18	0.10	0.35	0.23	0.10	0.37	▨	0.41	0.45	0.54	0.62	1.25	0.14	▨	0.19	0.21	0.22	0.11	1.17	0.10	▨	0.23	0.41	0.41	0.41	1.17
	Niigata (6.65, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Northridge (6.73, REV)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
	Loma Prieta (6.94, ROBL)	0.74	0.89	0.23	0.22	0.22	0.25	0.38	0.54	0.68	0.25	0.18	0.25	0.21	0.29	0.43	1.10	0.66	0.50	0.54	0.59	0.62	0.41	1.12	0.33	0.66	0.67	0.31	0.39
	Landers (7.22, SS)	0.34	▨	0.70	0.76	0.90	1.05	1.41	0.34	▨	0.24	0.41	0.34	0.69	1.05	0.27	▨	0.63	0.35	0.29	0.93	1.53	0.98	▨	1.07	0.29	0.29	1.17	2.08
	Average CA	0.64	0.87	0.36	0.26	0.40	0.32	0.68	0.49	0.77	0.24	0.22	0.28	0.29	0.59	0.37	1.15	0.56	0.42	0.46	0.55	0.84	0.40	1.16	0.61	0.42	0.42	0.54	1.04
	Average ALL	0.73	0.87	0.29	0.21	0.33	0.31	0.54	0.47	0.77	0.24	0.25	0.33	0.35	0.75	0.34	1.15	0.47	0.39	0.42	0.48	0.92	0.33	1.16	0.48	0.42	0.42	0.42	1.08
Rrup=]5-20] km	Whittier Narrows (5.89, REV)	0.78	0.88	0.28	0.26	0.28	0.30	0.22	0.51	0.29	0.32	0.20	0.18	0.21	0.24	0.91	0.63	0.21	0.50	0.56	0.44	0.29	1.28	1.02	0.37	1.12	1.05	0.81	0.19
	North Palm Springs (6.12, ROBL)	0.57	0.72	0.23	0.33	0.24	0.25	0.30	0.46	0.70	0.27	0.33	0.32	0.28	0.33	0.41	0.72	0.26	0.47	0.54	0.39	0.55	0.12	0.33	0.29	0.16	0.16	0.45	1.00
	Tottori (6.59, SS)	0.66	▨	0.47	0.28	0.50	0.60	0.56	0.31	▨	0.21	0.32	0.23	0.60	0.36	0.47	▨	0.21	0.25	0.29	0.22	0.48	0.31	▨	0.37	0.25	0.25	0.22	1.01
	Niigata (6.65, REV)	0.49	▨	0.34	0.40	0.40	0.48	0.28	0.28	▨	0.39	0.36	0.27	0.42	0.45	0.69	▨	0.34	0.62	0.67	0.47	0.40	0.74	▨	0.34	0.62	0.64	0.61	0.23
	Northridge (6.73, REV)	0.44	0.69	0.30	0.25	0.27	0.20	0.17	0.26	0.48	0.37	0.36	0.23	0.32	0.21	0.31	0.58	0.38	0.25	0.30	0.36	0.45	0.25	0.46	0.36	0.27	0.28	0.29	0.18
	Loma Prieta (6.94, ROBL)	0.32	0.27	0.33	0.20	0.25	0.26	0.18	0.27	0.22	0.27	0.21	0.25	0.29	0.25	0.55	0.75	0.27	0.62	0.67	0.18	0.19	0.32	0.73	0.27	0.46	0.46	0.23	0.56
	Landers (7.22, SS)	0.79	▨	0.46	0.60	0.56	0.33	0.26	0.44	▨	0.34	0.38	0.38	0.32	0.23	0.51	▨	0.44	0.54	0.56	0.23	0.17	0.61	▨	0.48	0.97	0.97	0.43	0.24
	Average CA	0.53	0.63	0.28	0.22	0.27	0.22	0.21	0.34	0.40	0.29	0.22	0.23	0.25	0.21	0.51	0.66	0.23	0.44	0.49	0.26	0.24	0.35	0.56	0.29	0.45	0.45	0.25	0.42
	Average ALL	0.54	0.63	0.25	0.20	0.30	0.25	0.27	0.33	0.40	0.28	0.25	0.23	0.31	0.26	0.52	0.66	0.24	0.44	0.48	0.26	0.24	0.41	0.56	0.28	0.43	0.43	0.28	0.47
Rrup=]20-70] km	Whittier Narrows (5.89, REV)	0.29	0.33	0.40	0.21	0.31	0.31	0.22	0.33	0.50	0.35	0.23	0.29	0.27	0.24	0.60	0.35	0.30	0.49	0.54	0.52	0.29	0.75	0.44	0.14	0.52	0.52	0.31	0.19
	North Palm Springs (6.12, ROBL)	0.81	0.72	0.62	0.41	0.46	0.42	0.35	0.60	0.49	0.31	0.25	0.28	0.29	0.24	0.23	0.39	0.44	0.27	0.33	0.41	0.25	0.50	0.59	0.34	0.50	0.50	0.09	0.28
	Tottori (6.59, SS)	0.35	▨	0.31	0.75	0.26	1.08	0.22	0.50	▨	0.34	0.35	0.37	0.53	0.48	1.04	▨	0.50	0.70	0.74	0.49	0.44	0.73	▨	0.20	0.55	0.55	0.36	0.39
	Niigata (6.65, REV)	0.61	▨	0.31	0.49	0.29	0.48	0.38	0.51	▨	0.29	0.35	0.38	0.33	0.34	0.99	▨	0.52	0.97	1.00	0.67	0.25	1.19	▨	0.40	1.12	1.12	0.72	0.25
	Northridge (6.73, REV)	0.22	0.30	0.21	0.18	0.59	0.32	0.17	0.38	0.51	0.29	0.24	0.52	0.24	0.21	0.49	0.51	0.57	0.38	0.44	0.38	0.45	0.64	0.61	0.35	0.63	0.63	0.27	0.18
	Loma Prieta (6.94, ROBL)	0.48	0.39	0.27	0.38	0.38	0.34	0.42	0.41	0.27	0.28	0.34	0.31	0.24	0.35	0.53	0.87	0.38	0.65	0.68	0.24	0.30	0.22	0.54	0.39	0.42	0.42	0.48	0.67
	Landers (7.22, SS)	0.29	▨	0.25	0.52	0.33	0.30	0.20	0.29	▨	0.39	0.48	0.39	0.29	0.31	0.72	▨	0.70	0.71	0.74	0.48	0.43	0.77	▨	0.44	0.91	0.91	0.41	0.25
	Average CA	0.28	0.34	0.28	0.28	0.33	0.27	0.22	0.30	0.44	0.26	0.30	0.35	0.25	0.26	0.55	0.56	0.49	0.53	0.58	0.40	0.32	0.57	0.56	0.30	0.70	0.70	0.27	0.29
	Average ALL	0.33	0.34	0.29	0.27	0.31	0.30	0.21	0.32	0.44	0.28	0.31	0.35	0.26	0.29	0.69	0.56	0.50	0.63	0.67	0.45	0.33	0.78	0.56	0.31	0.78	0.78	0.42	0.30
Rrup=]70-200] km	Whittier Narrows (5.89, REV)	▨	▨	▨	▨	▨	▨	0.14	▨	▨	▨	▨	▨	▨	0.49	▨	▨	▨	▨	▨	▨	0.15	▨	▨	▨	▨	▨	▨	▨
	North Palm Springs (6.12, ROBL)	0.36	0.12	0.15	0.14	0.20	0.25	0.38	0.56	0.15	0.46	0.37	0.43	0.43	0.38	0.27	0.52	0.46	0.39	0.30	0.35	0.50	▨	▨	▨	▨	▨	▨	0.60
	Tottori (6.59, SS)	0.30	▨	0.54	0.77	0.35	0.63	0.39	0.54	▨	0.53	0.43	0.61	0.38	0.38	1.00	▨	0.52	0.55	0.55	0.51	0.50	0.68	▨	0.81	0.48	0.45	0.32	0.59
	Niigata (6.65, REV)	0.67	▨	0.31	0.33	0.40	0.49	0.40	1.18	▨	0.44	0.65	0.32	0.81	0.46	1.57	▨	0.52	1.32	1.12	1.05	0.46	1.62	▨	0.33	1.53	1.22	0.92	0.25
	Northridge (6.73, REV)	0.41	0.55	0.27	0.48	0.33	0.18	0.49	0.53	0.87	0.32	0.55	0.44	0.40	0.53	0.64	0.52	0.87	0.48	0.51	0.56	0.46	0.21	0.15	0.58	0.29	0.29	0.18	0.00
	Loma Prieta (6.94, ROBL)	0.44	0.57	0.60	0.55	0.65	0.45	0.50	0.48	0.87	0.64	0.69	0.85	0.73	0.58	0.57	0.49	0.88	0.57	0.54	1.19	0.90	0.30	0.38	0.48	0.37	0.37	0.79	0.00
	Landers (7.22, SS)	0.49	▨	0.08	0.14	0.30	0.18	0.37	0.65	▨	0.32	0.22	0.41	0.22	0.21	0.46	▨	0.37	0.20	0.21	0.45	0.40	0.26	▨	0.35	0.24	0.43	0.78	0.72
	Average CA	0.36	0.48	0.22	0.21	0.23	0.23	0.36	0.47	0.73	0.25	0.28	0.31	0.34	0.31	0.42	0.44	0.36	0.29	0.28	0.56	0.31	0.26	0.36	0.36	0.25	0.40	0.77	0.66
	Average ALL	0.43	0.48	0.33	0.39	0.31	0.33	0.37	0.69	0.73	0.29	0.31	0.39	0.34	0.28	0.91	0.44	0.36	0.63	0.57	0.52	0.33	0.97	0.36	0.46	0.85	0.71	0.50	0.52
Mechanism	Reverse (REV)	0.37	0.43	0.29	0.26	0.33	0.28	0.24	0.39	0.39	0.27	0.28	0.32	0.31	0.26	0.81	0.50	0.42	0.67	0.68	0.56	0.30	1.12	0.54	0.32	1.05	0.95	0.66	0.19
	Reverse-Oblique (ROBL)	0.33	0.32	0.37	0.24	0.29	0.25	0.27	0.30	0.33	0.26	0.25	0.27	0.27	0.26	0.43	0.69	0.31	0.50	0.54	0.30	0.35	0.27	0.61	0.35	0.43	0.43	0.37	0.51
	Strike-Slip (SS)	0.36	▨	0.21	0.35	0.26	0.47	0.25	0.46	▨	0.29	0.29	0.31	0.35	0.27	0.75	▨	0.42	0.52	0.54	0.37	0.29	0.60	▨	0.37	0.55	0.54	0.30	0.62
	Normal (NM)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Total	**Average CA**	0.36	0.38	0.27	0.23	0.29	0.23	0.24	0.30	0.36	0.23	0.25	0.30	0.23	0.25	0.51	0.59	0.39	0.45	0.49	0.31	0.26	0.45	0.58	0.27	0.55	0.54	0.34	0.39
	Average ALL	0.36	0.38	0.29	0.28	0.27	0.30	0.25	0.39	0.36	0.25	0.28	0.29	0.28	0.26	0.70	0.59	0.39	0.58	0.59	0.42	0.27	0.76	0.58	0.29	0.72	0.68	0.42	0.41

Table 3.3.1. y_{SIM} with pass and fail thresholds of 0.35 and 0.70 in natural logarithm units.



Change the values below ⮷

Part A, GOF Validation Threshhold = 1.01

Unacceptable Threshhold = 1.50

weight= 0.50

Combined Metric Performance Level

🟩 Exp. to Work	Pot. Issues	🟥 Definite Issues

		PSA Period Range = [0.01-0.1] s							PSA Period Range =]0.1-1] s						
	Event (Mw, Mech.)	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM
Rrup=[0-5] km	Whittier Narrows (5.89, REV)														
	North Palm Springs (6.12, ROBL)	4.06	4.94	2.38	0.44	2.75	0.16	1.63	3.29	6.52	1.48	0.74	1.97	0.16	2.71
	Tottori (6.59, SS)	5.09		5.13	0.41	1.52	0.23	0.43	0.60		0.66	0.73	0.86	0.62	2.02
	Niigata (6.65, REV)														
	Northridge (6.73, REV)														
	Loma Prieta (6.94, ROBL)	2.94	3.56	0.90	0.86	0.86	0.25	1.50	2.61	3.32	1.20	0.88	1.22	0.21	1.41
	Landers (7.22, SS)	0.32		0.67	0.72	0.86	1.05	1.34	0.49		0.35	0.59	0.49	0.69	1.52
	Average CA	2.00	2.70	1.11	0.80	1.23	0.32	2.13	1.67	2.64	0.83	0.74	0.97	0.29	2.02
	Average ALL	2.38	2.84	0.95	0.69	1.08	0.31	1.76	1.35	2.22	0.68	0.72	0.94	0.35	2.18
Rrup=]5-20] km	Whittier Narrows (5.89, REV)	2.63	2.98	0.93	0.88	0.93	0.30	0.73	2.49	1.41	1.54	0.98	0.88	0.21	1.17
	North Palm Springs (6.12, ROBL)	2.33	2.94	0.94	1.35	0.98	0.25	1.22	1.63	2.48	0.95	1.16	1.14	0.28	1.18
	Tottori (6.59, SS)	1.09		0.78	0.46	0.83	0.60	0.93	0.52		0.34	0.54	0.38	0.60	0.60
	Niigata (6.65, REV)	1.02		0.72	0.84	0.83	0.48	0.59	0.67		0.93	0.86	0.64	0.42	1.06
	Northridge (6.73, REV)	2.20	3.43	1.48	1.25	1.35	0.20	0.83	0.81	1.50	1.14	1.11	0.70	0.32	0.66
	Loma Prieta (6.94, ROBL)	1.23	1.02	1.25	0.77	0.96	0.26	0.67	0.95	0.77	0.95	0.74	0.86	0.29	0.88
	Landers (7.22, SS)	2.43	0.00	1.42	1.85	1.72	0.33	0.80	1.40		1.08	1.21	1.19	0.32	0.73
	Average CA	2.39	2.86	1.27	0.98	1.20	0.22	0.97	1.34	1.58	1.14	0.88	0.90	0.25	0.82
	Average ALL	2.18	2.57	1.02	0.82	1.20	0.25	1.10	1.08	1.30	0.92	0.80	0.74	0.31	0.86
Rrup=]20-70] km	Whittier Narrows (5.89, REV)	0.93	1.07	1.31	0.67	1.02	0.31	0.70	1.22	1.83	1.30	0.85	1.07	0.27	0.89
	North Palm Springs (6.12, ROBL)	1.93	1.70	1.46	0.96	1.08	0.42	0.83	2.05	1.69	1.07	0.86	0.97	0.29	0.81
	Tottori (6.59, SS)	0.32		0.29	0.69	0.24	1.08	0.20	0.95		0.64	0.66	0.70	0.53	0.91
	Niigata (6.65, REV)	1.28		0.65	1.03	0.61	0.48	0.80	1.55		0.88	1.06	1.15	0.33	1.03
	Northridge (6.73, REV)	0.68	0.94	0.65	0.56	1.86	0.32	0.52	1.62	2.17	1.21	1.00	2.21	0.24	0.89
	Loma Prieta (6.94, ROBL)	1.40	1.13	0.78	1.12	1.12	0.34	1.22	1.72	1.15	1.17	1.45	1.32	0.24	1.47
	Landers (7.22, SS)	0.98		0.85	1.75	1.10	0.30	0.68	1.00		1.34	1.66	1.34	0.29	1.07
	Average CA	1.02	1.26	1.02	1.02	1.22	0.27	0.83	1.20	1.74	1.04	1.20	1.38	0.25	1.05
	Average ALL	1.10	1.15	0.97	0.92	1.03	0.30	0.70	1.24	1.71	1.08	1.22	1.37	0.26	1.12
Rrup=]70-200] km	Whittier Narrows (5.89, REV)														
	North Palm Springs (6.12, ROBL)	1.47	0.47	0.61	0.57	0.82	0.25	1.55	1.32	0.35	1.07	0.87	1.00	0.43	0.89
	Tottori (6.59, SS)	0.47		0.86	1.22	0.55	0.63	0.61	1.41		1.38	1.13	1.59	0.38	1.00
	Niigata (6.65, REV)	1.36		0.62	0.66	0.81	0.49	0.82	1.47		0.55	0.81	0.40	0.81	0.57
	Northridge (6.73, REV)	2.31	3.14	1.54	2.74	1.86	0.18	2.80	1.34	2.19	0.81	1.39	1.11	0.40	1.34
	Loma Prieta (6.94, ROBL)	0.98	1.27	1.33	1.22	1.44	0.45	1.10	0.66	1.19	0.87	0.95	1.16	0.73	0.79
	Landers (7.22, SS)	2.72		0.42	0.75	1.64	0.18	2.03	2.95		1.45	1.00	1.86	0.22	0.93
	Average CA	1.57	2.07	0.96	0.91	0.98	0.23	1.57	1.37	2.13	0.72	0.81	0.90	0.34	0.92
	Average ALL	1.30	1.44	1.00	1.18	0.94	0.33	1.12	2.06	2.16	0.85	0.91	1.15	0.34	0.82
Mechanism	Reverse (REV)	1.32	1.52	1.04	0.93	1.18	0.28	0.85	1.24	1.24	0.87	0.89	1.02	0.31	0.83
	Reverse-Oblique (ROBL)	1.35	1.29	1.49	0.96	1.16	0.25	1.09	1.09	1.20	0.96	0.91	0.98	0.27	0.95
	Strike-Slip (SS)	0.76		0.45	0.74	0.54	0.47	0.54	1.33		0.83	0.84	0.88	0.35	0.78
	Normal (NM)														
Total	**Average CA**	1.58	1.67	1.20	1.02	1.29	0.23	1.06	1.30	1.57	1.00	1.07	1.30	0.23	1.07
	Average ALL	1.20	1.27	0.97	0.95	0.92	0.30	0.85	1.40	1.31	0.89	1.00	1.05	0.28	0.95

		PSA Period Range =]1-3] s							PSA Period Range > 3s						
	Event (Mw, Mech.)	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM	CSM	UCSB	EXSIM	G&P	SDSU	GMPE	SMSIM
Rrup=[0-5] km	Whittier Narrows (5.89, REV)														
	North Palm Springs (6.12, ROBL)	3.80	8.73	1.33	4.00	4.33	0.15	2.47	1.96	3.24	0.16	2.16	2.18	0.50	
	Tottori (6.59, SS)	1.33		1.81	2.00	2.10	0.11	11.14	0.24		0.56	1.00	1.00	0.41	2.85
	Niigata (6.65, REV)														
	Northridge (6.73, REV)														
	Loma Prieta (6.94, ROBL)	0.73	1.87	1.13	0.85	0.92	0.59	1.05	1.34	3.67	1.07	2.16	2.20	0.31	1.28
	Landers (7.22, SS)	0.29		0.68	0.38	0.31	0.93	1.65	0.84		0.91	0.25	0.25	1.17	1.78
	Average CA	0.67	2.09	1.02	0.76	0.83	0.55	1.52	0.74	2.15	1.13	0.77	0.78	0.54	1.93
	Average ALL	0.71	2.42	0.99	0.81	0.87	0.48	1.94	0.79	2.76	1.13	0.99	1.00	0.42	2.58
Rrup=]5-20] km	Whittier Narrows (5.89, REV)	2.07	1.42	0.48	1.14	1.26	0.44	0.66	1.58	1.26	0.45	1.38	1.30	0.81	0.23
	North Palm Springs (6.12, ROBL)	1.04	1.85	0.67	1.21	1.37	0.39	1.41	0.27	0.72	0.64	0.36	0.36	0.45	2.22
	Tottori (6.59, SS)	2.14		0.93	1.14	1.32	0.22	2.18	1.42		1.70	1.14	1.16	0.22	4.70
	Niigata (6.65, REV)	1.48		0.73	1.32	1.44	0.47	0.85	1.21		0.56	1.02	1.04	0.61	0.37
	Northridge (6.73, REV)	0.86	1.61	1.04	0.68	0.82	0.36	1.24	0.86	1.60	1.26	0.95	0.98	0.29	0.63
	Loma Prieta (6.94, ROBL)	3.03	4.17	1.47	3.42	3.69	0.18	1.03	1.42	3.24	1.20	2.02	2.02	0.23	2.49
	Landers (7.22, SS)	2.22		1.91	2.33	2.43	0.23	0.74	1.44		1.12	2.28	2.28	0.43	0.56
	Average CA	1.98	2.57	0.90	1.73	1.90	0.26	0.96	1.43	2.29	1.16	1.82	1.84	0.25	1.70
	Average ALL	2.00	2.52	0.90	1.67	1.83	0.26	0.94	1.46	2.00	0.98	1.52	1.54	0.28	1.69
Rrup=]20-70] km	Whittier Narrows (5.89, REV)	1.16	0.67	0.57	0.94	1.05	0.52	0.56	2.46	1.44	0.46	1.70	1.70	0.31	0.62
	North Palm Springs (6.12, ROBL)	0.56	0.95	1.09	0.65	0.80	0.41	0.60	5.56	6.56	3.78	5.56	5.56	0.09	3.06
	Tottori (6.59, SS)	2.14		1.02	1.43	1.53	0.49	0.91	2.03		0.54	1.53	1.53	0.36	1.07
	Niigata (6.65, REV)	1.49		0.78	1.45	1.50	0.67	0.38	1.65		0.56	1.55	1.55	0.72	0.35
	Northridge (6.73, REV)	1.29	1.36	1.52	1.01	1.16	0.38	1.19	2.42	2.30	1.30	2.38	2.38	0.27	0.68
	Loma Prieta (6.94, ROBL)	2.21	3.60	1.56	2.71	2.83	0.24	1.25	0.46	1.11	0.80	0.86	0.86	0.48	1.40
	Landers (7.22, SS)	1.49		1.45	1.47	1.54	0.48	0.89	1.90		1.07	2.23	2.23	0.41	0.60
	Average CA	1.39	1.42	1.23	1.34	1.46	0.40	0.82	2.15	2.11	1.13	2.62	2.62	0.27	1.11
	Average ALL	1.52	1.24	1.10	1.39	1.48	0.45	0.73	1.86	1.33	0.73	1.86	1.86	0.42	0.72
Rrup=]70-200] km	Whittier Narrows (5.89, REV)														
	North Palm Springs (6.12, ROBL)	0.76	1.49	1.30	1.10	0.86	0.35	1.43							
	Tottori (6.59, SS)	1.96		1.02	1.07	1.07	0.51	0.98	2.16		2.56	1.52	1.41	0.32	1.87
	Niigata (6.65, REV)	1.50		0.50	1.25	1.06	1.05	0.43	1.77		0.36	1.67	1.33	0.92	0.27
	Northridge (6.73, REV)	1.14	0.94	1.57	0.86	0.91	0.56	0.82	1.20	0.86	3.31	1.66	1.66	0.18	
	Loma Prieta (6.94, ROBL)	0.47	0.41	0.74	0.48	0.45	1.19	0.75	0.38	0.48	0.61	0.46	0.46	0.79	
	Landers (7.22, SS)	1.02		0.81	0.44	0.46	0.45	0.88	0.33		0.45	0.30	0.55	0.78	0.93
	Average CA	0.76	0.79	0.65	0.51	0.50	0.56	0.56	0.33	0.46	0.46	0.32	0.52	0.77	0.85
	Average ALL	1.75	0.85	0.69	1.20	1.10	0.52	0.63	1.94	0.71	0.92	1.70	1.42	0.50	1.04
Mechanism	Reverse (REV)	1.45	0.89	0.75	1.20	1.22	0.56	0.54	1.70	0.82	0.49	1.60	1.45	0.66	0.28
	Reverse-Oblique (ROBL)	1.46	2.32	1.05	1.68	1.83	0.30	1.18	0.74	1.67	0.95	1.18	1.18	0.37	1.41
	Strike-Slip (SS)	2.01		1.12	1.39	1.45	0.37	0.77	2.03		1.25	1.85	1.81	0.30	2.09
	Normal (NM)														
Total	**Average CA**	1.65	1.90	1.24	1.45	1.58	0.31	0.85	1.32	1.71	0.78	1.60	1.59	0.34	1.14
	Average ALL	1.67	1.42	0.94	1.39	1.42	0.42	0.65	1.82	1.40	0.69	1.73	1.64	0.42	0.98

Table 3.3.2. y_{SIM}/y_{GMPE} with pass (green) and fail (red) thresholds of 1.01 and 1.5. The yellow column is for y_{GMPE}.

3.4 Summary of Part A Validation and Recommendations

Three methods, EXSIM, G&P and SDSU pass the Part A validation. These approaches appear suitable for broadband simulation of PSA over the period range 0.01 to 3 s, and distances from 1 to 200 km considering a mean bias, passing threshold of 0.5 natural log units with the exception that the SDSU method has problems in the 20-70 km distance range from 1-3 s. CSM and UCSB also perform well only showing problems in the near distance range (0-5km).

There are demonstrable systematic distance biases from the CSM and UCSB methods (Table 3.2.1). EXSIM, G&P and SDSU are found to have no distance dependent bias considering the 95% confidence region, and are consistent with the behavior of the GMPE relations. There is a suggestion that the three simulation methods outperform GMPEs in this respect between 0.1 to 1 s period, however the GMPEs have a superior behavior at the high-frequency, short-period passband (0.01 to 0.1 s). All five methods have greater difficulty matching observations at periods greater than 1 s, and at larger distances in the long-period passbands. This is most clearly shown in Table 3.3.1, which combines the mean bias, and the mean absolute bias, as well as in Table 3.3.2, which compares this metric directly with the GMPE. At periods longer than 1 s the simulation methods tend to over-predict the GMPE (demonstrated in section 4). This is likely due to the use of 1D velocity models that do not account for path-specific heterogeneity, and which due to the uniform nature of shallow layers in the model over-excite surface waves.

4. Part B Validation Results

In the figures that follow simulations are compared to four NGA-West2 GMPEs for specific distance, magnitude, and style of faulting cases. The median ground motions from each of the NGA-West2 GMPEs are shown as colored lines, and the average of the four as the black line. Acceptance criteria (dashed lines) were specified from the GMPEs by taking the largest and smallest value of all four GMPEs, adding 15%, and applying uniformly for all periods.

The bar plots show the mean (red square) and the standard deviation (blue box), while error bars show the extrema for all 50 realizations. Each method is plotted in a separate panel and the figures and interpretations are grouped by rupture scenario, station distance and velocity model . The simulations were computed using both a southern California and a northern California velocity model. The results from the point-source method, SMSIM were provided as reference.

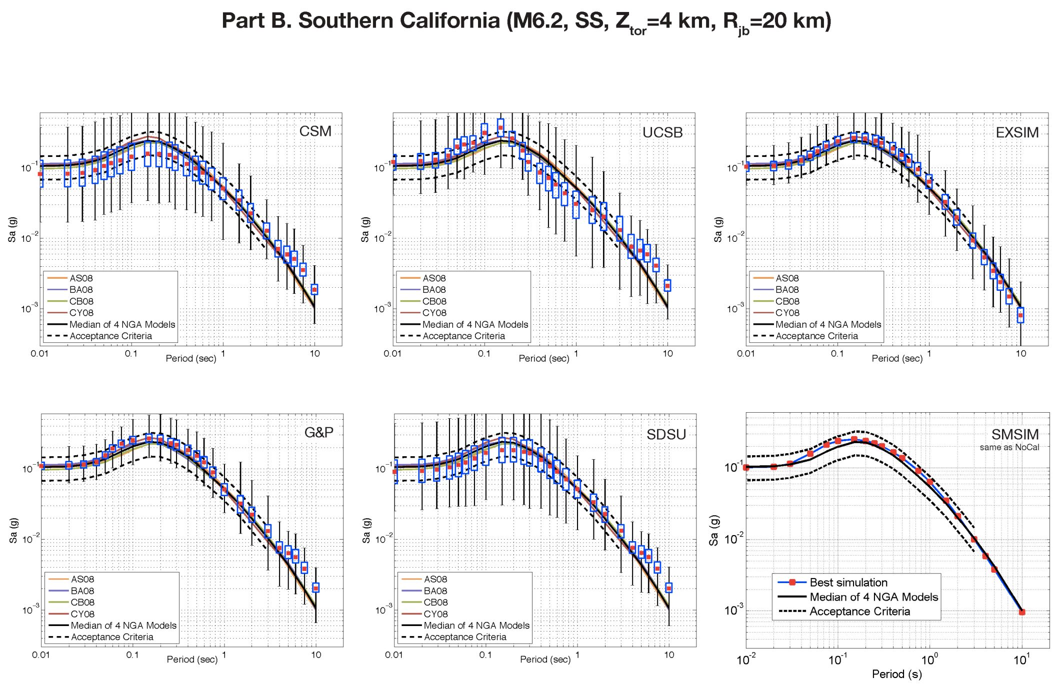
4.1 Southern California Velocity Model

M_w 6.2 Strike-Slip at 20 km distance

Four methods namely CSM, G&P, SDSU and EXSIM pass this validation.

The UCSB method deviates outside of the acceptance criteria upper bound between 0.1 to 0.2 s period, and the lower bound between 0.2 to 1 sd. The spectral shape in the range from 0.1 to 1 s period deviates significantly from that of the mean GMPEs.

All methods, with the exception of EXSIM, generate larger ground motions at periods longer than 3 s.



Part B. Southern California (M6.2, SS, Z_{tor}=4 km, R_{jb}=20 km)

Figure 2. Comparison of Sa with GMPE for a M_W6.2 strike-slip scenario at 20 km distance. Depth to the top of the fault is 4 km. The southern California velocity model was used in the simulations.

M_W 6.2 Strike-Slip at 50 km distance

Three methods namely G&P, SDSU, and EXSIM pass this validation.

The UCSB method lies below the lower bound acceptance criteria between 0.1 to 1 s period. A deviation from the GMPE spectral shape is also noted.

The CSM method lies below the lower bound acceptance criteria between 0.01 to 0.8 s period.

As previously noted all methods, with the exception of EXSIM, predict larger ground motions than do the GMPEs at periods larger than 3 s period.

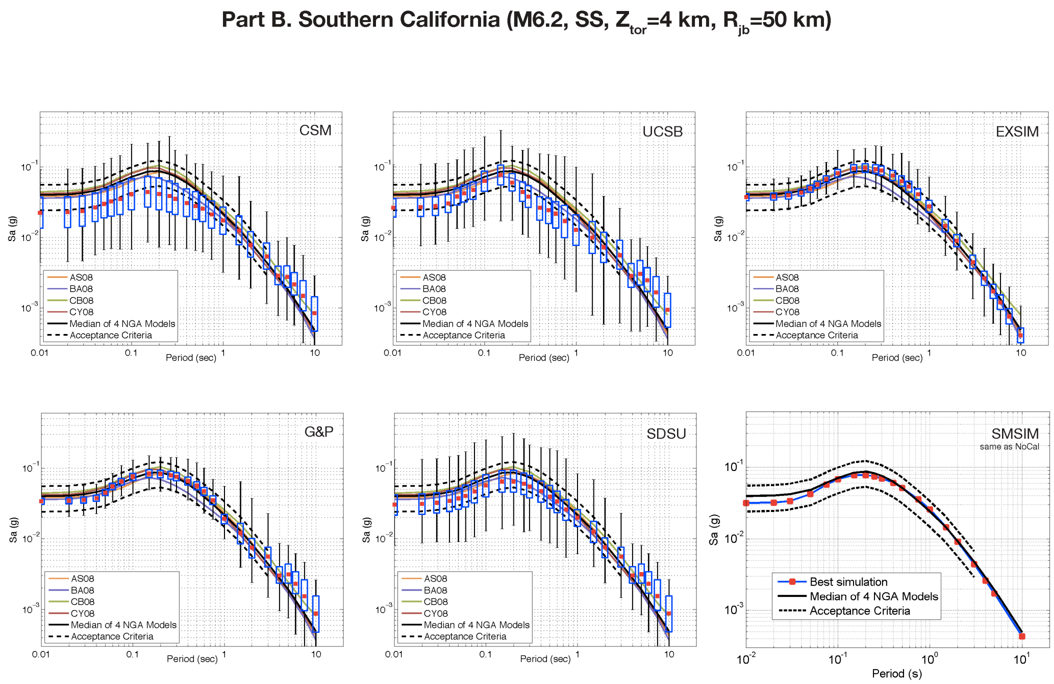


Figure 3. Comparison of Sa with GMPE for a M_W6.2 strike-slip scenario at 50 km distance. Depth to the top of the fault is 4 km. The southern California velocity model was used in the simulations.

M_w 6.6 Strike-Slip at 20 km distance

All five methods pass this validation test. The UCSB marginally passes with only one slight deviation above the upper bound of the acceptance criteria at the single period of 0.15 s.

As previously noted all methods, with the exception of EXSIM predict larger ground motions than do the GMPEs at periods larger than 3 s period.

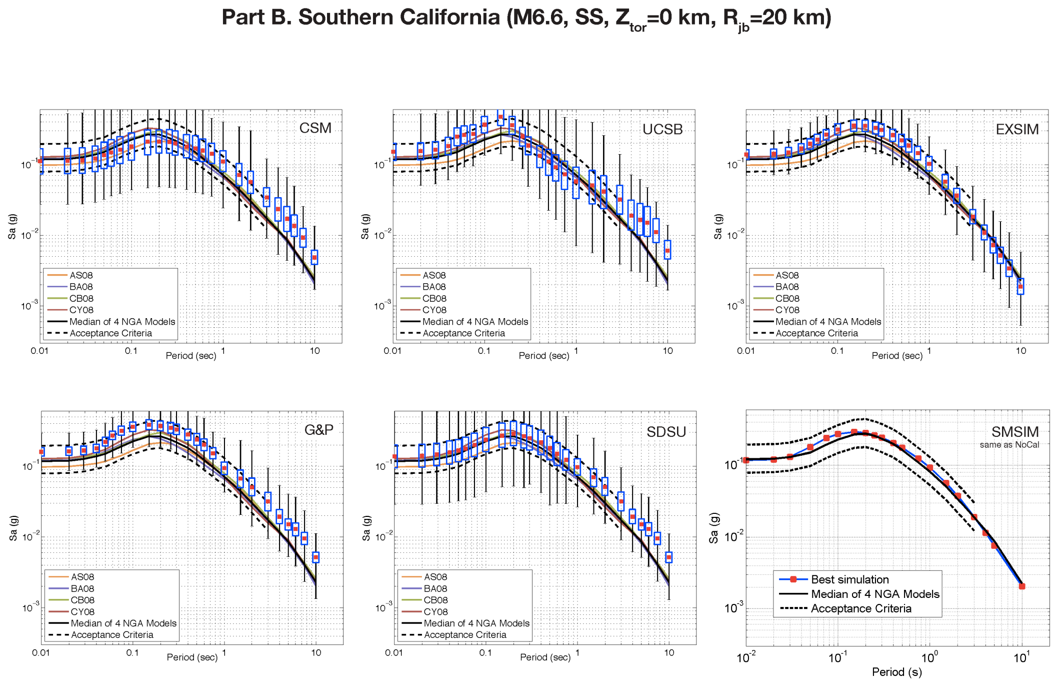


Figure 4. Comparison of Sa with GMPE for a M_W6.6 strike-slip scenario at 20 km distance. Depth to the top of the fault is 0 km. The southern California velocity model was used in the simulations.

M_W 6.6 Strike-Slip at 50 km distance

Three methods G&P, SDSU, and EXSIM pass this validation test.

The CSM and UCSB method marginally pass. Both methods are observed to lie on the lower bound acceptance criteria from 0.1 to 1 s period. It is noted that in both of these methods there is a significant deviation from the GMPE spectral shape.

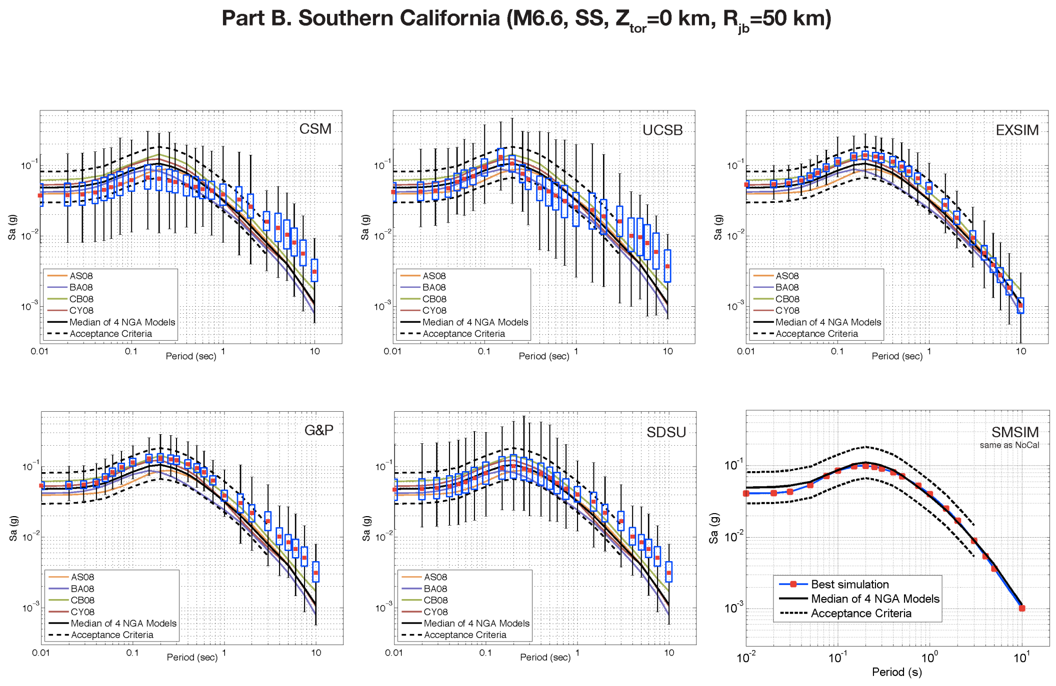


Figure 5. Comparison of Sa with GMPE for a M_W6.6 strike-slip scenario at 50 km distance. Depth to the top of the fault is 0 km. The southern California velocity model was used in the simulations.

M_W 6.6 Reverse-Slip at 20 km distance

Three methods G&P, SDSU and EXSIM pass this validation test.

The CSM method predicts motions below the lower bound acceptance criteria from 0.01 to 0.3 s period.

The UCSB method predicts motions above the upper bound acceptance criteria from 0.04 to 0.2 s period.

The CSM and UCSB method deviate significantly from the GMPE spectral shape.

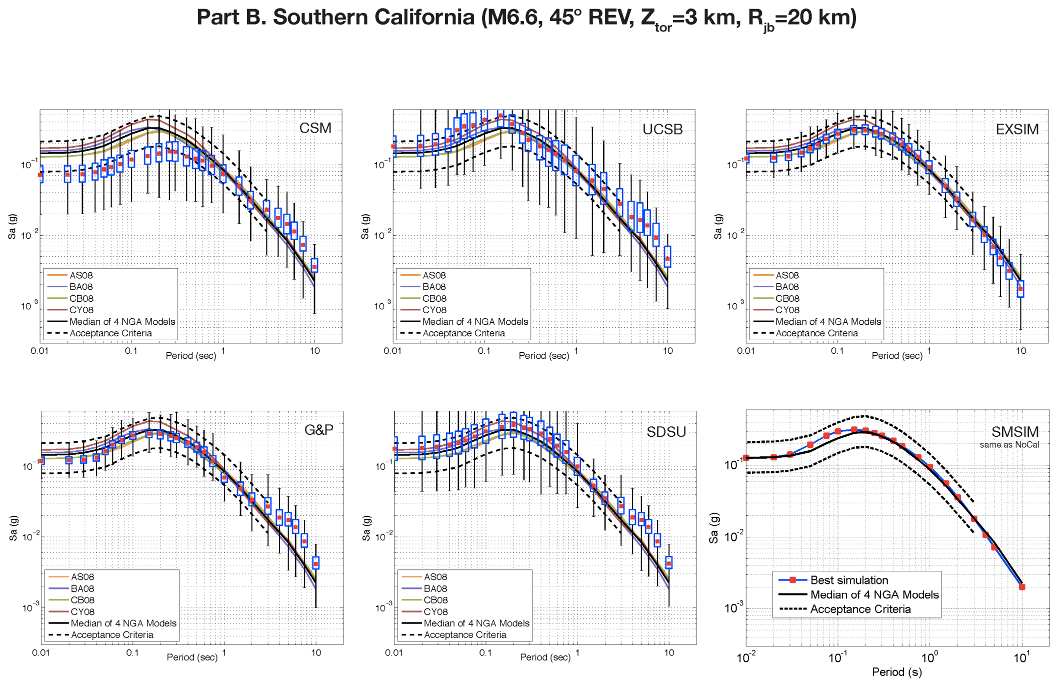


Figure 6. Comparison of Sa with GMPE for a M_W6.6 reverse-slip scenario at 20 km distance. Depth to the top of the fault is 3 km. The southern California velocity model was used in the simulations.

M_w 6.6 Reverse-Slip at 50 km distance

Four methods UCSB, G&P, SDSU and EXSIM pass this validation test.

The CSM method predicts motions below the lower bound acceptance criteria from 0.01 to 0.8 s period.

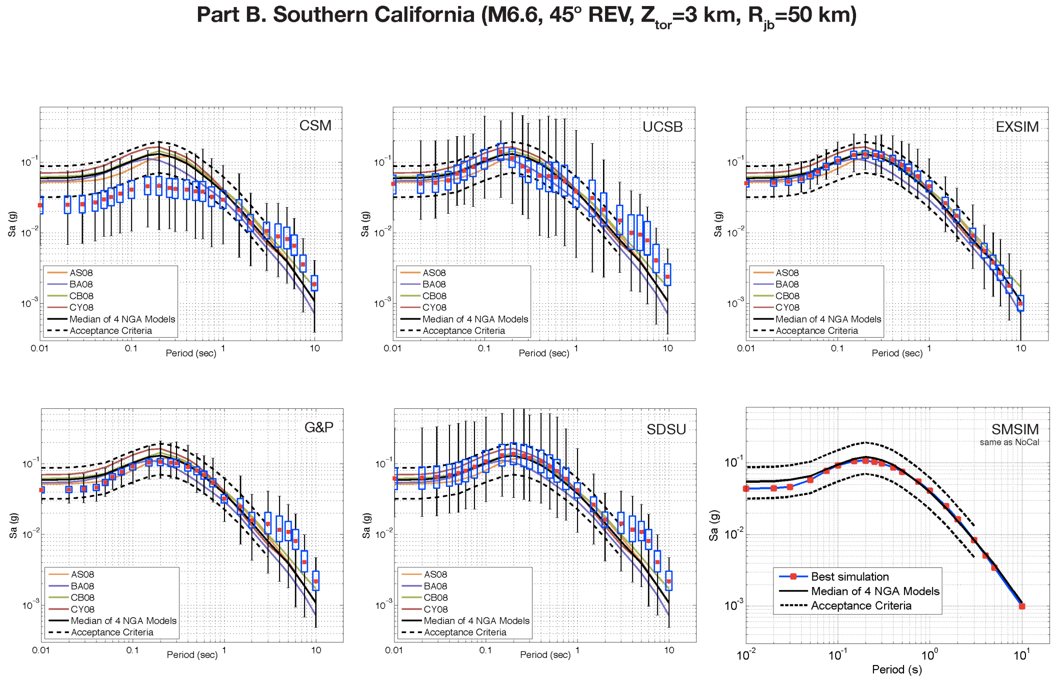


Figure 7. Comparison of Sa with GMPE for a M_w6.6 reverse-slip scenario at 50 km distance. Depth to the top of the fault is 3 km. The southern California velocity model was used in the simulations.

4.2 Northern California Velocity Model

M_W 6.2 Strike-Slip at 20 km distance

Four methods CSM, G&P, SDSU and EXSIM pass this validation test.

The UCSB method deviates above the upper bound acceptance criteria from 0.01 to 0.2 s period.

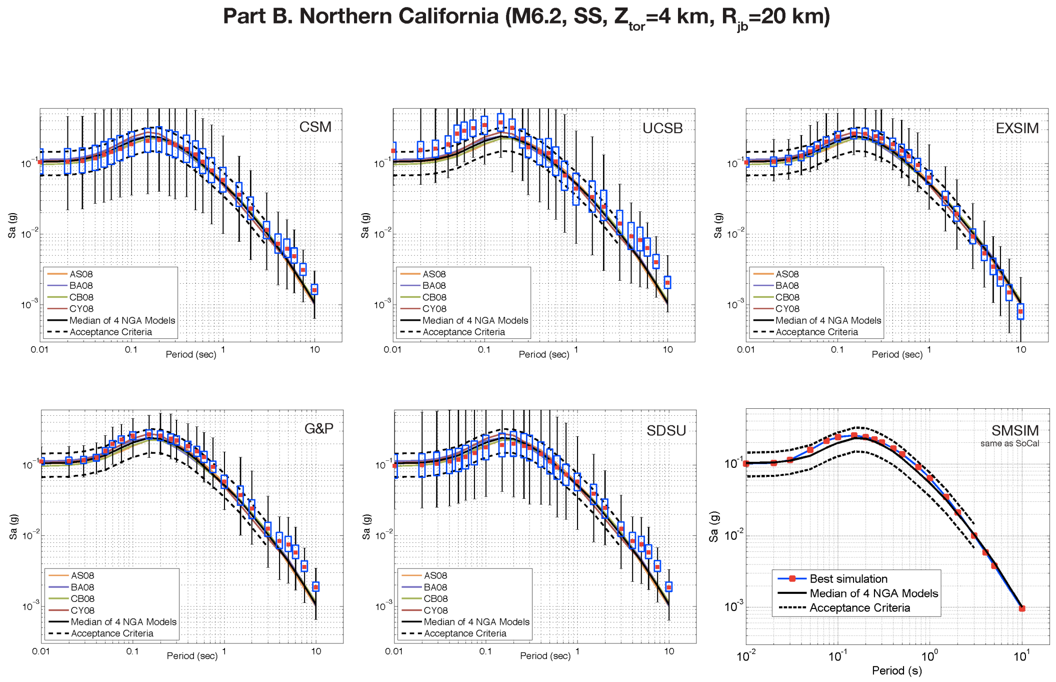


Figure 8. Comparison of Sa with GMPE for a M_W6.2 strike-slip scenario at 20 km distance. Depth to the top of the fault is 4 km. The northern California velocity model was used in the simulations.

M_w 6.2 Strike-Slip at 50 km distance

Three methods G&P, SDSU and EXSIM pass this validation test.

The UCSB method deviates below the lower bound acceptance criteria from 0.1 to 1.0 s period.

The CSM method deviates below the lower bound acceptance criteria from 0.01 to 0.4 s period.

Part B. Northern California (M6.2, SS, Z_{tor}=4 km, R_{jb}=50 km)

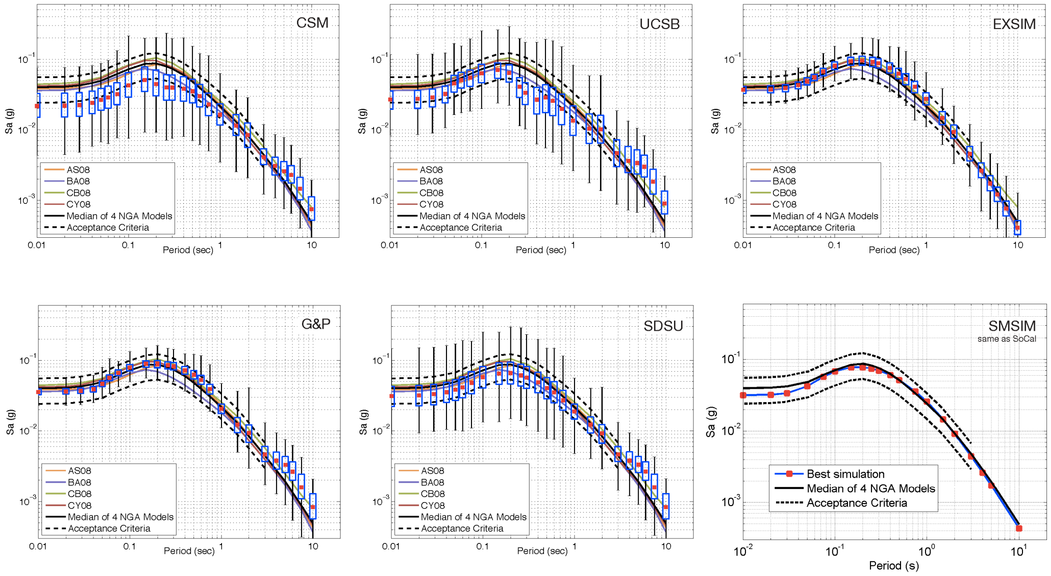


Figure 9. Comparison of Sa with GMPE for a M_W6.2 strike-slip scenario at 50 km distance. Depth to the top of the fault is 4 km. The northern California velocity model was used in the simulations.

M_W 6.6 Strike-Slip at 20 km distance

The five methods pass this validation test.

It is noted that G&P and UCSB marginally pass due to mean values lying on or slightly over the upper bound acceptance criteria over a narrow period range between 0.04 to 0.08 s.

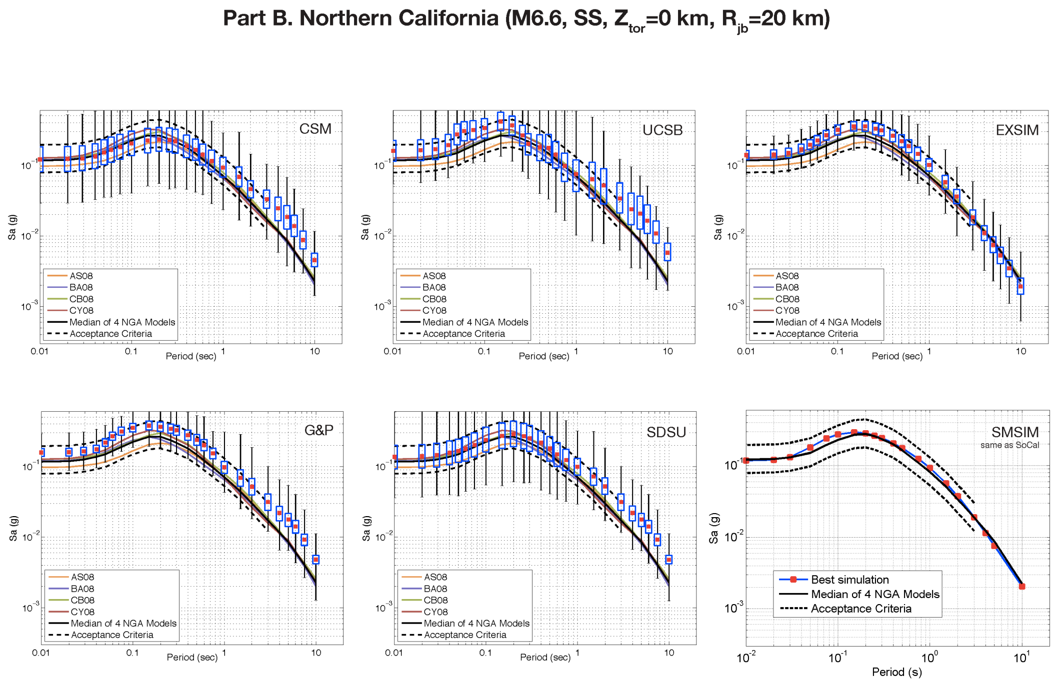


Figure 10. Comparison of Sa with GMPE for a M_W6.6 strike-slip scenario at 20 km distance. Depth to the top of the fault is 0 km. The northern California velocity model was used in the simulations.

M_w 6.6 Strike-Slip at 50 km distance

The five methods pass this validation test.

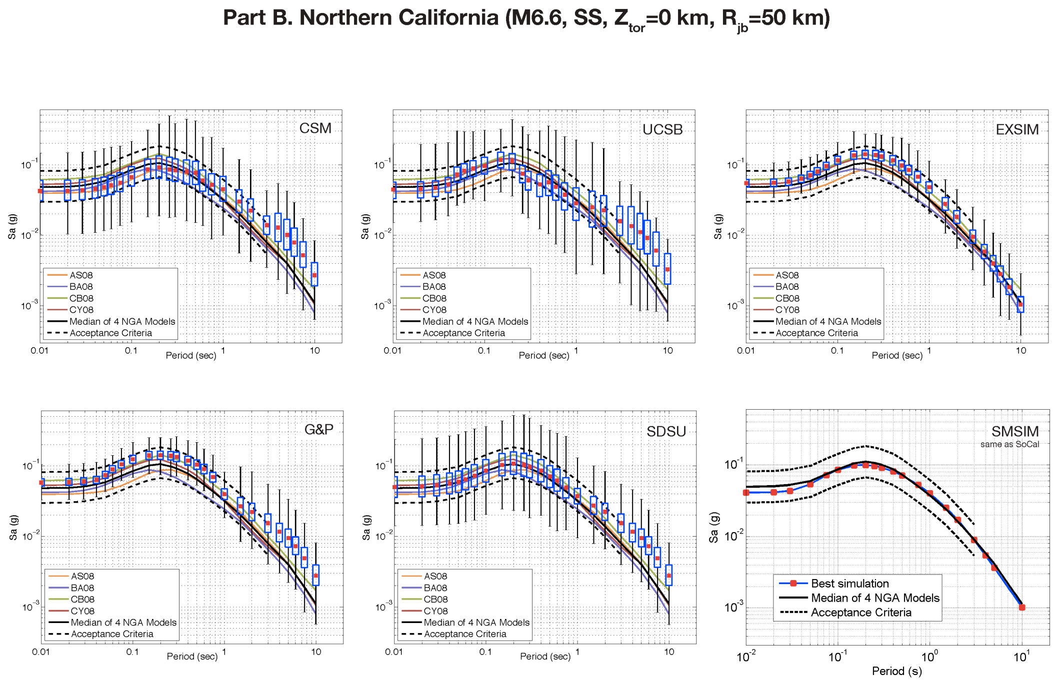


Figure 11. Comparison of Sa with GMPE for a M_W6.6 strike-slip scenario at 50 km distance. Depth to the top of the fault is 0 km. The northern California velocity model was used in the simulations.

M_w 6.6 Reverse-Slip at 20 km distance

Four methods UCSB, G&P, SDSU, and EXSIM pass this validation test.

It is noted that the UCSB method slightly over-predicts the 0.05 to 0.08 s period.

The CSM method under predicts between 0.01 to 0.8 s period.

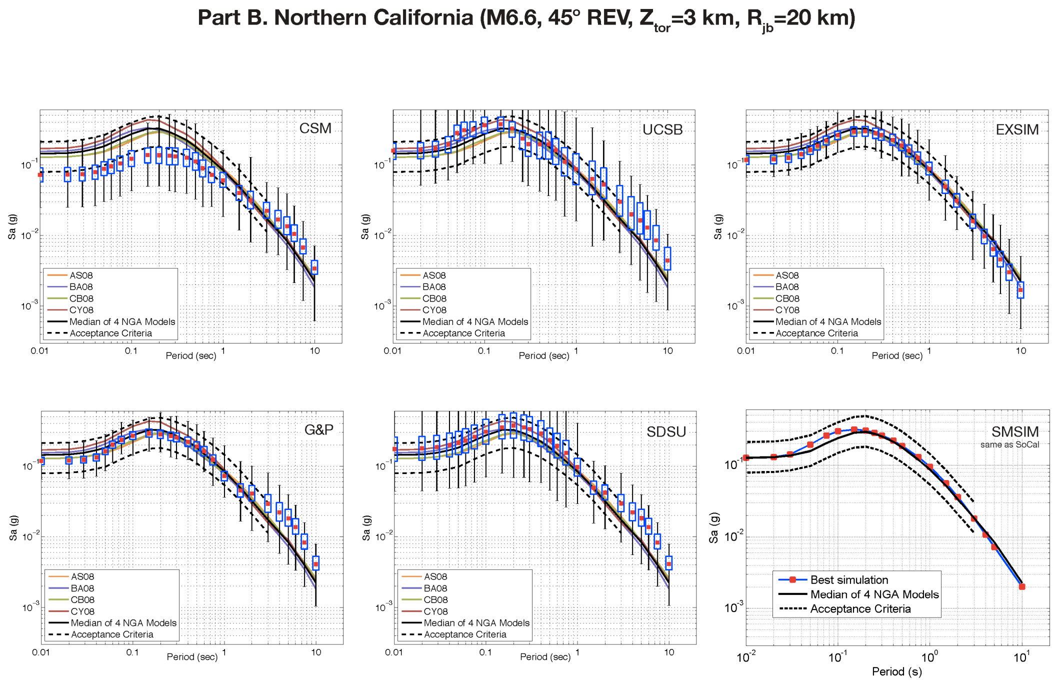


Figure 12. Comparison of Sa with GMPE for a M_W6.6 reverse-slip scenario at 20 km distance. Depth to the top of the fault is 3 km. The northern California velocity model was used in the simulations.

M_w 6.6 Reverse-Slip at 50 km distance

All five methods pass this validation test.

It is noted that the UCSB method over-predicts slightly from 0.05 to 0.08 s period, and that the G&P method over-predicts at 3 s period.

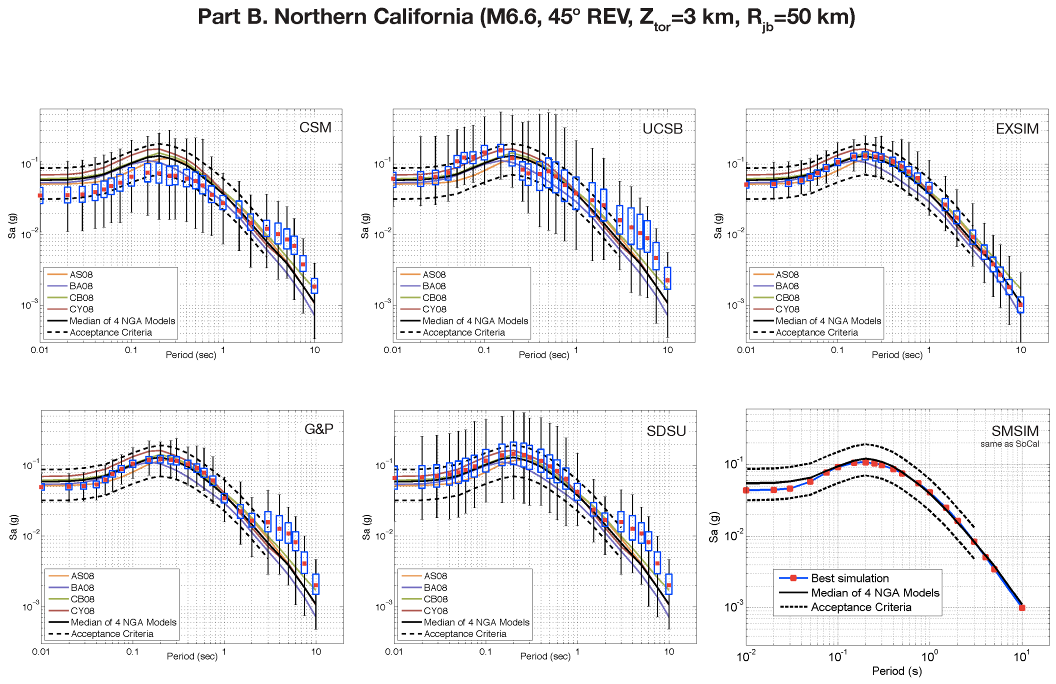


Figure 13. Comparison of Sa with GMPE for a M_W6.6 reverse-slip scenario at 50 km distance. Depth to the top of the fault is 3 km. The northern California velocity model was used in the simulations.

4.3 Summary for Part B Validation and Recommendations

All methods pass the acceptance criteria for at least one of the cases.

It is noted that in certain cases the CSM and UCSB method deviate significantly from the GMPE spectral shape whereas other methods, particularly EXSIM, are found to agree well with the spectral shape. The level of agreement by EXSIM is expected due to the empirical nature of the method.

All of the methods with the exception of EXSIM over-predict at periods longer than 3 s. This can be due to several factors including 1) the processing of the observed data and lack of sufficient numbers of observations, 2) possible over-prediction of surface waves due to the use of 1D velocity models, 3) specifics of the magnitude-area scaling used to generate the source models. These issues should be addressed in future phases of the BBP exercise.

The northern California results appear to be slightly better than the southern California cases, which is indicative of velocity model dependence.

Only the G&P, SDSU and EXSIM methods pass the acceptance criteria for all of the cases.

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6. Model Specific Discussion

A detailed review of the methodologies in terms of technical approach and rules for various components of each method is beyond the scope of this report. However, after reviewing the documentation provided for each model (Appendix E), the panel has not seen anything that precludes the validated methods from being used to simulate PSA.

7. Panel Recommendations

The recommendation of the panel for this phase of BBP development, based on Part A and Part B validation results, is that the EXSIM, G&P and SDSU methods are suitable for simulating PSA from 0.01 to 3 s period for distances from 1-200 km, though there are increased biases at periods longer than 1 second.

For this phase of the BBP the review panel had at its disposal estimates of the mean of ln(Obs/Syn), and the mean abs(ln(Obs/Syn)), where Obs and Syn are observed and simulated PSA (RotD50) for specified periods. These measures proved to be useful for the evaluation of methods within the range of applicability for each method, and also for comparison purposes between methods and a GMPE. An additional metric (Section 3.2) was defined to assess the distance dependence of the simulated ground motions.

In future validations of the BBP several other measures of goodness-of-fit should be considered. The specific metrics would depend on the desired engineering application, but could include 1) inelastic PSA, 2) time of PSA and other peak ground motion parameters, 3) limit of static offset in displacement time history in approach to the fault, and 4) measures that assess the spectral shape of PSA and Fourier amplitude spectra (adherence to $1/f^2$). Some of these will be important for applications that directly use time series. The distance metric (section 3.2) was very useful and as led to the development of new products such as ln(Obs(T)/Syn(T)) at each station (by distance) to enable a more robust estimate of distance dependent bias. It is also important for future work on the BBP to consider the dispersion of simulated ground motions.

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