Sixth International Conference on Urban Earthquake Engineering
March 3-4, 2009, Tokyo Institute of Technology, Tokyo, Japan

NEXT GENERATION ATTENUATION (NGA) PROJECT: EMPIRICAL GROUND MOTION PREDICTION EQUATIONS FOR ACTIVE TECTONIC REGIONS

K. Campbell[1], N. Abrahamson[2], M. Power[3], B. Chiou[4], Y. Bozorgnia[5], T. Shantz[6], and C. Roblee[7]

1) Vice President, ABS Consulting (EQECAT) Inc., Oakland, California, USA
2) Engineering Seismologist, Pacific Gas & Electric Company, San Francisco, California, USA
3) Principal Engineer, AMEC Geomatrix Consultants Inc., Oakland, California, USA
4) Senior Seismologist, California Department of Transportation, Sacramento, California, USA
5) Associate Director, Pacific Earthquake Engineering Research Center, University of California, Berkeley, California, USA
6) Senior Research Engineer, California Department of Transportation, Sacramento, California, USA
7) Senior Research Engineer, California Department of Transportation, Sacramento, California, USA
kcampbell@eqecat.com, mpower@geomatrix.com, brian.chiou@dot.ca.gov, naa3@earthlink.net, yousef@berkeley.edu, tom.shantz@dot.ca.gov, cliff.roblee@ dot.ca.gov,

Abstract: The "Next Generation Attenuation" (NGA) Project was a partnered research program conducted by the Pacific Earthquake Engineering Research Center-Lifelines Program (PEER-LL), U.S. Geological Survey (USGS), and Southern California Earthquake Center (SCEC). The project had the objective of developing updated ground motion prediction equations (attenuation relationships) for the western U.S. and other worldwide active shallow tectonic regions through a comprehensive and highly interactive research program. Five sets of updated attenuation relationships were developed by teams working independently but interacting throughout the development process. An overview of the NGA project components, process, and products developed by the project is presented in this paper.

1. INTRODUCTION

The objective of the "Next Generation Attenuation" (NGA) Project was to develop updated ground motion prediction equations (attenuation relationships) for shallow crustal earthquakes in the western U.S. (WUS) through a comprehensive and highly interactive research program that involved the following components: (1) development of separate sets of attenuation relationships by five teams (the "Developers"); (2) development of an updated and expanded PEER strong motion database to provide the recorded ground motion data and the supporting metadata on the causative earthquakes, source-to-site travel paths, and local site conditions needed by the Developers for their empirical model development; (3) a number of supporting research projects, including theoretical simulations of rock motions, soil site response and basin response, to provide an improved scientific basis for evaluating the functional forms of and constraints on the attenuation relationships; and (4) a series of workshops, working group meetings, Developer meetings, and external review that provided input into and review of the project results by both the scientific research community and the engineering user community. These project components are briefly described in subsequent sections of this paper. A more detailed overview of the NGA project is given in Power et al. (2008).

2. MODEL DEVELOPMENT

Developers of five pre-existing and widely used attenuation relationships participated in the concurrent development of the NGA models. The Developers are listed below with references to their updated attenuation relationships shown in parentheses: Norman Abrahamson and Walter Silva (Abrahamson and Silva 2008), David Boore and Gail Atkinson (Atkinson and Boore 2008), Kenneth Campbell and Yousef Bozorgnia (Campbell and Bozorgnia 2008); Brian Chiou and Robert Youngs (Chiou and Youngs, 2008), I.M. Idriss (Idriss 2008). These models are referred to as AS08, BA08, CB08, CY08, and I08, respectively, in the remainder of this paper. The NGA models and supporting studies have been fully documented in a special issue of *Earthquake Spectra* (Vol. 24, No. 1, February 2008) entitled "Special Issue on the Next Generation Attenuation Project" edited by Jon Stewart, Ralph Archuleta, and Maury Power.

To meet the needs of the engineering seismology and earthquake engineering communities, all of the NGA models were required to be applicable to (1) ground motion parameters of peak ground acceleration, velocity, and displacement (PGA, PGV, PGD), and 5%-damped linear elastic response spectral acceleration (S_a) in the period range of 0.01 to 10 sec, (2) average horizontal motion, defined as the orientation-independent geometric mean horizontal component, GMRotI50 (Boore et al. 2006), (3) shallow crustal earthquakes with strike slip, reverse, and normal fault mechanisms in the WUS, (4) moment magnitudes ranging from 5 to 8.5, (5) fault distances ranging from 0 to 200 km, and (6) commonly used site classification schemes, including the NEHRP classification scheme. In regards to this latter requirement, all of the NGA models, except I08, used the time-averaged shear-wave velocity in the top 30 m of the site (V_{S30}) to model site conditions.

2.1 Data Selection

To provide a common database of recorded ground motions and supporting metadata for the Developers, the NGA Project conducted an extensive update and expansion of the PEER strong motion database (Chiou et al. 2008). Although the NGA developers all started with the same database of 3551 recordings from 173 earthquakes (Fig. 1), the selected data sets used to develop the models had significant differences. The number of selected earthquakes and recordings are summarized in Table 1. A key difference in the data sets is the treatment of aftershocks. The AS08 and CY08 data sets included aftershocks, resulting in a much larger number of earthquakes than the BA08 and CB08 data sets. The I08 data set included aftershocks, but had the smallest number of recordings, because it only included rock sites (450 < V_{S30} < 900 m/s). The specific earthquakes and number of recordings selected by each Developer are listed in Abrahamson et al. 2008.

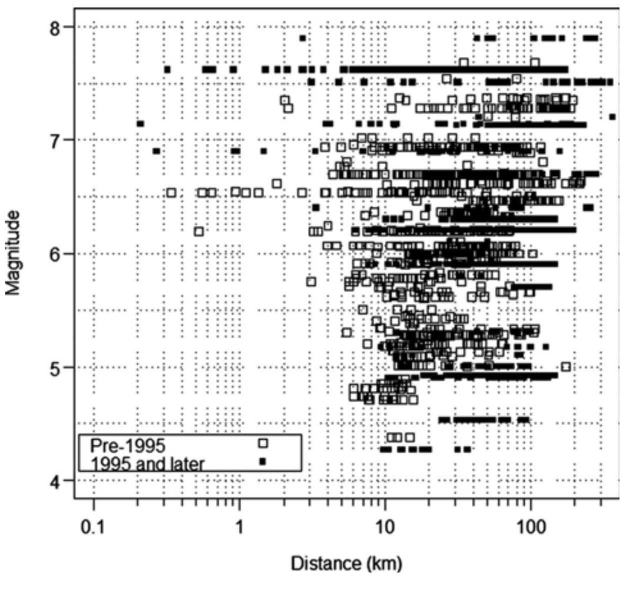

Figure 1 Distribution of Recordings Included in the NGA Strong Motion Database

An important issue in the selection of the earthquakes was the applicability of the well-recorded large-magnitude earthquakes from outside of the WUS (e.g., 1999 Chi-Chi and 1999 Kocaeli) to the prediction of ground motions in the WUS. All of the Developers considered both the Chi-Chi and Kocaeli data to be applicable to the WUS. Furthermore, comparisons of the NGA models with European data have shown that the NGA models are applicable to this region as well (Stafford et al. 2008). Similar preliminary studies in Iran, Taiwan, New Zealand, and South America suggest that the NGA models might be generally applicable to shallow crustal earthquakes in active tectonic regions worldwide.

Table 1 Summary of Data Sets Used by NGA Developers

Data	AB08	BA08	CB08	CY08	I08
No. Eqs.	135	58	64	125	72
No. Recs.	2754	1574	1561	1950	942

2.2 Functional Forms

The main features of the functional forms of the five NGA models are summarized in Table 2 (Abrahamson et al. 2008). Saturation at short distances is a feature of ground motion models that leads to weaker magnitude scaling at short distances as compared to larger distances. This is not the same as including a quadratic magnitude scaling that applies at all distances. In ground motion studies, a model is said to have “full saturation” if there is no magnitude scaling of the median ground motion at zero distance. A model is said to have over-saturation if the median ground motion decreases with increasing magnitude at zero distance. All of the NGA models include some form of saturation of the short-period ground motion at short distances through either a magnitude-dependent distance decay (AS08, BA08, CB08, I08) or a magnitude-dependent fictitious depth (CY08). In several cases, the selected data sets would have lead to over-saturation of the short-period ground motion at short distances had the regression not been constrained, but none of the Developers allowed over-saturation in their models.

Table 2 Effects Modeled by the NGA Models

Term	AB08	BA08	CB08	CY08	I08
Saturation Effects	X	X	X	X	X
Fault Mechanism	X	X	X	X	X
Rupture Depth	X		X	X	
Hanging-Wall Effects	X		X	X	
Nonlinear Site Effects	X	X	X	X	
Sediment Depth	X		X	X	
Magnitude effect on σ_T	X			X	X
Nonlinear Effect on σ_T	X		X	X	

As indicated in Table 2, besides saturation at short distances, other effects modeled by the functional forms of one or more of the NGA models include: (1) style-of-faulting and fault mechanism, (2) depth to the top of the rupture plane, (3) hanging-wall effects, (4) nonlinear site amplification, (5) sediment depth, (6) magnitude-dependent standard deviation (σ_T), and (7) nonlinear site-dependent σ_T.

2.3 Model Parameters

The model parameters used by each Developer are summarized below. I08, which is only for rock sites, has the simplest parameterization (magnitude, distance, and style-of-faulting). BA08 has the next simplest parameterization; in addition to magnitude, distance, and style-of-faulting, it has the added parameters of V_{S30} and rock outcrop motion to model nonlinear site response. AS08, CB08, and CY08 have the most complex parameterizations. In addition to the above parameters, these models include additional parameters to model hanging-wall effects, rupture-depth effects, and sediment-depth effects.

A complete list of the parameters used in the NGA models is as follows:

M	Moment magnitude
R_{RUP}	Closest distance to rupture plane
R_{JB}	Closest horizontal distance to rupture plane
R_X	Closest horizontal distance to top of rupture plane
Z_{TOR}	Depth to top of rupture plane
F_{RV}	Indicator variable for reverse faulting
F	Indicator variable for reverse faulting (I08)
RS	Indicator variable for reverse faulting (BA08)
F_{NM}	Indicator variable for normal faulting
NS	Indicator variable for normal faulting (BA08)
SS	Indicator variable for strike-slip faulting (BA08)
US	Indicator variable for unspecified faulting (BA08)
F_{AS}	Indicator variable for aftershocks (AS08)
AS	Indicator variable for aftershocks (CY08)
δ	Dip of rupture plane
W	Down-dip width of rupture plane
F_{HW}	Indicator variable for site on hanging wall
V_{S30}	Time-averaged S-wave velocity in top 30 m
$Z_{1.0}$	Depth to 1000 m/s S-wave velocity horizon
$Z_{2.5}$	Depth to 2500 m/s S-wave velocity horizon
PGA_{1100}	Median estimate of PGA on rock (AS08)
PGA4NL	Median estimate of PGA on rock (BA08)
Y_{REF}	Median estimate of S_a on rock (CY08)
τ, σ, σ_T	Inter-event, Intra-event, and total std. deviation

All five models are based on moment magnitude and all five models include a style-of-faulting (fault mechanism) term, although I08 does not distinguish between strike-slip and normal earthquakes. For the three models that include rupture-depth effects (AS08, CB08, and CY08), the rupture depth is parameterized by the depth to the top of the rupture plane. Of the three models that include aftershocks (AS08, CY08, and I08), AS08 and CY08 account for differences between the median ground motion for aftershocks and mainshocks, with aftershocks having smaller ground motions than mainshocks.

There are two primary distance measures used in the NGA models. BA08 uses the closest horizontal distance to the surface projection of the rupture plane, R_{JB}. The other four models use the closest distance to the rupture plane, R_{RUP}. For the hanging-wall (HW) term, AS08, CB08, and CY08 use additional distance measures to smooth this term. All three models use the R_{JB} distance measure in their HW scaling. AS08 and CY08 also use a third distance measure, R_X. This distance measure is defined as the horizontal distance from the top edge of the rupture plane, measured perpendicular to the fault strike (R_X is positive over the hanging wall and negative over the footwall).

All of the models except for I08 use the time-averaged S-wave velocity in the top 30 m of a site, V_{S30}, as the primary site parameter. In addition, all four models that model site response incorporate nonlinear site effects. Two different measures for the strength of the shaking are used to quantify nonlinear site response effects. AS08, BA08, and CB08 use the median estimate of PGA on a reference rock outcrop in the nonlinear site response term. CY08 uses the median estimate of spectral acceleration on a reference rock outcrop at the period of interest. BA08 defines reference rock as having V_{S30} = 760 m/s, CY08 defines it as having V_{S30} = 1130 m/s, and AB08 and CB08 define it as having V_{S30} = 1100 m/s. As mentioned previously, I08 is valid only for a reference rock outcrop with V_{S30} = 450-900 m/s. In all cases, a rock outcrop is assumed to have linear site response. Three models include sediment depth as an additional site parameter to model basin effects and other long-period site effects not modeled by V_{S30}. AS08 and CY08 use the depth to the 1000 m/s S-wave velocity horizon, $Z_{1.0}$, and CB08 uses the depth to the 2500 m/s velocity horizon, $Z_{2.5}$, to capture these additional effects.

3. MODEL COMPARISONS

The NGA models use different source parameters and distance measures. Some of the models include the depth to top of rupture as a source parameter. To compare with the NGA models that do not include this parameter, a median estimate of Z_{TOR} derived from the NGA data base was used as follows: 6 km for **M** = 5, 3 km for **M** = 6, 1 km for **M** = 7, and 0 for **M** = 8.0. To address the different distance measures used by the NGA models, the ground motions were computed for specified source-site geometries.

There is also an issue of an appropriate sediment depth to use in the comparisons. AS08 and CY08 give recommended values of $Z_{1.0}$ to use if the sediment depth is not known. However, the relations for the median estimate of $Z_{1.0}$ for a given value of V_{S30} are not consistent between these two models. For the general comparisons presented in this paper, the recommended median $Z_{1.0}$ values were used for each model. For CB08, which uses $Z_{2.5}$ as the sediment-depth parameter, the recommendation is to estimate $Z_{2.5}$ from the value of $Z_{1.0}$. For the comparisons, the value of $Z_{2.5}$ is estimated using the AS08 estimates of $Z_{1.0}$.

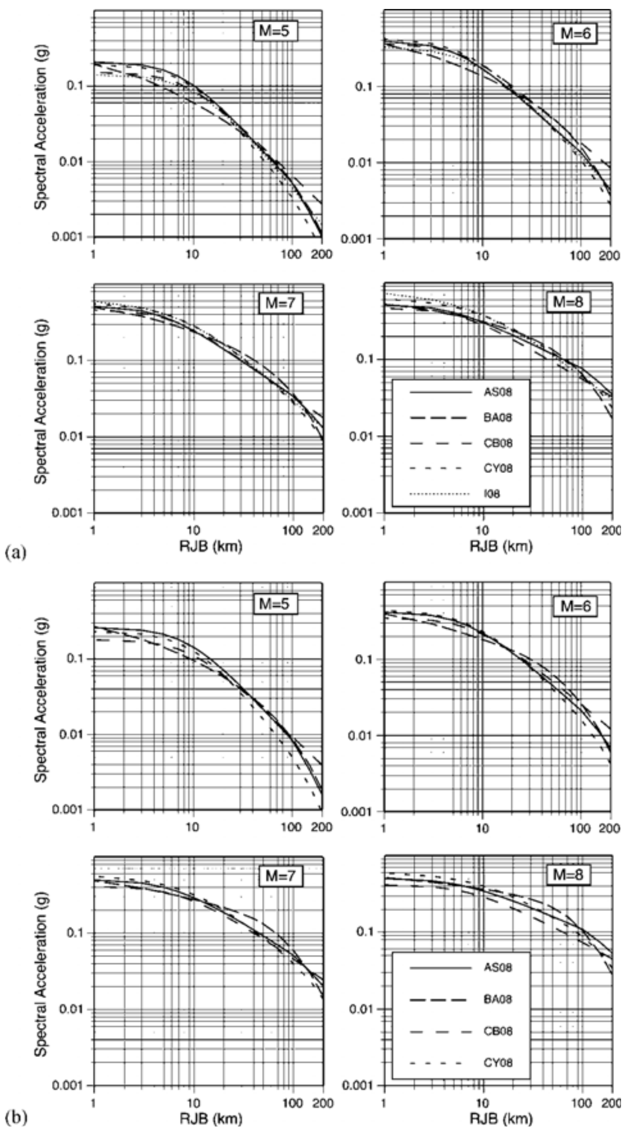

Figure 2 Predicted Distance Scaling for Strike-Slip Earthquakes and V_{S30} = 760 m/s: (a) PGA, (b) S_a at T = 1 s.

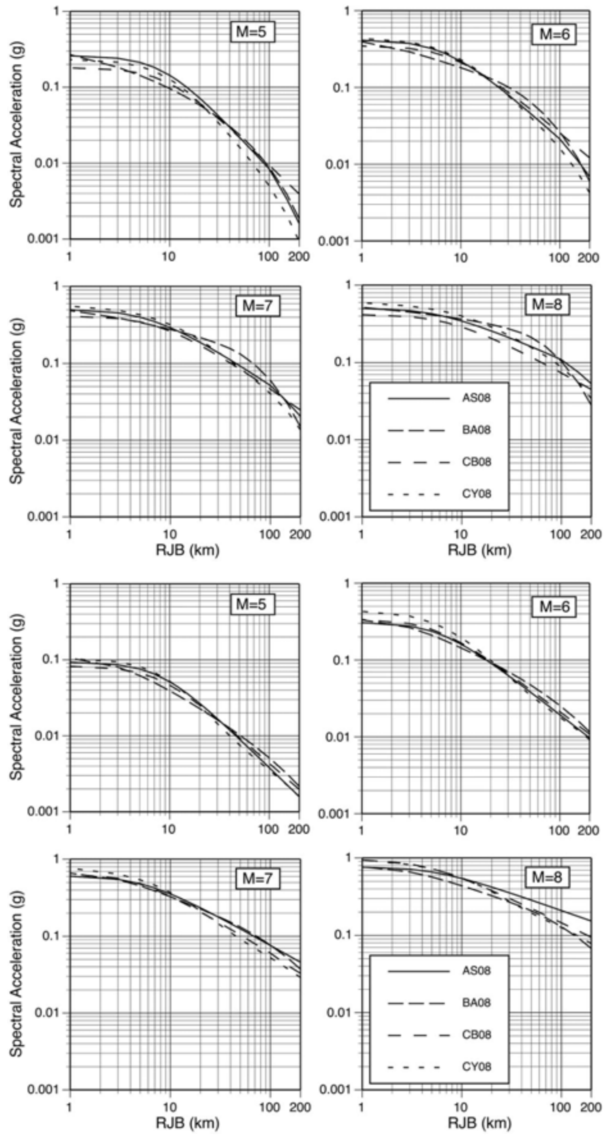

Figure 3. Predicted Distance Scaling for Strike-Slip Earthquakes and V_{S30} = 270 m/s: (a) PGA, (b) S_a at T = 1 s.

3.1 Attenuation Effects

The distance effects (attenuation) predicted by the NGA median models for vertical strike-slip faults and firm-rock site conditions (V_{S30} = 760 m/s, $Z_{1.0}$ = 340 m for AS08, $Z_{1.0}$ = 240 m for CY08, $Z_{2.5}$ = 640 m for CB08) is shown in Figures 1a and 1b for PGA and S_a at T = 1 s, respectively. For **M** = 6 and 7 earthquakes, the five NGA models lead to similar ground motions (within a range of a factor of 1.5). At **M** = 5 and 8, the differences between the NGA models become larger (up to a factor of 2) due to the smaller amount of strong motion data from earthquakes of these magnitudes. The distance scaling for soil sites is shown in Figures 2a and 2b for PGA and S_a at T = 1 s, respectively. The range of the soil ground motions for the four NGA models that are applicable to soil sites are similar to the range of ground motions for rock sites, indicating that the prediction of nonlinear site response in each of these models is similar, even though their nonlinear site response terms are different.

3.2 Magnitude Effects

The magnitude effects predicted by the NGA median models for vertical strike-slip faults and firm-rock site conditions is compared in Figure 4 for R_{JB} = 30 km. Overall, the magnitude scaling for the five NGA models is very similar. For short spectral periods, the median ground motions are within a factor of 1.5. At long periods, the range increases to a factor of 2 at **M** = 5 and 8. These plots clearly show the weaker magnitude scaling (saturation) at short periods predicted by all of the NGA models.

3.3 Rupture-Depth Effects

The rupture-depth effects predicted by the NGA median models vary with each model. For BA08, there is no dependence on depth, since this model uses R_{JB} as the distance measure. For I08, there is a systematic decrease in the median ground motion with increasing depth because this model uses R_{RUP} without including a rupture-depth term. AS08 and CY08 include a rupture-depth term for both strike-slip and reverse earthquakes in which the buried ruptures have stronger shaking than surface ruptures at the same distance. As a result of this depth scaling, these two models predict an increase in the median ground motion as the rupture depth increases. CY08 has a smooth increase from 0 to 7 km depth and then becomes almost constant, similar to the R_{JB} scaling of BA08. AS08 has a strong scaling with depth with a limit on the depth scaling of 10 km. This causes the AS08 model to have a peak in the scaling at a depth of 10 km. CB08 includes a rupture-depth term for reverse earthquakes only for depths greater than 1 km. As a result, CB08 predicts a systematic decrease in the PGA with increasing depth for strike-slip earthquakes and an increase from surface rupture to 1 km depth (buried rupture) for reverse earthquakes, followed by a smooth decrease.

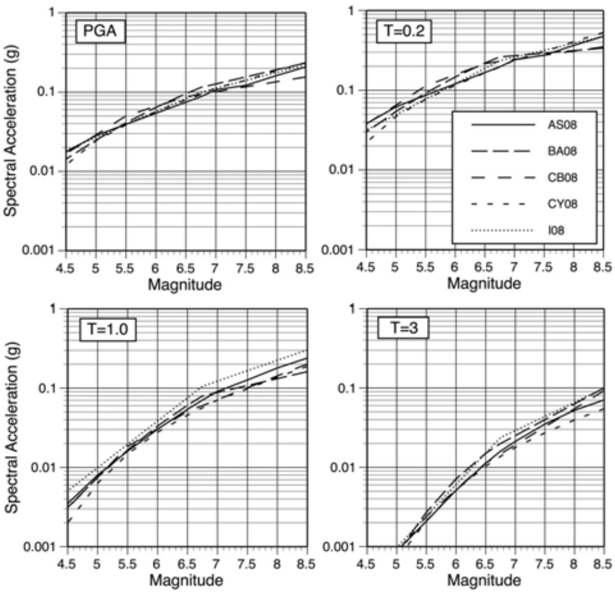

Figure 4 Predicted Magnitude Scaling for Strike-Slip Earthquakes, V_{S30} = 760 m/s, and R_{JB} = 30 km.

3.3 Effect of Site Conditions

The effect of site conditions (V_{S30}) predicted by the median NGA models is shown in Figures 5a and 5b for **M** = 7 strike-slip earthquakes and R_{RUP} = 100 and 10 km, respectively. For the 100 km case, the site response is nearly linear and the four models all show similar scaling. The 10 km case shows significant nonlinear site effects at short periods. There are two limits to V_{S30} scaling. First, there is a limit beyond which the amplification becomes constant. For AS08 this limit is period-dependent, whereas for CB08 and CY08 it is period-independent at V_{S30} = 1100 m/s. For BA08, this limit is not included as part of the model. The second limit is the maximum value of V_{S30} for which the models are considered to be applicable. The largest V_{S30} values recommended by the Developers are 1300 m/s for BA08, 1500 m/s for CB08 and CY08, and 2000 m/s for AS08.

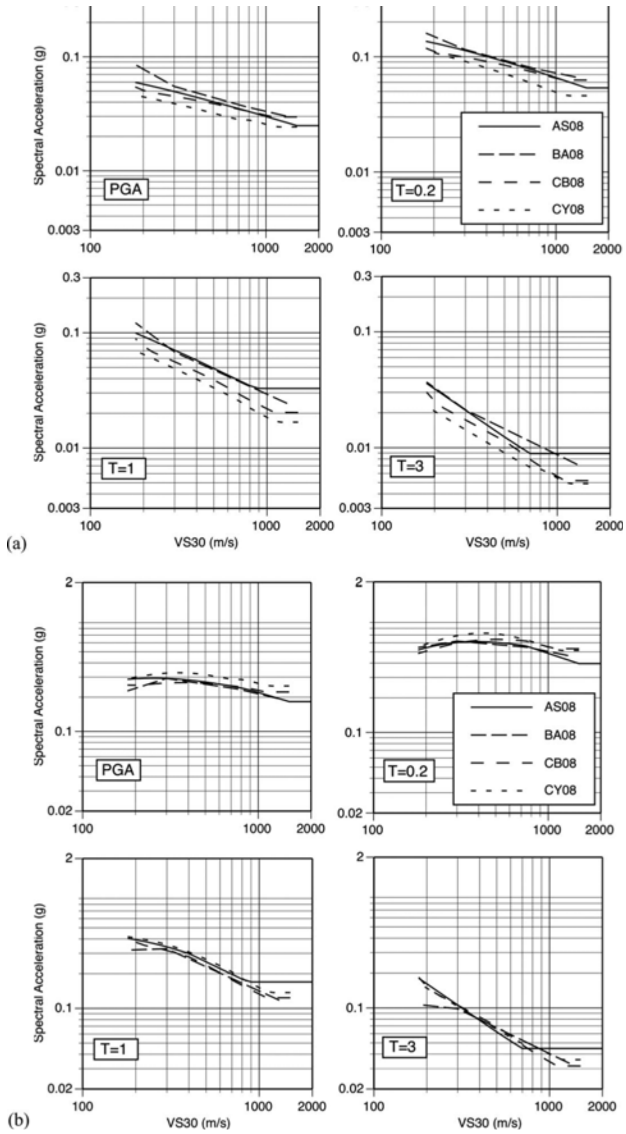

Figure 5 Predicted V_{S30} Scaling for **M** = 7 Strike-Slip Earthquakes: (a) R_{RUP} = 100 km, (b) R_{RUP} = 10 km.

3.4 Hanging-Wall Effects

The HW effects predicted by the median NGA models is shown in Figure 6 for reverse and normal **M** = 6.7 earthquakes with surface and buried rupture. For this example, the top of rupture for the buried case is at 6 km. AS08, CB08, and CY08 include explicit HW effects. BA08 implicitly includes HW effects through the use of the R_{JB} distance measure, which leads to constant ground motion for sites located over the rupture plane (R_{JB} = 0). I08 does not include HW effects so this model attenuates smoothly as a function of R_{RUP}. The buried rupture case leads to the largest difference in the models with a range of a factor of 2.5 for sites located over the hanging wall. CY08 has the strongest HW scaling for surface rupture and AS08 has the strongest HW scaling for buried rupture.

3.5 Response Spectra

The response spectra predicted by the NGA median models for **M** = 5, 6, 7, and 8, strike-slip earthquakes and firm-rock site conditions are shown in Figure 7. For **M** = 6 and 7, the spectra for the five models are similar (within a factor of 1.5). At **M** = 5 and 8, the range increases to a factor of 2.

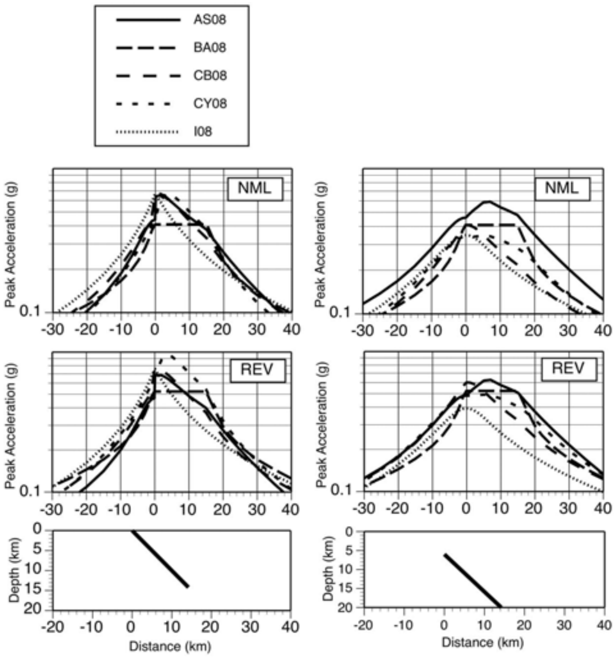

Figure 6 Predicted HW Effects on PGA for 45°-Dipping **M** = 6.7 Earthquakes and V_{S30} = 760 m/s: (left) Surface Rupture, (right) Buried Rupture (Z_{TOR} = 6 km).

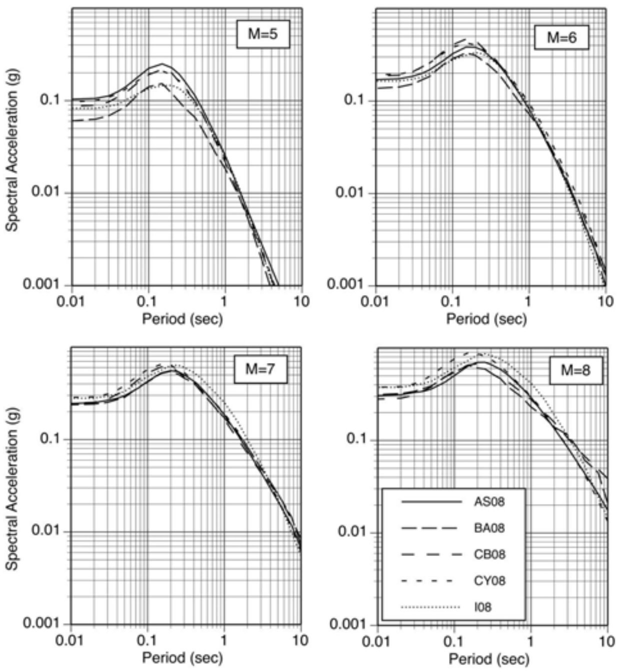

Figure 7 Predicted 5% Damped Response Spectra for Strike-Slip Earthquakes, V_{S30} = 760 m/s, and R_{JB} = 10 km.

The response spectra predicted by the NGA median models for **M** = 7 strike-slip earthquakes at R_{JB} = 10 km for different sediment depths is shown in Figure 8. Soil sites (V_{S30} = 270 m/s) are evaluated for sediment depths defined as shallow ($Z_{1.0}$ = 100 m, $Z_{2.5}$ = 900 m), average ($Z_{1.0}$ = 500 m, $Z_{2.5}$ = 2.3 km), and deep ($Z_{1.0}$ = 1.2 km, $Z_{2.5}$ = 4.8 km). Firm-rock sites are evaluated as before. I08 does not have a soil model and is not shown. BA08 does not include sediment depth as a parameter. For average depth conditions, the four models have very similar spectra (within a factor of 1.3). AS08, CB08, and CY08 all show a large increase in the long-period motion as compared to the BA08 model that does not include sediment depth as a parameter.

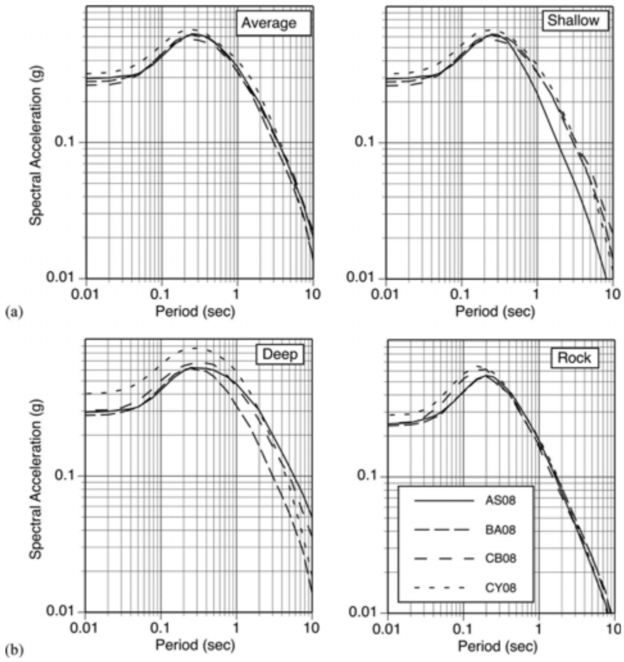

Figure 8 Predicted 5% Damped Response Spectra for Strike-Slip Earthquakes and R_{JB} = 10 km. Soil Sites (V_{S30} = 270 m/s) are Evaluated for Shallow, Average, and Deep Sediments (See Text). Firm-Rock Sites are Evaluated as in Figure 7.

3.6 Standard Deviations (Aleatory Variability)

The period dependence of the total standard deviation, σ_T, for **M** = 5 and 7 earthquakes is shown in Figure 9. For **M** = 7, the five models have similar standard deviations. However, for **M** = 5, there is a large difference in the standard deviations, with the three magnitude-dependent models exhibiting much larger standard deviations than the magnitude-independent models. The magnitude-dependence of the standard deviation is shown in Figure 10 for PGA and S_a at T = 1 s, respectively. The three models that include a magnitude-dependent standard deviation (AS08, CY08 and I08) all included aftershocks, whereas the two models that used a magnitude-independent standard deviation (BA08 and CB08) excluded them. Including aftershocks greatly increases the number of small-magnitude earthquakes, but there is a trade-off of significantly larger variability in predicted ground motions than if only large-magnitude mainshocks are used.

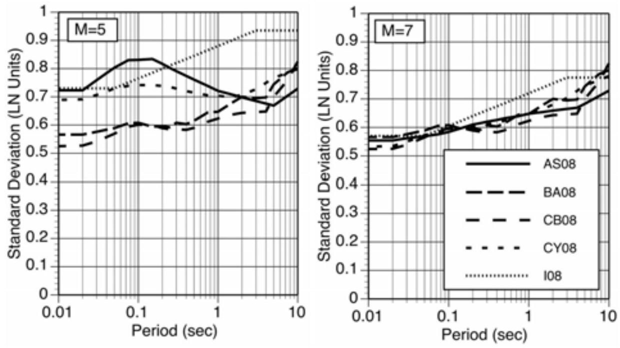

Figure 9 Period-Dependence of Standard Deviation (σ_T) for Strike-Slip Earthquakes, V_{S30} = 760 m/s, and R_{JB} = 30 km: (left) **M** = 5, (right) **M** = 7.

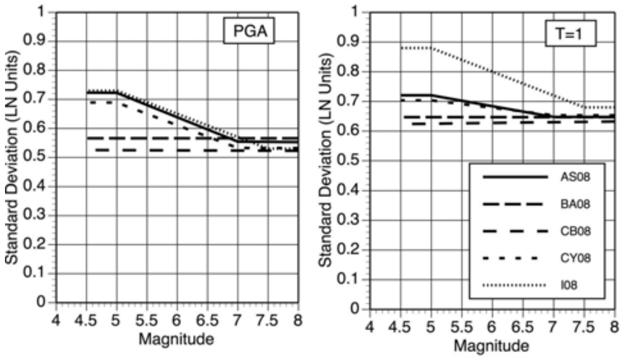

Figure 10 Magnitude-Dependence of Standard Deviation (σ_T) for Strike-Slip Earthquakes, V_{S30} = 760 m/s, and R_{JB} = 30 km: (left) PGA, (right) S_a (T = 1 s).

All four models that include nonlinear site effects on the median site amplification also include these effects on the standard deviation. AS08 and CY08 include the impacts on both τ and σ (inter-event and intra-event standard deviations). CB08 only includes the impact on σ. BA08 does not include the impact on either τ and σ. When nonlinear site effects are included, the standard deviations for the short-period ground motions are reduced as shown in Figure 11. At short distances (large ground motions), nonlinear effects lead to a σ_T reduction of 0.1 to 0.15 natural log units.

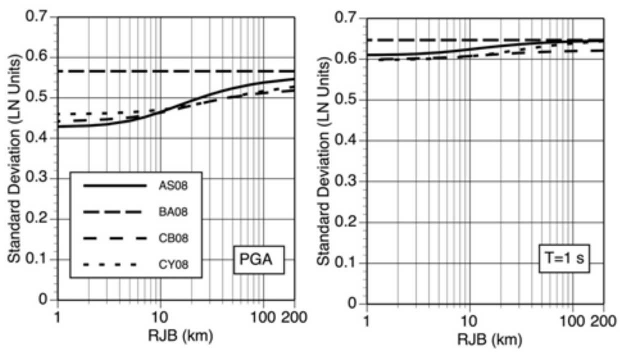

Figure 11 Distance-Dependence of Standard Deviation (σ_T) for **M** = 7 Strike-Slip Earthquakes: (left) PGA, (right) S_a (T = 1 s). This Dependence Shows the Strong Impact of Nonlinear Site Response on the Standard Deviation for Soil Sites (V_{S30} = 270 m/s).

4. CONCLUSIONS

The NGA project serves as an example of how a consistent and reliable set of attenuation relationships can be developed. Overall, the NGA models predict similar median values (within a factor of 1.5) for vertical strike-slip earthquakes with 5.5 < **M** < 7.5. The largest differences are for small magnitudes (**M** = 5), very large magnitudes (**M** = 8), and sites located over the hanging wall. The standard deviations are similar for **M** > 6.5 and firm-rock sites. The largest differences in the standard deviations are for small magnitudes (due to inclusion or exclusion of aftershocks) and for soil sites at short distances (due to inclusion or exclusion of nonlinear site effects on the standard deviation).

Acknowledgements:

This study was sponsored by the Pacific Earthquake Engineering Research Center's (PEER's) Program of Applied Earthquake Engineering Research of Lifelines Systems supported by the California Department of Transportation, the California Energy Commission, and the Pacific Gas and Electric Company. This work made use of the Earthquake Engineering Research Centers Shared Facilities supported by the National Science Foundation, under award number EEC-9701568 through PEER. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation.

References:

Abrahamson, N.A. and Silva, W.J. (2008). "Summary of the Abrahamson & Silva NGA Ground-Motion Relations," *Earthq. Spectra* **24**, 67-97.

Abrahamson, N., Atkinson, G., Boore, D., Bozorgnia, Y., Campbell, K., Chiou, B., Idriss, I.M., Silva, W., and Youngs, R. (2008). "Comparison of the NGA Ground Motion Relations," *Earthq. Spectra* **24**, 45-66.

Boore, D.M. and Atkinson, G.M. (2008). "Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA at Spectral Periods Between 0.01 s and 10.0 s," *Earthq. Spectra* **24**, 99-138.

Boore, D.M., Watson-Lamprey, J., and Abrahamson, N.A. (2006). "GMRotD and GMRotI: Orientation-Independent Measures of Ground Motion," *Bull. Seismol. Soc. Am.* **96**, 1502-1511.

Campbell, K.W. and Bozorgnia, Y. (2008). "NGA Ground Motion Model for the Geometric Mean Horizontal Component of PGA, PGV, PGD and 5% Damped Linear Elastic Response Spectra for Periods Ranging from 0.01 to 10 s," *Earthq. Spectra* **24**, 139-171.

Chiou, B.S.J. and Youngs, R.R. (2008). "An NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra," *Earthq. Spectra* **24**, 173-215.

Chiou, B., Darragh, R., Gregor, N., and Silva, W. (2008). "NGA Project Strong-Motion Database," *Earthq. Spectra* **24**, 23-44.

Idriss, I.M. (2008). "An NGA Empirical Model for Estimating the Horizontal Spectral Values Generated by Shallow Crustal Earthquakes," *Earthq. Spectra* **24**, 217-242.

Power, M., Chiou, B., Abrahamson, N., Bozorgnia, Y., Shantz, T., and Roblee, C. (2008). "An Overview of the NGA Project," *Earthq. Spectra* **24**, 3-21.

Stafford, P.J., Strasser, F.O., and Bommer, J.J. (2008). "An Evaluation of the Applicability of the NGA Models to Ground-Motion Prediction in the Euro-Mediterranean Region," *Bull. Earthq. Eng.* **6**, 144-177.