2003 SCEC REPORT

Strong Motion Simulations for Phase NGA-E of the Next Generation Attenuation (NGA) Program

Paul Somerville, Robert Graves, Arben Pitarka, and Nancy Collins, URS

Introduction

This report describes work performed by URS participants in 2003 in Phase NGA-E of the PEER-Lifelines/SCEC/USGS Next Generation Attenuation Project. The goal of the NGA project is to incorporate recent strong ground motion recordings from large earthquakes and current research results into a new suite of ground-motion attenuation models for shallow crustal earthquakes in active tectonic regions. The objective of the current phase of the NGA Project, NGA-E (Empirical), is to update existing ground-motion models derived from recorded strong motion data.

The NGA program is an ambitious effort requiring sustained focus, coordination and management. Participants in the NGA program are drawn from three broad groups:

- "Developers" consist of a small group of leading experienced attenuation modelers who will create new NGA-E or NGE-H products;
- "Collaborators" are leading researchers from organizations such as PEER-LL, PEER, USGS, and SCEC who are actively investigating phenomena that affect strong ground motion and its prediction;
- "Stakeholders" are individuals representing sponsors (Caltrans, CEC, PG&E) and both user and liaison organizations (e.g. ATC, BART, BSSC, CSSC, DOE, NRC, DSOD, DWR, EBMUD, FERC, LADWP, OES, SCE, COSMOS etc.) who have an interest in improved earthquake hazard assessment and/or actively use attenuation relations in earthquake engineering practice.

Ground Motion Effects Being Considered in NGA-E

Broadly, the NGA-E Program is considering the following issues:

- Development and review of a common database including extension of the database to incorporate new predictor variables;
- Validation of ground-motion simulation procedures used to guide model development;
- Evaluation of alternative methodologies for evaluation of site response including development of non-linear site amplification functions;
- Consideration of the following "fixed effects" for attenuation models:
    - Definition of reference "rock" site condition and soil site classes and quantification of site effects
    - Rupture directivity effects
    - Strike normal versus strike parallel effects
    - Footwall vs. hanging wall effects for dipping faults
    - Style of faulting effects
    - Depth to faulting effects (i.e. buried vs. surface rupture)
    - Fault slip rate (as a proxy for depth to faulting effects)
    - Static stress drop (or ruptured area)
    - Depth to basement rock
    - Basin effects
- Consideration of the following random effects:
    - Measurement errors in predictor variables
    - Dependency of standard error on M, R, and site type
    - A general covariance structure to model the types of correlation in residuals described below
    - Correlation between neighboring frequencies
    - Correlation (spatial) between neighboring recordings
    - Correlation between alternative ground-motion measures.

NGA-E Project Organization and URS Participation

The NGA-E Project consists of a set of 8 Tasks, which are guided by 7 Working Groups. Both the Tasks and the Working Groups are listed in Table 1; with relationships among them noted on the right hand side of the Task or Working Group title.

Table 1. NGA-E Tasks, Working Groups, and their Relationships

Tasks	W. Groups		Working Groups	Tasks
1. Database Development	1,2		1. Data Processing	1
2. 1-D Rock Simulation	3,4		2. Database Predictor Variables	1
3. Evaluation of Predictors	4		3. Validation of 1-D Rock Simulation	2
4. Site Classification and Site Effects	5		4. Source/Path Effects	2,3,7
5. Site Response Analysis	5		5. Site Classification and Associated Site Effects	4
6. Statistical Approaches	6		6. Statistical Modeling of Data	6
7. Simulation of 3-D Basin Response	4			
8. Evaluation of Final NGA-E Models				

URS has contributed to the NGA Program through participation by its members in Working Groups and in Tasks. The main focus of the work performed by URS is on ground motion simulations for Task 2 – 1D Rock Simulation, with participation also in Task 3 – Evaluation of Predictors. The role of the ground motion simulations in Task 2 is to guide the selection of predictor variables and the modeling of their effects. The simulations are designed to augment recorded strong motion data, especially in domains in which they are sparse. The main corresponding working group is WG 4 – Source/Path Effects, with involvement also in WG 3 – Validation of 1-D Rock Simulation. Work on Task 7 - Simulation of 3-D Basin Response - is in progress under the leadership of Steve Day. The work that URS has contributed to Task 7 is described in a separate report submitted by Steve Day.

The main work by URS investigators on the NGA-E Project described in this report consists of the following three activities, which are described in turn:

- validation of broadband strong motion simulation procedures (Task 2, Working Groups 3 & 4)
- simulation of strong motions that are specifically designed to interpolate the data set of strong motion recordings (Task 2, Working Groups 3 & 4)
- participation in NGA Working Group Meetings and NGA Workshops.

Validation of Broadband Strong Motion Simulation Procedures

The NGA-E work plan for validation of 1D strong motion simulations is described by Abrahamson and Chiou (2003). This work plan consists of the following four tasks:

- Task 1. Detailed documentation of broadband simulation procedures
- Task 2. Simulation of ground motion recordings of UNR foam rubber event no. JN59
- Task 3. Modeling the ground motions of the Bay Bridge scenario earthquake
- Task 4. Modeling the recorded ground motions of six earthquakes and comparison of the recorded and simulated ground motions.

In Task 4, we are using the Hybrid broadband ground motion simulation procedure of Pitarka et al. (2000) to simulate strong ground motions for use in the NGA program. This procedure computes the ground motions in two period ranges. At periods longer than 1 second, the ground motions are calculated for a 1D velocity structure using a standard kinematic source representation and frequency-wavenumber integration. At periods shorter than 1 second, the ground motions are calculated using a partly stochastic procedure. These two seismograms are then combined using matched filters to generate a broadband seismogram.

The performance of the Hybrid broadband ground motion simulation procedure in matching the recorded ground motions of the 1979 Imperial Valley, 1989 Loma Prieta, 1992 Landers, 1994 Northridge, 1995 Kobe, and 1999 Kocaeli earthquakes has been quantified. The goodness of fit is quantified using the procedure of Abrahamson et al. (1990), which is illustrated in Figure 1 for the Northridge earthquake. The left panel shows the bias, expressed as the natural logarithm of the ratio of the recorded to the simulated response spectrum. The dots show individual measurements, the solid line shows the median value of these values, and the dashed lines show the 90th percent confidence interval of the median. At almost all response spectral periods, these lines lie on either side of a ratio of 1 (bias of 0), indicating that the simulation procedure on average predicts the response spectra of the recorded ground motions without significant bias. The right panel shows the standard error of the prediction at a given recording site, representing the scatter of the points in the upper panel about the median value. The standard error of about 0.4 natural log units (a factor of about 1.5) is lower than that of empirical ground motion models.

Strong Motion Simulations for NGA-E

The ground motion attenuation models developed in NGA-E will span broader ranges of magnitude, distance and period than do current empirical ground motion models. The way in which the 1D simulations are designed to address eight different source and path scaling issues, described by Abrahamson (2003), is summarized in Table 2. A key objective of the 1D rock ground motion simulations is to guide the extrapolation of the recorded data in regions where they are sparse. The NGA model domains and the intervals of those domains in which extrapolation of recorded data by simulations is being done are:

- Magnitude 5.5 – 8.2, extrapolate from Mw 7 to Mw 8.2
- Distance 0 – 200 km, extrapolate from 10 to 0 km and from 70 to 200 km
- Period 0 – 10 sec, extrapolate from 3 sec to 10 sec

Table 2. Combinations of simulated events needed to address specific source and path scaling issues.

					1. Mag Scaling			2. Dist Scaling 0-10 km		3. Dist Scaling 70-200 km		4. Period Scaling		5.Directivity Scaling		6. Static $\Delta\sigma$ Scaling	7. Buried vs Shallow		8. HW / FW	
Event Name	Mag	Stress-Drop	Dip	Top Of Rup (km)	Const Stress-Drop	Hanks and Bakun	RV	SS	RV	SS	RV	SS	RV	SS	RV		SS	RV	Dip	Mag
SA	6.5	Med	90	0	X	X		X		X		X		X		X				
SB	6.5	Low	90	0												X	X			
SC	6.5	High	90	0												X				
SD	7.0	Med	90	0	X			X				X		X			X			
SE	7.5	Med	90	0	X			X		X		X		X		X				
SF	7.5	Low	90	0												X				
SG	7.5	High	90	0		X										X				
SH	7.8	Med	90	0	X			X				X		X		X				
SI	7.8	High	90	0		X										X				
SJ	8.2	High	90	0		X														
RA	6.5	Med	30	5															X	X
RB	6.5	Med	45	0			X		X		X		X		X			X		
RC	6.5	Med	45	5														X	X	
RD	6.5	Med	45	10														X		
RE	6.5	Med	60	5															X	
RF	7.0	Med	30	0			X												X	X
RG	7.0	Med	45	0			X		X				X		X			X	X	
RH	7.0	Med	45	5														X		
RI	7.0	Med	60	0															X	
RJ	7.5	Med	30	0			X													X
RK	7.5	Med	45	0			X		X		X		X		X					
RL	7.8	Med	30	0			X													X

For each of the 22 fault models listed in Table 2, 20 different rupture models, representing differences in slip distribution and hypocenter, are being used to calculate the ground motions on a grid of 162 stations, for a total of 71,500 broadband simulations.

The way in which the simulations can guide the extrapolation of the empirical models is illustrated in Figure 2, which shows the attenuation with distance of response spectral acceleration at a period of 1 second. The ranges of simulated values for hard rock are shown by the vertical bars, and the solid and dashed lines shown the median and 84th percentile values for an empirical model for soft rock (Sadigh et al, 1997). The simulations are lower than the model by an amount that is consistent with the difference in site conditions between hard and soft rock (2.8 km/sec vs. 0.6 km/sec). The simulations show that the far field slope decreases with increasing earthquake magnitude, consistent with the empirical model. However, the empirical model is not constrained beyond 100 km due to the lack of data. The simulations show that beyond 100 km, the ground motions attenuate more gradually than would be obtained by a linear extrapolation of the Sadigh et al. (1997) model beyond 100 km, due to crustal waveguide effects.

Participation in NGA Working Group Meetings and Workshops:

URS investigators have participated in all of the relevant NGA Working Group Meetings and Workshops, listed in Table 3. Robert Graves is leader of Scope Item 2 of WG 1, whose role is to make recommendations on whether and how to remove static ground motion displacements from the small subset of strong motion recordings that contain them. He organized a workshop held on November 7 to discuss this issue. He also participated in the 3D modeling work of Task 7, led by Steve Day. Deputizing for John Anderson, Leader of Working Group 4, Source and Path Effects, Paul Somerville is organizing the WG4 meeting to be held on December 2, 2003.

Table 3. NGA-E Workshops and Working Group Meetings attended by URS Investigators

Meeting	**Dates**	**Location**	**URS Participants**
Kickoff Workshop	October 24-25, 2002	Richmond	Graves, Somerville
Workshop 1	Feb 19-20, 2003	Richmond	Graves, Somerville
Working Group 4	March 24, 2003	Menlo Park	Somerville
Workshop 2	July 23-24, 2003	Richmond	Graves, Somerville
Working Group 4	September 24, 2003	Richmond	Somerville
Workshop 3	October 23-24	Richmond	Graves, Somerville
Working Group 1	November 7, 2003	Richmond	Graves
Working Group 4	December 2, 2003	Richmond	Graves, Somerville
Workshop 4	December 17-18, 2003	Richmond	Graves, Somerville

References

Abrahamson, N.A. (2003). Validation Guidelines for Numerical Simulation of Ground Motion on Rock Site Conditions, July 10, 2003.

Abrahamson, N.A., and B. Chiou (2003). NGA WG4 Plan for 1D Rock Motion Simulations, July 11, 2003.

Abrahamson, N.A., P.G. Somerville, and C. Allin Cornell (1990). Uncertainty in numerical strong motion predictions, *Proc. 4th U.S. National Conference on Earthquake Engineering,* **1**, 407- 416.

Pitarka, A., P.G. Somerville, Y. Fukushima, T. Uetake, and K. Irikura (2000). Simulation of near-fault ground motion using hybrid Green's functions. *Bull. Seis. Soc. Am*. 90, 556-586.

Sadigh, K., C.Y. Chang, J.A. Egan, F. Makdisi, and R.R. Youngs (1997). Attenuation relationships or shallow crustal earthquakes based on California strong motion data. *Seismological Research Letters* 68, 180-189.

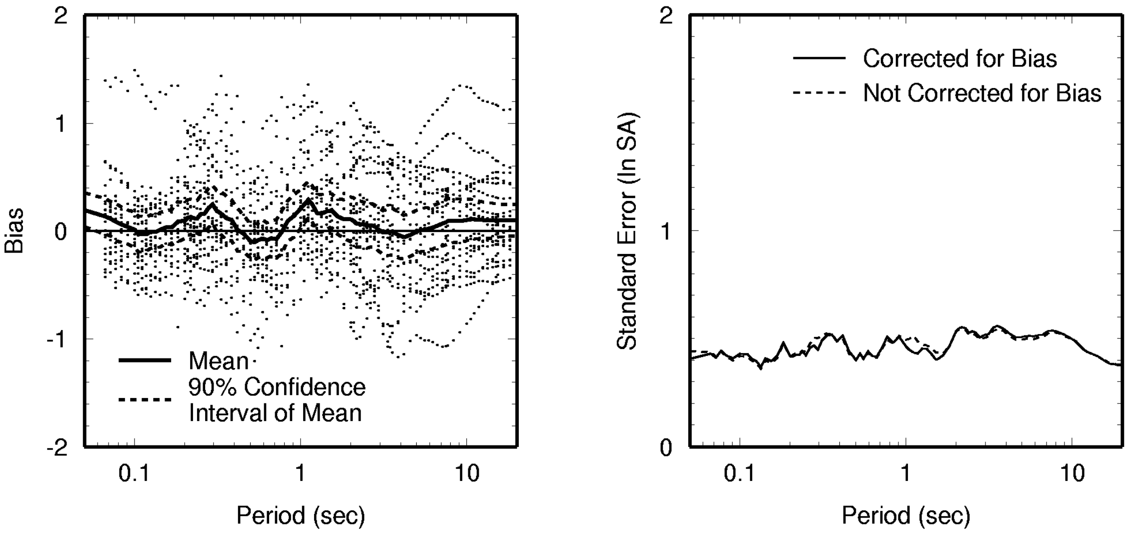

Figure 1. Bias (left) and standard error (right) in the simulation of ground motions recorded during the 1994 Northridge earthquake, using the procedure of Pitarka et al. (2000), as a function of response spectral period.

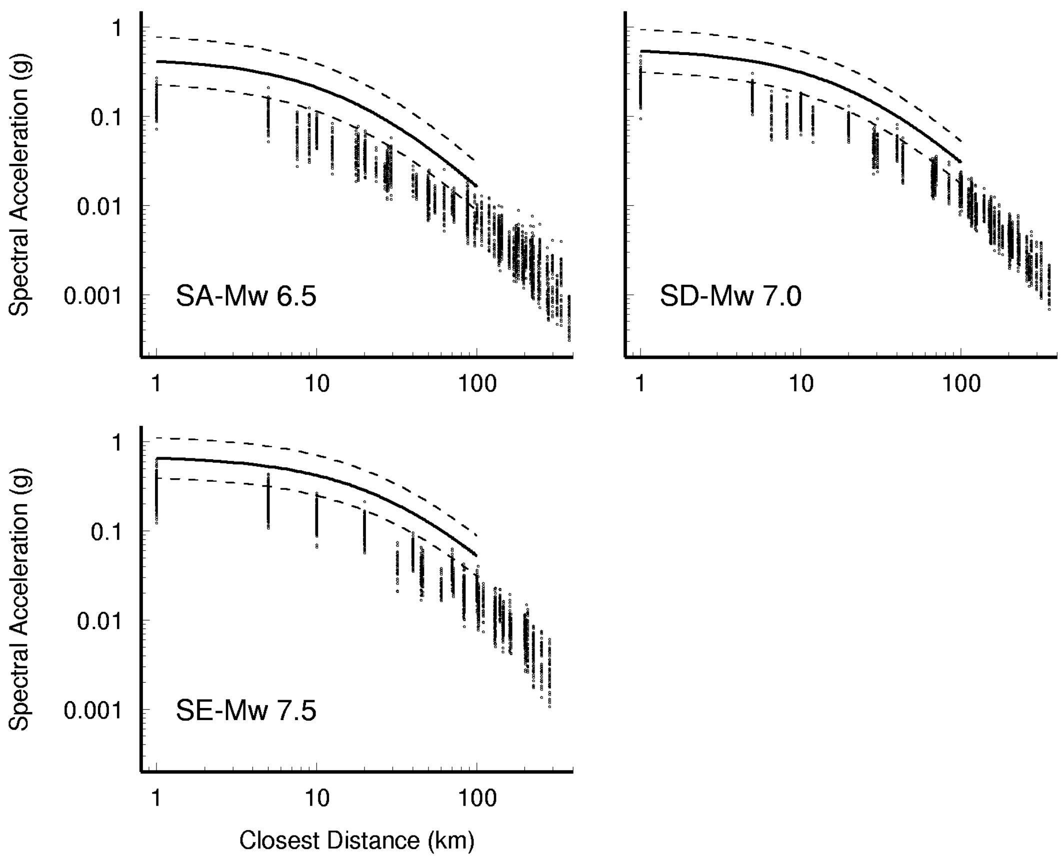

Figure 2. Comparison of NGA simulated response spectral acceleration at 1 second period for hard rock site conditions compared with the Sadigh et al. (1997) empirical model for soft rock conditions, showing magnitude and distance scaling features described in the text.