NGA-West2: A Comprehensive Research Program to Update Ground Motion Prediction Equations for Shallow Crustal Earthquakes in Active Tectonic Regions

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SUMMARY
The phase 2 of the Next Generation Attenuation models for shallow crustal earthquakes in active tectonic regions (NGA-West2) is an on-going research program to address several key issues in ground motion seismic hazard. NGA-West2 is a comprehensive multidisciplinary research project coordinated by the Pacific Earthquake Engineering Research Center (PEER) with several sub-tasks including: updating the NGA database for small, moderate and large magnitude events; updating NGA ground motion prediction equations (GMPEs); developing GMPEs for vertical ground motion; scaling response spectra for damping other than 5%; developing directivity and directionality models; further development of site response; and analysis of epistemic uncertainty for NGA GMPEs. This paper presents an overview of the NGA-West2 research program and its research sub-projects.

Keywords: ground motion prediction equations, attenuation relations, NGA, NGA-West, crustal earthquakes.

1. INTRODUCTION

In 2003, the Pacific Earthquake Engineering research Center (PEER) initiated a large research program to develop next generation attenuation relationships for shallow crustal earthquakes in active tectonic regions (now called NGA-West1). The project concluded in 2008 and provided several important deliverables, including a strong motion database of recorded ground motions and a set of peer-reviewed ground motion prediction equations, GMPEs (Power et al., 2008). Many researchers, practitioners, and organizations throughout the world are now using the NGA-West1 models and the NGA database for research and engineering applications. As successful as the original NGA-West1 program was, there were some additional and complementary ground motion issues and supporting research projects that could not be addressed in NGA-West1 program due to time constraints. The goal of a follow-up study, NGA-West2, is to fill these gaps.

The NGA-West2 project addresses the following technical topics*:*

1. Updating NGA-West models for moderate & large magnitude data,
2. Updating NGA-West models for small magnitude data,
3. Development of GMPEs for vertical ground motions,
4. Damping scaling of GMPEs for response spectra,
5. Directivity models for NGA GMPEs,

6. Directionality of ground motions,
7. Analysis of epistemic uncertainty for NGA models, and
8. Further development of site response.

Additionally, there are other on-going research tasks to better constrain the NGA GMPEs. This paper presents an overview of the NGA-West2 research program and the scopes of the sub-projects and on-going research tasks.

2. UPDATING NGA-WEST MODELS FOR MODERATE & LARGE MAGNITUDE DATA

Thousands of ground motions recorded worldwide since 2003 have been uniformly processed and added to the NGA database. The size of the NGA-West2 database is over a factor of two larger than that of NGA-West1. Figure 1 presents the evolution of the NGA database since 1997. The latest database, for example, includes comprehensive sets of ground motions recorded during the 2003 Bam (Iran), 2004 Parkfield (California), 2007 Niigata Chuetsu-oki (Japan), 2008 magnitude 7.9 Wenchuan (China), 2009 L'Aquila (Italy), 2010 Darfield (New Zealand), and 2011 Christchurch (New Zealand). More elaboration on the new database can be found in Ancheta et al. (2012).

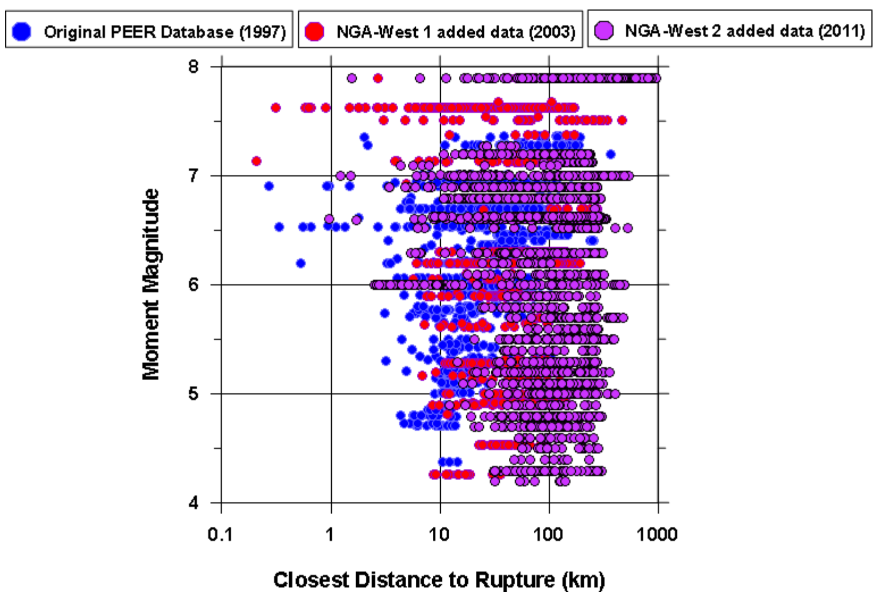

Figure 2.1. Magnitude-distance representation of the PEER ground motion databases since 1997.

The database is being used by the NGA-West2 GMPE developers to update the ground motion relations. It should be noted that in the NGA-West1, the GMPE developers used GMRotI50 (Boore, et al., 2006) as an intensity measure for combining the two horizontal components. With an intensity measure recently proposed in the US building code, the NGA-West2 researchers collectively reached a decision to use RotD50 (Boore, 2010), as a new intensity measure for the GMPE development for horizontal components. Overall, at the database level for the GMPE development, the difference between GMRotI50 and RotD50 is not large.

3. UPDATING NGA-WEST MODELS FOR SMALL MAGNITUDE DATA

In addition to the moderate-to-large magnitude database, thousands of ground motions recorded in small to moderate magnitude events in California are also compiled. The NGA-West1 GMPEs overestimated the small magnitude ground motions; therefore, by using this database, the “small-magnitude” scaling of the NGA GMPEs is being updated. In a future project (beyond the NGA-West2), the small magnitude database will also be used for constraining “Single-Station” (i.e., intra-site) standard deviation of the NGA GMPEs.

4. DEVELOPMENT OF GMPES FOR VERTICAL GROUND MOTIONS

The GMPEs developed in the NGA-West1 are for GMRotI50. Some structural and non-structural components are sensitive to the vertical input motion, especially in near-source areas. It is also now well-established that deriving vertical ground motion by scaling the horizontal motion by a factor of 2/3 has no scientific basis and tends to under-estimate the short period vertical motion and over-estimate the long period vertical motions at short distances (e.g., Figure 4.1).

The goal of this task is to develop new ground motion prediction equations for the vertical component. In a future project (beyond the NGA-West2) the plan is to also develop GMPEs for the V/H spectral ratio.

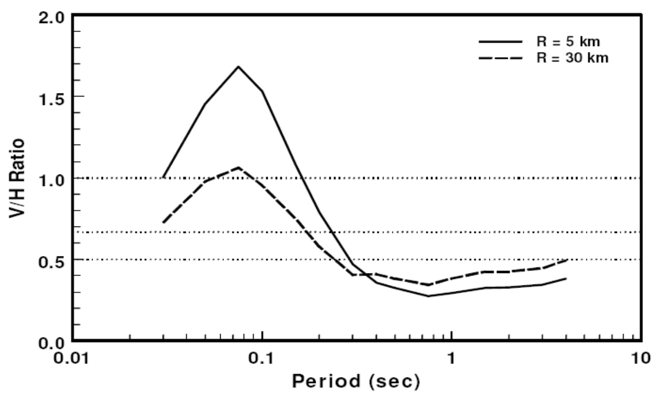

Figure 4.1. Vertical-to-horizontal spectral ratio (after Bozorgnia and Campbell, 2004a).

5. DAMPING SCALING OF GMPES FOR RESPONSE SPECTRA

The NGA-West1 models are for linear-elastic response spectra at the commonly used reference value of 5% damping. Structural and non-structural systems can have different damping ratios other than 5%, depending on the construction material, structural and non-structural systems, and the type and level of input ground motions (e.g., Bozorgnia and Campbell, 2004b), and require spectra at a range of damping values..

Current guidelines to translate the 5% damped elastic spectra to other damping values pre-date the NGA project and are possibly outdated. PEER has developed a new damping model that can be used to adjust the 5% damped response spectra to damping values ranging from 0.5% to 30%. The new damping scaling model has been developed based on the NGA-West2 database and is independent of any specific GMPE. Figure 5.1 presents the result of the scaling 5%-damped NGA spectra for a range of damping values (Rezaeian et al, 2012). Separate damping scaling models have been developed for the horizontal and vertical components of ground motion.

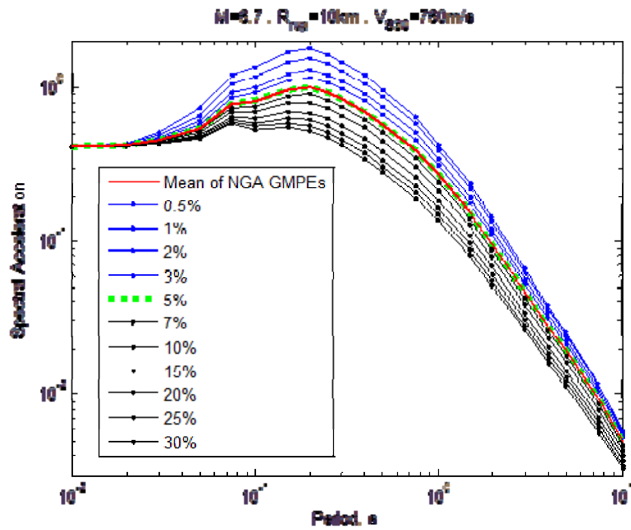

Figure 5.1. The geometric mean of the five NGA GMPEs (red) is scaled to adjust for various damping ratios from 0.5 to 30%. Assumptions: reverse fault, dip = 45°, hanging wall, fault rupture width = 15km, R_{jb}=0km, R_x=7km (after Rezaeian et al, 2012).

6. DIRECTIVITY MODELS FOR NGA GMPES

The NGA-West1 ground motion relationships were developed without explicitly including near-fault directivity effects. In NGA-West2, a working group on directivity was organized with a mission of developing various directivity models (Spudich, et al., 2012). This working group is closely collaborating with the "directionality" working group (see the next Section of this paper). The results and findings of the directivity working group will be published as a PEER report.

The NGA GMPE developers are examining the directivity models to add directivity terms to their GMPEs for horizontal component of ground motion.

7. DIRECTIONALITY OF GROUND MOTIONS

Direction (azimuth) and relative amplitudes of the maximum and minimum horizontal ground motions at a site located close to an active fault are important in determining the damage and loss to civil engineering facilities. For example, at sites very close to active faults, the fault-normal direction can experience larger intermediate- and long-period ground motions than the fault-parallel direction. The ground motions estimated from the current NGA-West1 models are for the GMRotI50 of the two horizontal components. A NGA-West2 directionality working group is examining the directionality effects. For example, Figure 7.1 presents the ratio of the maximum rotated motion over the "geometric mean" of the two horizontal components (Baker et al., 2012).

8. ANALYSIS OF EPISTEMIC UNCERTAINTY FOR NGA MODELS

There is a level of epistemic ("model-to-model") uncertainty that is not necessarily captured by the use of multiple NGA models, because the NGA models are based on overlapping data sets and involved interactions between the GMPE developers. As a result, the NGA models do not fully represent the epistemic uncertainty in the median ground motion. The goal of this task in NGA-West2 is to analyze epistemic uncertainty for the NGA-West2 models and provide guidance for users of these models.

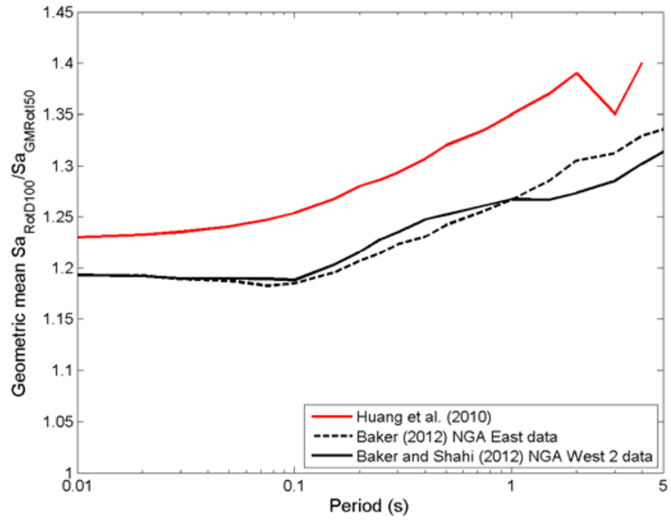

Figure 7.1: Geometric mean ratios of $Sa_{RotD100}/Sa_{GMRotI50}$ in stable continental regions from Huang et al. (2010) and the NGA East project (Baker 2012), compared with the equivalent Shahi and Baker (2012) ratios for active shallow crustal tectonic regions (after Baker, et al., 2012).

9. FURTHER DEVELOPMENT OF SITE RESPONSE

It is a common practice to: (a) perform a probabilistic hazard analysis using the NGA models for NEHRP B/C boundary site conditions corresponding to V_{S30} =760 m/sec, and then (b) apply the NEHRP site coefficients to adjust the estimated NGA ground motions to the desired NEHRP site class. The issue with this process is that the NEHRP site coefficients are not totally consistent with those predicted by the site terms included in the NGA models. In this task, PEER is examining the discrepancy between the NEHRP site coefficients and the site factors predicted by the NGA models and is attempting to resolve any discrepancy. The results will be used to propose an update of the NEHRP site factors to the Building Seismic Safety Committee.

10. OTHER ON-GOING RESEARCH TASKS

In addition to the sub-projects listed in the previous sections, there are other on-going research tasks to better constrain the NGA GMPEs. An example of such tasks is to carry out ground motion simulations to fill the gaps in the empirical database.

Another example is to constrain the **hanging wall scaling**. The NGA-West1 models showed that hanging wall effects can increase the short period ground motion by a factor of two; however, this effect was mainly constrained by only two earthquakes: the 1994 Northridge and the 1999 Chi-Chi. As a result, the hanging wall scaling was one of the main sources of differences between the five NGA-West1 GMPEs. The hanging wall scaling in the NGA-West2 models will rely on the expanded empirical dataset and a new suite of finite-fault simulations to constrain the dependence of the hanging wall effect on the magnitude, dip angle, depth, and location of the site over the rupture. This effort should greatly improve the application of the NGA-West2 models for sites located in the near-fault region over the rupture of dipping faults.

11. CONCLUDING REMARKS

NGA-West2 is a comprehensive multidisciplinary research program to address several important issues in ground motion seismic hazard for shallow crustal earthquakes in active tectonic regions. The existing NGA ground motion database is extensively expanded. We believe the new database is the largest uniformly processed ground motion database for crustal events in the world. The database is being used to update and revise the NGA GMPEs. Some tasks, such as damping scaling models, are at the final stage of development. The plan is to complete the preliminary models by late 2012. Various PEER reports will be published for the public to document all tasks and supporting research projects.

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