Region-specific ground motion relations for the Pacific Northwest

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Gail Atkinson, 280 McLean Ave., Arnprior, ON K7S 3T2, 613-623-3240. gmatkinson@aol.com

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Non-technical Summary: At present, the national seismic hazard maps in the PNW region rely on ground motion relations developed from data in other regions. The current practice may produce biased ground motion estimates, possibly by as much as a factor of two. It is important to have unbiased estimates of the seismic hazard so that informed engineering design and retrofit decisions can be made. This project utilizes recent high-quality seismographic and strong-motion recordings of moderate-to-large earthquakes in the Pacific Northwest (PNW), including the 1999 Satsop and 2001 Nisqually earthquakes, to develop region-specific ground motion relations for the PNW, including separate ground motion relations for crustal, in-slab and subduction earthquakes.

Introduction

There is growing recognition of the earthquake hazard from both crustal and subduction earthquakes in the Pacific Northwest (PNW) region. A priority task to enable reliable seismic hazard estimation for the region is the development of region-specific ground motion relations, which predict average ground motion amplitudes (response spectra and peak ground acceleration and velocity) as simple functions of earthquake magnitude (moment magnitude, **M**), focal depth, and distance. At present, it is generally assumed that ground motions from shallow crustal events in the PNW may be predicted using empirical ground motion relations developed for California, while ground motions from large subduction events may be predicted based on empirical relations developed from a global subduction database (eg. Frankel et al., 1996, 1999, 2002). These assumptions, born more of necessity than knowledge, do not appear to be well-supported by regional ground motion data. For example, high-frequency ground motions from moderate (**M**5.5) California earthquakes are consistent with an average 'Brune stress parameter' of about 100 bars (Atkinson and Silva, 1997, 2000), while similar studies for moderate shallow Cascadia events report an average stress parameter of 50 bars or less (Atkinson, 1995; Dewberry and Crosson, 1995; Atkinson and Boore, 1997). The **M** 5.1 Duvall, Washington event of 1996 and the **M** 4.3 Georgia Strait event of 1997 are characterized by stress drops of 70 bars and 45 bars, respectively (Atkinson and Cassidy, 1999). This suggests that, on average, California ground motion relations may overestimate the high-frequency motions from shallow crustal earthquakes in the Cascadia region by as much as a factor of two at near-source distances. On the other hand, the attenuation of high-frequency motions from shallow crustal events in Cascadia may be slower than in California, creating a compensating effect.

For the deeper subduction earthquakes, it is standard practice to use empirical ground motion relations developed from a global database (eg. Youngs et al., 1997). The relations most commonly used were developed from a pre-1990 database. Since that time, many more high-quality recordings have become available, from recent earthquakes in Cascadia (eg. 1999 Satsop, 2001 Nisqually), from the KNET strong-motion network in Japan (including a 2001 in-slab event of **M**6.7 that can be directly compared to Nisqually), and from the Guerrero network in Mexico. Clearly, it is important to understand regional differences in ground motion generation and propagation, and differences between crustal, in-slab, and interface events, in order to assess their implications for seismic hazard. The proposed research continues our current efforts to regress, model and understand these differences, for all three types of events, utilizing both regional and global databases.

Progress to Date

An expanded global subduction database has been compiled, containing about 10 times the number of recordings included in the widely-used relations by Youngs et al.(1997). Empirical regression of the expanded global database, using a maximum likelihood technique (Joyner and Boore, 1993), has been conducted and a paper submitted to Bull. Seism. Soc. Am. (Atkinson and Boore, 2002, currently under revision). The database will be published as an electronic supplement to this paper. The regressions have revealed some very major differences between the new relations and the previous relations of Youngs et al. (1997). In particular, the new relations demonstrate that the attenuation rates of in-slab and interface events are very different. This can be seen clearly in the data shown on Figure 1, for events in the magnitude range of most interest for hazard analysis (**M** 7 for in-slab events, or **M**≥8 for interface events). The new relations suggest that it is the interface events, rather than the in-slab events, that pose the largest seismic hazard in Cascadia. They also suggest that ground motions recorded in Japan may not be applicable to Cascadia unless regional differences in generic soil profiles (even within the same NEHRP class) can be first accounted for.

At present, we are working on the compilation and analysis of the regional crustal and subcrustal ground motion database in the Cascadia region, to better understand regional source and propagation processes. We have compiled and processed all of the 3-component broadband seismographic data for significant PNW events since the mid-1990's, in addition to selected strong-motion data from significant events. We are using these data to define empirical models of regional propagation and attenuation of crustal and in-slab events, using maximum likelihood regression techniques. This work will be completed during this current project year (Year 1 of 2).

With the regional attenuation characteristics defined empirically, we will then extend the combination of empirical study and event-based modeling of regional ground motions initiated in previous NEHRP projects (eg. Atkinson, 1995; Atkinson and Boore, 1997, 1998; Beresnev and Atkinson, 1999, 2001; Atkinson and Silva, 2000; Atkinson and Boore, 2000). Stochastic finite-fault modeling is a valuable tool for interpreting the observed ground motion data, particularly since region-specific attenuation parameters can be readily incorporated. The essence of the method is that a specified fault plane (specified by length, width, orientation in space) is subdivided into a 2D array of subfaults, each of which is small enough to be treated as a point source. The rupture initiates at a specified subfault, and propagates across the fault plane with a specified rupture velocity. The seismic radiation from each of the subfaults is modeled using the stochastic point-source model. The ground motion at a specified site is obtained by summing the contributions from all of the subfaults, lagged in time according to the time of rupture initiation on the subfault and the site-source geometry.

The stochastic finite-fault method has been shown to provide accurate ground motion predictions on average for events of moderate-to-large magnitude, over a wide frequency range (0.2 to 30 Hz), and in a variety of tectonic settings (eg. Schneider et al., 1993; Atkinson and Silva, 1997, 2000; Beresnev and Atkinson, 1997, 1998a,b; 1999, 2001). The accuracy of the finite-fault simulation method is comparable to that of deterministic methods based on more detailed modeling of wave generation and propagation (eg. Somerville et al., 1991), as was demonstrated for the 1985 Michoacan, Mexico earthquake of **M** 8 (Beresnev and Atkinson, 1997) and other events (Hartzell et al., 1999). We will therefore use a finite-fault stochastic model to develop ground-motion relations for Cascadia, for crustal, in-slab and subduction events, including estimates of uncertainty in results due to uncertainty in regional input parameters. The relations will be validated by comparison to the regional ground-motion database. The approach is analogous to the method used by Atkinson and Boore (1995) and Atkinson and Silva (2000) to develop stochastic ground-motion relations for eastern North America, and California, respectively. However in this case the underlying model will be the stochastic finite-fault model rather than the stochastic point-source model. This represents a significant advance, made possible by work over the last few years on calibrating the finite-fault stochastic models in a wide range of tectonic settings, over a wide range of magnitudes and distances (Beresnev and Atkinson, 2001). The ground motion relations will be developed during Year 2 of this project.

The resulting ground motion relations will be compared in detail to ground motion observations: 1) specifically for Cascadia; and 2) from the global subduction database. Aleatory uncertainty (eg. random scatter) will be evaluated. In the case of the crustal earthquakes, the relations will be compared not only to the limited Cascadia database, but also to ground motions from shallow crustal earthquakes in both Japan and California.

It is important to study and understand regional differences in ground motion characteristics in order to assess the extent to which data from other regions can be used to fill in the gaps in the sparse PNW ground motion database. This is particularly important to engineers, who often wish to use "real" time histories in nonlinear dynamic analyses of structures; such records are commonly imported from other regions when local records at the desired magnitude and distance are not available. Japan is a particularly fertile region for such comparisons, as it is well-covered by a high-quality strong-motion network with readily available data (KNET), including information on shear-wave velocity at each recording site. Therefore we have made detailed comparisons between Japanese and Cascadia ground motions, for both crustal and in-slab events. A comparison of particular interest is that between the recent **M**6.8 Nisqually earthquake in Washington, and a similar **M**6.7 in-slab event that occurred in Japan a few weeks later. Both events had focal depths of about 50 km. Both were well recorded. A paper comparing the ground motions from these events is in preparation and will be presented at the Fall 2002 AGU meeting. We find that there are significant differences between motions in the two regions, that appear to be due to differences in the generic soil profiles in the two regions (even within the same NEHRP site class).

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Figure 1 – Comparison of ground motion data for interface and in-slab events