I. Abstract

We present a new set of ground motion prediction equations for horizontal peak ground acceleration (PGA), peak ground velocity (PGV), and peak displacement (PDG), high-pass filtered at 3 sec) derived from ground motion records up to 250 km away from earthquakes over the magnitude range 2 < M ≤ 8 for PGA and PGV, and the magnitude range 2 ≤ M ≤ 7.3 for PDG. We adopt a functional form used by Cua (2005) and Cua and Hewit (2008) that allows for a linear dependence of the log of peak ground motion on magnitude for events with M > 5, and magnitude-distance dependence for events with M ≤ 5. We fit this functional form to a database of PGA and PGV from 1) a predominantly weak-motion southern California dataset, and 2) the Boore and Atkinson (2006) subset of the Next Generation Attenuation (NGA) project strong motion database (www.earthquake.usgs.gov/eqcenter/), at weak-motion levels. These results, based on southern California data and the NGA strong motion database, are in agreement with the findings of Bommer et al. (in press) from a European and Middle Eastern strong motion dataset.

II. Methodology

We use the functional form of Cua (2005) and Cua and Hewit (2008), which is in turn, based on a functional form originally proposed by Campbell (1997):

$$\log Y = a + (b R_s + c M)^{1/3} + \log R_s + (c M) + e$$

where $R_s = \sqrt{R_g R_w}$

$$C(M) = c \exp( (M - 5) / \alpha ) \times \text{arctan}(M - 3) + 3$$

In Equation 1, $R_s$ is a seismic distance for M ≤ 5, and the Joyner and Boorne distance (closest distance to the surface projection of the fault) when available for M > 5. For M ≤ 5, M is the magnitude reported to the Southern California Seismic Network (SCSN). SCSN local magnitudes have a 1:1 correspondence to moment magnitude, and are used for earthquakes from the NGA dataset, we use the listed Mw. Coefficients a, b, c, d, e are unknown, and are determined via a nonlinear least squares inversion. We solve for a separate set of coefficients for sites with Vs30 > 464 m/s (which we assign to the rock category, and 1,557 observations to the soil category. The Boore and Atkinson subset contributes 50 observations to the soil category, and 957 observations to the soil category. For this study, we refer to the Boore and Atkinson subset of the NGA dataset as the NGA dataset for brevity.

III. Dataset

We compare the median PGA and PGV levels predicted by our new equations with the median PGA and PGV levels predicted by the Boore and Atkinson (2006) and Campbell and Bozorgnia (2006) NGA equations, which are recommended for use above M = 5.5. Our findings suggest that our new equations are consistent with the small-amplitude equations (Quitoriano, 2006) and the NGA relationships at the M=5 level, which is the lower bound of the applicable magnitude range of the NGA equations. Our findings suggest that in order to develop prediction equations that adequately characterize the median ground motion level at a particular magnitude (for instance, the lower bound of the M=5 for the NGA equations), a sufficient quantity of data from lower magnitudes must be included. These results, based on southern California data and the NGA strong motion database, are in agreement with the findings of Bommer et al. (in press) from a European and Middle Eastern strong motion dataset.

IV. Discussion

Our relationships capture the magnitude-dependence of distance attenuation (Figure 2). This characteristics of ground motion scaling is most evident when large magnitude ranges are considered. We are consistent with what would be expected: - small magnitude and large distance amplitudes (acceleration, velocity, and displacement) scale with size of slip on the nearby fault (1) for near-source, low frequency ground motions, we expect peak displacements to scale with size of slip on the nearby fault segment, or

$$\text{Displacement Scaling} = \text{Displacement} \times \frac{\text{Size of Slip}}{\text{Displacement}}$$

- large magnitude and small distance displacements are completely saturated (which means that high frequency radiated energy scales as rupture area, which is Brune’s model without the stress drop term) for near-source, low frequency ground motions. We expect peak displacements to scale with size of slip on the nearby fault segment, or

$$\text{Displacement Scaling} = \text{Displacement} \times \frac{\text{Size of Slip}}{\text{Displacement}}$$

The displacement scaling in subplot (c) is consistent with these expectations.

Figure 1: The saturation function C(M) as a function of magnitude for the different regiments (rock and soil PGA and PGV). GMt shows saturation effects to come into play for M > 5 events by increasing the distance of a site from the source region. In general, soil ground motions exhibit stronger saturation effects than ground motions recorded on rock sites.

Figure 2: The distribution in magnitude and distance of PGA and PGV observations included in this study in (a) sites with Vs30 > 464 m/s (termed rock sites in this study), and (b) sites with Vs30 > 464 m/s (termed soil sites). Of the southern California data, 98% observations are for rock sites, and 2% from soil sites. We use the Boore and Atkinson (2007) subset of the NGA strong motion dataset. The Boore and Atkinson subset contributes 50 observations to the rock category, and 1,557 observations to the soil category. For this study, we refer to the Boore and Atkinson subset of the NGA dataset as the NGA dataset for brevity.

Figure 3: Observed PGA amplitudes from the combined southern California and NGA datasets for 4.5 < M ≤ 5.5 recorded on (a) rock and (b) soil sites, along with the median M=5-7 PGA levels predicted by the relationships in this study, Boore and Atkinson (2007), and Campbell and Bozorgnia (2007). Subplots (a) and (b) show similar plots for PGA data in the magnitude range 6.5 ≤ M ≤ 7.5, with the median M=7 PGA predicted by the same set of relationships. The NGA amplitudes are expressed in terms of GM(50), a measure of horizontal ground motion that is independent of sensor orientation (Boore, 2005). The southern California ground motion (subplots (c) and (d)) show similar plots for PGA data in the magnitude range 6.5 ≤ M ≤ 7.5, with the median M=7 PGA predicted by the same set of relationships. The NGA amplitudes are expressed in terms of GM(50), a measure of horizontal ground motion that is independent of sensor orientation (Boore, 2005).

Figure 4: Saturation effects are strongest for PGA, and decrease with decreasing frequency. The total saturation of near-source PGA for large magnitudes is consistent with near-source high frequency ground motions being incoherent noise, independent of magnitude and source. The implications for earthquake source physics. These characteristics are not evident when considering more limited magnitude ranges.

IV. Conclusions

We develop new equations for PGA, PGV, and high pass filtered displacement that are derived from data in the magnitude range 2 ≤ M ≤ 8. These relationships can be used for earthquake early warning, or ShakeMap-type applications, which, while most relevant for large, damaging (but infrequent), earthquakes, must be tested, validated, and calibrated on smaller, more frequently occurring events. We compare the median PGA and PGV levels predicted by our new equations with the Boore and Atkinson (2007) and Campbell and Bozorgnia (2007) NGA relationships, as well as the ShakeMap small amplitude relationships. Our relationships span the combined magnitude range of the NGA and ShakeMap equations.