ON THE INFLUENCE OF GROUND MOTION PREDICTIVE EQUATIONS AND THEIR VARIABILITY ON PROBABILISTIC SEISMIC HAZARD ESTIMATES

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This study examines the role of ground motion prediction equations (GMPE) and that of the variability of ground motion models (i.e. aleatory sigma) on probabilistic seismic hazard (PSH). As known, GMPEs are stochastic models that estimate the probability distribution associated to the possible shaking levels induced at a site by an earthquake as a function of several parameters, such as magnitude, source-to-site distance, style of faulting, and ground type. Their parameterization implies statistical analyses on a large number of observations which, in turn, are subjected to a heavy work of processing in order to achieve uniform data sets. The signal processing and the homogenization of data coming from different institutions is certainly the most critical step in the derivation of a GMPE. Signal must be corrected and filtered; earthquake magnitude must be converted to a uniform scale as well as distances are converted to a uniform distance metrics; site conditions at recording stations have to be determined (at least in the form of soil categories) along with the fault mechanism of the relevant seismic source. Despite of the great efforts in developing GMPEs, it is not so unusual to listen that predictions are biased because of inaccuracies in the regression data sets. For instance, it is anything but a joke to listen that ground motion values are wrong due to a wrong setup (e.g., wrong seismometer’s generator constant) of the recording instruments. It is more frequent to discuss that the reliability and accuracy of predictions is affected by gross site classifications based on large-scale geological mapping. It is also frequent listening that GMPEs neglect topographic effects or, better, that ridges and crests are lost inside the large number of sites considered in the definition of a GMPE (e.g., Barani et al., 2013). The sensation of the writers is that the time goes by and regression data sets become larger and larger, functional forms are increasingly complex, and the variability of ground motion increases although additional explanatory variables (e.g., variables that allow for soil nonlinear behavior, rupture directivity, high-frequency attenuation) are incorporated into the mathematical models. Throughout this proliferation of data sets and GMPEs, scientists (including the writers) are losing sight of the limitations of their models and, possibly, the steady improvement in the performance of brand new GMPEs. This is reflected in PSH estimates and, particularly, in the logic trees, which are increasingly leafy. Are GMPE branches really healthy or do they act as knots making the wood timber to sound worse?

The previous question is intentionally provocative, although it reflects a common feeling. The purpose here is to compare dated and recent GMPEs (see Table 1) in order to quantify 1) their predictive power with reference to real case studies, 2) their impact on the mean hazard, and 3) the influence of sigma on PSH estimates.

The predictive effectiveness of the GMPEs under examination is evaluated by comparing the median ground shaking values with real recorded data, possibly not included in the data sets used for

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the GMPE calibration. Comparison is provided for target sites located on reference soil conditions that are representative of different hazard levels in Italy.

Table 1. List of GMPEs; Hm is for maximum horizontal, Gm is for geometric mean, and GmRot50 indicates that the geometric mean is determined from the 50th percentile values of the geometric means computed for all non-redundant rotation angles

<table>
<thead>
<tr>
<th>GMPE</th>
<th>No. of events</th>
<th>No. of recordings</th>
<th>Magnitude type and range</th>
<th>Distance type and range</th>
<th>Ground motion parameters</th>
<th>Components</th>
<th>Area</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP96</td>
<td>17</td>
<td>95</td>
<td>Ms (ML) 4.6-6.8</td>
<td>Rjb (epi) &lt; 200km</td>
<td>PGA, PGV, PSV up to 2s</td>
<td>Hm, V</td>
<td>Italy</td>
<td>Sabetta and Pugliese, 1996</td>
</tr>
<tr>
<td>AMB96</td>
<td>157</td>
<td>422</td>
<td>Ms (ML) 4.0-7.9</td>
<td>Rg (up) &lt; 200km</td>
<td>PGA, PSA up to 2s</td>
<td>Hm, V</td>
<td>Europe</td>
<td>Ambraeys et al., 1996 (a,b)</td>
</tr>
<tr>
<td>AMR05</td>
<td>128</td>
<td>595</td>
<td>Ms 5.0-7.6</td>
<td>Rjb (epi) &lt; 100km</td>
<td>PGA, PSA up to 2.5s</td>
<td>Hm, V</td>
<td>Europe</td>
<td>Ambraeys et al., 2005 (a,b)</td>
</tr>
<tr>
<td>MEA08</td>
<td>82</td>
<td>624</td>
<td>ML 3.5-6.3 (Ms 4.0-6.5)</td>
<td>Repl &lt; 100km</td>
<td>PGA, PGV, PSA up to 2s</td>
<td>Hm, V</td>
<td>North Italy</td>
<td>Masa et al., 2008</td>
</tr>
<tr>
<td>CF08</td>
<td>60</td>
<td>1155</td>
<td>Ms 5.0-7.2</td>
<td>Rhip &lt; 150km</td>
<td>PGA, RD up to 20s</td>
<td>Gm</td>
<td>Global</td>
<td>Caccia and Fasciotti, 2008</td>
</tr>
<tr>
<td>BOAT00</td>
<td>58</td>
<td>1154</td>
<td>Ms 5.0-8.0</td>
<td>Rjb (epi) &lt; 400km</td>
<td>PGA, PGV, PSA up to 10s</td>
<td>GmRot50</td>
<td>Global</td>
<td>Boore and Atkinson, 2008</td>
</tr>
<tr>
<td>AKBO10</td>
<td>131</td>
<td>532</td>
<td>Ms 5.0-7.6</td>
<td>Rjb (epi) &lt; 100km</td>
<td>PGA, PGV, PSA up to 3s</td>
<td>Hm, V</td>
<td>Italy</td>
<td>Akkar and Bommer, 2010</td>
</tr>
<tr>
<td>IT08</td>
<td>107</td>
<td>561</td>
<td>Ms (ML) 4.0-6.9</td>
<td>Rjb (epi) &lt; 100km</td>
<td>PGA, PGV, PSA up to 2s</td>
<td>Hm, V</td>
<td>Italy</td>
<td>Bindi et al., 2010</td>
</tr>
<tr>
<td>IT10</td>
<td>218</td>
<td>1231</td>
<td>Ms (ML) 4.0-6.9</td>
<td>Rjb (epi) &lt; 200km</td>
<td>PGA, PGV, PSA up to 2s</td>
<td>Gm, V</td>
<td>Italy</td>
<td>Bindi et al., 2011</td>
</tr>
<tr>
<td>BEA13</td>
<td>372</td>
<td>2120</td>
<td>Ms (ML) 4.0-7.6</td>
<td>Rjb (epi) &lt; 300km</td>
<td>PGA, PGV, PSA up to 3s</td>
<td>Gm, V</td>
<td>Europe</td>
<td>Bindi et al., 2013</td>
</tr>
</tbody>
</table>

The second objective of the work is achieved through a sensitivity analysis aimed at quantifying the impact of each GMPE on the mean hazard. To this end, we performed different computational runs by varying one GMPE at a time and keeping constant the value of sigma (i.e., assuming the same sigma for all GMPEs). This allows us to quantify the effect of the median ground motion predicted by a GMPE on the hazard (Sabetta et al., 2005). The analysis is repeated for different mean return periods.

The influence of sigma on PSH estimates is always quantified via sensitivity analysis. Conversely to the previous objective, we keep constant the attenuation model and vary the value of sigma. This allows us to make considerations about the underestimation of the hazard whenever one neglects the propagation of the uncertainties related to parameter conversions (e.g., magnitude scale and source-to-site distance conversions, conversion for site class, etc.) into the GMPE sigma (e.g., Bommer et al., 2005) or, in the case of site-specific PSH analyses, whenever one neglects the contribution of the variability associated with the soil response functions (e.g., Bazzurro and Cornell, 2004; Barani et al., 2012; Barani et al., 2013).

Finally, with the aim of ranking the GMPEs considered, we compare PSH analysis results obtained by applying competing attenuation models with observed data. To this end the likelihood approached is applied (e.g., Schorlemmer and Gerstenberger, 2007; Schorlemmer et al., 2007; Albarello and D’Amico, 2008; Zechar et al., 2010).

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Cauzzi C., Faccioli E (2008), “Broadband (0.05 to 20s) prediction of displacement response spectra based on worldwide digital records”, Journal of Seismology, 12:453-475