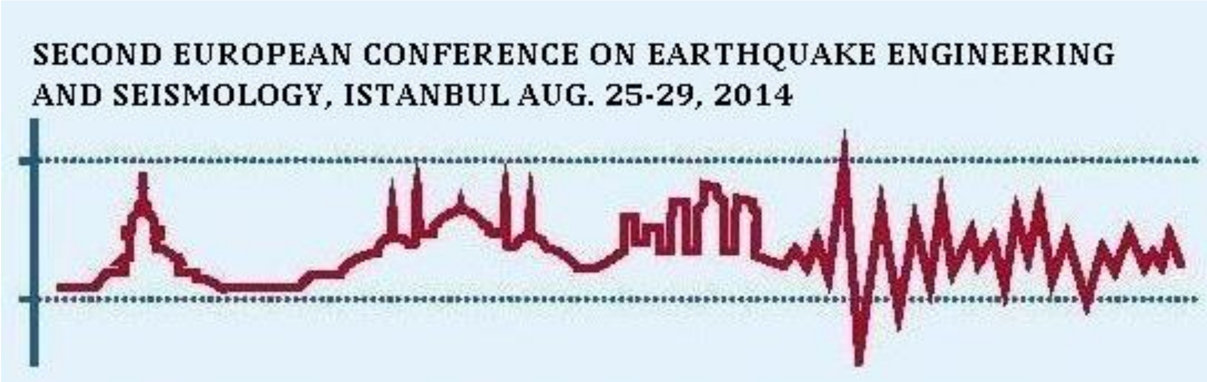

ON THE INFLUENCE OF GROUND MOTION PREDICTIVE EQUATIONS AND THEIR VARIABILITY ON PROBABILISTIC SEISMIC HAZARD ESTIMATES

Simone Barani[1], Marco Massa[2], Daniele Spallarossa[3] and Dario Albarello[4]

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

[1] Ph.D., DISTAV – University of Genoa, Genoa (Italy), barani@dipteris.unige.it
[2] Ph.D., Istituto Nazionale di Geofisica e Vulanologia – INGV, Milan (Italy), marco.massa@mi.ingv.it
[3] Prof., DISTAV – University of Genoa, Genoa (Italy), daniele@dipteris.unige.it
[4] Prof., DSFTA – University of Siena, Siena (Italy), dario.albarello@unisi.it

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

GMPE	No. of events	No. of recordings	Magnitude type and range	Distance type and range	Ground motion parameters	Components	Area	Reference
SP96	17	95	Ms (ML) 4.6-6.8	Rjb (epi) < 200km	PGA, PGV, PSV up to 2s	Hm, V	Italy	Sabetta and Pugliese, 1996
AMB96	157	422	Ms (ML) 4.0-7.9	Repi < 200km	PGA, PSA up to 2s	Hm, V	Europe	Ambraseys et al., 1996 (a,b)
AMB05	128	595	Mw 5.0-7.6	Rjb (epi) < 100km	PGA, PSA up to 2.5s	Hm, V	Europe	Ambraseys et al., 2005 (a,b)
MEA08	82	624	ML 3.5-6.3 (Mw 4.0-6.5)	Repi < 100km	PGA, PGV, PSA up to 2s	Hm, V	North Italy	Massa et al., 2008
CF08	60	1155	Mw 5.0-7.2	Rhipo < 150km	PGA, RD up to 20s	Gm	Global	Cauzzi and Faccioli, 2008
BOAT08	58	1154	Mw 5.0-8.0	Rjb (epi) < 400km	PGA, PGV, PSA up to 10s	GmRot50	Global	Boore and Atkinson, 2008
AKBO10	131	532	Mw 5.0-7.6	Rjb (epi) < 100km	PGA, PGV, PSA up to 3s	Hm	Europe	Akkar and Bommer, 2010
ITA08	107	561	Mw (ML) 4.0-6.9	Rjb (epi) < 100km	PGA, PGV, PSA up to 2s	Hm, V	Italy	Bindi et al., 2010
ITA10	218	1231	Mw (ML) 4.0-6.9	Rjb (epi) < 200km	PGA, PGV, PSA up to 2s	Gm, V	Italy	Bindi et al., 2011
BEA13	372	2120	Mw (ML) 4.0-7.6	Rjb (epi) < 300km	PGA, PGV, PSA up to 3s	Gm, V	Europe	Bindi et al., 2013

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).

REFERENCES

Akkar S, Bommer JJ (2010), “Empirical Equations for the Prediction of PGA, PGV and Spectral Accelerations in Europe, the Mediterranean Region and the Middle East”, *Seismological Research Letters*, 81(2):195-206

Albarello D, D’Amico V (2008), “Testing probabilistic seismic hazard estimates by comparison with observations: an example in Italy”, *Geophysical Journal International*, 175:1088-1094

Ambraseys NN, Douglas J, Sarma SK, Smit PM (2005a), “Equations for estimation of strong ground motions from shallow crustal earthquakes using data from Europe and the Middle East: horizontal peak ground acceleration and spectral acceleration”, *Bulletin of Earthquake Engineering*, 3:1-53

Ambraseys NN, Douglas J, Sarma SK, Smit PM (2005b), “Equations for estimation of strong ground motions from shallow crustal earthquakes using data from Europe and the Middle East: vertical peak ground acceleration and spectral acceleration”, *Bulletin of Earthquake Engineering*, 3:55-73

Ambraseys NN, Simpson KA (1996b), “Prediction of vertical response spectra in Europe”, *Earthquake Engineering and Structural Dynamics*, 25:401-412

Ambraseys, NN, Simpson KA, Bommer JJ (1996a), “Prediction of horizontal response spectra in Europe”, *Earthquake Engineering and Structural Dynamics*, 25:371-400

Barani S, Massa M, Lovati S, Ferretti G (2012), “Topographic effects in probabilistic seismic hazard analysis: the case of Narni, Central Italy”, *Proceedings of the 15th World Conference on Earthquake Engineering*, Lisbon, Portugal, 24-28 September, Paper No 5823.

Barani S, Massa M, Lovati S, Spallarossa D (2013), “Effects of surface topography on ground shaking prediction: implications for seismic hazard analysis and recommendations for seismic design”, *submitted to Geophysical Journal International*

Bazzurro P, Cornell CA. (2004), “Nonlinear soil-site effects in probabilistic seismic-hazard analysis”, *Bulletin of the Seismological Society of America*, 94:2110-2123

Bindi D, Luzi L, Massa M, Pacor F (2010), “Horizontal and vertical ground motion prediction equations derived from the Italian Accelerometric Archive (ITACA)”, *Bulletin of Earthquake Engineering*, 8(5):1209-1230

Bindi D, Massa M, Luzi L, Ameri G, Pacor F, Puglia R, Augliera P (2013), “Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-damped PSA at spectral periods up to 3.0 s using the RESORCE dataset”, *Bulletin of Earthquake Engineering*, doi 10.1007/s10518-013-9525-5

Bindi D, Pacor F, Luzi L, Puglia R, Massa M, Ameri G, Paolucci R (2011), “Ground motion prediction equations derived from the Italian strong motion database”, *Bulletin of Earthquake Engineering*, 9(6):1899-1920

Bommer JJ, Scherbaum F, Bungum H, Cotton F, Sabetta F, Abrahamson NA (2005), “On the use of logic trees for ground-motion prediction equations in seismic hazard analysis”, *Bulletin of the Seismological Society of America*, 95:377-389

Boore DM, Atkinson GM (2008), “Ground motion prediction equations for the mean horizontal component of PGA, PGV and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s”, *Earthquake Spectra*, 24(1):99-138

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

Comitè Europèen de Normalisation, (2004), “Eurocode 8: Design of structures for earthquake resistance, Part 1: General rules, seismic actions and rules for buildings”, Brussels, Belgium

Massa M, Morasca P, Moratto L, Marzorati S, Costa G, Spallarossa D (2008), “Empirical ground motion prediction equations for Northern Italy using weak and strong motion amplitudes, frequency content and duration parameters”, *Bulletin of the Seismological Society of America*, 98(3):1319-1342

Ministero delle Infrastrutture e dei Trasporti (2008), “Norme tecniche per le costruzioni”, D.M. 14 Gennaio 2008, Supplemento ordinario alla Gazzetta Ufficiale No. 29, 4 Febbraio 2008

Sabetta F, Lucantoni A, Bungum H, Bommer JJ (2005), “Sensitivity of PSHA results to round motion prediction relations and logic-tree weights”, *Soil Dynamics and Earthquake Engineering*, 24:317-329

Sabetta F., Pugliese A (1996), “Estimation of response spectra and simulation of non-stationary earthquake ground motions”, *Bulletin of the Seismological Society of America*, 86(2):337-352

Schorlemmer D, Gerstenberger MC (2007), “RELM testing center”, *Seismological Research Letters*, 78(1):30-36

Schorlemmer D, Gerstenberger MC, Wiemer S, Jackson DD, Rhoades DA (2007), “Earthquake likelihood model testing”, *Seismological Research Letters*, 78(1):17-29

Zechar JD, Gerstenberger MC, Rhoades DA (2010), “Likelihood-based test for evaluating space-rate-magnitude earthquake forecasts”, *Bulletin of the Seismological Society of America*, 100(3):1184-1195