Fifty years of ground-motion models

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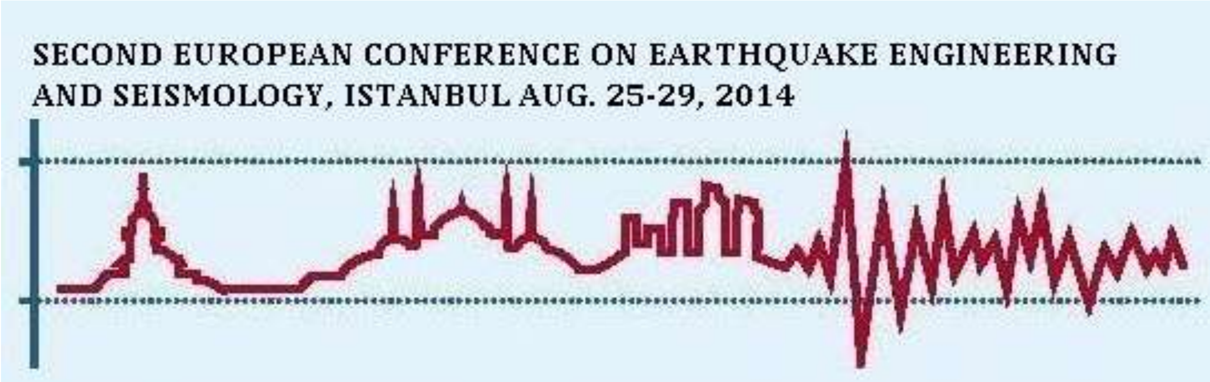

FIFTY YEARS OF GROUND-MOTION MODELS

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It has now been fifty years since the first model for the prediction of earthquake ground motions accounting for both magnitude and distance dependence was derived directly from strong-motion data (Esteva and Rosenblueth, 1964). Such models are now called: ground-motion models or ground-motion prediction equations (GMPEs), but originally were referred to as (strong-motion) attenuation relation(ship)s. Models are currently published at the rate of more than one a month and at the last count the total number of equations for the prediction of peak ground acceleration (PGA) was roughly 300 (Douglas, 2011). They are one of the key components of seismic hazard assessment since they predict the median ground motion at a site and its variability given the occurrence of a particular earthquake at a certain distance.

The purpose of this study is to summarise the current state of the art in the field of GMPEs. The improvements made since the first GMPEs were developed in the 1960s are highlighted in terms of, for example: the increase in the quantity and quality of ground-motion data used; the increase in the complexity of the models; and improvements in the derivations methods. Progress in ground-motion modelling is highlighted based on a meta-analysis of the recent GMPE compendium of Douglas (2011).

Douglas (2003) provided a review of empirical GMPEs published until the early 2000s for PGA and linear elastic response spectral ordinates. In the decade since then, GMPE developers have concentrated on: improvements in the estimation of the ground-motion variability (standard deviation, σ) associated with their models and its components, including estimating single-station σ (Atkinson, 2006); a move away from simple regression-based curve fitting; attempts at using non-parametric techniques; the use of much more and better (e.g. in terms of site characterisations) data; attempts at including additional independent parameters to reduce σ; a better appreciation of epistemic uncertainty (multiple models by same developer or by various teams using the same master database); extensions of spectral models to shorter (<0.1s) and longer (>2s) periods using individually-processed records; a more careful consideration of how the models perform at small (M_w<5) and large (M_w>7) magnitudes; and making the models easier to use within PSHA. In addition, until the early 2000s the vast majority of published GMPEs were for PGA and elastic response spectral ordinates but, as shown by Douglas (2012), there has been a grow interest in developing models for other intensity measures, e.g. peak ground velocity and displacement, Arias intensity and various duration measures.

As shown by Douglas (2010, 2012) average predicted ground motions for scenarios close to the barycentre of available data (M_w~6, R~20km) have remained roughly constant over the past few decades despite improvements to GMPEs. However, predictions for scenarios closer to the edges of available observations (e.g. M_w>7 and R<10km) show larger differences. As strong-motion networks become denser the average number of stations that record a given earthquake increases (e.g. singly-recorded events are rarer), which means that model source terms (e.g. style-of-faulting factors) and the

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inter-event variability (τ) are better constrained in recent GMPEs. Similarly a modern station generally records more earthquakes leading to better estimates of the site terms and single-station σ. Site terms are now less biased since fewer stations that contribute a large proportion of records to the strong-motion database. The reduction of epistemic uncertainty (differences in predictions among models) remains a considerable challenge. It is vital that this uncertainty is not artificially reduced but seismic hazard assessments correctly account for the true uncertainty in ground-motion prediction.

Following Douglas (2003), Strasser et al. (2009) observe that σ associated with GMPEs has shown little or no decrease since the 1970s despite the increasing complexity of models. This fact and the importance of σ on the results of probabilistic seismic hazard assessments, especially at long return periods, has encouraged attempts to increase the complexity of models to account for other effects than simply magnitude, distance and site class. To date these attempts have not led to significant reductions in σ since GMPEs remain simple representations of complex physical phenomena. However, one of the major areas of engineering seismology research in the past decade has been in separating σ into its different components (Al Atik et al., 2010) and using the appropriate components when conducting a hazard assessment (e.g. Walling and Abrahamson, 2012).

Some recent authors (e.g. Field et al., 2003; Atkinson, 2012) have argued that GMPEs will soon be replaced by numerical simulations of earthquake shaking. Such simulations will provide a much richer representation of the earthquake hazard to engineers (full time-histories rather than simply intensity measures) and they will allow source- and site-specific calculations. Although ground-motion simulations show significant advances with the advent of high-performance computing and developments of better procedures (e.g. Douglas and Aochi, 2008), GMPEs are likely to remain a key component of hazard assessments for the foreseeable future. This is because: reliable simulations of short-periods (<1s), generally the most important for engineering studies, remain problematic; defining the required input parameters and their variabilities is difficult and prone to large uncertainties; and ground-motion simulations remain time-consuming and expensive. In consequence, even if it is unlikely that GMPEs will continue to be a key component of hazard assessments for all of the next fifty years they will remain so for the next decade or two.

REFERENCES

Al Atik L, Abrahamson N, Bommer JJ, Scherbaum F, Cotton F and Kuehn N (2010) "The variability of ground-motion prediction models and its components," *Seismological Research Letters*, 81(5), 794-801.

Atkinson GM (2006) "Single-station sigma," Bulletin of the Seismological Society of America, 96(2), 446-455, DOI: 10.1785/0120050137.

Atkinson GM (2012) "Integrating advances in ground-motion and seismic-hazard analysis," Proceedings of the 15th World Conference on Earthquake Engineering.

Esteva L and Rosenblueth E (1964) "Espectros de temblores a distancias moderadas y grandes," *Boletin Sociedad Mexicana de Ingenieria Sesmica*, 2, 1-18. In Spanish.

Douglas J (2003) "Earthquake ground motion estimation using strong-motion records: A review of equations for the estimation of peak ground acceleration and response spectral ordinates," *Earth-Science Reviews*, 61(1–2): 43–104.

Douglas J (2011) Ground-motion prediction equations 1964-2010, Final report, BRGM/RP-59356-FR, PEER 2011/102, 444 pages, 9 illustrations.

Douglas J (2012) "Consistency of ground-motion predictions from the past four decades: Peak ground velocity and displacement, Arias intensity and relative significant duration," *Bulletin of Earthquake Engineering*, 10(5), 1339-1356, DOI: 10.1007/s10518-012-9359-6.

Douglas J and Aochi H (2008) "A survey of techniques for predicting earthquake ground motions for engineering purposes," Surveys in Geophysics, 29, 187-220, DOI: 10.1007/s10712-008-9046-y.

Field EH, Jordan TH and Cornell CA (2003) "OpenSHA: A developing community-modeling environment for seismic hazard analysis," *Seismological Research Letters*, 74(4), 406–419.

Strasser FO, Abrahamson NA and Bommer JJ (2009) "Sigma: Issues, insights, and challenges," *Seismological Research Letters*, 80(1), 40-56, DOI: 10.1785/gssrl.80.1.40.

Walling MA and Abrahamson NA (2012) "Non-ergodic probabilistic seismic hazard analyses," *Proceedings of the 15th World Conference on Earthquake Engineering*, Paper 1627.