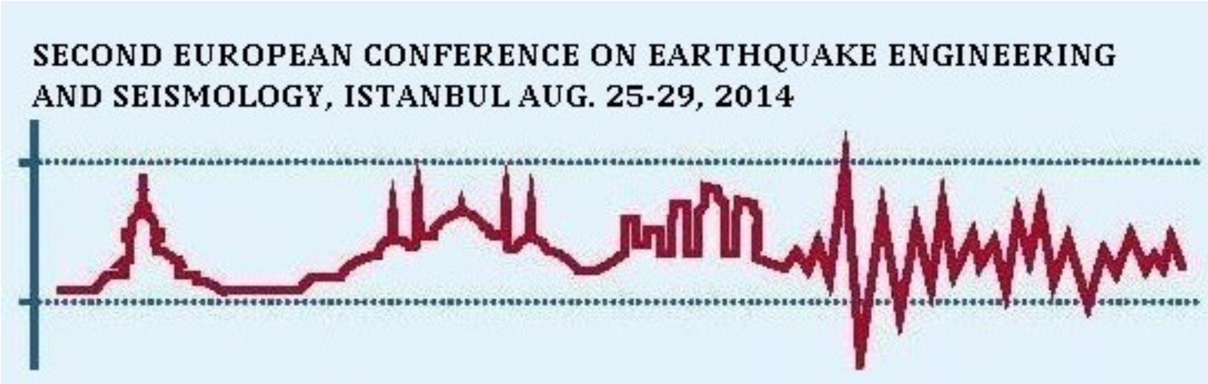

DECREASING GROUND MOTION UNCERTAINTY (SIGMA) THROUGH SITE MONITORING AND CHARACTERISATION: THE EXAMPLE OF EUROSEISTEST

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In PSHA, the greatest reduction of uncertainty in seismic risk can be gained by reducing uncertainty in ground motion estimation, which is primarily done with ground motion prediction equations (GMPEs). The global aleatory uncertainty (σ) in GMPEs is large, despite recent improvements in networks and data. One reason is that, in the ergodic approach, we combine data in space to make up for lack of data in time (Anderson and Brune, 1999). To reduce σ, first we need adequate data to estimate the systematic site and path response on a deterministic case-to-case basis, and then remove its (now epistemic) uncertainty from the global (aleatory) uncertainty. Then we can make site-specific or even path-specific GMPEs, and substitute global σ with a lower site- (or path-) specific uncertainty (single-station σ, or φ_{ss} after Al Atik et al., 2010). Site monitoring and characterisation (e.g., seismological stations located within critical facilities, on-site geotechnical or geophysical measurements) help characterise site-specific properties (e.g. local attenuation and/or amplification) and reduce part of the seismic hazard uncertainties. To date, no clear cost-benefit analyses has been conducted on how such on-site measurements contribute to this reduction. In this work we show the impact of monitoring and characterisation on the uncertainty of the ground motion estimates.

For this study of single station sigma we choose the EUROSEISTEST valley (Figure 1), a geologically complex and seismically active region with a permanent strong motion array consisting of 14 surface and 6 downhole stations (Pitilakis et al., 2013; http://euroseisdb.civil.auth.gr). Site conditions range from soft sediments to hard rock, with Vs_{30} ranging from 190 to 1840 m/s (EC8 classes A to C/D). We create a database of 690 records based on quality criteria. The final dataset includes 133 crustal events, with moment magnitudes from M2.0-M5.6 and depths less than 16 km, recorded at 22 stations, at distances from 5-220 km (Figure 2).

One of the distinct advantages of our dataset is the good existing knowledge of site conditions, which is a result of more than 20 years of geophysical, geotechnical, and site response studies. The key to using lower σ values in site-specific GMPEs is being able to achieve a reliable site-specific site/path term. This knowledge makes it possible to test our analysis for different levels of site information, starting from crude soil vs. rock descriptions, and moving to a more elaborate site description based on Vs_{30}. Another advantage of this dataset is that the events have been carefully relocated and magnitudes re-estimated (this study; Galanis, 2010) with respect to routine parameters retrieved from monthly seismic bulletins. Hence, we can also test our analysis for different levels of source information, i.e. for the typical catalogue quality and for expert relocation quality.

We create a simple GMPE from our data, constraining it with the help of global parameters. We then analyse between-event and within-event residuals to compute standard deviations. First we

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investigate the effect of source parameter quality. The improvement achieved with the relocations and magnitude re-estimations significantly decreases the between-event variability τ (Figure 3, shown for period T=0), which in turn leads to a reduction in the total σ. We then experiment with the type of functional form of the GMPE, going from the forms typically used in Greece to more advanced forms including a quadratic magnitude term. The τ variability and σ are thus further decreased (Figure 3).

Similarly, we study the effect of the gradual improvement in site information. We first assume no site data, then use a binary rock/soil switch (typical practice in Greece until recently), then introduce Vs_{30}, following recent advances. This improvement is clearly reflected in the decrease of φ_{S2S}, the systematic site-to-site variability, which again leads to a reduction in the total σ (Figure 4). In the last panel of this figure, we show how the total ergodic σ and the φ can be reduced even further, by removing the ergodic assumption, and using instead σ_{ss} and φ_{ss}. This would be possible in this site thanks to the good knowledge of site conditions and the available recorded data that allow us to compute site response both theoretically and empirically. In this case, we stress that the global median of the GMPE can no longer be used and a new, site-specific one, should be estimated. We note that our values of φ_{ss} are low compared to global values and this may be due to a lack of ray coverage in all directions across our site. Indeed, our φ_{ss} values are similar to published φ_{sp} values, i.e. single-path sigma, which means that using them corresponds to a fully rather than partially non-ergodic approach.

In closing, we have shown an example of how good site monitoring and characterization can: 1. help decrease the total uncertainty of global GMPEs in the traditional ergodic approach and 2. how they permit its further reduction through partially or fully non-ergodic approaches, provided new, local GMPEs are used for that purpose.

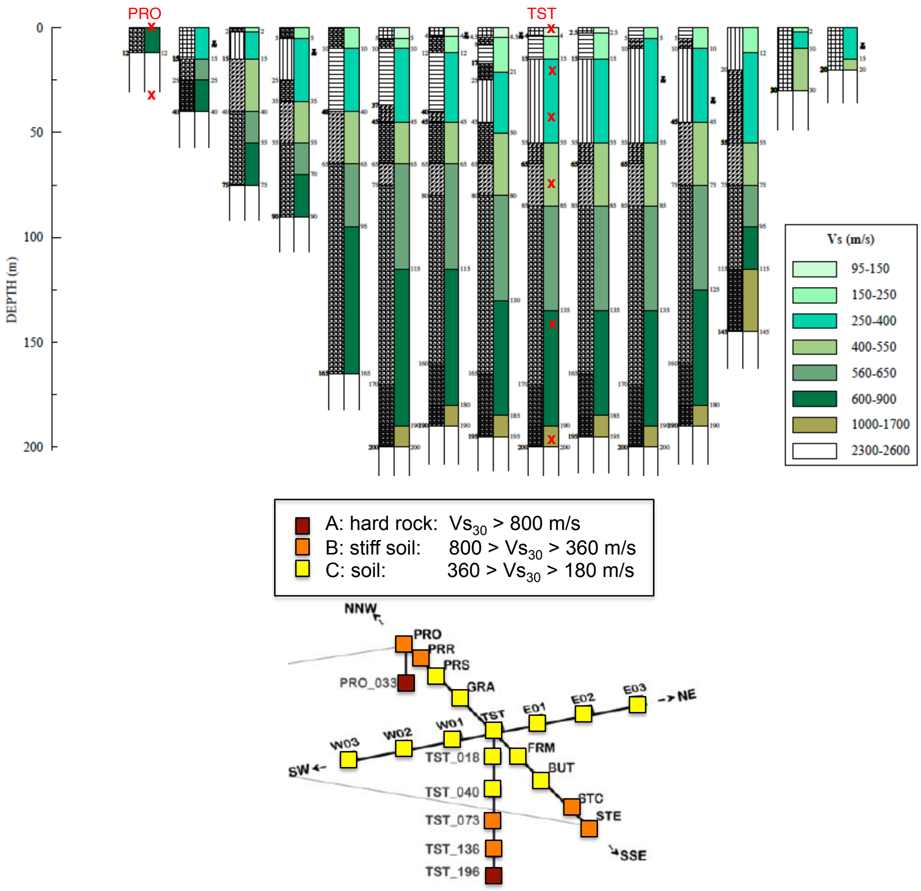

Figure 1. Left: Indicative geotechnical section and Vs profiles, including location of surface stations and downhole instruments in the two boreholes. Right: 3D sketch of the array, with a colour code indicating EC8 classification (adapted from Pitilakis et al., 1999 & 2013).

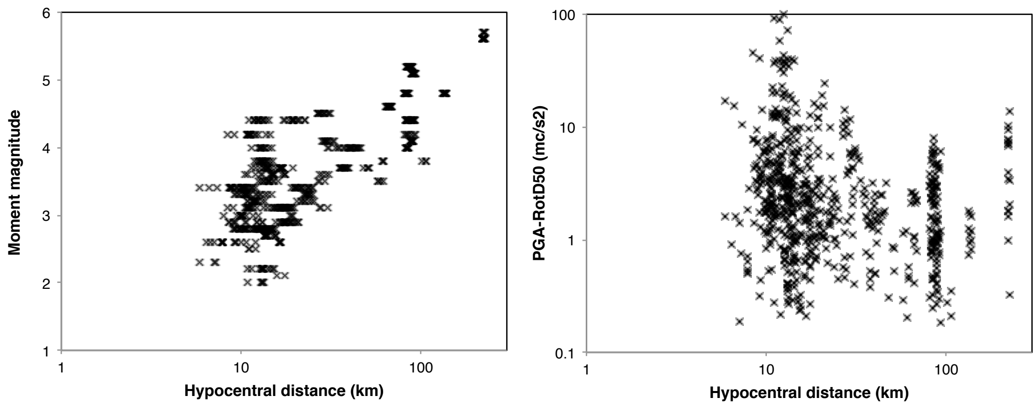

Figure 2. Magnitude (left) and PGA (right) distribution of the dataset with distance.

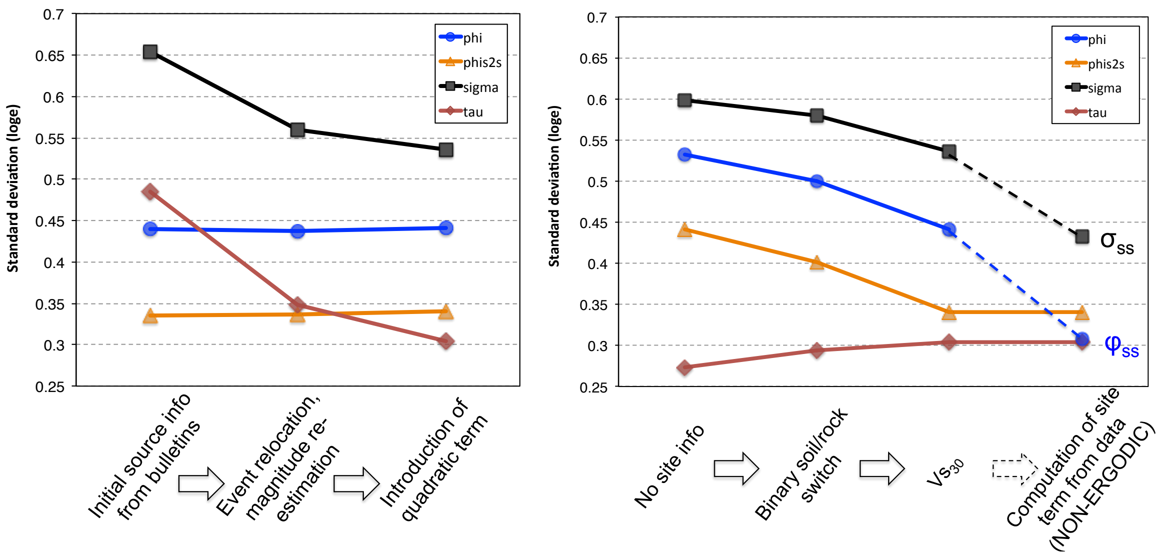

Figure 3. Left: The decrease of τ (and hence of σ) with the improvement of source parameter knowledge and magnitude scaling (for the ergodic case, assuming knowledge of Vs_{30}). Right: The decrease of φ_{S2S} (and hence of φ and σ) with the improvement of site parameter knowledge (for the ergodic case, assuming revised source parameters and magnitude scaling) and the passing to non-ergodic values. All values shown for T=0.

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