SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING
AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

PHYSICS OF KAPPA: INSIGHTS FROM EUROSEISTEST DATA

Olga-Joan KTENIDOU[1], Stephane DROUET[2], Fabrice COTTON[3], and Norman ABRAHAMSON [4]

At high frequencies, the acceleration spectral amplitude decreases rapidly. Anderson and Hough (1984) modelled this with the spectral decay factor κ. κ may have source, path, and site components. Its site component, κ_0, is used widely in ground motion prediction and simulation and is particularly important for the response of critical facilities. Numerous approaches exist to measure κ_0. Ktenidou et al. (2014) defined a taxonomy of the main approaches and group them together based on conceptual consistency.

In this study we estimate κ for 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 (EC8 classes A to C/D).

We use two different but conceptually consistent approaches according to the taxonomy: measuring κ on the high-frequency part of the S-wave acceleration spectra (κ_{r_AS}, after Ktenidou et al., 2013), and on the site transfer function (κ_{0_TF}, after Drouet et al., 2008a,b). For the AS approach, we separate the site (κ_{0_AS}) and path (regional Q attenuation) components of κ_{r_AS}. We then compare κ_0 results from the two approaches and find them similar. The differences between the methods provide an estimate of epistemic uncertainty (Figure 2). The regional Q results are also in agreement with independent crustal attenuation studies.

We take advantage of the existing knowledge of the geological profile and soil/rock properties to examine the correlation of κ_0 with site characterisation parameters Vs_{30}, resonant frequency, and depth-to-bedrock (Figures 2,3). κ_0 correlates to Vs_{30} as expected, though the scatter is large. It also correlates with the geological structure below 30 m (and down to 200 m). Thus, correlations with the entire soil column may complement the correlation of κ_0 with the very shallow geology.

Based on the observed relation of κ_0 with Vs_{30}, we suggest an alternative model that contradicts existing empirical correlations. Most correlations predict a continuous decrease of κ_0 for very high Vs values. But the similarity in our results for Vs_{30} values from 500-1800 m/s suggests that κ_0 may reach a minimum value for rock and stabilize. That value may possibly depend on the characteristics of the region, such as the crustal profile and the tectonic setting (Figure 4). This would mean that existing correlations, which are poorly constrained for high Vs_{30}, may underestimate κ_0 for hard rock.

Finally, using the known the geological profile we compute κ_0 at the surface of the two boreholes theoretically: we compute travel times based on the known Vs and Q profile, and add them to the measured downhole κ_0 at depth. We find that material damping may not suffice to account for the total measured surface κ_0 (Figure 5). A possible source of additional attenuation is scattering from small-scale variability in the profile (Faccioli et al., 1989). If so, geotechnical damping measurements may not suffice to infer the overall crustal attenuation under a site, but starting with a regional (or borehole) value and adding damping could help define a lower bound for site-specific κ_0.

---

[1] Dr, ISTerre, Université de Grenoble 1, CNRS, Grenoble, France, olga.ktenidou@ujf-grenoble.fr
[2] Dr, Observatório Nacional, Rio de Janeiro, Brazil, st.drouet@gmail.com
[3] Prof., ISTerre, Université de Grenoble 1, CNRS, Grenoble, France, fabrice.cotton@ujf-grenoble.fr
[4] Prof., University of California, Berkeley, USA, abrahamson@berkeley.edu

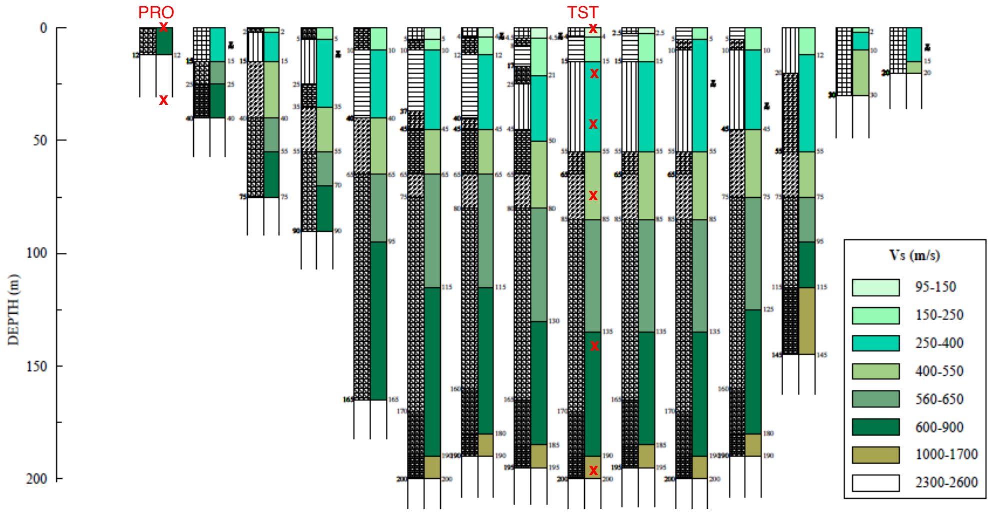

Figure 1. Indicative geotechnical section and Vs profiles, including location of surface stations and downhole instruments in the two boreholes (adapted from Pitilakis et al., 1999).

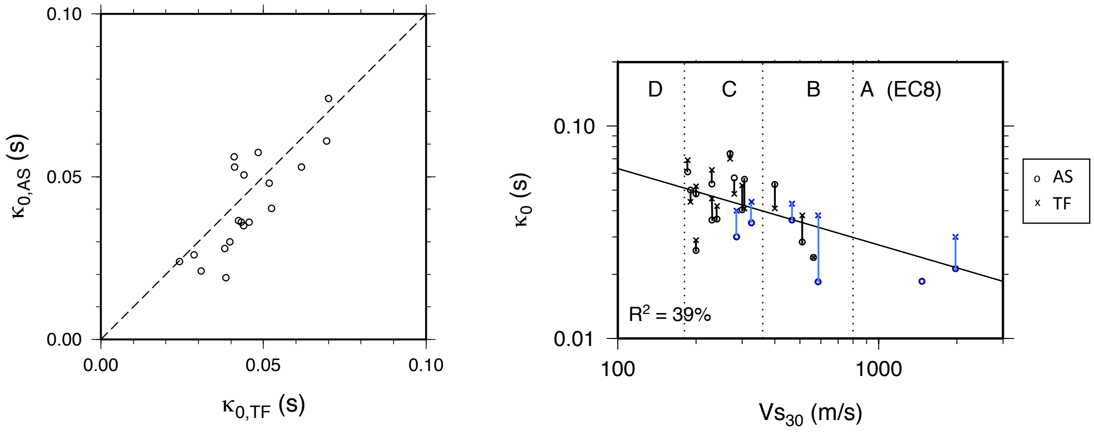

Figure 2. a. Comparison of the AS and TF approaches for κ_0. b. Correlation of κ_0 values with Vs_{30} with AS and TF approach. For each station, the vertical lines connect the results derived from the two approaches to illustrate the epistemic uncertainty of κ_0 due to the method of measurement. Blue indicates downhole stations.

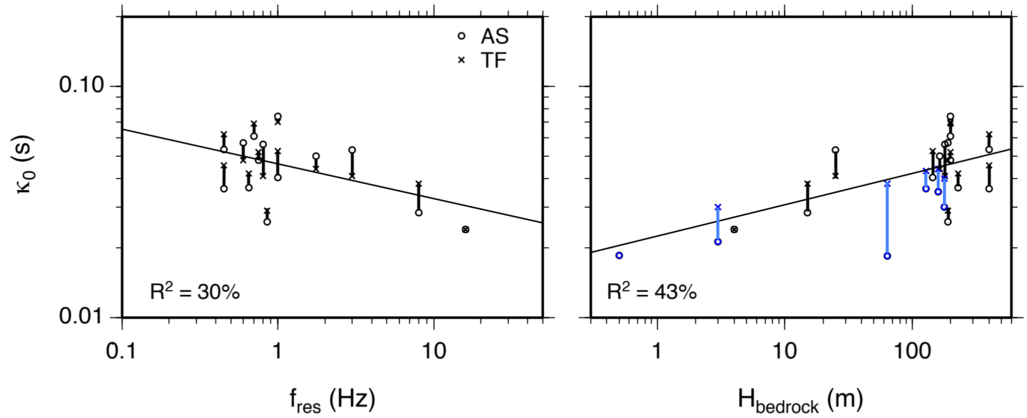

Figure 3. Correlation of κ_0 values with resonant frequency (left) and depth to bedrock (right). Circles denote AS and crosses denote TF method. Correlation coefficients are also shown. Blue indicates downhole stations. Correlation with these parameter supports the deeper origins of κ_0.

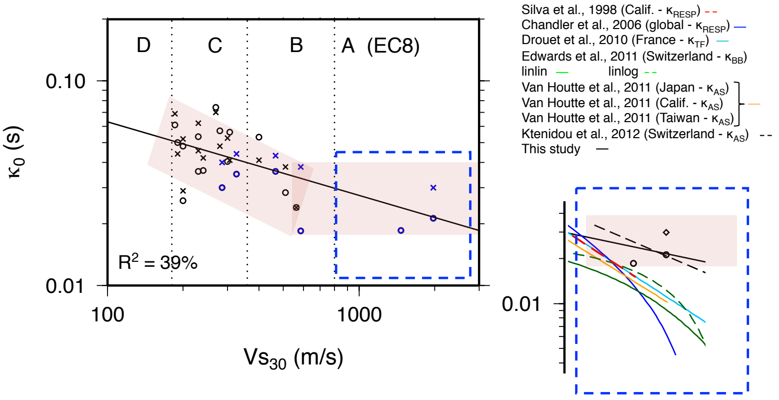

Figure 4. A possible alternative model for the correlation of κ_0 with Vs: stabilization to a regional minimum κ_0 value for hard rock. The inset shows a comparison of our results with existing empirical κ_0-Vs_{30} correlations. Most of these predict continuous decrease and do not account for regional stabilization, hence possibly overestimating hard rock κ_0. Our results agree with Swiss κ_0 values by Ktenidou and Van Houtte (2012).

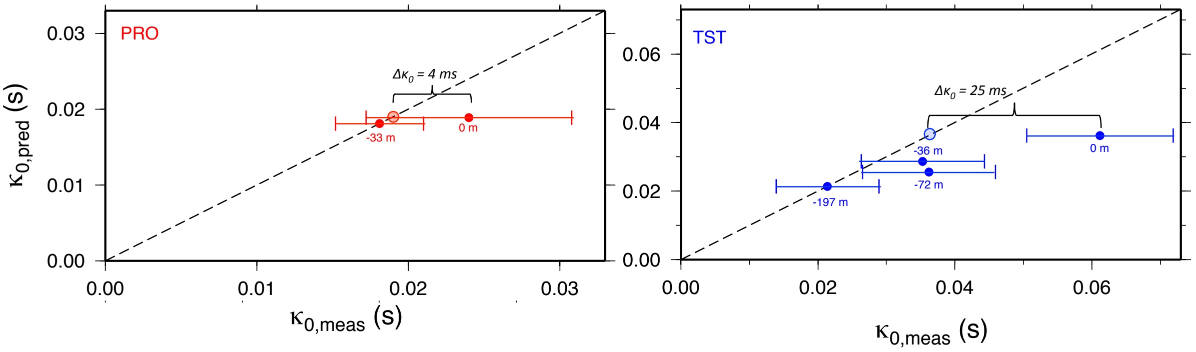

Figure 5. Predicted vs measured κ_0 values at every station in the PRO (left) and TST (right) boreholes. For the deepest downhole stations the starting points lie on the diagonal. Nearing the surface, the points move away from it, as measured κ_0 becomes larger than predicted. For TST we only show stations with more than 10 records. $\Delta\kappa_0$ measured the difference between the final predicted and measured values at the surface.

REFERENCES

Anderson, J.G. and S.E. Hough (1984). "A model for the shape of the Fourier amplitude spectrum of acceleration at high frequencies", *Bull. Seism. Soc. Am*. 74: 1969-1993

Drouet S, S. Chevrot, F. Cotton, and A. Souriau (2008a). "Simultaneous inversion of source spectra, attenuation parameters and site responses. Application to the data of the French Accelerometric Network", *Bull. Seism. Soc. Am.* 98: 198-219

Drouet S., N. Theodulidis and A. Savvaidis (2008b). "Site effects from parameterised generalised inversions", *Proceedings of the ESC 31st General Assembly*, Hersonissos-Crete, Greece, 8-12 Sept.

Faccioli, E., A. Tagliani, and R. Paolucci (1989). "Effects of wave propagation in random earth media on the seismic radiation spectrum", in *Structural Dynamics and Soil-structure Interaction*, A.S. Cakmac and I. Herrera, (Editors), Computation Mech. Pub., Southampton: 61-75.

Ktenidou O.-J., C. Gelis, F. Bonilla (2013). "A study on the variability of kappa in a borehole. Implications on the computation method used", *Bull. Seismol. Soc. Am.* 103: 1048-1068

Ktenidou O.-J., Van Houtte, C. (2012). Empirical estimation of kappa from rock velocity profiles at the Swiss NPP sites (19.02.2012). Report TP2-TB-1090, Pegasos Refinement Project.

Ktenidou O.-J., F. Cotton, N. Abrahamson, J.G. Anderson (2014). "Taxonomy of κ (kappa): a review of definitions and estimation methods targeted to applications", *Seismol. Res. Letts* 85: 135-146

Pitilakis, K., D. Raptakis, K. Lontzetidis, Th. Tika-Vassilikou & D. Jongmans (1999). "Geotechnical & Geophysical description of EURO-SEISTEST, using field, laboratory tests and moderate strong-motion recordings", *J. Earthq. Eng*. 3: 381-409

Pitilakis K., Z. Roumelioti, D. Raptakis, M. Manakou, K. Liakakis, A. Anastasiadis, and D. Pitilakis (2013). "The EUROSEISTEST Strong-Motion Database and Web Portal", *Seismol. Res. Letts* 84: 796-804