ESC2016-345, 2016
35th General Assembly of the European Seismological Commission

In situ nonlinear analysis at boreholes using seismic interferometry by deconvolution and the PGV/Vs30 strain proxy

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Low velocity, soft sediments are generally considered to be a critical component of seismic hazard, amplifying the seismic ground motion and partly controlling the spatial variability of building damage. On the other hand, it is also commonly assumed that unconsolidated sediments tend to respond in a nonlinear manner, which can serve to modify seismic ground motion. As a result, new equations are being developed to introduce nonlinearity and to consider its effects on the standard deviation of seismic ground motion predictions according to specific parameters, such as magnitude and distance, which always require geotechnical in situ characterization of the site and a way of characterizing the nonlinear response in the data. The nonlinear response of sediments is usually considered as the result of the degradation of the shear modulus G and the increase in damping ζ as the soil shear strain γ increases. Nonlinear site characterization is required to estimate the seismic ground motion variability observed in data and influencing the uncertainties of prediction equations. Such estimates are based on the characterization of shear wave velocity in the upper sediment layers and the testing of soil samples in the laboratory by cyclic and/or dynamic tests. Differences exist between laboratory results and in situ observations due to the difficulties of reproducing stress-strain conditions and of separating nonlinear effects from site amplification effects, including for example 2D/3D geometrical effects. Moreover, it is difficult to generalize laboratory tests to all recording sites and all depths where nonlinearity can be expected. However, nonlinear response is directly related to the variation of shear (modulus and strain) and one solution consists in assessing the shear-wave velocity (Vs) of soil during strong ground strain.

In this study, we present synthesis from several sites on the efficiency of the ratio between particle velocity and shear wave velocity as a strain proxy for evaluating the nonlinear seismic response of sediments. The in-situ stress-strain relationships are derived from accelerometric vertical array recordings at several boreholes (TST site in Volvi, Thessaloniki, Greece; LIQF site in Belleplaine, Guadeloupe, France; Wide-Life refuge and Garner valley site in California, USA) and using numerical modeling and centrifuge tests. First, the shear wave velocity between two successive sensors was computed by seismic interferometry and strain was computed as PGV/Vs. The shear-wave velocity profile and in situ shear modulus degradation curve with strain were compared with previous studies performed at each sites. Finally, the stress-strain relationships were derived from data recorded at the surface by extending the strain proxy and stress values to the ratio between peak ground velocity and the Vs30 parameter used for site classification, i.e. without requiring the accelerometric vertical array.