Spatial Variation of Seismic Ground Motions from European Rock- and Soil-site Dense Arrays

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A significant part of spatial variation of seismic ground motions (SVSGM) over very short distances (e.g., dimensions of large engineering structures) is introduced by the effects of complex wave propagation and scattering as the seismic waves encounter heterogeneities at the shallow geology of the site. The stochastic models of SVSGM, expressed as coherency functions, account for the random phase variability of such non-uniform seismic excitations. However, the lack of association of these models with physical site-parameters renders them barely applicable in site-specific risk assessment of infrastructures. The present study, ongoing under the framework of the project EXAMIN (EXperimental Assessment and Modelling of ground motion spatial variability for performance based seismic risk assessment of industrial plants and INfrastructures; http://anr-examin.brgm.fr/) 2017-2019, funded by the French National Research Agency, attempts to shed light on this area of research. We present SVSGM estimated from low to moderate magnitude, local and regional earthquakes, recorded by different dense arrays of seismic stations in Europe. We studied one soft-rock and two soil arrays from the Cephalonia island of Greece, one soil array from the Fucino basin in Italy, along with one hard-rock array from the Saint-Guerin dam site and one soil array from the Grenoble basin in France. We quantified the coherency of shear-wave phases between two seismograms recorded by a pair of stations at 1-20 Hz frequencies. For each array and dataset, we averaged estimations from all pairs of stations having interstation distances falling into 10 m interval ranges between 10 and 200 m. Then, we examined the contribution of different physical parameters (e.g., wave characteristics, shear wave velocity) to the spatial variability of ground motion. Our observations indicate a largely site-dependent nature of spatial coherency and its strong correlation with characteristics of locally generated wave-field, likely to be associated with two- or three-dimensional geometrical effects and near-surface heterogeneities of the sites. Higher coherency is observed at rock sites, the highest being at the hard rock. However, at soil sites, the loss of coherency seems to be dominated by diffracted surface waves (Love and Rayleigh) propagating along the valley-edge directions. We eventually drew a comparison with the existing parametric models and found weaker correlations with our observed decay patterns. An analysis of three orthogonal directions of ground motions showed that the statistics of coherency is not sensitive to the orientation of the horizontal components. However, the vertical coherency, particularly at soil sites, is systematically lower than that of horizontal, and demonstrates an apparent increasing tendency at higher frequencies (>5 Hz) and shorter distances (<50 m), which has not been reported so far in the current literature. The results and understanding acquired through the analysis of these experimental data will be utilized in physics-based simulation of spatially variable ground motion in order to achieve the main goal of the project EXAMIN that is to develop a comprehensive approach for risk assessment of infrastructure networks.