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Vs profile derived from surface-wave and down-hole methods: comparison at some case studies in Central Italy

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Site characterization is a basic step in any study involving the estimation of local seismic amplifications. A main product of a site characterization analysis is the shear-wave velocity (Vs) profile, which is often obtained in the one-dimensional (1D) case through geophysical methods integrated to geological information. Among geophysical methods, surface-wave techniques based on passive seismic data are increasing of popularity and are usually employed within the seismological and engineering community to derive shallow 1D Vs profiles.

In this study we used surface-wave passive techniques to characterize four Italian sites situated in different geological context. At each target site, a down-hole survey was also executed by other researcher groups (Cnr-Igag, Università degli Studi di Firenze and Università La Sapienza di Roma) providing the subsurface Vs profile for a maximum depth of investigation of about 50 m. Because the passive non-invasive seismic experiments were conducted before and independently from the down-hole results, we had the opportunity to compare the 1D velocity models obtained with the two methods (i.e. passive seismic data and down-hole tests) in a blind way.

The four sites have been selected in the framework of two projects: i) three sites were investigated during the microzoning activity of the Amatrice area (Ocdpc n. 394 of September 19, 2016) after the 2016 seismic sequence of the Central Italy (Amatrice downtown, and the nearby villages Sommati and Sant'Angelo where the main geological formation is the Laga Flysch); ii) one site (ROM9.IV in Rome) was investigated for a characterization analysis regarding the Italian seismic network following an agreement between Department of Civil Protection (DPC) and Istituto Nazionale di Geofisica e Vulcanologia (INGV) (DPC-INGV 2012-2021, Allegato B2-Obiettivo1, Task B).

We used arrays of three-components seismic stations arranged in 2D configuration and we recorded, at each target site, some hours of ambient vibrations (i.e. seismic noise). The array geometry was defined according to the logistic, and, when possible, two geometries with a progressive larger aperture were used at a same site to increase the frequency band of analysis. The maximum aperture of the 2D arrays varied approximately from 100 to 200 meters using 12 seismic stations. The 2D arrays measured the dispersion curve using frequency-wavenumber and spatial auto-correlation methods. The resonance frequency (f0) was also computed by the horizontal-to-vertical (HV) noise spectral curves. A joint inversion of f0 and dispersion curves in terms of surface waves has provided the local Vs profile and the consequent soil class category, based on the mean value of the best Vs model in the uppermost 30 m of the subsurface (Vs30 as prescribed by the national Italian seismic design code). Additionally, a joint inversion under the diffuse field assumption was also tentatively tested to derive the subsurface velocity structure.

Our blind test between 2D array and down-hole methods shows some discrepancies between Vs profiles derived at the same site: forward computations of theoretical dispersion and ellipticity models, using the Vs profile resulting from array and down-hole surveys, show an overlapping only in a narrow frequency band, highlighting the different resolution of the two methods. In particular, we observe a general agreement in the main trend of the velocity-depth profile (Vs discrepancies are within 20% range) at soft sites, but thin layers with different elastic properties documented by the down-hole surveys cannot be reproduced by array methods. Moreover, the resonance frequency of the HV curves in the low frequency range (i.e. < 2 Hz) is not reproduced by forward ellipticity-model computation assuming the Vs profile from down-hole data; this is expected because the down-hole surveys have smaller investigation depth (<50 m) and cannot reveal deeper seismic contrast responsible of the low-frequency resonance. However, the main differences for Vs are observed at IV.ROM9 where borehole data show at the shallow (approximately at a depth of 20 m) the presence of a strong velocity reversal, which is related to a stiffer volcanic deposit overlaying a soft sedimentary layer.

To conclude, the comparison at our case studies from borehole and array methods provides some differences in terms of Vs profile. This can be partially explained considering that a borehole test is a punctual survey whereas array experiment is an areal survey influenced by the average elastic properties of the investigated subsurface. A secondary factor to consider is the different resolution provided by the two methods. We believe that, for the assessment of the Vs profile to compute the local seismic response, it is likely a good compromise to combine the results derived from borehole and 2D array for the shallowest and deeper part, respectively.