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Spectral ratio techniques as a tool for soil-structure interaction assessment

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In the last years many papers focused the attention on the estimation of site effects in correspondence of inhabited areas with the aim to evaluate if the free oscillations of a structure are able to modify the estimation of the fundamental frequency of the soil.
In particular, a correct understanding of the source of a resonance amplification peak becomes relevant in the case where the frequencies of vibration of the buildings fall into the range where soil amplification is expected: in this case damage might increase in case of an earthquake due to an amplified structural response of the structure.
In this work the results coming from ambient seismic noise measurements computed at 4 sites of Northern Italy, where seismic stations are installed inside buildings, are presented and discussed.
The considered sites were selected in correspondence of very populated areas where both civil structures and industrial facilities are present: moreover in a such area, since the high level of background noise, where is not simple to find out site for a good seismic installation.
The noise measurements were performed closed to 4 strong motion stations characterized by different types of installation: Bagolino station (BAG8), managed by the INGV (Italian National Institute for Geophysic and Vulcanology), installed in the basament of a primary school, with the sensor directly connected to the rock (limestone and dolomite); Aulla station (AUL), managed by the DPC (Italian Civil Protection), installed in the cellar of an ancient medieval fortress with the sensor directly connected to the rock (serpentine); Asolo station (ASO7), managed by the INGV, installed at the bottom of an ancient medieval fortress builded on an isolated hill (hard sandstone); in this case the sensor is installed on the foundations; Vobarno station (VOBA) managed by the INGV, located at the bottom of a primary school with the sensor installed on the foundations (plate foundation). The school, a two-stories RC structure, is built on lithological units characterized by alluvial deposits.
All noise measurements, characterized by a minimum duration of 30 minutes (sampling rate 100 Hz), were performed using a Lennartz LE3D-5s seismometer (flat response 0.2 - 40 Hz) coupled with a 24 bits Reftek 130/01 digital recorder.
To investigate the dynamic characterization of buildings both standard spectral ratio (SSR) and horizontal to vertical spectral ratio (HVNR) techniques were applied to the recorded data; in the first case two simultaneous measures, computed at the bottom and at the top of the structure were considered.
For the stations where earthquakes recordings were available, the results from ambients noise were compared, to those obtained from earthquakes (HVSR). For all records the linear trend and the instrumental response were removed and a band-pass Butterworth 4 poles filter between 0.2 and 25 Hz was applied. Then each component of noise was windowed in time series of 120 s length (cosine taper 5%), the horizontal components were rotated between 0° and 175° with step of 5° and the power spectral density (PSD) were calculated using a Konno and Ohmachi (1998) window (b=20). Finally, for each considered azimuth average HVNRs were computed calculating for each time window the spectral ratio between the spectrum of the radial component over the spectrum of the vertical one.
For earthquake the data processing were performed as described for noise but considering different portion of signal: 5 s and 15 s of S waves, starting 0.5 s before the S-waves picking, and 20 s of coda were selected. Also in this case for each selected window HVSR were calculated through a directional analysis as that described for HVNR.
The results highlight the fundamental role of the installation. For BAG8 and AUL, where the sensors are directly installed on rock, the vibrations of the structure do not affect HVNR at the bottom, which show flat responses in the whole frequency range: in both cases the eigenfrequency of the building is given by the HVNR computed at the top of the structure.

On the contrary for ASO7 and VOBA, where the sensors are directly connected with the foundations, both the amplification peaks between 5 and 9 Hz (ASO7) and between 5.5 and 7 Hz (VOBA) include the contribution of the free oscillations of the buildings. Particularly for VOBA, HVNRs performed outside building highlight possible soil-structure resonance effects in case of an earthquake.