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Ground motion model for reference rock sites in Italy

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ABSTRACT

To assess site-specific ground motion it is common practice to calculate seismic hazard at bedrock and then multiply it by a deterministic site-amplification factor typically computed from 1D numerical simulation. For this reason, the ground motion at bedrock should be free from amplification phenomena and its site response flat. Ground Motion Prediction Equations are generally calibrated using records at stations classified as rock that, however, can be affected by site-effects, caused by peculiar morphological/stratigraphic features.

In this work, we propose six proxies based on geological, topographical and geophysical data to identify reference rock sites. We apply these proxies to the same set of recording stations used to derive the most recent ground-motion attenuation model for Italy [6] - ITA10. We find that about half of the analyzed sites, classified as rock on the basis of $V_{S,30}$ or geological conditions, are unaffected by amplifications and can be actually considered as reference rock sites.

Then, we re-calibrate the ITA10 prediction equations for horizontal peak ground acceleration at 20 spectral ordinates in the period range 0.04–2 s, accounting for sites that we identify as references rock sites. The resulting reference median values are, on average, 35–40% lower than those calculated by Bindi et al. (2011) model for rock sites. Conversely, the ground motion variability is not significantly changed, even if we introduce a new site soil category to describe the reference rock stations.

1. Introduction

It is well known that local soil conditions and, to some extent, topographic irregularities, play a key role on the characteristics of ground motion observed at a given site during an earthquake. Therefore, site effects should be taken into account in any site-specific seismic hazard evaluation [4,13,25,26]. Traditionally, this goal can be reached modifying the hazard results for rock condition by means of deterministic site-specific amplification factors.

The seismic actions defined in the European (Eurocode 8 - EC8, [9]) and Italian (*Norme Tecniche per le Costruzioni* - NTC08, [10]) provisions adopt a soil classification scheme based on the average shear-wave velocity in the uppermost 30 m ($V_{S,30}$) and then associate to each soil class a specific site amplification factor, used to modify the design spectrum at rock. For example, NTC08 exploits the seismic hazard study by Stucchi et al. [31] and provides the expected maximum horizontal ground acceleration, evaluated on generic rock conditions and associated with prescribed return period, on a regular grid covering the national territory. The site effects are then included either by means of the NTC08 amplification coefficients or by the results of specific seismic site response analysis.

Seismic codes identify the generic rock conditions on the base of the $V_{S,30}$ value, which, for the European standards, should exceed 800 m/s (soil category EC8-A). Nevertheless, this assumption does not imply that the ground-motion recorded at sites having $V_{S,30}$ larger than 800 m/s is completely unaffected by amplification. There are several cases in literature that describe site-effects observed at rock-sites, such as amplification at intermediate and high-frequency [5,18,27,28] and polarization [8,19,22].

To evaluate the response of different soils, empirical approaches, based on Ground Motion Prediction Equations (GMPEs), generally define the reference ground motion, i.e. the ground motion recorded at stations unaffected by site-effects, such that their amplification functions could be assumed flat with amplitude equal to one.

In practice, this behavior is associated to the generic rock condition, usually identified only through the $V_{S,30}$ exceeding a given threshold. However, this assumption may cause inaccurate prediction of the expected motion when hazard is evaluated including site effects, due to the amplified response of the rock motion. The identification of reference rock sites, where the amplification response is expected to be negligible, would be of great help to avoid this ambiguity in the predictions.

In this study, we propose a procedure to recognize reference sites according to six proxies, based on geological, topographical and

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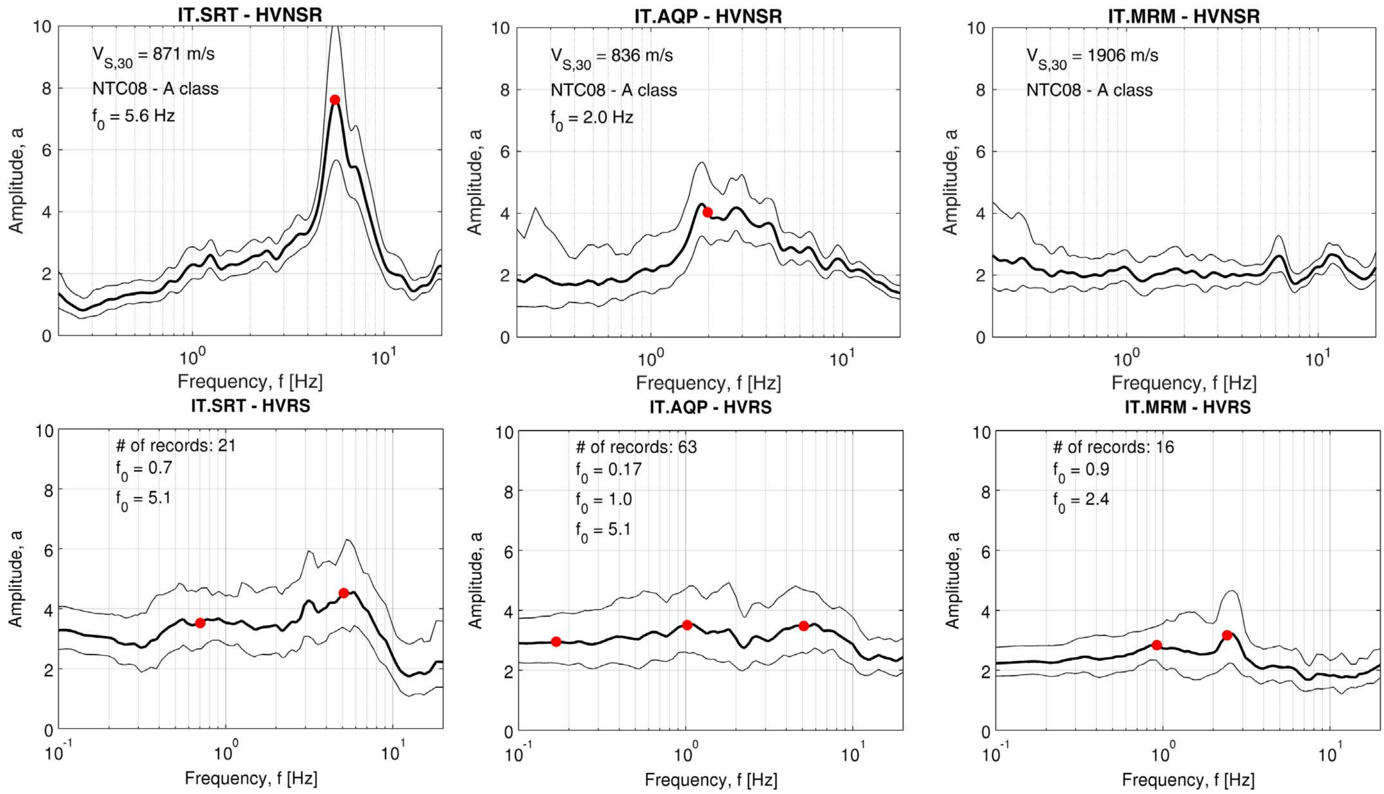

Fig. 1. Spectral analysis at IT.SRT (left), IT.AQP (centre) and IT.MRM (right) stations. Top: Horizontal to Vertical Spectral Ratios (HVNSRs) from ambient vibrations measurement. Bottom: Horizontal to Vertical acceleration Response Spectra (HVRS) from earthquakes. $V_{S,30}$ values, EC08 subsoil categories, number of records and fundamental frequencies (f_0) are also reported.

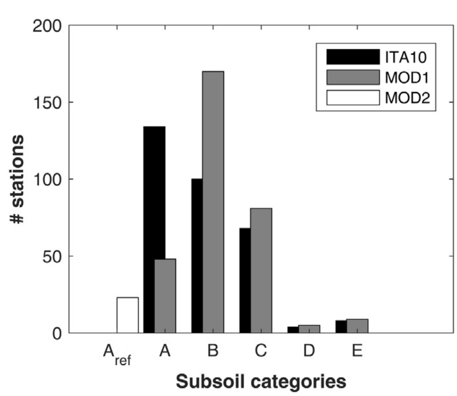

Fig. 2. Distribution of stations according to the EC8 site classification, before and after the updating of the site information.

geophysical indicators. These proxies have been applied to the set of stations classified as EC8-A, used for the calibration of the most updated GMPEs for Italy (ITA10, [6]). The impact of the selection of reference rock versus generic rock condition is examined through the variation of the median and standard deviation associated to the GMPEs.

2. Proxies for identification of reference rock sites

We propose six proxies to identify reference-rock sites: 1) $V_{S,30} \geq$ 800 m/s; 2) rock conditions on the base of surface geology; 3) flat topographic surface; 4) absence of interaction with structures; 5) flat horizontal to vertical spectral ratio of noise measurements without directional effects; 6) flat or moderately broad-band horizontal to vertical spectral ratio of acceleration response spectra of earthquake waveforms.

Three proxies out of six are based on geophysical and seismological data (1, 5 and 6), whereas the remaining on geologic and geomorphological features (2, 3 and 4).

The first proxy requires that geophysical tests have been conducted in order to evaluate the shear wave velocity profile, at least in the uppermost 30 m. The second one implies the availability of geological maps at detailed scale, which are usually produced for specific studies, such as seismic microzonation or urban planning. The third proxy implies that the site is located on a flat surface or isolated slopes or reliefs with average ground inclination less than 15 degrees (as in the definition of NTC08-T1 topographic class). This proxy is introduced to exclude sites with amplification effects related to topographic settings [19,21]. The fourth proxy is necessary to remove stations with possible seismic soil-structure interaction [14,30].

The last two proxies have been selected as the horizontal to vertical spectral ratios (HV) are good indicators of the presence of site effects and have low execution costs. The approach proposed by Puglia et al. [24] is adopted to compute the HV obtained from noise measurements (HVNSR) and estimate the fundamental frequencies. The spectral ratio from earthquake recordings are calculated from 5% damped acceleration response spectra (HVRS) rather than S-wave Fourier spectra.

The main advantages on the use of HVRS instead of S-wave Fourier spectra are that no smoothing is required and that the sharp peaks of the Fourier spectra that would lead to large variability of the average HV Fourier spectral ratios are not present in the response spectra [32]. Even though the use of damped response spectra not guarantee that only the S-wave portion of a record contributes to the spectral analysis, they can be efficiently employed to characterize the site response of a large number of station using all available records [7,32]. That means substantial reduction of the computational cost in calculating spectral ratios.

As an example, we consider three stations (Sortino, IT.SRT; L'Aquila Pettino, IT.AQP; Mormanno, IT.MRM) classified as EC8-A in the Italian Accelerometric Archive (ITACA 2.2, http://itaca.mi.ingv.it; [17,20]) on