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Analysis and Modeling of HVSR in the Presence of a Velocity Inversion: The Case of Venosa, Italy

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Abstract The aim of this work is to check the stability of the horizontal-to-vertical spectral ratios (HVSRs) calculated at the Venosa station site (Italy). This site lies over a layer of anthropogenic fill (4 m thick), a rigid layer of conglomerates (15 m thick), and a thick layer of clays (about 300 m thick) above the seismic bedrock. The velocity inversion, which takes place at the conglomerates–clays interface, is of main importance for the amplification behavior of this site. We have analyzed nearly 2 years of data, composed of 244 triggered noise records and 44 earthquakes. The results obtained by the two data sets show different site-response characteristics. In particular, the earthquake HVSR is not deamplified in the frequency range 1–8 Hz like the triggered noise HVSR. To find out the origin of this difference, we modeled both the triggered noise and the earthquakes, taking advantage of an improved version of the Thompson–Haskell propagation matrix method. The differences between triggered-noise- and earthquake-amplification functions might be explained by the difference in composition and propagation of the seismic wave fields. Moreover, we show that the nonlinear behavior of the anthropogenic fill might explain the presence of the misfit of the resonance frequency attributed to this layer between triggered noise and earthquakes.

Introduction

Surface geology has long been recognized to affect the intensity of the ground shaking. In particular, sites characterized by soft soils amplify the ground motion in specific frequency bands. Therefore, the site effect produced by the sedimentary covering has to be quantified. Recently, the horizontal-to-vertical spectral ratio (HVSR) technique (Nakamura, 1989, 2000) has been used by many authors (for a detailed review see Mucciarelli and Gallipoli, 2001) as one of the cheapest ways to study site effects by using ambient seismic noise. This technique utilizes the Fourier amplitude spectral ratio between the horizontal and the vertical component of the signal recorded at the surface at a given site to estimate the presence of site effects. Its wide use is due to the difficulty in finding a reliable reference site for application of the reference site method (RSM; Borcherdt, 1970). Lermo and Chavez-Garcia (1993) proved that the HVSR technique can also be applied to the strongest part of the earthquake recordings (*S* waves). Since then, many studies (among others, Lachet and Bard, 1994; Castro *et al.*, 1997; Mucciarelli, 1998; Parolai *et al.*, 2004) have been accomplished to determine the applicability and the limitations of the HVSR technique, both for earthquakes and seismic noise. It is commonly accepted, however, that the HVSR technique permits detection of the fundamental resonance frequency of soft deposits, even though the amplification values can be quite different from those obtained with other site-response estimation techniques (besides the RSM technique, the generalized inversion technique, coda-wave method, etc.), as explained by Field and Jacob (1995), Bonilla *et al.* (1997), Riepl *et al.* (1998), and Parolai *et al.* (2000).

In this article, we report on investigating the stability of the HVSR at the Venosa station site (southern Italy) by analyzing triggered noise and earthquake recordings. The main feature of the Venosa site is the presence of a shallow velocity inversion in the seismic-velocity profile that might be of fundamental importance for the characteristics of the HVSR of this site. The shallow velocity inversion is a common feature of many sites in Italy, and it may represent a problem for simplified zonation methods like V_s30. We show whether the characteristics of the HVSR are influenced by:

1. the existence of any periodicity pattern in the time sequences
2. an azimuthal dependence of the fundamental frequency (for earthquakes only)
3. a dependence on the choice of the horizontal recording component (for earthquakes and triggered noise)
4. the correlation between amplitude of the recordings and fundamental frequency.