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Short Note

New Relationships between V_s, Thickness of Sediments, and Resonance Frequency Calculated by the H/V Ratio of Seismic Noise for the Cologne Area (Germany)

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Abstract Noise measurements were carried out in the Cologne area (Germany), and the resonance frequency of each site was estimated from the main peak in the spectral ratio between the horizontal and vertical component. For 32 of these sites, the thickness of the sedimentary cover was known from boreholes, and a clear correlation between resonance frequency and sediment thickness was observed. A formula that correlates cover thickness with frequency of the main peak in the horizontal-to-vertical spectral ratio was derived. In addition, a best-fitting shear-wave-velocity distribution with depth, $v_s(z)$, as well as a relationship between average shear-wave velocity *Vs* and thickness of the sedimentary cover, was calculated. By using all of the noise measurements and applying the derived relationships, we obtained a subsoil classification for the Cologne area.

Introduction

It is widely accepted amongs the earthquake engineering community that local geology has a significant and sometimes large effect on seismic motion. Therefore, a detailed study of this effect is a matter of great importance in civil engineering. Drilling boreholes allows investigators to obtain detailed information, but it is expensive and slow. Geophysical techniques are an alternative that allow coverage of wide areas at reduced time and cost of investigation. The horizontal-to-vertical technique applied to ambient noise recordings (Nakamura, 1989) has been extensively used in recent times. The theoretical basis of the method is controversial, but the horizontal-to-vertical technique has been validated by comparison with both simulations and earthquake recordings (e.g., Field and Jacob, 1993; Lachet and Bard, 1994; Lermo and Chavez-Garcia, 1994; Bard, 1999; Bindi *et al.*, 2000; Fäh *et al.*, 2001). In general, these studies confirm that the horizontal-to-vertical (H/V) ratio, in the case of a large impedance contrast between sediments and bedrock (2.5), provides a good estimate of the fundamental frequency of soft soils but not of the higher harmonics. On the other hand, numerical simulations carried out for sedimentary basins (Dravinski *et al.*, 1996; Coutel and Mora, 1998; Al Yuncha and Luzon, 2000) yielded less optimistic conclusions. Simulations, however, strongly depend on the model assumption about the true character of the actual noise field (Bard, 1999).

Recently, different studies (Yamanaka *et al.*, 1994; Ibs-von Seht and Wohlenberg, 1999; Delgado *et al.*, 2000a, b) showed that noise measurements can be used to map the thickness of soft sediments. Quantitative relationships between this thickness and the fundamental frequency of the sediment cover, as determined from the maximum of the H/V spectral ratio of ambient noise (Nakamura, 1989), were calculated for both the Segura River valley (Spain) (Delgado *et al.*, 2000a), and the Lower Rhine Embayment (Germany) (Ibs-von Seht and Wohlenberg, 1999). The limitations of this approach were investigated by Delgado *et al.* (2000b) and recently by Bindi *et al.* (2001).

A subproject of the Deutsches Forschungsnetz Naturkatastrophen ([DFNK]; German Research Network for Natural Disaster) aims at investigation of the site effects on earthquake shaking in the Cologne area (Germany) (Parolai *et al.*, 2001). This area lies in a region where the intensities for an exceedance probability of 10% within 50 years range between 6 and 7 of the European Macroseismic Scale (Grünthal *et al.*, 1998). During the first year of the DFNK project, seismic noise was recorded at 381 sites, some of them close to boreholes drilled down to bedrock. More details on this experiment can be found in Parolai *et al.* (2001).

The aim of this article is to derive new relationships between the main resonance frequency of the soft sedimentary cover, obtained by using the H/V spectral ratio, the thickness of sedimentary cover, and the shear-wave velocity in the Cologne area.