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Evidence of nonlinear site response in HVSR from SMART1 (Taiwan) data

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Abstract

Deamplification of strong motion and the increase of the effective period of soil deposits are typical nonlinear effects; we seek them in SMART1-array data by applying the horizontal-to-vertical spectral ratio (HVSR) technique. The recordings, from four soil and one rock stations, represent 23 earthquakes (M_L 4.9–7.0); PGA varies between 20–260 cm/s^2. For each station, mean HVSR curves are calculated for two PGA ranges: <75 cm/s^2 and >100 cm/s^2 (weak and strong motion). At the soil stations, the "weak" (linear) and "strong" (nonlinear) responses are significantly different. Below 1–1.8 Hz, the nonlinear response exceeds the linear one. Above 2 Hz, the nonlinear response drops below the linear one and above 4–6 Hz below unity (deamplification). From 10 to 16 Hz, the two responses converge. One soil site shows significant negative correlation between resonance frequency and ground acceleration. Such behaviour agrees with other empirical studies and theoretical predictions. Our results imply that the HVSR technique is sensitive to ground-motion intensity and can be used to detect and study nonlinear site response.

Keywords: Strong motion; Horizontal-to-vertical spectral ratio; Standard spectral ratio; Nonlinear soil response; Deamplification; Effective resonance frequency

1. Introduction

Seismologists have recently come to recognise something that geotechnical engineers have known for decades, namely the importance of nonlinear effects in site response (e.g. see the review article by Field et al. [1]). This recognition came as a result of a number of "nonlinear" studies, in turn made possible by the availability of a large amount of quality strong-motion data. Nonlinear effects are typically sought by examining the amplitude-dependence of the Fourier spectral ratios between soil and rock surface motions — a technique known as the standard spectral ratio (SSR) method, introduced by Borcherdt [2]. The most characteristic and often cited nonlinear effects are: (1) deamplification of strong motion; and (2) the increase of the effective (resonance) period of soil deposits as the level of excitation increases (e.g. Jarpe et al. [3], Darragh and Shakal [4], Beresnev et al. [5]). Both effects can be expected from theoretical considerations (e.g. Beresnev and Wen [6]) and have been modelled numerically (e.g. Yu et al. [7]).

The application of the SSR method in practice encounters certain important obstacles. First, a suitable reference (rock) site is often difficult to find in the vicinity of the soil site of interest (e.g. Cranswick [8], Steidl et al. [9], Boore and Joyner [10]). And second, the spatial separation of the soil and rock sites requires correcting the recordings for path and finite-source effects (e.g. Field et al. [11]). Therefore, another nonreference-site technique — the horizontal-to-vertical spectral ratio (HVSR) method — has been lately gaining popularity in site-response analyses (e.g. Theodulidis and Bard [12]; Theodulidis et al. [13], Chavez-Garcia et al. [14], Lachet et al. [15], Bonilla et al. [16], Raptakis et al. [17], Dimitriu et al. [18]). Yet the question remains open whether this technique is sensitive to the amplitude of the ground motion and hence can be used to assess nonlinear site response. In a recent study, Dimitriu et al. [19] applied the HVSR method to (mostly near-field) acceleration data recorded at a soil site in the town of Lefkas (on Lefkas Island, Ionian Sea, western Greece) and found an impressive increase in the site's effective resonance period with increasing excitation level. No accompanying deamplification of strong motion relative to weak motion was noticed. These results were attributed to the nonlinear behaviour (shear-modulus degradation) of the surface soft sandy-silt layer.

In the present study we apply the HVSR technique to data from five stations (four soil and one rock) of the SMART1

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