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Application of horizontal-to-vertical (H/V) Fourier spectral ratio for analysis of site effect on rock (NEHRP-class B) sites in Taiwan

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Abstract

The frequency-dependent amplification for rock (NEHRP-class B) sites was studied using earthquake ground-motion database collected in Taiwan during implementation of the Taiwan Strong Motion Instrumentation Program. The database used includes several hundred records from earthquakes of M_L 4.0–7.3 occurred between 1993 and 2004. The characteristics of amplification were evaluated using the well-known technique of horizontal-to-vertical Fourier spectral ratio (H/V) of the S-wave phase [Lermo J, Chavez-Garcia FJ. Site effect evaluation using spectral ratios with only one station. Bull Seism Soc Am 1993;83:1574–94]. The study allows us to analyze peculiarities of rock sites amplification in Northern and Eastern Taiwan. It was suggested to divide the NEHRP-class B site amplification into four types based on frequency of maximum amplification and the shape of amplification function. The applicability of the technique was also checked for a few stiff and soft soil sites (NEHRP-classes D and E).

Keywords: Site classification; Site effect; H/V spectral ratio technique on earthquake data; Taiwan strong-motion data

1. Introduction

The seismicity in the Taiwan area is very high, and many large earthquakes ($M > 6$) occurred in the region during the last hundred years. The effective earthquake protection requires the efficient construction codes and seismic design, which, in turn, are based on study of the regional strong-motion data. The large number of ground motion acceleration recordings, obtained during the execution of the Taiwan Strong Motion Instrumentation Program (TSMIP) since 1991 [2] provides an opportunity to study both regional source scaling and attenuation models for the Taiwan region, as well as local site response on earthquake ground motion.

The Fourier amplitude spectrum (FAS), among other parameters of earthquake ground motion, is widely used for strong ground motion prediction and estimating seismic hazard. The FAS allows evaluation of engineering ground motion parameters (peak ground acceleration and response spectra amplitudes) using a stochastic technique [3]. One of the widely used approaches to describe the dependence of Fourier amplitude spectra on magnitude, distance and local soil condition, does consider the source, propagation, and site effects [3,4]. First, the source spectral model is introduced as a function of magnitude (seismic moment) and stress parameter or maximum slip velocity. Second, the source spectrum is modified as it propagates through the crust and the modification includes attenuation of ground motion with distance and amplification of motion by near-surface velocity gradient. Finally, the site amplification through the soil column by means of frequency-dependent amplification functions is introduced.

In certain cases (e.g. building code provisions), it is sufficient to describe the variety of local soil conditions by a few generalized site classes. In recent years, attempts were made to develop frequency-dependent amplification functions, for both response spectra [5,6] and Fourier

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amplitude spectra [7–9], which describe typical soil columns (site classes). A widely used site classification system [10–11] is based on the properties of the top 30 m of the soil column, disregarding the characteristics of the deeper geology. Six site categories are defined on the basis of average shear wave velocity, namely: A—hard rock; B—rock; C—very dense or stiff soil; D—stiff soil; E—soft soil; F—soils requiring special studies. The approach could not be considered as ‘‘completely site-specific’’, however the classification scheme provides the possibility of converting typical geotechnical data available from near-surface boreholes into site- and frequency-depending seismic coefficients. As far as the term ‘‘site effect’’ includes also crustal amplification, the generalized site amplification curves should also be considered as region-dependent functions.

The free-field strong-motion sites in the Taiwan region were classified by Lee et al. [12] using a scheme compatible with the 1994 and 1997 NEHRP provisions [10]. The existing geological and geomorphologic data were analyzed and the response spectral shape (RSS) and the horizontal-to-vertical (H/V) spectral ratio of response spectra (HVSR) were used for the classification. It has been shown recently by Sokolov et al. [9] that particular stations within the same site class, which was assigned on the basis of the rock age and geological classification, are characterized by large variations of amplitudes and predominant frequencies. Therefore, as it has been also noted by Lee et al. [12], further studies on site classification should be carried out in the Taiwan region.

In this work, we analyzed records obtained at 54 stations of the TSMIP network, which are characterized as ‘‘rock’’ or Class B sites. Site Class A (hard rock) is not applicable in Taiwan due to the wet climate and extremely high weathering. The site effect was evaluated using the H/V Fourier amplitude spectral ratios of the S-wave phase [1]. The empirical H/V ratios were compared with theoretical modeling based on available geotechnical information and generalized amplification ratios obtained for other regions. The results allow us to perform additional division of the B-class amplification into typical sub-classes regarding the shape and amplitude of frequency-dependent amplification. We also checked applicability of the technique for the case of few non-rock sites located within the alluvium-filled Taipei basin.

2. Database and processing

In this study we used recordings of earthquakes ($M > 4.0$), which were occurred in 1993–2004 (Fig. 1). The data were obtained during implementation of the Taiwan Strong Motion Instrumentation Program [2]. The program is conducted by the Seismological Observation Center of the Central Weather Bureau (CWB), Taiwan, ROC. The program installed more than 650 digital free field strong-motion instruments. Each station includes one strong-motion instrument—a force-balanced three-component accelerometer. Most of the recorders (Geotech and Terra Tech instruments) have 16-bit resolution and several instruments (Kinemetrics) have 24-bit resolution. These instruments are capable to record high-resolution ground motion within ± 2 g and with a pre-event and post-event memory. All stations have AC power, and when the power system is shut down by an earthquake or other problem, the internal DC power of the recording system can still operate for about 4 days.

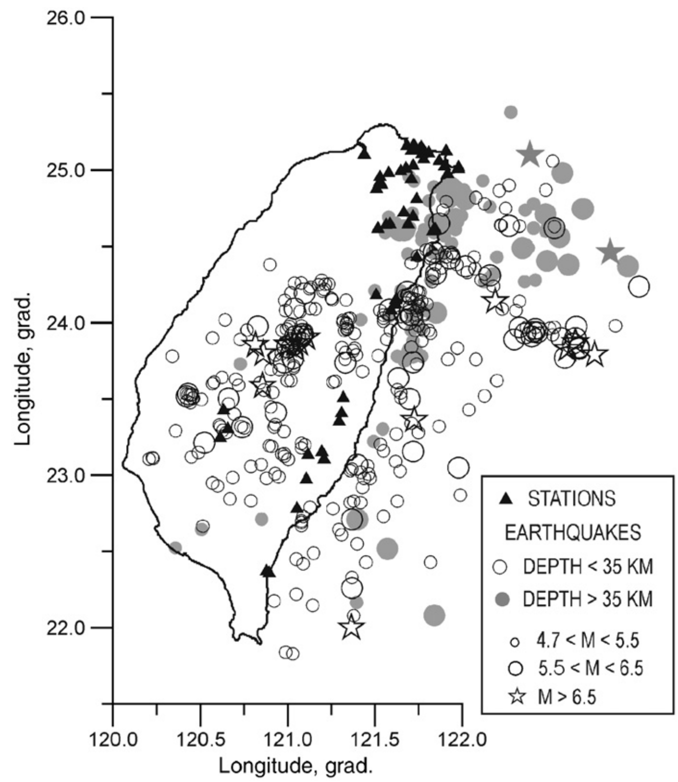

Fig. 1. Distribution of Class-B sites and epicenters of earthquakes, records from which were used in this study.

The site classification of the strong-motion station sites is as follows: B (rock); C (soft rock or very dense soil), D (stiff soil), and E (soft soil). Site Class A (hard rock) is not applicable in Taiwan due to the wet climate and extremely high weathering. Site Classes B, C, and D can be distinguished by geological age and rock type. Site Class B may include igneous and metamorphic rocks, limestone and hard volcanic deposits. Sandstones, shales, conglomerates of Miocene age or older are all classified as Class B. Most Class B sites are located in the hilly and mountainous highlands, except for some on limestone, igneous and metamorphic rock sites at lower elevations. Detailed description of the classes, as well as the list of the stations, may be found in Lee et al. [12]; see also http://gis.geo.ncu.edu.tw/query/site/site_classification_final.htm). Fig. 1 shows location of Class-B free-field stations, recordings of which were used in this study. Table 1 presents list of the stations. As can be seen, due to technical reasons in this study we used mostly stations located in Northern and Eastern Taiwan.