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Site effect study in central Mexico using H/V and SSR techniques: Independence of seismic site effects on source characteristics

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ABSTRACT

We study the influence of different source characteristics (depth, distance, type and azimuth) on the site effect in Acapulco and the Valley of Mexico. Site amplification was estimated by means of spectral ratios (both horizontal-to-vertical spectral ratio and standard spectral ratio techniques were applied) from earthquake recordings at soft and hard sites. In Acapulco, 125 Mexican earthquakes covering a hypocentral range of 7–290 km and a depth range (H) of 3–61 km were analyzed in three different groups of hypocentral distances. In the Valley of Mexico, we estimate site effect at five locations using recordings from shallow-coastal interplate ($200 \leqslant \Delta \leqslant 570$ km; $H \leqslant 35$ km) and normal-faulting, intermediate-depth inslab ($132 \leqslant \Delta \leqslant 738$ km; $32 \leqslant H \leqslant 178$ km) earthquakes, as well as from teleseismic events. Our results seem to point to negligible dependence of site effects on the source location and type.

1. Introduction

In the analysis of local seismic hazard, site effect studies are of great interest. It is well known that local geological conditions largely affect the amplitude, frequency, composition and duration of ground motion [1,2]. An important question is if the site amplification depends only on the local geology and the geotechnical characteristics or also on other factors, in particular the source location. In principle, source characteristics could have an important effect on the seismic wave amplification because of the influence of distance, depth and azimuth on the incident wave fields and angles of incidence, as has been proposed by different authors using local numerical modeling in 1D, 2D and 3D [3–8]. In highly seismic regions with complex tectonic settings, where different types of earthquakes occur, it may be of importance to know if site effect is in fact sensitive to source type and location and what effects can be expected for each source type. This is the case of Mexico, especially the very populated Valley of Mexico and the highly seismic Pacific coast. The present study focuses on Acapulco and the Valley of Mexico because of their great interest for site effect studies and seismic hazard predictions.

Previous studies in Acapulco [9–11] reported important local effects at soft sites in the Bay at frequencies of 4–5 Hz. Gutiérrez and Singh [9] analyzed spectral amplifications of strong motion from eight local shallow moderate events, with hypocentral distances $R < 74$ km, and also from microtremor data at four soft sites with respect to a reference station in Acapulco. They pointed out that there is no evidence of nonlinear effects and that, to a first approximation, the spectral amplification at a soft site in Acapulco is independent of source depth and epicentral location. The lack of more recent and exhaustive results about the amplification dependence on source characteristics in Acapulco makes it necessary to carry out a new and thorough study based on a greater number of events in order to attain statistically significant conclusions. To deeply investigate this issue, we applied both standard spectral ratio (SSR) [1] and horizontal-to-vertical spectral ratio (HVSR) [10] methods to 125 local events, covering a wide hypocentral range, recorded at one soft site (ACAD) and two hard sites (ACPD and VNTA) in Acapulco. We then compare the average amplification for three different groups of (S–P) travel-time intervals and also the results obtained with both empirical techniques.

In the case of the Valley of Mexico, the important amplification of seismic waves and the anomalous large duration of ground shaking during destructive earthquakes has been a main issue on site effect researches since the 1985 Michoacan earthquake

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[6,12–14]. These effects have been reported not only at soft sites in the valley but also at hard rock sites. In fact, Singh et al. [12,15] and Ordaz and Singh [16] pointed out that the hill zone in the Valley of Mexico suffers notable amplification with respect to that predicted by the attenuation laws due to the low *S*-wave velocity in the upper volcanic layers below the hill-zone stations. The influence of the heterogeneous crustal structure on seismic wave propagation from the subduction Pacific coast through the Mexican mainland, and the role of the Mexican Volcanic Belt (MVB) on the incident wavefield from interplate and inslab earthquakes have been the focus of interest of several studies [17–20]. Numerical 2D and 3D simulations have shown differences in the generated wavefield (frequency content and incidence angles) and in the character of wave propagation between both types of events. The effective propagation of the characteristic large Lg phases for interplates through the MVB, their conversion to other surface waves and the amplification in the low-velocity sedimentary basin of Mexico City are suggested as the reasons for the modeled differences in the amplification level and damage in the Valley of Mexico [18,19]. In contrast with the predictions of those numerical studies, empirical attenuation investigation by García et al. [21] showed that amplification functions for inslab events at hill-zone sites in the Valley of Mexico with respect to other hard sites outside the MVB were about the same as those obtained by Ordaz and Singh [16] for interplate events for frequencies up to 3 Hz. Also, Reinoso and Ordaz [22] reported that spectral ratios for the lake-bed zone with respect to hill-zone sites in the Mexico City Valley were relatively constant regardless of the magnitude, epicentral distance, azimuth and origin. Nevertheless, these last authors based their conclusions in the study of only 11 subduction and one intraslab earthquakes.

Regarding the discrepancies between numerical modeling and empirical results, and considering that these empirical results were based in regional attenuation or in spectral ratios of reduced data sets, it is necessary to further investigate whether the observed amplification in the Valley of Mexico for interplate earthquakes is similar to that for inslab and to check if the modeling results are supported by empirical evidence. In this work, we focus on the comparison of empirical amplification curves from both types of events in the valley, to evaluate the role of source characteristics (i.e. type of event, distance and azimuth) in the ground amplification. We use an important data set of 52 moderate-magnitude seismic events covering a wide azimuthal, epicentral and depth range including Mexican events (subduction shallow-coastal interplate and intermediate-depth inslab earthquakes) generated along the subduction zone of the Cocos plate beneath the Mexican mainland, and also deep teleseismic earthquakes. SSR are applied to estimate local amplification. According to this method, transfer functions of the horizontal Fourier spectra (FFT) at different soft sites with respect to a reference station are calculated. We also compute HVSR of earthquake data at each station. Finally, we have compared the results from both empirical methods.

2. Data and site description

In Acapulco, we analyzed accelerograph recordings from 125 Mexican earthquakes ($2.8 \leqslant Mc \leqslant 7.3$; $3 \leqslant H \leqslant 70$ km) that occurred during the period 1985–2000 and were recorded at three different sites (Fig. 1a). These events are distributed covering a wide azimuthal range along the Pacific coast, and with hypocentral distances between 7 and 290 km. In order to investigate possible amplification dependence on source location, three different groups of hypocentral distance were analyzed: $(S–P) < 5$ s, $5 \leqslant (S–P) \leqslant 10$ s and $(S–P) > 10$ s (where $(S–P)$ is the travel-time interval). The recording stations ACAD, ACPD and VNTA belong to the Guerrero Accelerograph Network and are equipped with 3-channel digital accelerographs with sampling rates of 100, 200 and 250 Hz. Station ACAD is situated on soft soil, mostly composed of sand and clay deposits; ACPD is situated in a borehole on rock, 63 m below ACAD, and VNTA is located on granitic rock site, 9.4 km away from the other stations (see Fig. 1b). Both rock sites are used as reference stations in this study. The number of earthquakes of each type analyzed at each station or pair of stations is given in Table 1.

In the Valley of Mexico the data set consists of strong-motion digital records from 36 Mexican subduction earthquakes and

Table 1
Number of earthquakes of each hypocentral group recorded at Acapulco recording sites

Station	$(S–P) < 5$ s	$5 \leqslant (S–P) \leqslant 10$ s	$(S–P) > 10$ s
ACAD	67	28	13
ACPD	18	17	7
VNTA	33	21	4
ACAD-VNTA	21	12	3
ACAD-ACPD	29	20	8

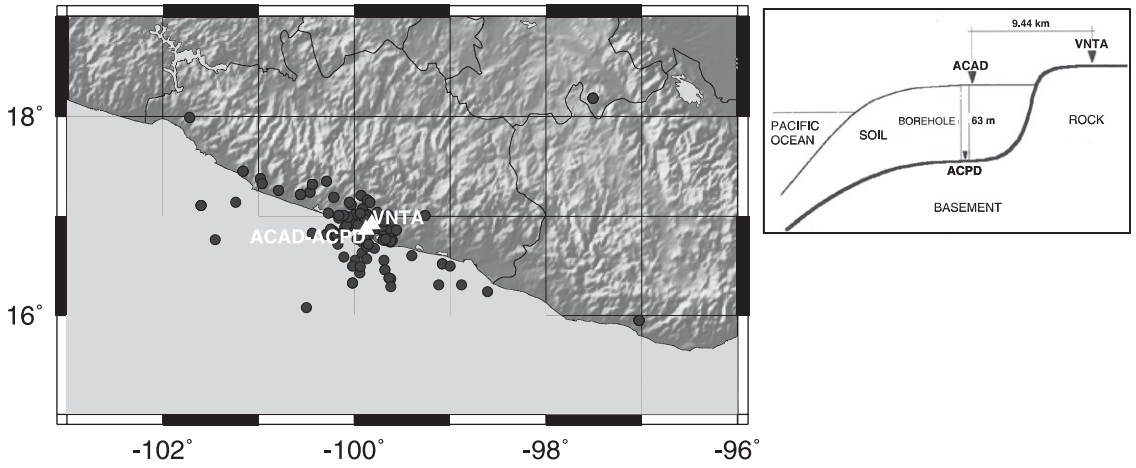

Fig. 1. (a) Location of the epicenters and recording stations used in Acapulco. (b) Schematic situation of the accelerograph stations ACAD, ACPD and VNTA (modified from Lázares, 2003 [11]). Note that at present there is not enough detailed information about the thickness distribution of the sedimentary cover in the zone.