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Site response in Tecoman, Colima, Mexico—I: Comparison of results from different instruments and analysis techniques

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ABSTRACT

This paper presents a study of site effects in the urban area of Tecoman in Colima, Mexico. A variety of instruments (both accelerometers and seismometers) were used to record earthquakes and ambient vibration throughout the city. Earthquake records were analysed using several techniques to estimate site effects: spectral ratios relative to a reference station, spectral ratios of the horizontal components relative to the vertical recorded at the same site, and a parametric inversion of Fourier spectra. Ambient noise records were used to estimate a local transfer function using horizontal to vertical spectral ratios. The results show that local amplification at Tecoman is significant. Dominant frequency varies between 0.5 and 0.7 Hz, suggesting a large thickness of the soft sedimentary deposits. We did not observe systematic variations throughout the city. Our more reliable estimates indicate that maximum amplification is comprised between a factor 6 and 8. Comparisons among different sensors and recorders show that all combinations between velocimeters, accelerometers, and recorders provide reliable results provided that the electronic noise is smaller than the noise being recorded. This is notably not the case for accelerometers at quiet sites and for frequencies smaller than 2 Hz. This explains why previous studies disagree as to the usefulness of accelerometers to record ambient noise for site effect studies. This factor is, however, a function of noise amplitude at each site.

1. Introduction

It is well known that seismic motions may be increased significantly in surface sedimentary basins. The subsoil impedance contrast can amplify the vibration level and increase the duration of strong ground motion. It is also widely accepted that the most reliable estimates of the amplification due to soft surficial layers is obtained analyzing earthquake records. For example, if a suite of events is recorded simultaneously on soft soil and at a reference site, free of local amplification, spectral ratios provide a reliable estimate of the soft soils transfer function (e.g. [1,2]). However, if the seismicity rate is moderate, or an adequate reference site cannot be found, it becomes a difficult method to apply. For this reason, alternatives based on records of ambient vibration have gained popularity. Noise records, usually analysed using horizontal to vertical spectral ratios [3,4], have proved reliable to determine a dominant frequency of soft soil deposits. Regarding the maximum amplification, results have been mixed. Although it is mostly accepted that a simple geometry and large amplification factors usually mean that amplification is reliable, more sites where noise results are compared with earthquake estimates are required.

An additional problem regarding site effect estimation using noise records concerns the recording instrument. It is generally accepted that seismometers are more reliable than accelerometers to record ambient vibration. However, good results have been found sometimes using ambient vibration recorded with accelerographs. There are still few places where noise results to estimate site effects have been compared using several types of instruments at the same sites.

In this paper we present a site effect study in the city of Tecoman, Mexico, located close to the Pacific coast, at the northern end of the Mexican subduction zone (Fig. 1). The seismicity rate there is much smaller than further south, in Guerrero. However, large earthquakes do occur. The two more recent destructive Mexican earthquakes occurred there in 1995 [5] and 2003 [6,7]. The study in Tecoman allowed us to investigate site effects comparing results from earthquake and ambient vibration data recorded using accelerometers and seismometers. Our results provide a reliable determination of local amplification at Tecoman and show significant amplification at relatively low frequencies. Surprisingly, amplification functions determined using noise records prove to be more stable than those

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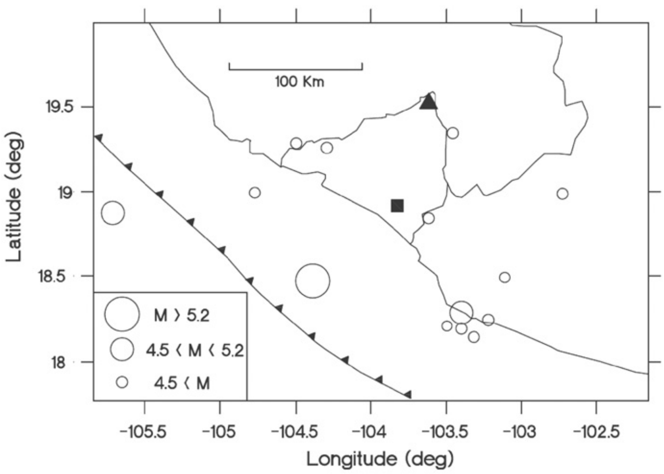

Fig. 1. Location map of Colima and Tecoman in Mexico. Subduction zone is shown as the solid line, parallel to the coast, with the solid triangles. The solid square shows the location of Tecoman city. The open circles show the epicenters of the recorded events while the open triangle shows the location of Colima volcanoe. The event shown were recorded between September 16, 2006, and January 1, 2007, and their coordinates are given in Table 1.

Table 1
Relevant data of earthquakes recorded by our weak motion array over a period of 4 months.

	Date	Latitude	Longitude	Depth (km)	Magnitude
1	16-09-2006	18.89	−105.69	39	4.6
2	20-09-2006	19.00	−104.76	21	3.7
3	13-10-2006	19.29	−104.50	20	4.2
4	14-10-2006	19.34	−103.47	40	4.1
5	19-10-2006	19.00	−102.78	74	4.0
6	21-10-2006	18.24	−103.53	05	4.2
7	06-11-2006	18.86	−103.62	15	3.8
8	12-11-2006	19.26	−104.31	28	4.2
9	19-11-2006	18.49	−104.44	18	5.2
10	21-11-2006	18.60	−101.89	59	4.3
11	25-11-2006	18.22	−103.44	06	4.0
12	10-12-2006	18.31	−103.44	07	4.6
13	27-12-2006	18.51	−103.15	15	4.0
14	29-12-2006	18.17	−103.36	05	3.7
15	05-01-2007	18.27	−103.27	10	4.3

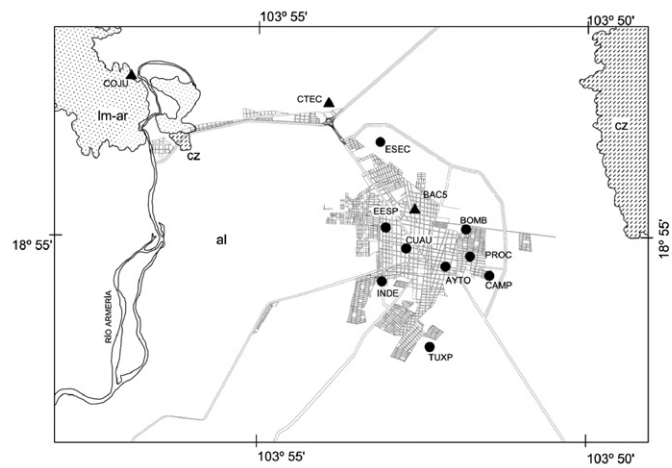

Fig. 2. Geologic map around the city of Tecoman. Dashes indicate limestone outcrops (cz). Dots indicate outcrops of limolite–sandstone (ar-li). The rest of the map corresponds to alluvial deposits (al). Solid triangles indicate the location of the accelerographic stations both permanent (COJU) and temporal (CTEC and BAC5). The solid circles show the location of the stations of the temporal seismograph array.

determined using earthquake data, a result that is due to the limited number of events recorded by our temporary seismic arrays but which is likely to affect results obtained in similar regions of moderate seismicity. Finally, we are able to shed some light on the reason for the occasional differences between results using accelerometers and seismometers. We show that this difference is related to the amplitude of seismic noise and is therefore site dependent. This paper is complemented by a second part [8], where the relation of site amplification with subsoil structure is studied.

2. Data

We recorded both earthquake data for small events and ambient seismic noise, using a variety of recorders and sensors installed temporally at Tecoman. We took advantage of a permanent acceleration station operating close to this city on rock: COJU (Etna recorder by Kinematrics coupled to an Episensor accelerometer) installed on limolite–sandstone. We used this station as reference. It is located 9.0 km from the center of Tecoman. In addition to that station, we have earthquake records from two arrays: a large scale linear array covering more than 100 km and a small one, installed specifically to determine site effects in Tecoman. From the first array we use the two stations located in Tecoman: BAC5, where a Geosig GSR18 operated, and CTEC, where a Kinematrics Etna accelerograph was installed. This array operated from March to August, 2006. BAC5 station recorded 9 events (5 of which were also recorded at COJU, the reference station) and CTEC station recorded 3 events (2 of which were also recorded at COJU). The second array was installed in September, 2006, and operated 9 seismographs for 4 months. Each station consisted of three 4.5 Hz geophones coupled to a SADC-20 digitization card by Sara. The resulting data streams were recorded by a dedicated PC at each site. This weak motion array recorded 15 events at three stations or more. Table 1 gives relevant data of all recorded events, while Fig. 2 shows the location of the stations.

In addition to earthquake data, ambient seismic noise was also recorded. Short noise records were obtained from false triggers at the permanent acceleration station COJU, and at stations BAC5 and CTEC. The 9-station seismograph array recorded continuously ground motion. Thus, we had plenty of noise windows for analysis at those sites. In addition, we recorded ambient vibration at some of those sites using three additional combinations of sensor and recorder: a K2 accelerograph by Kinematrics coupled either to a FBA-23 acceleration sensor or to a Guralp CMG40 velocity sensor and an Etna accelerograph by Kinematrics coupled to an Episensor acceleration sensor. Not all sites were covered with all instrument arrangements. However, we have enough sites to be able to discuss the results obtained using different instrument types.

3. Techniques of analysis

The analysis of the earthquake data to estimate a local transfer functions made recourse to spectral ratios and to a parametric inversion of the Fourier spectra. In both cases, input data were Fourier amplitude spectra of a 20 s window centered on the S-wave train. We computed spectral ratios relative to a reference station (SSR) following the standard procedure (e.g., [1,2]). This technique is accepted as providing a reliable estimate of local amplification when results for several (the number varies according to the author) events are averaged. Unfortunately, in regions of moderate seismicity, it is not easy to obtain simultaneous records in the reference and soft soil stations. This was our