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Microtremor observations from the seismic network RESNOM of Baja California, Mexico

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Abstract - We evaluated the site and instrument response of eight stations of the seismic network RESNOM of Baja California, Mexico using spectral analysis of microtremors recorded by measurements made *in situ*. We determined the resonant frequency of the stations using spectral ratios between the horizontal and the vertical components of motion. We found that only one site shows a clear resonance frequency (PBX), at 2.5 Hz. The rest of the stations have a site response approximately constant between 0.4 and 25 Hz. Although PBX is on rock, topographic effects and the near surface characteristics of this site may influence the response. In general, the spectral ratios calculated separately for the N-S and E-W components have the same spectral shape and the amplification level is within the error bars of the estimates. We also used microtremors recorded by the permanent stations in combination with recordings *in situ* to test the instrument response of RESNOM stations. We show that since the spectral characteristics of the microtremors are approximately invariant with time, it is possible to use well-calibrated measurements of ambient noise to verify the instrument response of the permanent stations.

1. Introduction

It is broadly recognized that sedimentary deposits and topography have an important effect on earthquake ground motion (e.g. Aki, 1988; Finn, 1991). The evaluation of the amplification induced by low-velocity layers located near the surface and by changes of elevation near seismic stations is useful for routine estimations of magnitude and other source parameters. Many studies of ambient noise (Kanai and Tanaka, 1954; Ohta et al., 1978; Kagami et al., 1982; Celebi et al., 1987; among others) show that the maximum spectral amplitudes of the microtremors

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are controlled by the natural frequency of resonance of the sites. Although microtremor data is commonly used to obtain general features of site response, several studies have reported good agreement between results obtained using earthquake and microtremor data. In particular, the ambient noise is useful for identifying the resonant frequency of the sites (e.g. Lermo et al., 1988; Morales et al., 1991; Field and Jacob, 1995; among others).

In this paper we used microtremors recorded *in situ* and by 8 telemetric stations of the seismic network RESNOM of northern Baja California, Mexico to identify the frequency band where maximum amplifications are expected due to the natural frequency of resonance of the recording sites. In addition, we verified the instrument response of the system by comparing records of microtremors obtained *in situ* with records digitally telemetered. This approach requires well-calibrated portable instrumentation but the method permits us to verify routinely the instrument response of a permanent network like RESNOM without using standard calibration processes that are usually complicated and time consuming.

2. Method and data

Although the determination of site effects using ambient noise measurements is relatively inexpensive and easy to make, one disadvantage of this method is that the presence of local sources of noise can affect the spectral shape and the amplitude level (e.g. Udwadia and Trifunac, 1973). To overcome this problem, we minimized the source effect by calculating spectral ratios between the horizontal and the vertical components of motion as proposed by Nakamura (1989). In this approach it is assumed that the vertical component of the microtremor records is not influenced by the local site conditions. Thus, we can represent the horizontal component of the spectral amplitude as:

$$R_h\,(f) = S\,(f)\,P\,(f)\,Z\,(f)\,I_h\,(f), \tag{1}$$

where $S\,(f)$ is the effect of the noise source, $P\,(f)$ the effect of the path, $Z\,(f)$ the effect of the site conditions and $I_h\,(f)$ the instrument response. Similarly, the spectrum of the vertical component can be represented as:

$$R_v\,(f) = S\,(f)\,P\,(f)\,I_v\,(f). \tag{2}$$

Then, by taking the ratio between these two components we can obtained the site response:

$$Z\,(f) = \frac{R_h\,(f)}{R_v\,(f)}\,\frac{I_h\,(f)}{I_v\,(f)}\,. \tag{3}$$

When the spectral amplitudes have been corrected by the effect of the instrument response, Eq. (3) reduces to

$$Z(f) = \frac{R_h(f)}{R_v(f)}\,. \tag{4}$$

When microtremors are recorded simultaneously by two different instruments (i and j) at the same site and the instrument response of one of them is unknown (i.e. the i instrument), the spectral amplitude of this record can be represented as:

$$R^i_k(f) = S(f)\, P(f)\, Z(f)\, I^i_k(f), \tag{5}$$

where $I^i_k(f)$ is the unknown instrument response of component k. The ratio between the uncorrected spectra and the spectral record, corrected by instrument response I^j_k gives:

$$I^i_k(f) = \frac{R^i_k(f)}{R^j_k(f)}\,. \tag{6}$$

To eliminate the effect of possible temporal variations of the ambient noise, due to the time dependence of $S(f)$, we averaged spectral records of microtremors recorded at different times of the day. The use of an average spectral amplitude also releases the constraint of recording microtremor signals simultaneously.

The seismic network of northern Baja California, Mexico (RESNOM) is an eleven three-component station network with short period seismometers Teledyne, model S-500 (f_0 = 1.3 Hz) and Mark, model L-4C (f_0 = 1.0 Hz). Fig. 1 shows the distribution of the 8 stations used for the analysis. The signals detected by the network are filtered with a low-pass antialiasing 5-pole Butterworth filter with a cutoff frequency of 15 Hz. The amplification is different between the stations, ranging from 40 to 320 depending on the level of the signal. The signals are digitized at 40 samples per second with a 12 bits analog/digital converter before they are telemetered to the central base at CICESE, in Ensenada (Hinojosa et al., 1984; Vidal, 1987). All the stations of the network are on volcanic rock except for LMX that is on compacted sand. Several of them are in regions with important topographic variations. The elevations of the stations vary between 25 m at LMX and 2835 m at SPX (see Table 1).

Table 1 - Station coordinates, type of sensor of the permanent stations and their natural frequency. For the measurements made in situ we used velocity sensors with a natural period of 5 seconds.

STATION	LAT °N	LON °W	ELEV. (m)	SITE GEOLOGY	SENSOR TYPE	f_0 (Hz)
CBX	32.3132	116.6637	1215	Rhyolite	S-5000	1.3
CPX	32.4178	115. 304	180	Basalt	S-5000	1.3
ECX	31.6570	116.5978	1040	Rhyolite	L-4C	1.0
ENX	31.8835	116.6627	230	Rhyolite	L-4C	1.0
LMX	32.1088	114.9627	25	Sand	S-5000	1.3
PBX	31.7420	116.7255	330	Volcanic rock	S-5000	1.3
RDX	31.9282	115.9422	708	Granodiorite	S-5000	1.3
SPX	31.0452	115.4637	2835	Granodiorite	L-4C	1.0

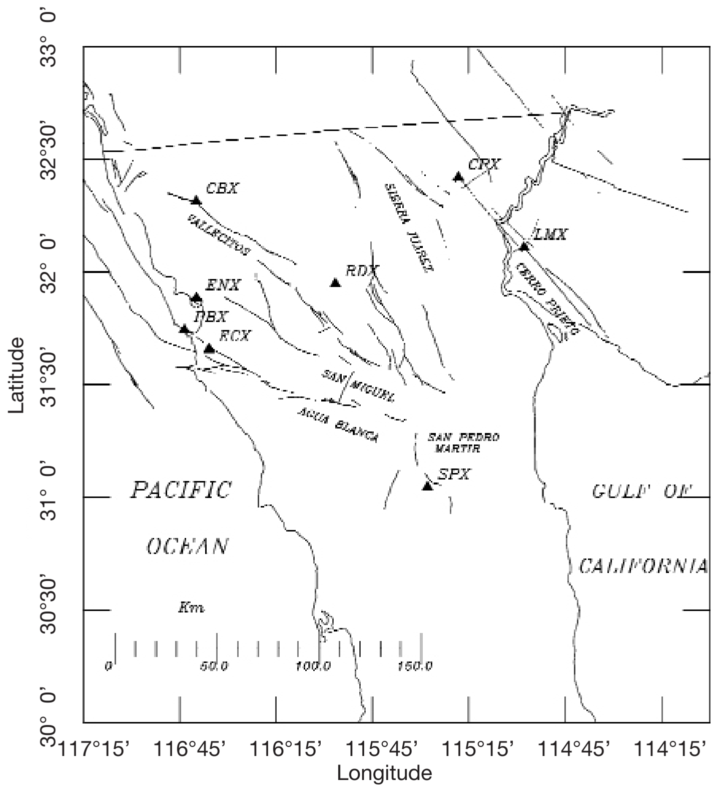

Fig. 1 - Location of the stations used to measure ambient noise. ENX correspond to Ensenada, where the central base is located.

In order to test Eq. (6), we measured ambient noise *in situ* using a portable seismograph (Kinemetrics model SSR-1) and velocity sensors (Kinemetrics SV-1 and SH-1) with a natural period of 5 seconds. The seismograph SSR-1 is a 3-channel recorder with a 16-bit A/D converter and dynamic range of 96 db. A 60 db preamplifier in steps of 20 dB can increase the sensitivity of the seismograph. For these measurements the signals were sampled at 200 sps and band-pass filtered between 0 and 50 Hz.

To verify the instrument response of the stations, we carried out calibration tests *in situ* for both portable and telemetric systems before the ambient noise was measured. The sensor-recorder system was tested applying a pulse of constant amplitude to the calibration coil of the sensors.

We recorded at each site 60 s-long signals of microtremors at different times of the day. Figs. 2 and 3 show a sample of the records obtained *in situ* and from the telemetric system respectively. The records were base line corrected by subtracting the mean. Then, we selected 15 s-long sub-windows, which we visually inspected to remove local transients or low amplitude sectors that show clipping. Since the time windows do not overlap, we obtained up to four spectral records every time the microtremors were recorded. The beginning and end of the sub-windows were tapered with a 10% cosine taper before the Fourier transform was calculated. The resulting spectrum was smoothed using a variable frequency band of ±25% of the central

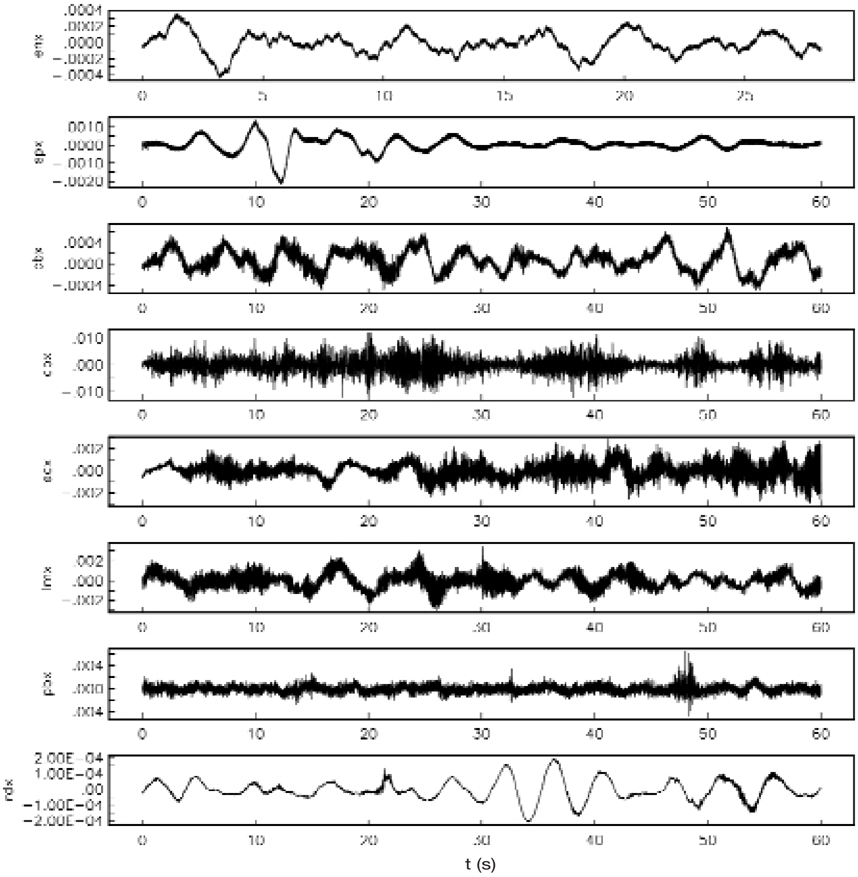

Fig. 2 - Microtremors recorded in situ using digital recorders (SSR-1) and intermediate period (5 s) seismometers. The amplitudes of the velocity records shown are in cm/s.

frequency. We selected 28 central frequencies between 0.1 and 50 Hz for the records obtained *in situ* and 24 central frequencies between 0.1 and 20 Hz for the telemetric records. We chose the same central frequencies for both systems between 0.1-20 Hz. Since the telemetric data is cutoff at 15 Hz and the instrument response of the portable seismographs is constant for f > 0.4 Hz; we limited our analysis between 0.4 and 15 Hz. The amplitude spectra were instrument corrected dividing the spectrum of the signal by the transfer function obtained from the calibration pulses.

3. Results

Fig. 4 shows acceleration spectra calculated using 15 s-long windows and averaged over a 60 s interval. The spectra were obtained using microtremors recorded by the telemetric system at different times of the day between 8:00 and 18:00 hr. Although in Fig. 4 we only display the spectra for CBX, similar plots were also obtained for the other sites to analyze the temporal variation of the ambient noise. In general, as shown in Fig. 4, the shape of the spectrum remains the same regardless of the time of day. This is because the stations are located in remote sites away from sources of noise induced by human activities.

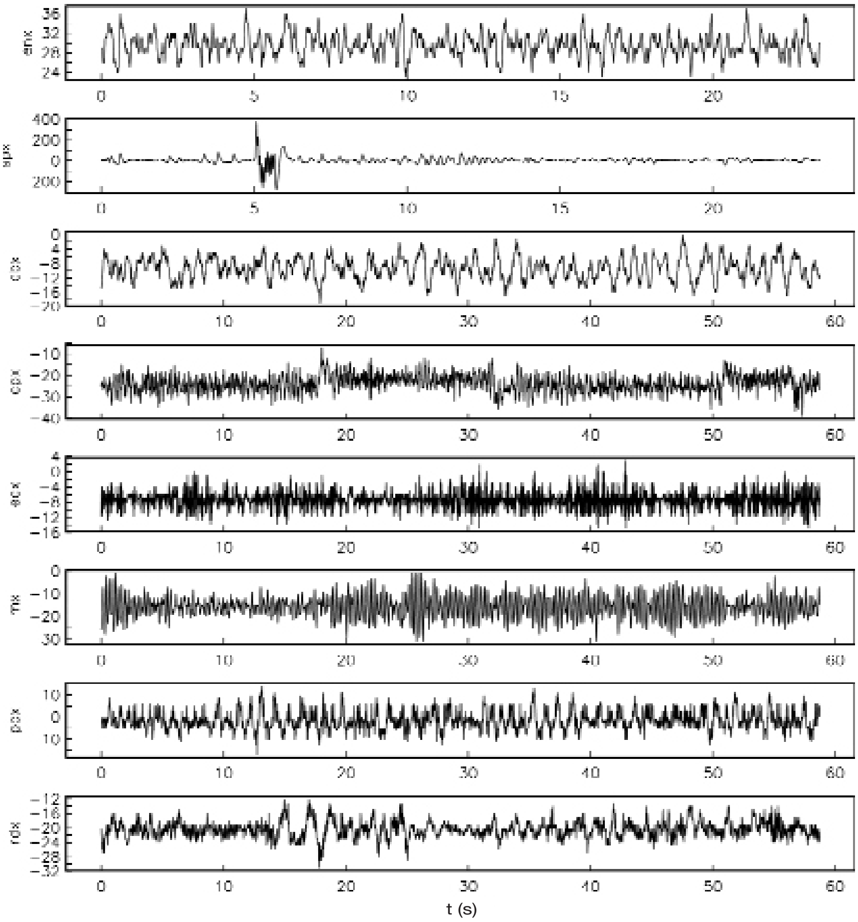

Fig. 3 - Ambient noise recorded by the telemetric system of RESNOM. The amplitudes of the records are in counts.

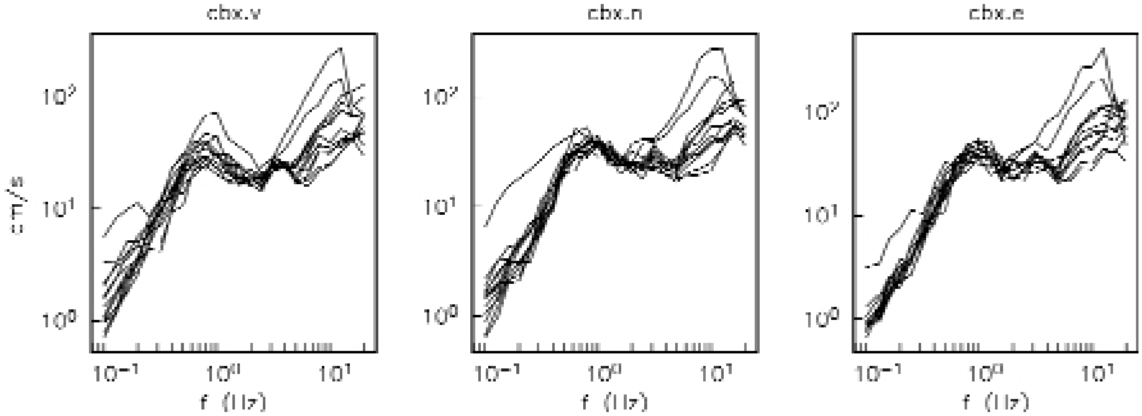

Fig. 4 - Spectral amplitudes calculated using microtremors recorded by the telemetric system at different times of day at CBX. The frame on the left shows spectral records from the vertical component, the central frame from the north component and the right frame from the east component.

The average site response estimated using H/V ratios from the measurements *in situ* (Eq. (4)) was calculated as:

$$\langle H / V \rangle = \exp \left(\frac{1}{n} \sum_{i=1}^{n} \log (H / V)_i \right). \tag{7}$$

Fig. 5 displays the average ±1 standard deviation (SD) estimated from the N-S component (circles) and the average from the E-W component (filled circles). In general, the upper limit of the site response, defined by the SD of the estimates, is less than a factor of 1.5 of the average. The main feature of the curves is that although the amplitudes vary with frequency, they do not show important amplifications.

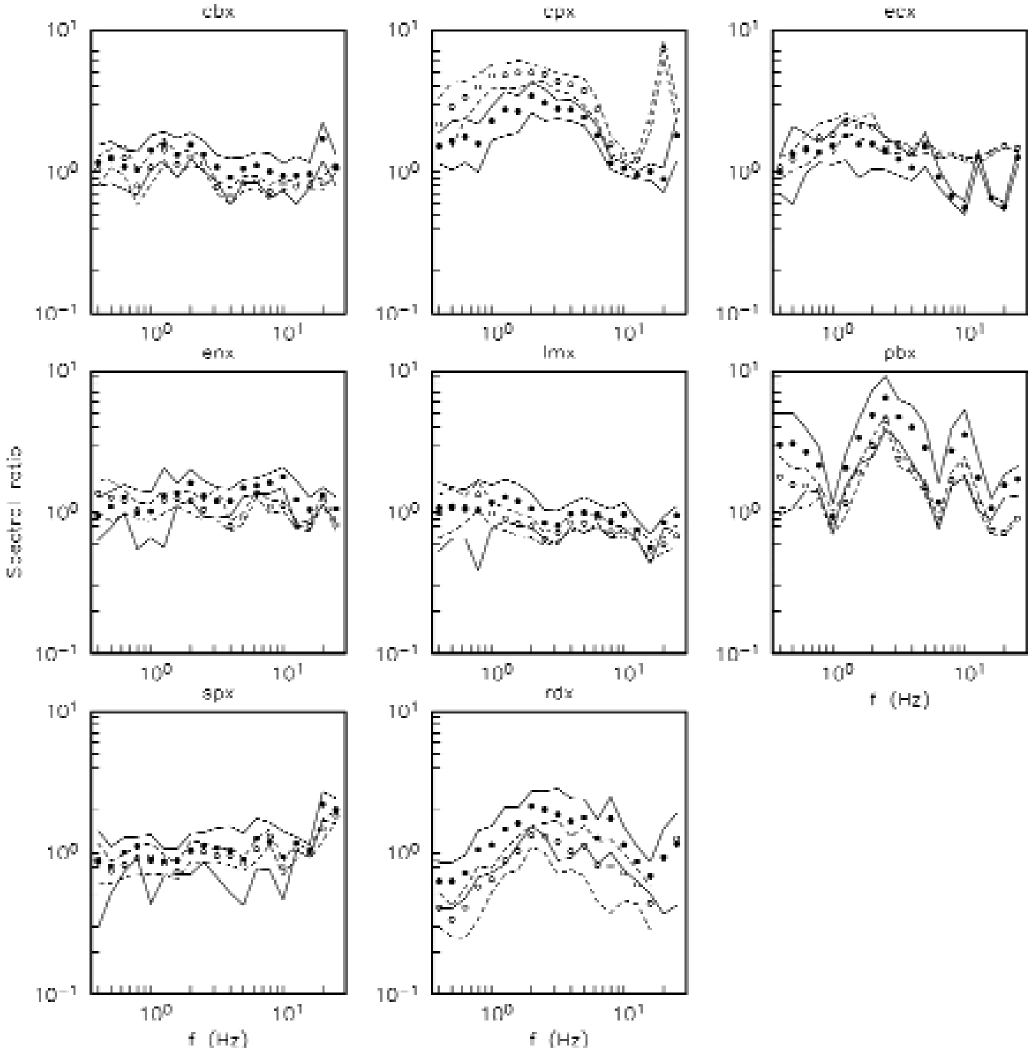

Fig. 5 - Mean site response obtained from microtremors recorded in situ (with the SSR-1 instrument). The circles are the average H/V ratio calculated using the N-S component and ±1 SD (dashed lines). The filled circles are the average H/V ratio calculated using the E-W component ±1 SD (solid lines).

Since all the stations are on hard-rock sites, we did not expect important site effects. In fact, most of the site functions shown in Fig. 5 are approximately constant. Only station PBX shows clear amplitude peaks (above one) that can be interpreted as due to site resonance. Although PBX is located on volcanic rocks (andesites), this site shows higher values of the H/V ratio than CPX and RDX, which are also located on volcanic rocks. This suggests that the H/V ratio, at least for hard rock sites, may not give a good estimate of site amplification or that the amplification at PBX is due to topographic effects. Other studies have found that the H/V ratio can predict predominant frequencies successfully but in some cases the method fails when used to estimate amplification factors (e.g. Lachet and Bard, 1994; Field and Jacob, 1995).

It is also interesting to note in Fig. 5 that although LMX is on sand, this station does not show amplification between 0.4 and 15 Hz. LMX is located in the Imperial-Mexicali Valley where the sediments have a thickness of between 3.7 km and 4.8 km and a mean shear wave velocity Vs = 2.0 km/s (Fuis et al., 1984; Frez and Gonzalez, 1991). Using this velocity and a mean thickness H = 4.3 km, we can estimate the natural frequency of resonance (fo = Vs/4H) to be near 0.12 Hz. Since this frequency is below the frequency band analyzed, we did not observe the site amplification of this station.

A common problem that arises when analyzing seismic data from permanent stations is the uncertainty of the instrument response. Ideally, the systems should be calibrated periodically or when a component of the system is changed, to assure that the response remains the same. Standard calibration processes are usually complicated and time consuming. To overcome this problem, we tested the plausibility of using microtremors recorded in well-calibrated instruments to routinely verify the instrument response of a system like RESNOM.

Under the assumption that the average spectrum of microtremors is invariant in time, we can use Eq. (6) to calculate the instrument response of a permanent station. Once the spectral amplitude of typical microtremor motion is determined with a well-calibrated instrument ($R_k^j(f)$) and the uncorrected average spectra is retrieved from the permanent system ($R_k^i(f)$), the instrument response can be estimated using Eq. (6). Fig. 6 shows the instrument response estimated using the average spectral ratio between uncorrected and instrument corrected spectral amplitudes for a sample of three stations (ENX, CPX and ECX). We chose these stations because the instrumental constants are known and it is possible to calculate the theoretical instrument response (triangles in Fig. 6). We calculated the ratios separately for each component. It is interesting to note that the magnification is different among the components. This is probably due to differences in gain among the recording channels, variations of seismometer constants, such as damping, or a combination of all. In spite of this, the observed instrument response shown in Fig. 6 is similar to that predicted by the theoretical curve (triangles).

The advantage of using microtremors to verify the instrument response of the permanent system is that only the portable instrumentation needs to be calibrated using the standard calibration process. When the instrument response of the portable instrument is known, then, average noise spectra can be calculated for each site and this “master spectral amplitude” can be used to verify the response of the permanent system periodically. The main limitation of this method is that the phase response remains unknown and the accuracy of the instrument magnification depends on the standard deviation of the master spectral amplitude.

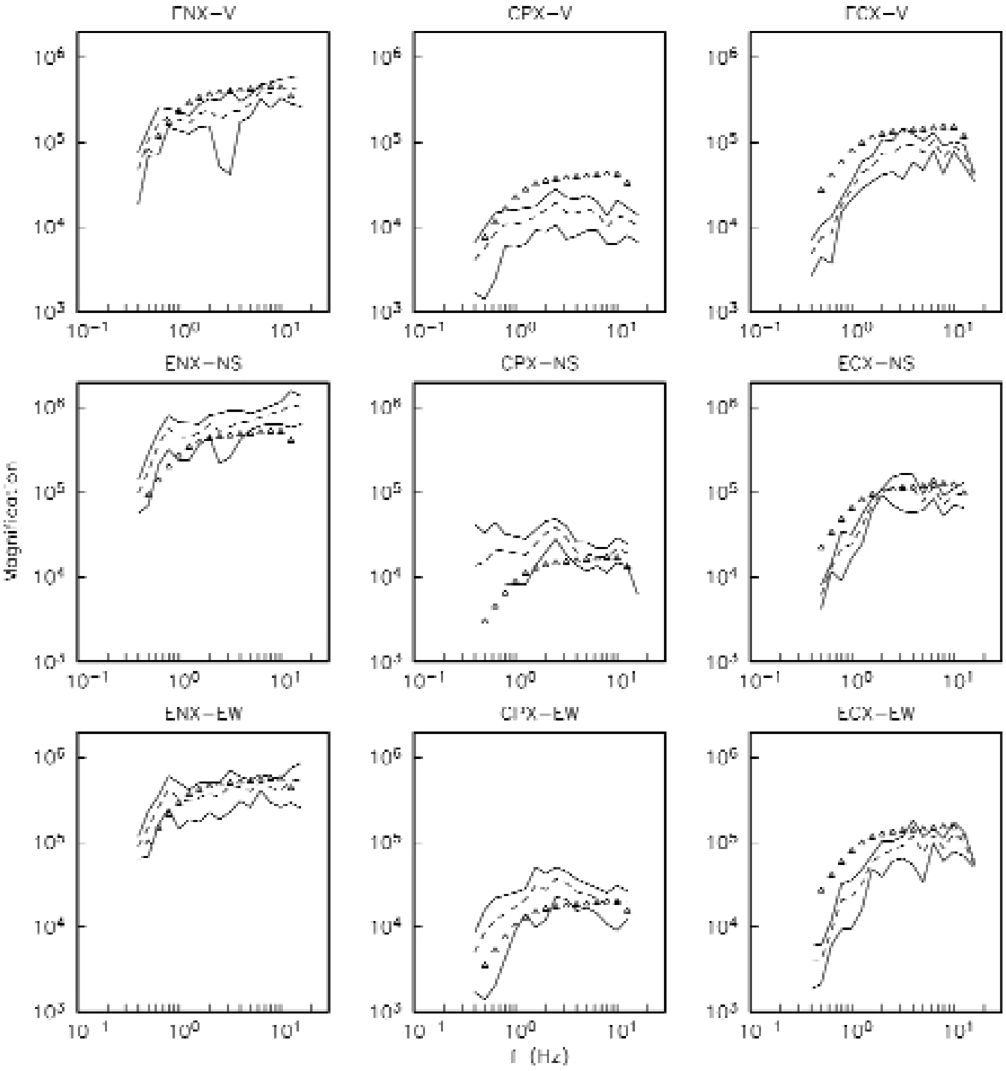

Fig. 6 - Instrument response calculated using the mean spectral ratio between the uncorrected spectral records of the permanent stations of RESNOM and the instrument corrected spectral records from the portable instrument. The dashed line is the mean value and the solid lines ±1 SD. The first row corresponds to the vertical component, the middle to the north-south and the last row to the east-west component. The triangles are the theoretical instrument response.

4. Conclusions

We determined the site response of eight stations of the seismic network RESNOM by making microtremor measurements *in situ* and using the method proposed by Nakamura (1989) to minimize the effect of the source. We found that in the frequency band analyzed (0.4-25.0 Hz) the site response is approximately constant for all stations but PBX that exhibits a clear resonant frequency at 2.5 Hz. We also show that it is plausible to use microtremors recorded by the permanent stations in combination with well-calibrated recordings *in situ* to estimate the instrument response of seismic systems like RESNOM.

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