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# Site response in the Granada basin (Southern Spain) based on microtremor measurements

J. Morales, J. A. Peña, J. M. Ibañez & F. Vidal
*Instituto Andaluz de Geofisica y PDS, Observatorio de Cartuja, Universidad de Granada, Spain*
K. Seo & T. Samano
*The Graduate School, Nagatsuta, Tokyo Institute of Technology, Midori-ku, Yokohama, Japan*

ABSTRACT: The microtremor measurements in short and long period range predicting frequency-dependent amplification effects due to local site geology was investigated in the Granada basin and Granada city (Southern Spain). Following a seismic reflection profile crossing the Granada basin and using information given by the profile (surface geology and depth to basement), 12 points of microtremor measurements in different sites were recorded. Peaks centred at 0.7 seconds (1.5 Hz) have been detected in the microtremor spectra in short period and 3-4 second in the long period range. The first one is interpreted in terms of microtremors and the second one as microseisms. 0.7 sec appear clearly in points placed on Pliocene and Quaternary materials while 3-4 seconds appear at all points regardless of the surface geology although with differences at the spectral level. In order to investigate the possible influence of some geologic parameters with long period motion, the maximum spectral amplitude value in the range from 1 to 5 seconds was estimated at all points in Granada basin. A good linear relation between maximum spectral amplitude value and surface geology and depth to underground basement was found. However for short period range only the surface geology has any relation with the maximum spectral amplitude value.

## 1 INSTRUMENTATION AND DATA ACQUISITION

For the measurement of microtremors a three component system belonging to the Tokyo Institute of Technology with the natural period of the seismometers of To=1 sec was used. The system consists of three sensors, amplifiers and a PC-AT portable computer with a A/D add-on card where the microtremor records were digitized at the rate of 50 sps by a 12-bits A/D converter. With an internal circuit it was possible to extend the natural period of the sensors up to 5 seconds. In this way we simultaneously used measurements of microtremors in short periods range (To=1 sec) with flat response to displacement approximately from 0.03 sec to 1 sec as well as long period measurements (To=5 sec) with flat response approximately from 0.03 sec to 5 sec.

Following a seismic reflection profile crossing the Granada basin from the south to the north and extending the line in both directions in order to have more coverage, we recorded microtremors at 12 points. Figure 1 shows the position of the points selected with respect to the surface geology and figure 2 shows the position of the points in the reflection profile as well as information about the superficial geology and the underground basement structure. Only point number 12 is located on compact limestone from the Jurassic (Liass) age belonging to the Sudiberic domain basement outcrop. The rest of the points are located on the sediment-filled materials of the basin. In this case we have extensive information with respect to the surface geology (Bedrock, Upper Miocene continental sediments "Messinian", Pliocene and Quaternary) and also good information of the depth to the basement in each point.

Each recording was divided into seven parts, each one with a length of 41 sec (2048 points). The spectrum of velocity using an algorithm of Fast Fourier Transform (FFT) was computed for the seven partial temporal windows. For the horizontal components the two-dimensional (2-D) spectra were calculated by the vector composition of the two orthogonal components (NS and EW). To obtain a stable estimation, the values of the Fourier amplitude were smoothed with a Parzen window with a bandwidth of 0.3 Hz. Finally the seven partial spectral were averaged to minimize any artificial disturbance and to enhance the predominant site period at each point.

## RESULTS

By using the information provided by the profile of reflection referring to data of superficial geology (type of sediment) and to the structure of the basement (depth to basement) it is possible to determine whether there is any type of relationship between these variables and the spectral characteristics of the microtremors in short and long period.

If we observe figures 3 and 4 where we can see the spectra of velocity of the ground in the 12 points selected, some interesting characteristics can be pointed out from the same. So, the presence of a spectral peak in the short period zone (< 1 sec) centred around 0.7 sec, can be shown, this being more clearly notorious in the points situated on materials from the Pliocene and Quaternary, although they also appear at points on Miocene material as is the case of number 5 or not appear at point 11 (Quaternary). This peak interpreted in terms of microtremor can suggest a sediment resonance.

The spectral information is more complete in figure 4 where the velocity spectra of the ground are represented using 5 seconds of period of the seismometers, thus observing how a peak around 3-4 seconds appears at the 12 points regardless of the geological characteristics in the surface. We interpret this peak in terms of microseisms. This spectral peak would not thus be interpreted as a natural period for which the seismic ground motion can be amplified. However we do not discard this information since from the detailed analysis of spectra and fundamentally for periods greater than 1 sec, we can clearly appreciate how there are significant differences in the spectral level from some points to others. These variations in the spectral level can not be attributed to changes in the meteorological conditions because the day on which the microtremor survey was carried out in the Granada basin the meteorological conditions (atmospheric pressure, wind speed) were stable and without significant differences that can explain these variations in the spectral level of some points to others.

In order to know whether the characteristics observed in the spectra in short as well as in long period have their origins in the geological characteristics in surface and in depth, and to establish what type of relation exists between the different variables, we have followed the following procedure. Under the implicit hypothesis that the spectral characteristics in the base of the basin are similar to those that can be observed in point number 12 (basement outcrop), we should expect variations in the spectral level in accordance with the geological characteristics in the surface and at depth (site transfer function). Moreover if we take into account a simple one dimensional model given by the law of quarter wavelength $T=4H/\beta$ where T is the natural period. H is the thickness and $\beta$ is the shear velocity, the input in the base of the basin should be modified by the site transfer function and so should give us information about the natural period in each site of this range of periods. However this does not happen in the way we would expect of this model and as it occurs in other regions (Otha et al 1978; Lermo et al 1988; Lermo et al 1989). However perhaps this lack of information can give us some data about the resonance behaviour of the basin just as the two or three-dimensional models postulate (Kagami et al 1982, 1986; Field et al 1990; Morales et al 1991).

In order to determine whether there is any type of relationship between the geological information available and the spectral characteristics of the microtremors in the interval between 1 and 5 sec, the maximum spectral amplitude (MSA) has been calculated at the 12 points. As a first step the values of the MSA have been represented at the 12 points as opposed to the thickness of sediments at each point. Observing figure number 5 the good linear relation between both variables is shown, where the MSA systematically grows with the thickness of sediments. Only point number 6 separates from the fitting. By using the classical method of spectral ratios between a sediment/bedrock pair stations and even when the location of the source that generates the microseisms is unknown in the interval of 1 to 5 secs, we suppose this to be sufficiently far away for the attenuation by distance and by inelastic absorption between the pair of stations is minimal with respect to the distance and total absorption. So we will have the results of the relative amplification in the 11 points located on sediment in the interior of the basin with respect to point 12 taken here as reference. Confronting the values of amplification with respect to the total column of sediment in each point (figure 6) we can appreciate a good relation between amplification and thickness of sediments, where the factor of amplification increases as a function of depth to the basement and reaching factors of up to 6.5.

Finally and to know whether there is any type of relation between the ground movement in the long period range and the superficial geology (age and lithology), we have represented the values of the MSA at each point grouping together the 12 points in four categories in accordance with the type of sediment and the age. In figure 7 we observe how there is a clear increase of the value of the MSA with respect to the surface geology. The lowest value is obtained at point 12 (basement outcrop) and the maximum values are situated in the sands and clays of the recent alluvial Quaternary (numbers 8, 9, 10 and 11).

With respect to the short period zone (0.5-1 sec) in the ground velocity spectra, the most important feature is the existence of a clear peak centred around 0.7 sec, which is more clearly visible in the points located in the Pliocene and Quaternary (Figure 8 and 9). By analyzing the spectral characteristics in this range and in order to know whether there is any type of relation with the variables previously put forward, we have represented the MSA in the 12 points with respect to the total thickness of sediments and the surface geology (age and lithology) at each point in an analogous way to that carried out for the long period analysis. In figure 12 where the MSA is represented with respect to the depth to basement we can clearly appreciate how there is a greater dispersion in the values without observing any type of linear relation between both variables. Analogously in figure 13 the values of the MSA with respect to the surface geology (age and lithology) are confronted. In this case it is possible to observe how as the lowest value is associated to point 12 where more basement arises and how the highest values are associated to points of the Pliocene and Quaternary. We should also point out how to the contrary to the long period, there is no good discrimination between the values of the MSA associated to points of the Pliocene and those of the Quaternary. The explanation for this is given by the fact that the Granada depression can be considered as a calm zone, where the sources that originate the microtremor in the short period range are not uniformly distributed to generate a uniform background level of microtremor and so the values of the MSA can partly be influenced by the greater or lesser proximity to the sources that generate the microtremor. However, and as will be commented in the following section, for the case of Granada city where we can speak about a uniformity in the distribution of the sources of the microtremor and thus of a background of stable microtremor, we can appreciate a clear difference between the spectral characteristics in the short period range for points located in the Pliocene with respect to those situated on the recent alluvial Quaternary.

## CONCLUSIONS

In this work we tried to investigate the reliability of the use of microtremor measurements to know the seismic response in the Granada basin in addition to knowing how to determine that geological parameters control the response for long and short period. The results deduced from the spectral analysis of microtremors show the following conclusions for the long period range (1-5 sec):

- The presence of a spectral peak around 3-4 sec at all the points analyzed regardless of the geological characteristics of the surface. This peak interpreted would thus not be natural period.
- Under the hypothesis that the spectral characteristics in the base of the basin are similar to those observed at the point situated on the basement outcrop, no variation in the predominant period is observed as would be expected of a one-dimensional model of the T=4H/ß type.
- To the contrary the spectral level (MSA) is observed to be strongly dependent on the depth to basement as well as the most superficial geological characteristics (lithology and age).
- The factors of amplification obtained show a good concordance with the depth to basement and by extrapolation with the surface geology.

With respect to the analysis in the short period range (0.5 to 1 sec) the presence of a clear peak centred around 0.7 sec (1.5 Hz) is observed. This peak would inform us about sediment resonance in the basin in this period range. The MSA in this range for the points analyzed, that at almost all the points coincides with the MSA of the peak to 0.7 sec, is greater for the points located on Pliocene materials and those of the Quaternary although high values situated on Miocene materials also appear. To the contrary the MSA does not show a good fitting with the depth to the basement.

The fact that the Granada basin can be considered as quiet and that the distribution of the sources that originate the microtremors in short period range in our zone is relatively disperse, not producing a homogeneous level of microtremor in the zone can partly condition the not good discrimination in the MSA between Pliocene and Quaternary materials.

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## FIGURES

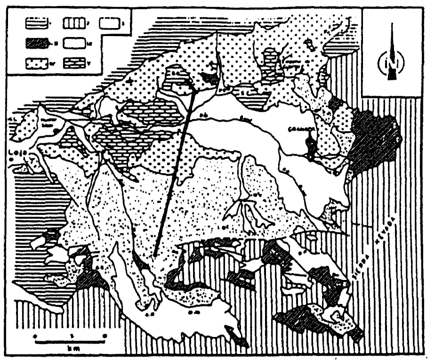

FIGURE 1.- Geological scheme of the Granada basin (Rodriguez Fernandez et al 1991).
1.- Subbetic domain 2.- Betic domain
3.- Quaternary I-II.- Upper Miocene (marine sediments) III.- Upper Miocene (continental sediments) IV.- Pliocene V.- Pleistocene

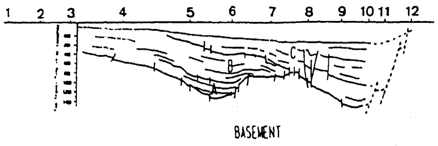

FIGURE 2.- Seismic reflection used to select the microtremors measurements points used in the Granada basin. The numbers show the position with respect to the seismic line.

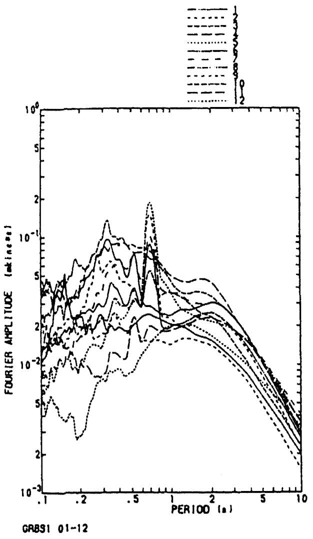

FIGURE 3.- 2-D ground velocity spectra of microtremors determined for the points selected in the Granada basin. Natural period of the seismometers To= 1 sec

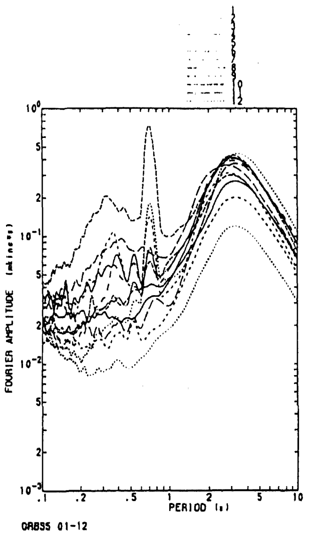

FIGURE 4.- 2-D ground velocity spectra of microtremors determined for the points selected in the Granada basin. Natural period of the seismometers To= 5 sec

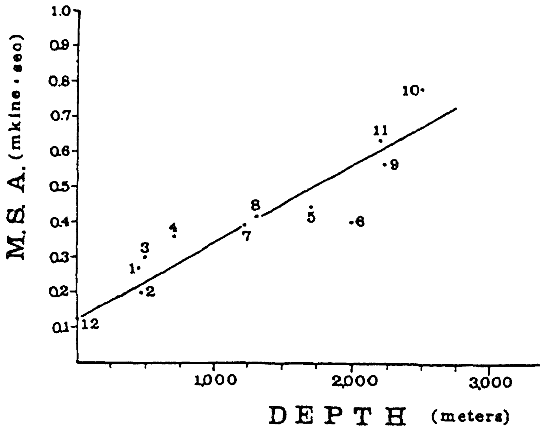

FIGURE 5.- Maximum spectral amplitude of microtremors for long period range (microseisms) and depth to the basement in the 12 points selected in the Granada basin

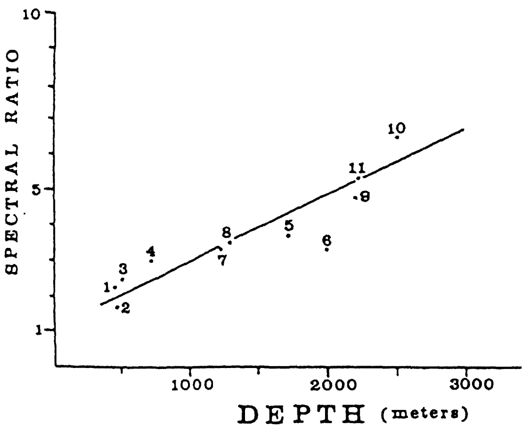

FIGURE 6.- Spectral ratio and depth to the basement for long period microtremors (microseisms) for the points selected in the Granada basin.

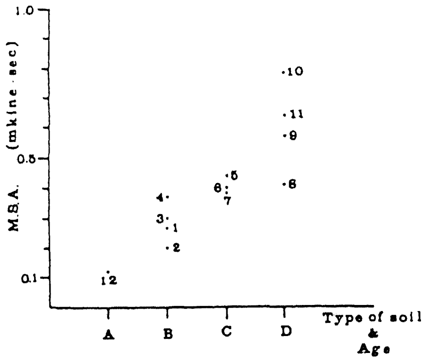

FIGURE 7.- Maximum spectral amplitude for long period microtremors (microseisms) with respect to the type of soils and age.A= Compact limestones from the basement outcrop (Jurassic) B= Upper Miocene (Messinian) continental sediments (marls with gypsum, lacustrian limestones). C= Pliocene sediments (conglomerates,sands and clays) D= Quaternary sediments (clays and watersatured sands)

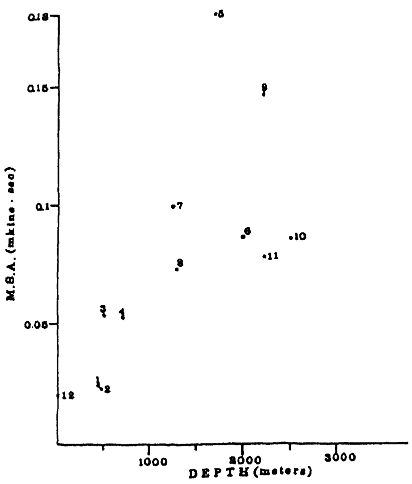

FIGURE 8.- Maximum spectral amplitude of microtremors for short period range and depth to the basement in the 12 points selected in the Granada basin.

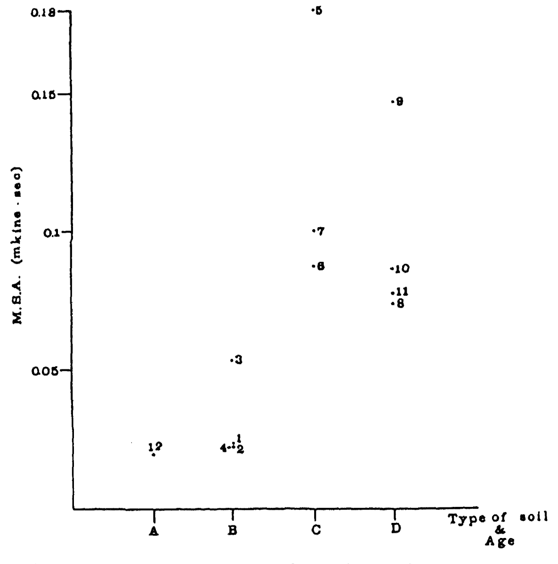

FIGURE 9.- Maximum spectral amplitude for short period range with respect to the type of soils and age.