PREDICTION OF FOURIER SPECTRA IN ZONES OF MODERATE SEISMICITY. APPLICATION TO SITES IN SPAIN

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ABSTRACT

In regions with moderate seismicity, where few strong motion records have been obtained, a problem is presented for estimating seismic action at a certain site aimed to engineering purposes. In these conditions it is necessary to introduce models and methods which allow the prediction of spectra, in a more or less simple way.

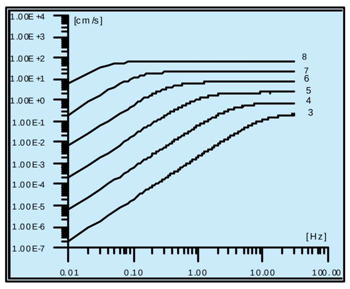
In this paper we present a new prediction model of Fourier spectrum in rock sites, derived from the stocastic model developed by Toro and Mc Guire (1990). This model is adapted to simulate the ground motion for earthquakes of low-moderate magnitude (2-5), like these recorded in the Iberian Peninsula.

Some details about the application of the method are: the use of a relationship moment-magnitude, Mo=f(M), the assumption of an stress drop in the fault related to Mo, spectral shape for high frequencies according to w^2, and the anelastic attenuation Q as a function of Q_0 and frequency. The method has been applied for predicting Fourier spectra linked with the main recent earthquakes occurred in Spain, all of them with magnitudes higher than 4.5. The results have been compared with the spectra derived from the instrumental records and a good agreement is found. Therefore, the method may provide a reliable approximation to the ground motion expected.

Introduction

Different methods are being developed in spectral prediction. On one hand, empirical methods aim to obtain relationships from regression analysis of records in zones with high seismic activity (Trifunac et al, 1989; Trifunac et al, 1993). On the other hand, some studies use data of small earthquakes in order to establish a source model by means of Green funtions (Irikura, 1983). These funtions may include, in a more complex model, the path and local efects (Wennerberg et al, 1990). Finally, a theoric prediction is also developed, in which stocastic models try to define the characteristics of radiation, using few parameters empirically estimated. In all cases, the size of the fault is considered small with respect the epicentral distance, therefore the prediction is suitable in far field. But this hypothesis harms the prediction in near field where many uncertainties are introduced. (Herrero et al, 1994).

The majority of the seismological studies assumes the shape of shear wave Brune´s spectra for modeling the spectral amplitudes. These models are built with some parameters such as: seismic moment, Mo, corner frequency, fc, the stress drop in the fault plane, $\Delta\sigma$ and a low-pass filter with a characteristic frequency depending on the source or the attenuation (Hanks, 1981) .



Acceleration spectra according to Brune´s model, for earthquakes of different magnitudes and epicentral distance of 60 km.
The following values are taken:
$K = 2$, $R_{\theta j} = 0.4$, $\rho = 2.8$ g/cm³ y $\beta = 3.2$ Km/s.

Stress drop analysis

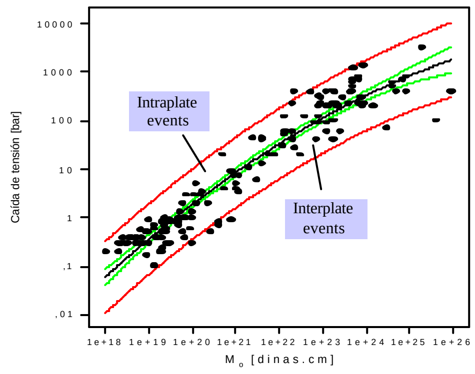
The value of $\Delta\sigma$ is very important in the definition of corner frequency. Many studies consider that $\Delta\sigma$ is constant around the fault. However, stress drop increases when the size of the earthquake is bigger, then a more real approximation becomes necessary.

As it has been observed, the stress drop in interplate zones is smaller than in intraplate regions (Kanamori et al., 1975; Atkinson, 1993). Thus, the constant value taken for interplate earthquakes (100 bars) is not a good approximation for the other earthquakes.

On the other hand, a dependence between the stress drop and seismic moment is clearly observed for small earthquakes (M< 5). This is a conclusion obtained from data of earthquakes all over the world. (De Natale et al, 1987; Mc Garr et al, 1985; Frankel, 1981; Scherbaum et al, 1984; Olivera, 1983; Roca, 1990 y Susagna, 1990)

Starting from different couple of values (Mo, $\Delta\sigma$), we have carried out a non-lineal regression analysis and fit the data to the following expresion (units in bar and dyne cm):

$$\text{Log } \Delta s = (-25.960 \pm 3.640) + (1.939 \pm 0.339)(\text{Log } M_0) + (-0.031 \pm 0.008)(\text{Log } M_0)^2$$



The figure shows the dependence between seismic moment and stress drop, as well as the dispersion of values of stress drop, which may be explained by the different values in interplate and intraplate zones.

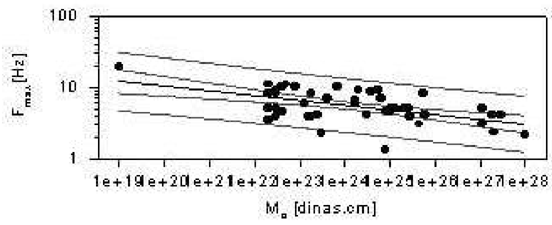
f_{max} analysis

In practice, the acceleration spectra don´t remain plane for high frequencies (as the Brune model proposes), but also a decreasing from a characteristic frequency, f_{max}, is observed. The explication of this frequency is controversial. Some authors attribute its appearance to process in the fault; others to the anelastic attenuation in the path and also to a time related with the stoped-phases during the rupture process.

Last trends may assume that f_{max} is explained as a combination of all the above quoted factors, thus its prediction becomes more complicated. (Herrero y Bernard, 1994).

The analysis of data obtained by different authors (Aki 1988; Roca 1990), taking data of earthquakes in a wide range of magnitudes and sites, gives as result the following fit (units are Hz and dyne cm)

$$\text{Log } f_{max} = (2.530 \pm 0.369) + (-0.067 \pm 0.015) \text{ Log } M_0$$



A clear trend is observed in the figure: f_{max} decreases when seismic moment M_0 increases. The dispersion of data is minor for small magnitudes.

Proposed Model

In the case of intraplate eartquakes (as most part of our study zone, Spain), different authors have developed models based in the original Brune model, with the same behavior in low and intermediate frequencies but different characterization of the drop for high frequencies. As an example, the model proposed by G. Toro y R. McGuire (1992) has been applied in zones of moderate seismicity in Norway.
Starting from Toro and McGuire´s model, we have adopted a new one, for which the behavior of the high frequency part given by f_{max} becomes now dependent on Mo, as the main difference with respect to the former model. Thus, we propose the following shape for the acceleration spectrum:

$$A(f) = A_1(f) \cdot A_2(f) \cdot A_3(f) \cdot A_4(f)$$

Where:
$$A_1(f) = \Omega_0 \frac{w^2}{1+(f/f_c)^2} \qquad A_2(f) = \frac{1}{1+(f/f_{max})^2} \qquad A_3(f) = \frac{1}{r} \quad \forall \cdot r \leq 100\, Km \qquad A_4(f) = -\frac{p \cdot f \cdot r}{b_c \cdot Q(f)}$$

$$A_3(f) = \frac{1}{\sqrt{r * 100}} \quad \forall \cdot r > 100\, Km$$

Being: $$\Omega_0 = \frac{K \cdot R_{qj} \cdot PRIN \cdot M_0}{4 \cdot p \cdot r \cdot b^3}$$

f : frequency
r : hipocentral distance
$K = 2$
$PRIN = 0.71$
$Q(f) = 140 \cdot f^{0.75}$ Quality factor used in the studied zone

R_{qi} =0.6
b_c =3.2 km/s; Lg velocity average
r =2.8 g/cm³
$f_c = 4.9 \cdot 10^6 b_c \cdot (\Delta s / M_0)^{1/3}$ Hz

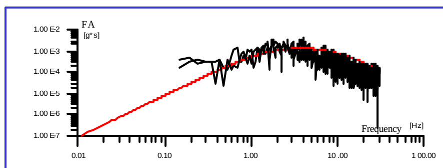
And taking in account:
$$Log \cdot M_0 = 1.5 \cdot M + 23$$
$$Log \cdot \Delta s = -25.96 + 1.939 \cdot (Log \cdot M_0) - 0.031 \cdot (Log \cdot M_0)^2$$
$$Log \cdot f_{max} = 2.5345 - 0.067 \cdot Log \cdot M_0$$

Results

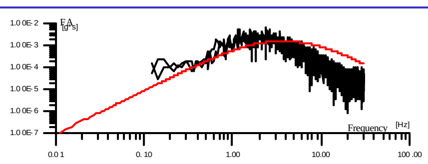
The proposed model has been applied to several events ocurried in Spain (considered as intraplate), in order to obtain the Fourier spectra in similar conditions to those of the real records (magnitude, distance and soil). The estimated spectra in our work have been compared with the spectra derived from some of the accelerograms recorded by the IGN, during these events. A brief summary of the parameters corresponding to the analyzed records is given in the following table.

In the lower part the figures with the results are included. They show the comparison between the Fourier acceleration spectra for the two horiziontal components (in black) and the estimated spectra by our model (in red).

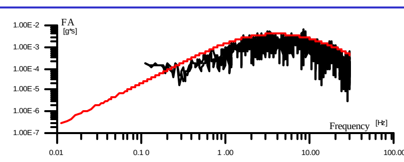
Earthquake	Date	Station	Dh[Km]	M	Recorded in
Mula	02-02-99	Orihuela	47	4.8	ROCA
Mula	02-02-99	Jumilla	43	4.8	ROCA
Mula	02-02-99	Lorquí	21	4.8	ROCA
Mula	02-02-99	Torrevieja	71	4.8	ROCA
Mula	02-02-99	Lorca	51	4.8	ROCA
Adra	04-01-94	Adra	27	4.9	ROCA
Adra	23-12-93	Adra	11	5.0	ROCA
Perpignan	18-02-96	Olot	71	5.0	ROCA



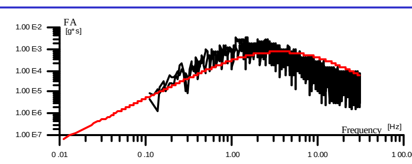
Mula 1999-Orihuela



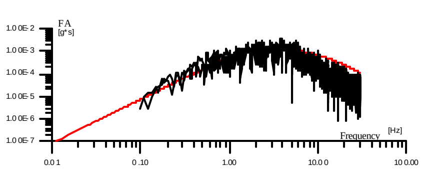
Mula 1999-Jumilla



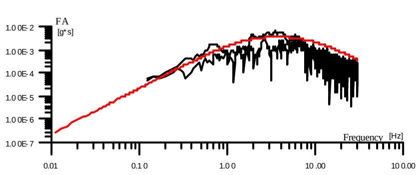
Mula 1999-Lorquí



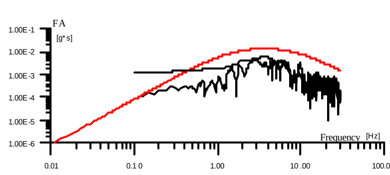
Mula 1999-Torrevieja



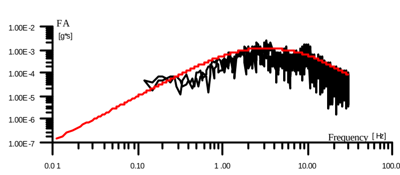
Mula 1999-Lorca



Adra 1994-Adra



Adra 1993-Adra



Perpignan 1996-Olot

Conclusions

- The fit carried out for controlling the stress drop (and corner frequency) supplies satisfactory results
- The attenuation of high frequencies obtained with our model is near to the real observed. This means that a good fit has been reached through the previous funtions.
- Some records show bigger amplitudes in low frequencies and smaller in high frequencies than the ones predicted here. This fact may be atributed to the non-lineal behavior of soil.
- The simple model proposed in this work allows the prediction of FAS and the derived parameters.