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ENGINEERING PARAMETERS OF SPANISH ACCELEROGRAMS. COMPARISON WITH CODE PROVISIONS

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ABSTRACT

Engineering parameters computed from a representative sample of digital accelerograms recorded by the Spanish strong-motion network are presented. The available information is being used mainly for testing the current software for data processing and analyzing the trends of weak-motion records from the engineering viewpoint. Attention is focused on the attenuation laws and spectral characteristics of the events, which are compared with the values prescribed by the Spanish Seismic Code.

KEYWORDS

Earthquake accelerograms. Data bank. Attenuation laws. Response spectra. Spanish Seismic Code.

INTRODUCTION

In 1989, the National Geographic Institute of Spain (IGN) began the installation of a digital network of accelerographs in the main seismic areas of the country, most of them in the free field (Fig. 1-a). Prior to that date, there were only nine analog instruments located at geophisical observatories, nuclear power plants and large dams, which had only provided a couple of records.

Due to the moderate seismicity of the country - approximately one damaging earthquake of intensity $I \geq IX$ (MSK) per century - a very low trigger point was set for the forty eight instruments of the present configuration of the network, located mainly in the south and south-east parts of the country. As a result, more than a hundred accelerograms have been recovered so far (Dec. 1995), all of them but one with low magnitude ($m_b \leq 5.0$) and small peak acceleration values ($a_{max} \leq 60$ cm/s^2). Multiple records, that caused light damage to building and roads, have been obtained from recent events in southern Spain (Adra series, Dec. 93 and Jan. 94).

However, with the exception of two accelerograms recorded in one Alhambra tower, which had been employed for structural studies, the available information has been used mainly for testing the software for data processing and obtaining the trends for weak-motion behaviour of the ground.

ANALYSIS OF EARTHQUAKE RECORDS

In this paper, a subset of the Spanish data bank has been chosen in order to elucidate the engineering characteristics of the records, particularly the attenuation pattern and spectral properties. The accelerograms used in the study are selected on the basis of events with greater magnitude at the source and peak acceleration at the site(s) (Table I). Figure 1-b shows the geographical location of the epicenters and recording stations for the above events.

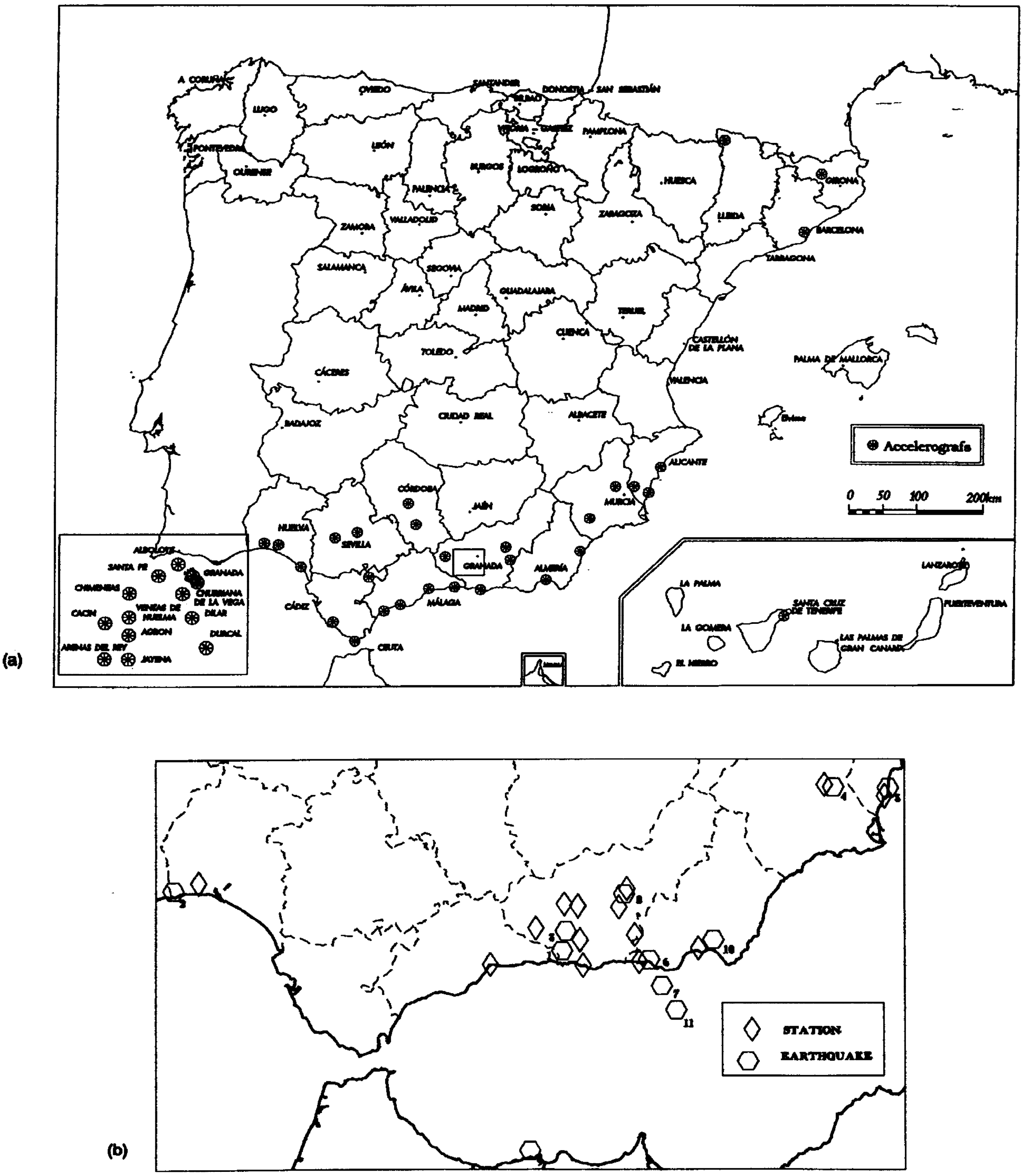

Figure 1. (a) Map of stations of the Spanish Strong-Motion Network (Carreño *et al.*, 1995).

(b) Locations of the epicenters of the earthquakes studied and recording stations.

Earthquake	Date	Origin time (GTM)	Epicentral coordenates		Depth (km)	Magnitude
			Longitude	Latitude		
(1) Almuñecar (GR)	24/06/84	14:30	-3° 44'	36°50'	5	5.0
(2) Ayamonte (H)	20/12/89	04:15	-7°23'	37°13'	23	4.8
(3) Padul (GR)	07/11/90	07:25	-3°42'	36°59'	5	4.0
(4) Molina de Segura (MU)	19/05/93	23:34	-1°10'	38°04'	4	3.0
(5) Mediterranean sea	11/12/93	02:51	-0°39'	38°03'	9	3.4
(6) Adra (AL)	23/12/93	14:22	-2°55'	36° 46'	3	5.0
(7) Adra (AL)	04/01/94	08:03	-2°48'	36° 34'	2	5.0
(8) Guadix (GR)	08/04/94	00:04	-3°09'	37°16'	5	2.8
(9) Alhucemas	26/05/94	08:27	-4°01'	35°18'	3	5.7
(10) Almería (AL)	08/11/94	00:17	-2°19'	36°55'	8	4.0
(11) Adra (AL)	10/11/95	17:50	-2°40'	36°23'	10	3.9

Table I. Seismological characteristics of the earthquakes used in this study.

ENGINEERING PARAMETERS

In general, the factors governing the shape of strong-motion records are related to the source and path and topographical properties of the site. Nonlinear soil effects are important for ground motions in the strong range ($a_{max} \geq 0.2g$). However, for weak motions the influence of the soil in the aspect of the records is debatable. Besides, soil properties for most stations of the Spanish Accelerographic Network are still quantitatively uncertain. For this reason, only the following parameters are considered herein in the characterization of the accelerograms: peak acceleration, epicentral distance, duration, predominant period and response spectrum. Table II summarizes the values of these parameters for the earthquakes analyzed. These values are discussed next.

Peak Acceleration

Values of this parameter, for the horizontal components, range from 0.5 cm/s^2 to 60 cm/s^2, depending on epicentral distance and type of earthquake. As for the vertical components, maximum accelerations are very often lower than horizontal accelerations. However, at a few points it has been observed that vertical accelerations are greater than horizontal ones, particularly at locations very near to the epicenter, where high-frequency seismic waves are rather significant.

Figure 2 depicts the correlation between peak horizontal and vertical accelerations at the sites considered. It should be noted that the horizontal accelerations reported in this work correspond to the component with the highest value of the two possible motions (longitudinal and transversal).

Epicentral Distance

It is important in order to calibrate the accuracy of the attenuation law implicitely specified in the Spanish Seismic Code (NCSE-94), which is based in macroseismic observations. Figure 3, that has been drawn for the Adra series earthquakes, exemplifies this assert. It is seen in the figure that acceleration values taken from instrumental data attenuate faster with distance than the corresponding

Earthquake	Station	Component	Epicentral distance (km)	Significant duration (s)	a_{max} (cm/s²).	Predominant period (s)	PSA_{max} (cm/s²)
24/06/84 Almuñecar (GR)	Beznar (GR) Alh. de Granada (GR) Santa Fe (GR)	V V E-W	20.0 28.4 38.6	3.0 4.0 4.5	29.0 35.5 35.5	0.26 0.20 0.25	- - -
20/12/89 Ayamonte (H)	Cartaya (H)	E-W	17.0	5.0	60.0	0.35	291.4
07/11/90 Padul (GR)	Canales (GR) Santa Fe (GR)	N-S N-S	17.0 20.0	1.4 4.5	15.7 14.7	0.18 0.35	- -
19/05/93 Molina de Segura (MU)	Lorqui (MU)	N-S	6.6	1.3	4.6	0.10	39.2
11/12/93 Mediterranean sea	Torrevieja (A)	V	6.8	6.7	5.7	0.18	58.8
23/12/93 Adra (AL)	Adra (AL) Motril (GR) Comares (Alhambra, GR)	E-W N-S E-W	6.2 53.7 72.9	1.1 20.5 30.0	25.3 8.7 9.0	0.16 0.85 0.52	98.1 35.3 176.4
04/01/94 Adra (AL)	Adra (AL) Almería (AL) Motril (GR) Comares (Alhambra, GR)	N-S E-W E-W E-W	27.7 44.0 68.9 97.2	3.4 15.1 11.0 20.5	30.0 10.2 8.3 11.2	0.15 0.10 1.35 0.45	196.0 147.0 44.1 166.6
08/04/94 Guadix (GR)	Guadix (GR)	N-S	6.2	2.7	5.6	0.18	29.4
26/05/94 Alhucemas	Málaga (MA) Motril (GR) Ugijar (GR)	E-W E-W E-W	162.3 164.9 204.4	16.7 16.7 35.6	0.5 2.3 0.8	0.15 1.00 1.02	8.8 8.8 8.8
08/11/94 Almería (AL)	Almería (AL)	V	15.9	9.4	7.3	0.12	88.2
10/11/95 Adra (AL)	Almería (AL) Adra (AL)	E-W V	44.0 50.5	5.9 4.4	2.7 2.8	0.20 0.12	17.6 39.2

Table II. Engineering parameters of the earthquakes reported on Table I.

values taken from the hazard map of the Code (full line in Figure 3). This result may be due to the shallowness of the rupture zone and the relatively low magnitude of the earthquake series (m_b=5.0).

Duration

For the purposes of this work, the concept of significant duration - first introduced by Trifunac and Brady (1975) - has been used to estimate the temporal length of the records. Accordingly, the times needed to build up between 5 and 95 % of the total Arias intensity have been evaluated for all records and the so-called Husid diagrams have been plotted. These graphs are defined by the expression:

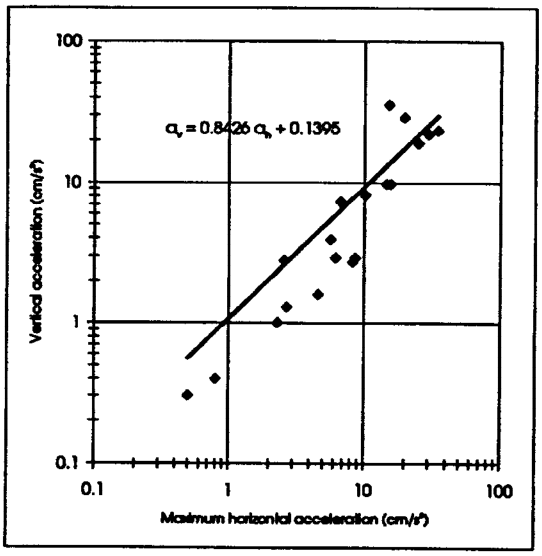

Figure 2. Relationship between peak horizontal and vertical accelerations.

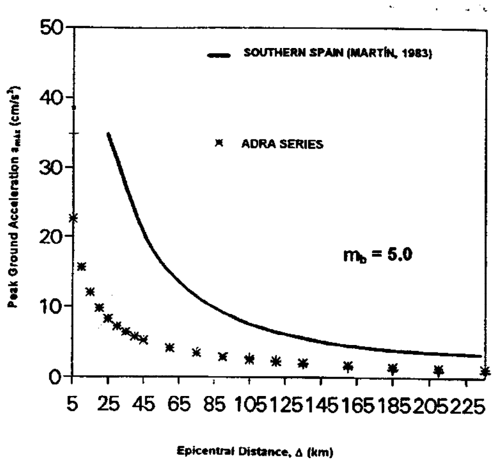

Figure 3. Attenuation curves for recorded accelerograms in Spain.

$$\frac{I(t)}{I_{ARIAS}} = \frac{\frac{\pi}{2g}\int_0^t a^2(t)dt}{\frac{\pi}{2g}\int_0^{t_f} a^2(t)dt} \qquad (1)$$

which corresponds to a monotonically increasing function of time (Fig. 4).

The variation of Husid diagrams with the magnitude and epicentral distance of the earthquakes is shown in Figures 5-a and 5-b, respectively. As expected, significant durations increase with magnitude (for a fixed epicentral distance) and with epicentral distance (for a fixed magnitude). Also, the correlation obtained between significant duration and epicentral distance for rock and hard soil locations is portrayed in Fig. 6. Obviously, the duration of the records is greater at longer distances from the epicenter, although it is no clear if the relationship between both parameters is linear (as indicated in the figure) or nonlinear (as suggested for strong-motion records by other authors, Dobry *et al.*, 1978).

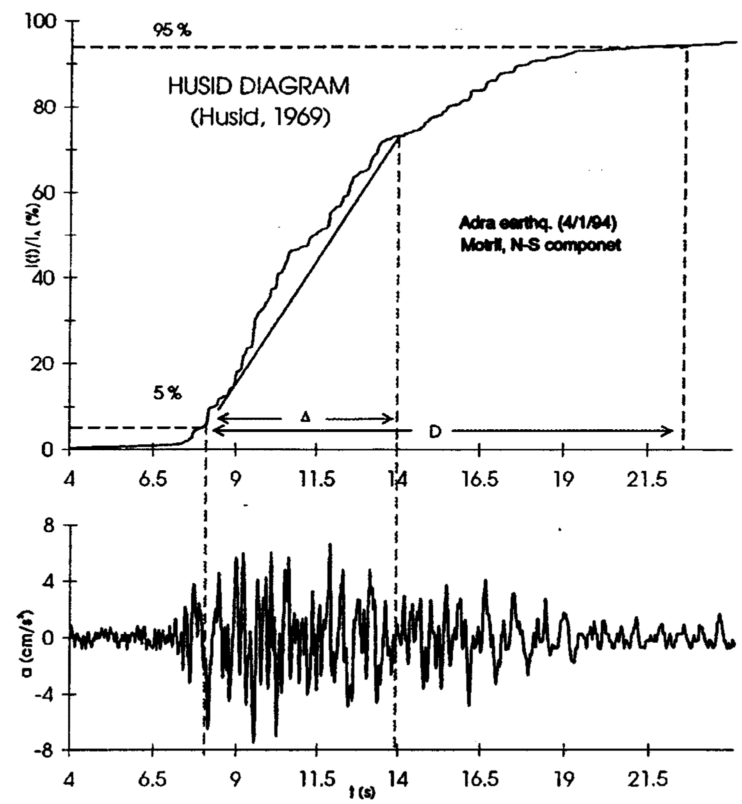

Figure 4. Example of computation of significant duration.

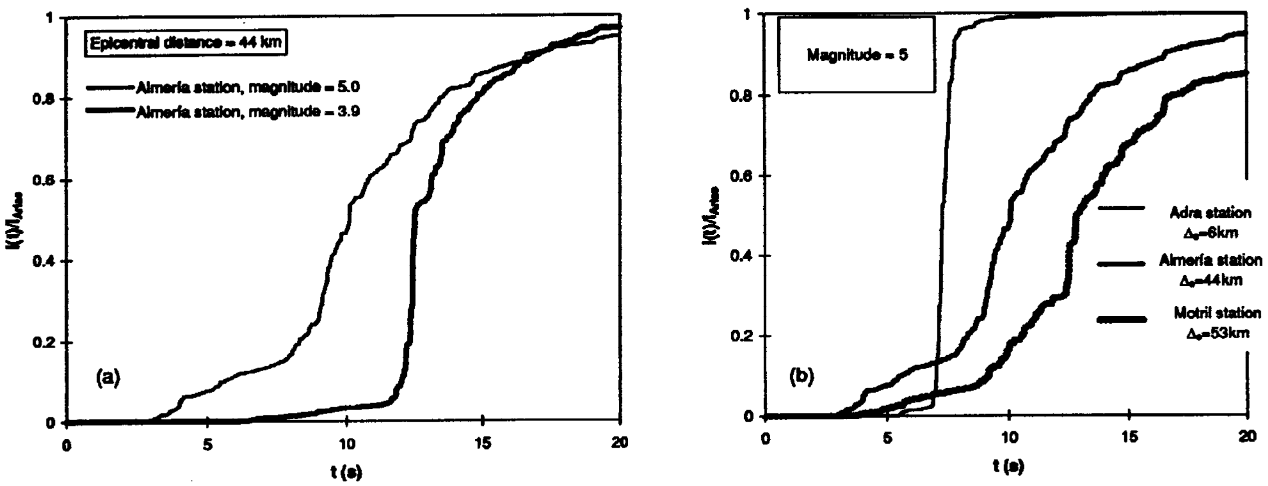

Figure 5. Variation of Husid diagrams with magnitude (a) and epicentral distance (b).

<u>Predominant Period</u>

It is defined as the period for which the Fourier spectrum of the acceleration record reaches its maximum value. The predominant period increases with magnitude and epicentral distance, the relationship being linear for stations on rock outside the epicentral area of the earthquake (Fig. 7). A similar trend has been reported by Seed *et al.* (1968), using California data and the distance to the fault as a reference parameter.

Fig. 8 represents interpolated isolines of predominant periods for the area affected by the Adra earthquake of Dec. 23, 1993. This type of plot is useful in microzonation studies for visualizing the geographical distribution of the periods that carry most of the energy of the seismic waves.

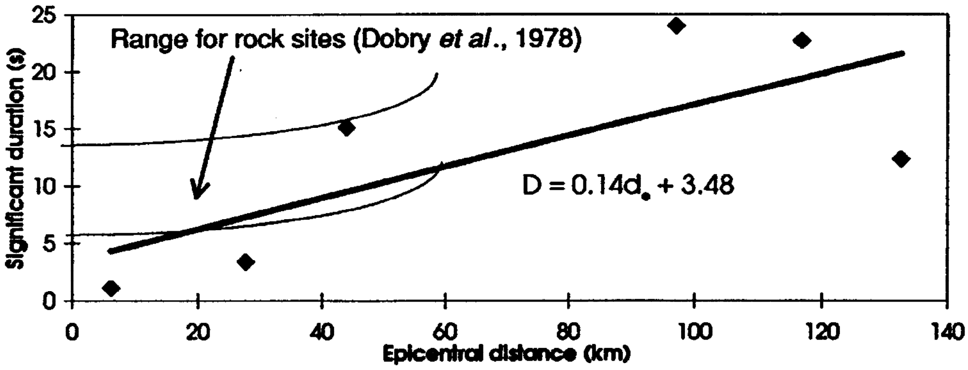

Figure 6. Correlation of significant duration with epicentral distance (Adra series, 1993-94).

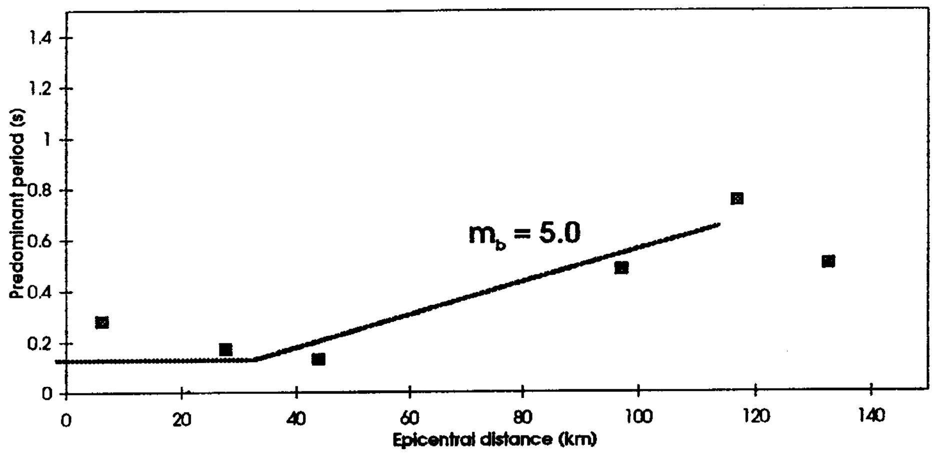

Figure 7. Correlation of predominant period with epicentral distance, for rock sites (Adra series, 1993-94).

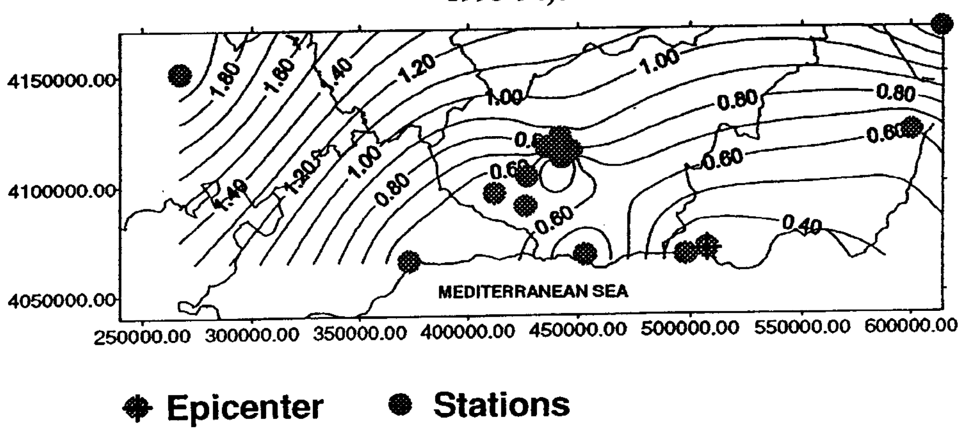

Figure 8. Isolines of predominant periods (Adra earthquake of Dec. 23, 1993).

Response Spectra

They give a clear picture of the distribution of the seismic energy for different periods within the range of interest, either in the linear or trilogarithmic scale. In this research only normalized pseudo-response spectrum curves of acceleration records (so-called pseudo-spectral amplification curves) have been used. Again, the variation of the spectral content has been determined for two opposite situations: epicentral distance fixed (and varying magnitude) and viceversa (fixed magnitude and varying epicentral distance). Figures 9-a and 9-b show the bahaviour of the response spectra in these two cases. As could be anticipated, the predominant period and the long period spectral ordinates shift to higher values when the magnitude and/or the epicentral distance increases. This tendency seems to be more pronounced in the last case, meaning that, for weak ground motions, the epicentral distance largely controls the shape of the acceleration response spectra.

Furthermore, this parameter plays a crucial role in the evaluation of spectral attenuation laws. Such laws have been generally represented by expressions of the form (Kawashima *et al.*, 1984):

$$\log PSA = a - b\log(\Delta_e + \delta) \tag{2}$$

where the coefficients a and b depend on magnitude, period and site geological conditions, and δ is a parameter related to the focal depth of the seismic event. In our case, these coefficients have been

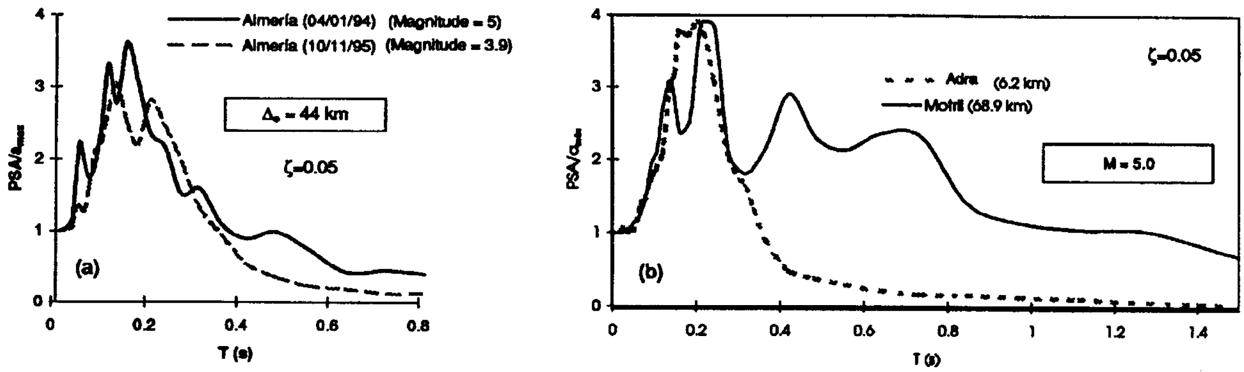

Figure 9. Variation of normalized spectral shapes with magnitude (a) and epicentral distance (b).

estimated for earthquakes with different magnitudes by means of a multiple regression analysis. Figures 10-a and 10-b illustrate the results obtained in the cases m_b=5.0 and m_b=3.9, respectively, for three different periods, namely T=0.25 s, T=0.50 s and T=1.00 s. It is clearly shown in the figures that the attenuation of pseudospectral horizontal accelerations is faster for low periods in both cases, whereas the attenuation rate decreases as the magnitude increases.

Another parameter of engineering interest that can be derived from instrumental records is the Housner intensity. This parameter is in fact an index of potencial damage of the earthquake and is defined as the area below the damped pseudovelocity response spectrum (ζ=5%) between the periods T=0.1 and T=2.5 seconds:

$$I_{H(\zeta=5\%)} = \int_{0.1}^{2.5} S_v(\zeta, T)_{(\zeta=5\%)} dT \tag{3}$$

Figure 11 summarize the Housner intensities computed from the two main shocks of the Adra series earthquakes. Bearing in mind that these two events have the same magnitude and very close epicenters, the consistency of the local Housner intensity values is remarkable.

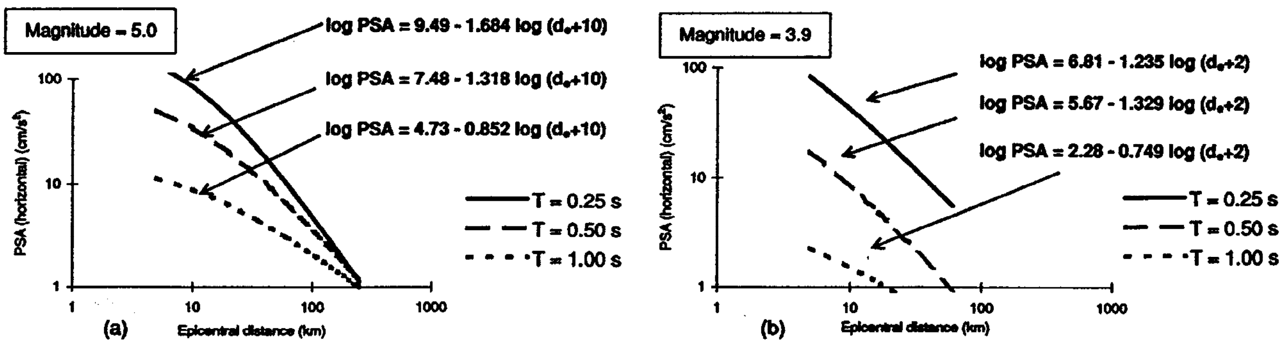

Figure 10. Spectral attenuation curves for different periods and earthquake magnitudes.
(a) Magnitude = 5.0 (Adra series, Dec. 93 - Jan. 94).
(b) Magnitude = 3.9 (Chimeneas earthquake, 1995).

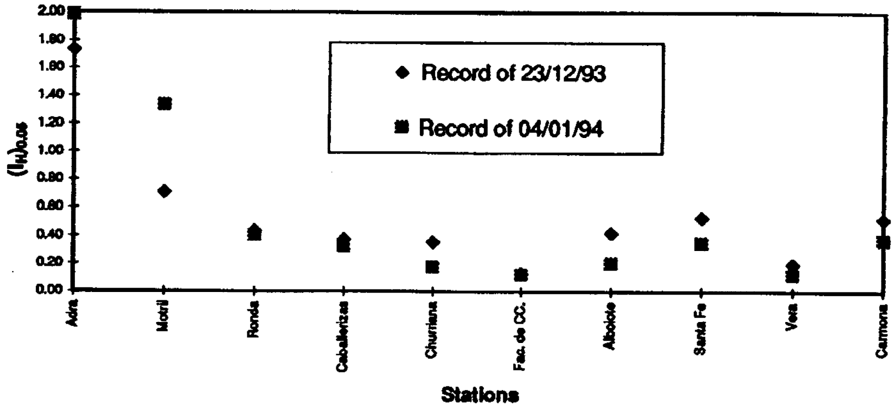

Figure 11. Values of Housner intensities at the stations which have recorded the two main shocks of the Adra series, Dec. 93 - Jan. 94.

COMPARISON WITH CODE

The new version of the Spanish Seismic Code (approved in December 1994) combines the concepts of spectral definition of the seismic actions and modal analysis for the seismic design of structures. Site-dependent spectra are specified in the Code for different classes of soil and earthquake sources. Special attention is given to the great magnitude events originating in the Azores-Gibraltar fault as opposed to Peninsular events that have faster attenuation rates. Consequently, different spectral shapes are assigned to both types of earthquakes, depending on the value of the so-called "contribution coefficient", k, which is listed in the code for the main towns of the country. Then, the prescribed spectra can be compared, at least qualitatively, with the data obtained from the available instrumental records.

Figure 12-a shows such a comparison for two near-field accelerograms of the Adra earthquakes (k=1), recorded at the same site. In this case (epicentral region, hard soil) neither the effect of the distance nor the effect of the site at long periods are expected to be significant. Nevertheless, it is remarkable the amplification of the high-frequency waves in the resonance region of the spectrum, due to the quasi-linear behaviour of the ground; this observation agrees with the macroseismic information.

The influence of the seismic source at one place relatively close to the fault Azore-Gibraltar is illustrated in Fig. 12-b. It can be seen that, for inland earthquakes, the contribution factor specified by the Code (k=1.4) yields spectral amplifications which are overconservative in the long period range. Figure 12-b shows also that, in this case, the range of periods defining the plateau of the recorded spectrum matches better with the spectrum given in the code for near-field earthquakes than with the one for far-field events.

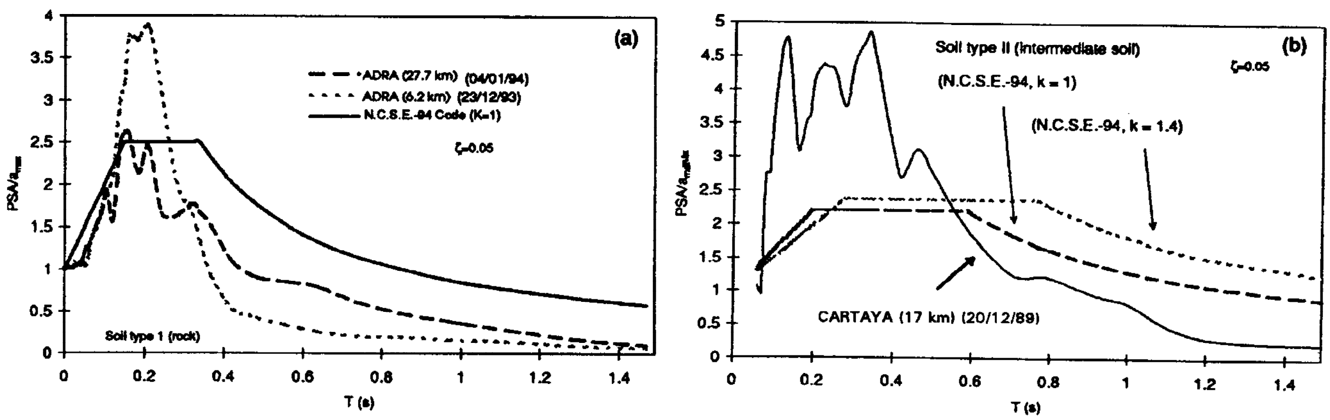

Figure 12. Effect of the contribution coefficient in the anticipated response spectrum of the earthquake. Comparison between recorded data and code provisions.

CONCLUSIONS

- For weak-motion, epicentral distance is the factor controlling the engineering parameters of acceleration records.
- Peak acceleration values taken from weak-motion records attenuate faster with distance than code provisions, probably due to the shallowness of the rupture zone.
- Nonlinear soil behaviour for low magnitude seismic events is not that significant. Pseudoresonance effects at the natural period of the layered ground appear in the records.
- Housner intensity is a reliable index for local damageability, since it keeps a constant level for fixed values of the magnitude and epicentral distance of the earthquakes.
- For Peninsular earthquakes, pseudo-spectral amplification factors given by the Spanish Code are too conservative in the long period range, specially when applied to locations closer to the Azores-Gibraltar fault.
- Pseudoespectral horizontal accelerations attenuate more rapidly for low periods. As the magnitude increases the attenuate rate decreases.

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