

Anelastic attenuation and pseudoacceleration relations in eastern Iberia

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ABSTRACT: The horizontal and vertical anelastic attenuation of the L_g waves have been investigated to determine the degree of anelastic anisotropy in the eastern side of the Iberian Peninsula. Regionalization of the anelastic attenuation using two regions, the northern and the southern sides of the studied zone, seems to indicate that the amount of anelastic attenuation is almost the same in both subregions.

Pseudoacceleration formulas have been derived for the vertical component and for the horizontal one presenting the maximum acceleration values. A good correlation is observed between the few acceleration data observed in the Iberian Peninsula and the theoretical formulation obtained in this study. Comparison between the theoretical horizontal and vertical pseudoacceleration formulas indicate that the horizontal acceleration is approximately 1.3 times the vertical one.

1. INTRODUCTION

The best way to determine acceleration-distance relationships is using observed acceleration data. In the Iberian Peninsula the lack of acceleration data is really a fact. Therefore, it must be applied indirect methods to determine expected accelerations. The L_g waves usually present the highest amplitudes on the seismograms for local earthquakes with moderate magnitude ($m_b L_g \leq 6$). The frequency content of the signal (Dwyer et al., 1983) are near to most of the man-made structures (1 Hz - 10 Hz). In the Iberian Peninsula, and particularly in the eastern side, the earthquakes present moderate magnitudes; therefore, L_g waves are the appropriate ones to infer pseudoacceleration formulas.

Determination of pseudoacceleration formulas, using L_g waves, involves the determination of the L_g anelastic attenuation coefficients in the time domain (Nuttli 1973) or in the frequency domain (Shin and Herrmann 1987). To obtain the frequency dependence of the coefficients the best way is to work in the frequency domain.

Previous work, carried out in the Iberian Peninsula, to determine the L_g anelastic attenuation coefficients and pseudoacceleration formulas have been performed by several authors. De Miguel and Vidal (1982), working in the time domain and using earthquakes located in Iberia and surrounding areas, determined 1-second γ_{Lg} value of 0.48/grade for the whole Iberia. Canas

et al. (1987), using coda waves of earthquakes located in Iberia, determined Q values for four regions: the whole Iberia, the southern side, the northeastern side and the central-western side; the determined time domain anelastic attenuation coefficients of L_g waves (γ_{Lg}), inferred from the Q values, were: $0.0025 km^{-1}$, $0.0045 km^{-1}$, $0.0027 km^{-1}$ and $0.0021 km^{-1}$, respectively. García (1989) carried out a frequency domain study of the vertical component of the L_g waves for four regions of Iberia: the whole Iberia, the northeastern side, the south-southeastern side and the Granada basin; the obtained 1 Hz - γ_{Lg} values were: $0.0025 km^{-1}$, $0.0041 km^{-1}$, $0.0093 km^{-1}$ and $0.0173 km^{-1}$, respectively. He found also that, in general, lower attenuation coefficients correspond to a high volume of stable geologic unit in the studied regions.

Vertical pseudoacceleration formulas, using L_g waves, have been obtained by Canas et al. (1988) for the region of Iberia located among the Pyrenees, the Iberic chain and the coastal region of Catalonia, and by García (1989) for the regions: the whole Iberia, the northeastern side and the south-southeastern side.

The purposes of this study are: a) to find possible lateral variations of L_g anelastic attenuation in the eastern Iberia, b) to evaluate the degree of anelastic attenuation anisotropy in the region, and c) to find the relationship between horizontal and vertical pseudoacceleration formulas for the studied region.

2. METHODOLOGY

2.1 Spectral anelastic attenuation of L_g waves

To determine the anelastic attenuation coefficients ($\gamma(f)$) in the frequency domain we have used the expression (Shin and Herrmann 1987):

$$A(f) = A_0(f)r^{-1/2}e^{\gamma(f)r} \quad (1)$$

where A_0 is the spectral amplitude at the focus for a given frequency f , and r is the epicentral distance. Determination of γ 's, for a set of frequencies, can be made using displacement, velocity or acceleration spectra of L_g waves. The final result must be the same because the acceleration spectra is obtained from the velocity or from the displacement spectra multiplying by the angular frequency ω or by ω^2 , respectively.

Expression (1) can be applied to a set of spectral amplitudes corresponding to one earthquake and several observations or to a set of earthquakes-observations. In the last case, the magnitudes must be reduced to a reference one (De Miguel and Vidal 1982). In this case, the proper expression is given by:

$$\log A(f) - \log A^*(f) = m - m^* \quad (2)$$

where $A(f)$ is the observed spectral amplitude, as a function of the frequency f , corresponding to an earthquake of magnitude m , and $A^*(f)$ is the reduced spectral amplitude corresponding to the reference magnitude m^* (usually taken as the arithmetic average of the magnitudes involved in the study).

The frequency dependence of γ_{L_g} can be determined using the following expression (Hasegawa 1985):

$$\gamma(f) = \gamma_0 f^\nu \quad (3)$$

where γ_0 is the value of γ corresponding to a reference frequency of 1 Hz, and ν is a real exponent indicating the degree of frequency dependence.

Determination of the anelastic coefficients, $\gamma(f)$, can be obtained applying the linear least-squares method. Taking natural logarithms in expression (1), we arrive to the expression:

$$y = B - \gamma(f)r \quad (4)$$

where $y = \ln(A(f)r^{1/2})$ and $B = \ln A_0(f)$.

To determine the frequency dependence of $\gamma(f)$, given by expression (3), the least-squares method described before can be applied.

2.2 Pseudoacceleration formulas

To determine pseudoacceleration formulas using displacement or velocity seismograms we have applied the following procedure. The amplitude of the Fourier displacement spectra, FD , has the form:

$$FD = \left| \int_{-\infty}^{\infty} f(t)e^{-i\omega t} dt \right| \quad (5)$$

where $f(t)$ is the seismic signal, t is the time and ω is the angular frequency.

The spectral acceleration, FS , can be determined using:

$$FS = \omega^2 FD \quad (6)$$

If the starting data come from a velocity seismogram, FS is given by:

$$FS = \omega FV \quad (7)$$

where FV indicates the amplitude of the Fourier velocity spectra.

For engineering purposes is usual to work with pseudoparameters (Jennings 1983). The approximate relationship between the pseudo-response spectra of the velocity, PSV , and the acceleration Fourier spectra of the ground, considering that in PSV , the damping coefficient is zero, is given by:

$$PSV \approx FS \quad (8)$$

Expression (8) is very important when using displacement or velocity seismograms to determine pseudovelocity response spectra. The pseudo-acceleration response spectra can be obtained from the expression:

$$PSA = \omega PSV \quad (9)$$

In general, the empirical relations used to determine peak acceleration have the form (Idriss 1983):

$$\ln y = C_0 + f_1(m) + f_2(r) + f_3(l) \quad (10)$$

where C_0 is a constant, m is the earthquake magnitude, r is the epicentral distance and l represents the local characteristics of the ground. The terms in the right hand side of expression (10) usually can be represented as products of exponentials or potentials functions. There are several ways to characterize these terms (Donovan and Bornstein 1978; McGuire 1978; Joyner and Boore 1981). In this work, to determine peak pseudoaccelerations, we have adopted the following

form (Hasegawa 1985; Canas et al. 1988):

$$PSA = Ae^{Bm}e^{-\gamma(f)r}r^{-1/2} \quad (11)$$

where γ is the anelastic attenuation coefficient of the L_g waves and A and B are constants. The factors $r^{-1/2}$ and $e^{-\gamma(f)r}$ account for the geometrical distribution and anelastic effects.

Once $\gamma(f)$ is known (see section 2.1), the least-squares method, applied to a set of PSA data, lets, using expression (11) previously linearized, to determine A and B and, therefore, a general formula can be derived for the studied region.

3. DATA

The earthquake locations and the seismographic station used appear in the Figure 1.

To carry out the study of the horizontal and vertical components of the L_g waves, we have selected the EBR seismographic station due to the following reasons: 1) There are enough short-period records, with clear signals, susceptible to be digitized, 2) A broad range of magnitudes ($2.0 \leq m_b \leq 4.9$), considering the magnitudes in the region, is covered, and 3) The short-period station is a three component seismograph. The studied region has been divided into two subregions: the northern

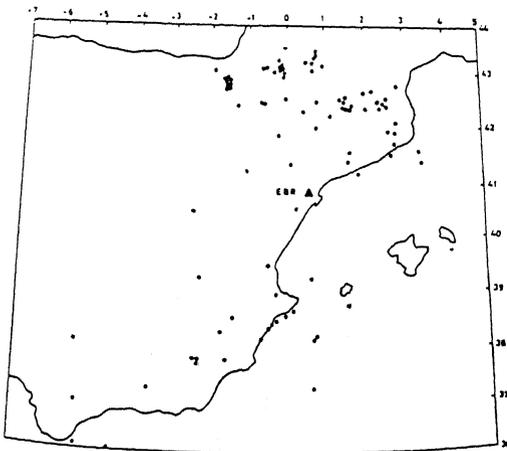


Figure 1. Location of the earthquakes and the seismographic station of EBR used in the study.

side, formed by the region located north of the EBR station, and the southern side, formed by the region located south of the station.

Magnification curves for the EBR station and for the time period expanded for the earthquakes

represented in Figure 1 (1976-1984), has been extensively studied by people in the ETSICCP of Barcelona; in particular, Canas and Pujades (1992) have obtained their analytical magnification curves applying generalized inversion methods.

The short-period three-component seismograms were selected in such a way that the L_g wave signals appear clearly on the seismograms and, therefore, the digitization procedure was the easiest possible. Digitizing techniques trying to avoid as much as possible the most important errors in these procedures (Barbat et al. 1988) have been applied. In short, we have tried to eliminate errors due to: a) The digitization made by different people. In this case only one person has digitized all the seismograms, b) Base line selection. We have applied the methodology described by Mitchell and Landisman (1969), and c) Inadequate interpolation between digitized points. We have used cubic spline techniques (Sarrate et al. 1988).

Spectral Fourier analysis has been applied to the digitized seismograms, and using the methodology described in sections 2.1 and 2.2 we have determined the anelastic attenuation coefficients of the L_g waves and the pseudoacceleration formulas for the vertical and the horizontal components.

4. RESULTS

4.1 Anelastic attenuation relations

In this study we have only considered frequencies up to 5 Hz because of the instrumental characteristics of the EBR short-period seismographic station.

The Z (vertical), NS (north-south), EW (east-west), R (radial), and the T (transversal) components of the motion have been initially considered in the study. The R and T motions were obtained rotating adequately the NS and EW components. Finally, only the Z and the NS results will be presented because the NS motion is the horizontal component giving the highest spectral levels and, therefore, the highest horizontal accelerations.

The frequency dependence results of the anelastic attenuation coefficient, γ_{L_g} , corresponding to the Z and to the NS components, for the northern, southern and total region of this study, obtained using expression (3) and the data in section 3 can be written as:

a) Vertical component

$$\text{north region, } \gamma = (0.0045 \pm 0.0006) f^{(0.5404 \pm 0.0682)} \quad (12)$$

$$\text{south region, } \gamma = (0.0040 \pm 0.0010) f^{(0.6129 \pm 0.0637)}$$

$$\text{total region, } \gamma = (0.0042 \pm 0.0007) f^{(0.5792 \pm 0.0591)}$$

The γ_0 and ν values are indicated together with their standard deviations.

b) North-south component

$$\text{north region, } \gamma = (0.0034 \pm 0.0001) f^{(0.6444 \pm 0.0739)}$$

$$\text{south region, } \gamma = (0.0037 \pm 0.0002) f^{(0.6227 \pm 0.0697)} \quad (13)$$

$$\text{total region, } \gamma = (0.0035 \pm 0.0001) f^{(0.6347 \pm 0.0716)}$$

It must be said that the results obtained for the EW, R and T components of the horizontal motion were similar to the ones determined for the NS horizontal component.

Comparing the vertical and horizontal values - expressions (12) and (13) - it is possible to infer the following: a) The northern, the southern and the total regions of each of the studied components present a similar degree of anelastic attenuation. The degree of frequency dependence is quite similar. b) Comparing the vertical values with the horizontal ones it is possible to infer a small anisotropic effect. The corresponding frequency dependence seems to be about the same.

4.2 Pseudoacceleration formulas

Using expression (11) and the data mentioned in section 3, we have determined a set of formulas for the same regions and for the same components mentioned before. The obtained results are:

a) Vertical component
northern region

$$\log PSA = -2.05(\pm 0.36) + 0.91(\pm 0.13)m_b L_g - 0.5 \log r - 0.011 \ln r$$

southern region

$$\log PSA = -2.04(\pm 0.39) + 0.92(\pm 0.11)m_b L_g - 0.5 \log r - 0.012 \ln r \quad (14)$$

total region

$$\log PSA = -2.05(\pm 0.37) + 0.91(\pm 0.12)m_b L_g - 0.5 \log r - 0.011 \ln r$$

b) North-south component
northern region

$$\log PSA = -2.01(\pm 0.34) + 0.93(\pm 0.11)m_b L_g - 0.5 \log r - 0.010 \ln r$$

southern region

$$\log PSA = -2.00(\pm 0.31) + 0.92(\pm 0.10)m_b L_g - 0.5 \log r - 0.011 \ln r \quad (15)$$

total region

$$\log PSA = -2.00(\pm 0.33) + 0.93(\pm 0.11)m_b L_g - 0.5 \log r - 0.011 \ln r$$

Figure 2 presents the results for the entire region of this study and for the vertical and the north-south components. Magnitude $m_b L_g = 6$ is extrapolated from expressions (14) and (15). They must be only considered as orientative results. Strictly speaking, both expressions are only valid in the approximate magnitude range: $2 \leq m_b L_g \leq 5$.

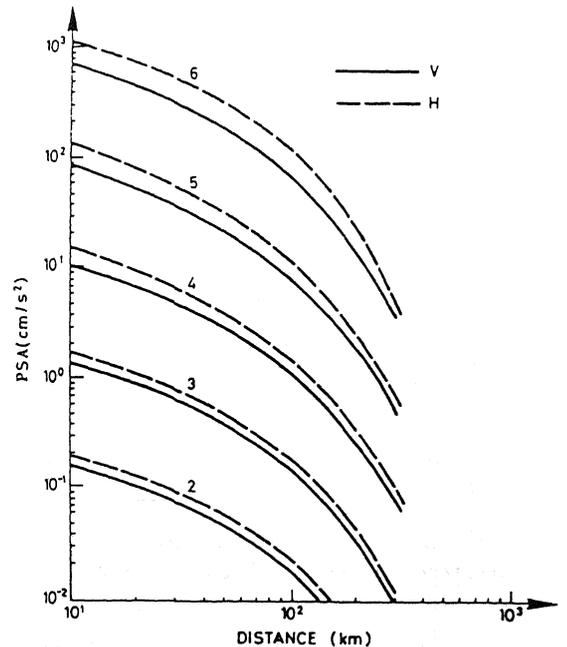


Figure 2. Vertical (V) and horizontal (H) pseudoacceleration formulas determined in this study. Numbers on the top of each pair of curves indicate the corresponding m_b magnitudes.

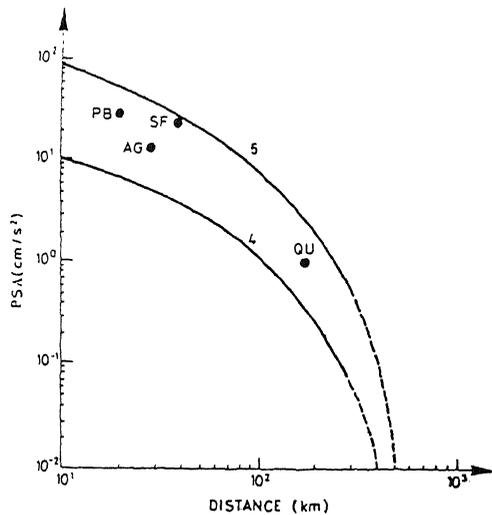


Figure 3. Comparison between the theoretical vertical pseudoacceleration formulas ($m_b = 4$ and $m_b = 5$) determined in this study and the observed vertical acceleration data. PB, SF and AG correspond to the 24/Jun/84 earthquake (Beznar region; $m_b = 5$) (Carreño et al. 1989), and QU corresponds to the 6/Jan/89 earthquake (French Pyrennees region; $4.6 \leq m_b \leq 4.9$) (A. Roca, personal communication).

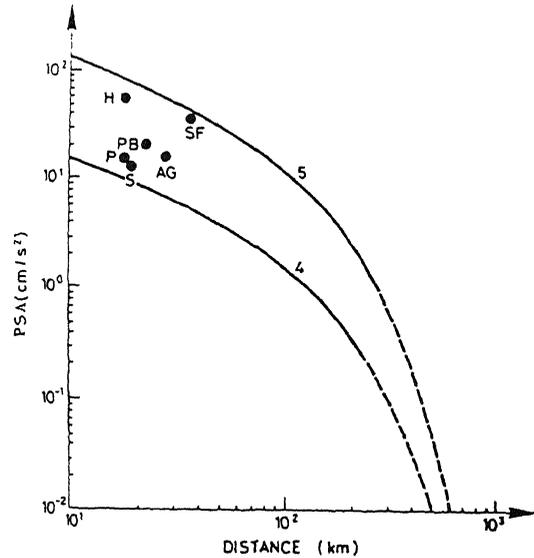


Figure 4. Comparison between the theoretical horizontal pseudoacceleration formulas ($m_b = 4$ and $m_b = 5$) determined in this study and the observed horizontal acceleration data. PB, SF and AG correspond to the 24/Jun/84 earthquake (Beznar region; $m_b = 5$) (Carreño et al. 1989), H corresponds to the 20/Dec/89 earthquake (near Huelva region; $m_b = 4.8$) (E. Carreño, personal communication), and P and S correspond to the 7/Nov/90 earthquake (near Beznar region; $m_b \approx 4.0$) (E. Carreño, personal communication).

It can be noted in Figure 2 that the horizontal accelerations seem to be a little bit higher than the vertical ones (*horizontal psa* ≈ 1.3 *vertical psa*). Comparing the anelastic and the pseudoacceleration results obtained in this study with other results established for the Iberian Peninsula corresponding to the vertical component (see section 1), it is possible to infer the following. The γ_0 values determined for Iberia by De Miguel and Vidal (1982) ($0.48/\text{grade} \approx 0.004\text{km}^{-1}$), is very close to the corresponding value determined in this study for the total region (0.0035km^{-1}). The inferred γ_0 value from coda waves determined by Canas et al. (1987) -0.0025km^{-1} and by García (1989) -0.0025km^{-1} for all the Iberian Peninsula are similar to the value determined in this study. Pseudoacceleration formulas determined by Canas et al. (1988) and García (1989) for the northern side of the eastern part of Iberia and for the whole Iberia, respectively, are congruent with the ones determined in this study. In fact, comparing the vertical formula obtained in this study for the northern region, and the formula determined by Canas et al. (1988) it is possible to observe that the differences in pseudoacceleration levels for equal magnitudes do not exceed the value of 1.1. When the vertical formula determined in this study for the total region is compared with the general one established by García (1989) for Iberia, it is possible to see that the pseudoacceleration

levels are similar for distances less than about 70 km, being appreciable different for higher distances. This is due mainly to the different anelastic attenuation in the studied regions. At our knowledge there are not horizontal studies relative to the matter of this work.

Figure 3 presents the comparison between the determined theoretical pseudoacceleration formulas for the vertical component, and the observed vertical acceleration data in Iberia (Carreño et al., 1989). Figure 4 presents the same than in Figure 3, but for the horizontal component. The observed horizontal data come also from Carreño et al. (1989), Emilio Carreño (Instituto Geográfico Nacional, personal communication), and from Antoni Roca (Servei Geològic -Generalitat de Catalunya- personal communication). From Figures 3 and 4 it can be seen that the theoretical approach followed in this study, using velocity seismograms, explains adequately the observed data.

5. CONCLUSIONS

The principal results are the following. a) The obtained anelastic results for the vertical

component agree very well with previous vertical anelastic attenuation values determined in Iberia. b) The determined pseudoacceleration formulas for the vertical component compare well with several vertical ones established in Iberia. c) Comparison between the results obtained in this study for the vertical and for the horizontal components indicates that 1) the anelastic attenuation is slightly anisotropic, and 2) the relationship between the vertical and the horizontal pseudoaccelerations is about 0.76. d) Comparison between the pseudoacceleration formulas and the observed ground acceleration in Iberia indicates that the determined formulas predict adequately well the observed acceleration data.

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REFERENCES

- Barbat, A.H., Canas, J.A. and J.M. Canet. 1988. Engineering definition of the seismic action by using seismograms. In *Seismic Risk Assessment and Design of Building Structures*. E. Koridze (ed.): 113-134. London: Omega Scientific.
- Canas, J.A. and L. Pujades. 1992. The Valencia Trough: coda Q. *Tectonophysics* (in press).
- Canas, J.A., Egozcue, J.J., Pujades, L. and J.A. Pérez. 1987. Crustal coda-Q in the Iberian Peninsula. *Annales Geophysicase* 5B: 657-662.
- Canas, J.A., Egozcue, J.J., Barbat, A.H., Canet, J.M. and E. Banda. 1988. Peligrosidad Sísmica en Catalunya. Los autores (eds.). Barcelona: ETSICCP.
- Carreño, E., López-Casado, C., Martínez-Solares, J.M., Peláez, J.A., Tejedor, J.M. y J. Mezcua. 1989. Análisis de los acelerogramas del terremoto de 24 de Junio de 1984. *Publicación Técnica* N° 22. Instituto Geográfico Nacional, Madrid.
- De Miguel, F. and F. Vidal. 1982. Regional propagation of L_g waves in and near Iberian Peninsula. Report 3.1982. Observatorio Universitario de Cartuja. Universidad de Granada.
- Donovan, N.C. and A.E. Bornstein. 1978. Uncertainties in seismic risk procedures. *Journal Geotechnical Engineering Division ASCE* 104: 869-887.
- Dwyer, J.J., Herrmann, R.B. and O.W. Nuttli. 1983. Spatial attenuation of the L_g wave in the central United States. *Bulletin Seismological Society of America* 73: 781-796.
- García, M. 1989. Atenuación espectral de ondas L_g y pseudoaceleración máxima del terreno en la Península Ibérica. PhD Thesis University of Barcelona, Spain.
- Hasegawa, H.S. 1985. Attenuation of L_g waves in the Canadian Shield. *Bulletin Seismological Society of America* 75: 1569-1582.
- Idriss, I.M. 1983. Evaluation of earthquake hazard. In *Assesment and Mitigation of Earthquake Risk in the Arab Region*. K. Cidlinsky and B.M. Rouhban (eds.): 79-113. UNESCO.
- Jennings, P.C. 1983. Engineering Seismology. In *Earthquakes: Observation, Theory and Interpretation*. H. Kanamori and E. Boschi (eds.): 138-173. Amsterdam: North-Holland Publ. Comp.
- Joyner, W.B. and D.M. Boore. 1981. Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California earthquake. *Bulletin Seismological Society of America* 71: 2011-2038.
- McGuire, R.K. 1978. Seismic ground motion parameter relations. *Journal of the Geotechnical Engineering Division ASCE* 104: 481-490.
- Mitchell, B.J. and M. Landisman. 1969. Electromagnetic seismograph constants by least-squares inversion. *Bulletin Seismological Society of America* 59: 1335-1348.
- Nuttli, O.W. 1973. Seismic wave attenuation and magnitude relations for eastern North America. *Journal Geophysical Research* 78: 876-885.
- Sarrate, J., Canas, J.A., Barbat, A.H. and J.J. Egozcue. 1988. Spectral analysis of seismic ground motion: application to the Beznar dam accelerogram. In *Seismic Risk Assessment and Design of Building Structures*. E. Koridze (ed.): 161-173. London: Omega Scientific.
- Shin, T.C. and R.B. Herrmann. 1987. L_g attenuation and source studies using 1982 Miramichi data. *Bulletin Seismological Society of America* 77: 384-397.