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Regional *Lg*-wave attenuation and estimation of peak ground acceleration in the Iberian Peninsula

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ABSTRACT: Spectral amplitudes of digitized short–period analog records of *Lg*–waves from regional earthquakes in the Iberian Peninsula have been used to calculate regional values of the anelastic attenuation coefficient, γ, at fixed frequencies and to obtain a simple model of its frequency dependence. Moreover, an approximation to the regional peak values of ground acceleration has been obtained in terms of the pseudo–acceleration represented empirically as a function of the earthquake magnitude, the epicentral distance and the anelastic attenuation coefficient. The few available measurements of peak ground acceleration in the Iberian Peninsula are in good agreement with the empirical predictions given by the pseudo–acceleration values.

1 INTRODUCTION

Lg waves usually represent the dominant carrier of ground motion energy for moderate size earthquakes at regional distances in continental paths, for wave motion in the frequency range of 1 to 10 Hz, which is related to damaging ground accelerations and where natural frequencies of the most common structures lie (Dwyer *et al.*, 1983; Nuttli, 1973, 1978). Therefore, the studies based on *Lg*–wave observations, starting by the analysis of the *Lg*–phase attenuation, are very important in relation to seismic risk assessment and Engineering Seismology.

Attenuation analysis can be performed using *Lg*–wave amplitudes either in the time domain or in the frequency domain. The second approach has been applied to spectral amplitudes of digitized vertical–component short–period analog records of *Lg* waves from regional earthquakes in the Iberian Peninsula, to calculate regional values of the anelastic attenuation coefficient, γ, at fixed frequencies and to obtain a simple model of the frequency dependence of γ.

When no acceleration records are available in a region due, either to a lack of specific instrumentation or to moderate to low seismic activity, or to both; it is necessary to develop alternative methods to estimate the peak ground acceleration at a site as a function of known parameters. By simple hypothesis — valid, in general, when acceleration has the main influence on damaging ground motion — the spectral analysis of short-period *Lg*–wave records can provide an approximation to the peak values of ground acceleration in terms of the pseudo-absolute acceleration which can represent upper limit estimates of observed values.

Using the same data set and the results from the attenuation analysis mentioned above, regional empirical relationships of the pseudo-absolute acceleration as a function of the earthquake magnitude, the epicentral distance and the anelastic attenuation coefficient, γ, have been obtained for different regions in the Iberian Peninsula.

2 FREQUENCY DOMAIN *Lg*–WAVE SPATIAL ATTENUATION

The attenuation of *Lg* waves can be model in the frequency domain, at regional distances, by:

$$F = F_0\, r^{-1/2}\, e^{-\gamma r} \tag{1}$$

where F is either the Fourier amplitude spectrum of displacement, FD, velocity, FV, or acceleration, FA, at epicentral distance r (usually FA), F_0 is a frequency–dependent coefficient and γ is the coefficient of anelastic attenuation.

Equation (1) can be linearized to form:

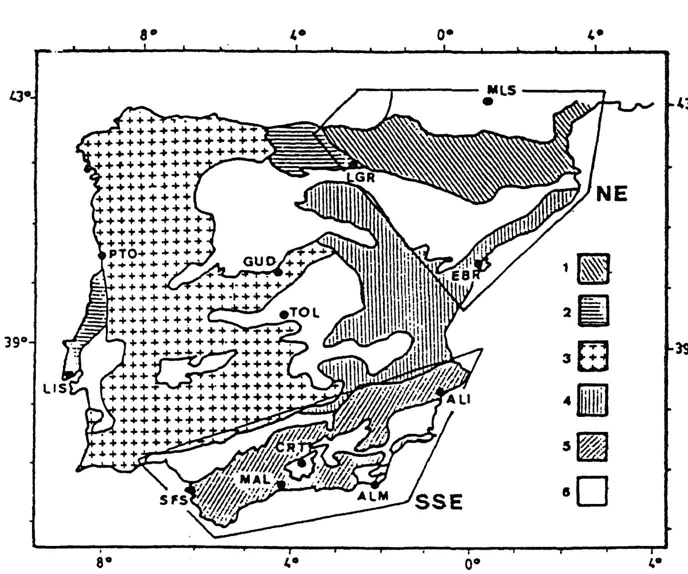

Figure 1: Selected regions, seismic stations and major geotectonic units of the Iberian Peninsula (1 Pyrenees; 2 Mesozoic basins; 3 Hesperic Massif; 4 Celtiberian and Catalan chains; 5 Betics; 6 Tertiary basins).

$$Y = B - \gamma r \tag{2}$$

where,

$$Y = \ln(F\, r^{1/2}) \quad \text{and} \quad B = \ln F_0$$

Solving Equation (2) by least-squares provides values of the unknown coefficients B and γ.

The anelastic attenuation coefficient is, in general, frequency dependent. This dependence can be fit by a simple model of the form:

$$\gamma(f) = \gamma_0\, f^N \tag{3}$$

where γ_0 is the value of γ at a reference frequency, usually 1 Hz, and f is the frequency.

2.1 Regional attenuation of *Lg* waves in the Iberian Peninsula

The regional study of the *Lg*-wave attenuation has been performed for three regions in the Iberian Peninsula (see Figure 1):

IP The Iberian Peninsula as a whole.

NE The North-East part of the Iberian Peninsula, including the Pyrenees, the Catalan Coastal Ranges, the Celtiberian chain and the Ebro basin.

SSE The South South-East part of the Iberian Peninsula, from the Guadalquivir basin to the Mediterranean Sea, including the Betics Cordillera.

Table 1. Seismic stations and records. (STN: Station name, LAT N: N-Latitude, LON E: E-Longitude, ELV: Elevation [m], REC: Number of records).

STN	LAT N	LON E	ELV	REC
ALI	38.355	−0.487	35	11
ALM	36.853	−2.460	65	27
CRT1	37.190	−3.598	774	46
EBR	40.821	0.494	50	57
GUD	40.643	−4.154	1393	24
LGR	42.456	−2.503	446	28
LIS	38.716	−9.149	77	21
MAL	36.728	−4.411	60	38
MLS	42.958	1.083	450	22
PTO	41.139	−8.602	88	36
SFS	36.462	−6.205	24	18
TOL	39.881	−4.049	480	39

Table 1 summarizes the station coordinates and the number of vertical-component short-period analog records used in the calculations.

Special care has been taken on the digitization process, particularly with respect to the following items:

- Baseline selection
- Unequally spaced time intervals
- Cubic spline interpolation
- More sampling at peaks and kinks
- Comparison of digitized and original seismograms

Simple regional models of the frequency dependence of γ (Equation 3) were calculated by linear least–squares fit of the regional values of the anelastic attenuation coefficient, γ, obtained at fixed frequencies (1, 2, 4 and 5 Hz) from Equation 2, and they are given in Table 2.

Table 2. Regional values of the coefficient of anelastic attenuation, γ [km^{-1}], and its frequency dependence (γ_0 is the γ value at 1 Hz).

Region	$\gamma = \gamma_0 f^N$
IP	$\gamma = 0.003 f^{0.3}$
NE	$\gamma = 0.004 f^{0.6}$
SSE	$\gamma = 0.009 f^{0.4}$

3 ESTIMATION OF PEAK GROUND ACCELERATION

For an undamped single degree of freedom system, the following approximate relations among the response spectra can be derived (e.g. Hudson, 1979; Jennings, 1983)

$$SV_0 \simeq \omega_n SD_0 \quad (4)$$

$$SA_0 \simeq \omega_n^2 SD_0 \quad (5)$$

were ω_n is the undamped natural frequency in radian/s and SD_0, SV_0 and SA_0 are the relative displacement, the relative velocity and the absolute acceleration response spectra, respectively. On the basis of the relationship between the peak values of displacement, velocity and acceleration for a sinusoidal motion, pseudo-spectral values have been defined as follow (e.g. Idriss, 1983)

$$PSV \equiv \omega_n SD_0 \quad (6)$$

$$PSA = \omega_n PSV \quad (7)$$

being *PSV* and *PSA*, the pseudo-relative velocity and the pseudo-absolute acceleration, respectively. There is a relationship between the Fourier amplitude spectrum of acceleration, *FA*, and the undamped relative velocity response spectrum, SV_0, of a single degree of freedom system, of the form (e.g. Hudson, 1962, 1979; Jennings, 1983)

$$FA \leq SV_0 \quad (8)$$

Because the maximum response of the undamped oscillator often occurs near the end of the excitation, equality is often approached in Equation 8. In this case, combining Equations 4 to 8, we obtain

$$PSA \simeq \omega_n FA \quad (9)$$

These approximations tend to be valid for the natural frequencies of the most common structures. Therefore it is possible to estimate the peak ground acceleration by using the maximum values of the pseudo-absolute acceleration obtained from Fourier analyzed *Lg*-wave short period seismograms.

Moreover the pseudo-absolute acceleration can be represented regionally as a function of the earthquake magnitude, M, the epicentral distance, r, and the anelastic attenuation coefficient, γ, by an empirical model of the form:

$$PSA = C_0 \, e^{C_1 M} \, e^{-\gamma r} \, r^{-1/2} \quad (10)$$

where C_0 and C_1 are constants and γ should be the regional value which corresponds to a frequency representative of damaging ground acceleration (García-Fernández, 1989).

3.1 Regional values of peak ground acceleration in the Iberian Peninsula

The above approach has been applied to the three regions of the Iberian Peninsula defined in 2.1 (see Figure 1), obtaining the regional empirical relationships of the maximum pseudo-absolute acceleration as a function of the magnitude, M, the epicentral distance, r, and the coefficient of anelastic attenuation of the Lg waves, γ, for a characteristic frequency value of 5 Hz, given in Table 3.

The available measurements of vertical peak ground acceleration in the Iberian Peninsula are plotted in Figure 2 together with the regional *PSA* relationships of the corresponding regions (*NE* and *SSE*), for different values of magnitude.

Table 3. Empirical predictions of the regional value of the maximum vertical pseudo–absolute acceleration in the Iberian Peninsula.

$$\textit{IP region:}\quad \log_{10} PSA = -2.23 + 0.92\,M - 0.5\log_{10} r - 0.004(\log_{10} e)\,r$$
$$\textit{NE region:}\quad \log_{10} PSA = -2.06 + 0.90\,M - 0.5\log_{10} r - 0.011(\log_{10} e)\,r$$
$$\textit{SSE region:}\quad \log_{10} PSA = -2.30 + 0.96\,M - 0.5\log_{10} r - 0.018(\log_{10} e)\,r$$

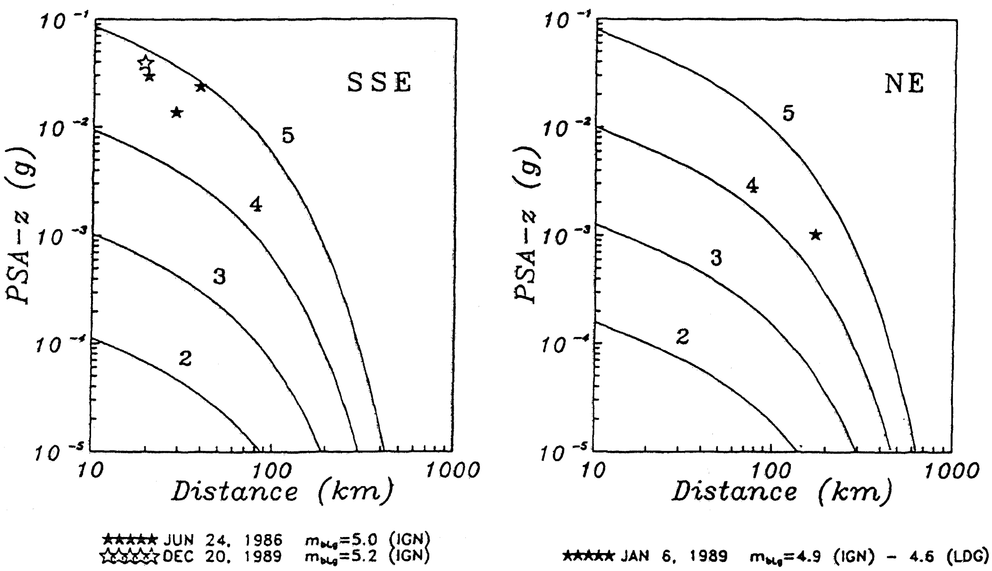

Figure 2: Comparison of maximum vertical *PSA* predicted values with available observations of peak ground acceleration. (IGN: Instituto Geográfico Nacional, Spain; LDG: Laboratoire de Detection et Geophysique, France).

The empirical predictions are in good agreement with the measured values in both regions. This result proves the usefulness of the proposed method to estimate regional values of peak ground acceleration from short-period seismograms, in areas with few or no available acceleration records.

4 CONCLUSIONS

- The use of analog seismograms in spectral analysis studies gives suitable results when no digital data are available, provided that great attention is paid to the digitization process and that all the involved limitations are taken into account.
- The Iberian Peninsula as a whole (*IP* region) has the lower regional value of the *Lg*–wave attenuation, due to the larger geographical extension of stable geotectonic units; the North–East part (*NE* region) has an intermediate value, while the higher one corresponds to the South South–East part (*SSE* region), which is the most seismotectonically active. The anelastic attenuation coefficient was found to be frequency dependent up to 5 Hz, the upper limit imposed by the use of analog records.
- A method to estimate regional values of peak ground acceleration, using the Fourier amplitude spectrum of acceleration of *Lg* wave short–period seismograms, has been proposed. The maximum pseudo–absolute acceleration values obtained can be represented regionally as a function of the earthquake magnitude, the epicentral distance and the regional anelastic attenuation coefficient. These regional empirical relationships provide a suitable upper limit estimation of the regional peak ground acceleration values.
- Since the available measurements of peak ground acceleration in the area are in good agreement with the empirical predictions, the proposed method proves to be very useful to estimate re-

gional values of peak ground acceleration in areas with few or no available acceleration records.

REFERENCES

Dwyer, J.J, R.B. Herrmann y O.W. Nuttli 1983. Spatial Attenuation of the *Lg* Wave in the Central United States, *Bull. Seism. Soc. Am.* 73, 781–796.

García-Fernández, M. 1989. *Spectral attenuation of Lg-waves and peak ground pseudo acceleration in the Iberian Peninsula*, Ph.D. diss., University of Barcelona (in Spanish).

Hudson, D.E. 1962. Some problems in the application of spectrum techniques to strong motion earthquake analysis, *Bull. Seism. Soc. Am.* 52, 417–430.

Hudson, D.E. 1979. *Reading and interpreting strong motion accelerograms.* Engineering Monographs on Earthquake Criteria, Structural Design and Strong Motion Records, Vol. 1, Earthquake Eng. Res. Inst., Berkeley.

Idriss, I.M. 1983. Evaluation of earthquake hazards, *in:* K. Cidlinsky, B.M. Rouhban (eds.), *Assessment and mitigation of earthquake risk in the Arab region*, 79–113. Paris: UNESCO.

Jennings, P.C. 1983. Engineering Seismology, *in:* H.Kanamori, E. Boschi (eds.), *Earthquakes: Observation, Theory and Interpretation*, 138–173. Amsterdam: North-Holland Publ. Comp.

Nuttli, O.W. 1973. Seismic Wave Attenuation and Magnitude Relations for Eastern North America, *J. Geophys. Res.* 78, 876–885.

Nuttli, O.W. 1978. A Time-Domain Study of the Attenuation of 10 Hz Waves in the New Madrid Seismic Zone, *Bull. Seism. Soc. Am.* 68, 343–355.