STATISTICAL CHARACTERIZATION OF THE RESPONSE SPECTRA IN THE ARGENTINE REPUBLIC

C A MONGUILNER[1], N PONTI[2], S B PAVONI[3] And D RICHARTE[4]

SUMMARY

An empirical model to obtain pseudo acceleration spectra for the western region of Argentina is herein presented. It is based on the parameters which are typical of an earthquake and have a non-excess probability associated to them from a database with more than 50 records of the quakes obtained from the region since the 23/11/77 earthquake in San Juan Province.
Most of these records corresponds to surface earthquakes with intermediate magnitudes and epicentral distances less than 80 km. In order to normalize the database to use them in the analysis, a weight was put on their spectra. It considers magnitude, epicentral distance and type of soil in the record location.

It was considered that the spectra amplitudes and shapes depend on the parameters describing the seismic source (magnitude and dimensions), nature of the wave propagation (epicentral distance, depth), the local ground conditions, record direction and the frequency content of the recorded movement,
The pseudo acceleration spectra for different non-excess probabilities obtained from this statistical analysis, were compared with those given by the earthquake-resistant regulations in force in this Country and with those obtained for the conditions representing the epicentral zones of Argentine historical earthquakes. It proved that the design spectra given in the codes underestimate the seismic effects in the short and intermediate period rank and overestimate in the high periods rank, without giving a uniform seismic protection to the different types of structures.

INTRODUCTION

The main purpose of this work is to provide relationships that can be used in the construction of the hazard-consistent design spectra in the west region of Argentine Republic. This goal is achieved by an empirical Pseudo Acceleration Spectra model in function of some characteristic earthquake parameters that have a probability of not - exceeding associate. So a database consisting of seismic movement records produced in the zone was used. Subsequently these spectra will be compared with the prescribed in the Seismic Codes in force in the country.
A common approach used in the Seismic Codes, one which is currently applied in Argentina to obtain the design spectra, is to perform a hazard analysis in terms of parameters such as the peak ground acceleration and then to anchor a standard spectral shape to the design value of zero-period acceleration. This procedure often results in spectra, which do no represent the same hazard level at all periods. A way to overcome this inconsistency is to carry out the seismic hazard analysis in terms of spectral ordinates at different periods, using frequency-dependent attenuation equations. This methodology was used in this paper.

DATA

The west region of the Argentine Republic is seismically the most active zone in the country. Networks of strong-motion accelerographs belonging to the National University of San Juan and other Governmental Institutions are operating since the decade of the 60`s in this zone.

[1] *Universidad Nacional de San Juan - Argentina*
[2] *Universidad Nacional de San Juan - Argentina*
[3] *Universidad Nacional de San Juan - Argentina*
[4] *Universidad Nacional de San Juan - Argentina*

These networks operate two types equipment: 1) SMAC (Japanese manufacture) with the following characteristics: controller mechanical type, own frequency of 10 HZ, record range between 10 to 1000 Gal and record system in waxing paper; 2) SMA-1 (American manufacture) whose characteristics are: servo type controller, approximate frequency of 18 HZ, maximum record range af 1000 Gal, record system in photographic paper and damping of the 60% of the critical one.

Since its installation in this zone more than 50 accelerograms were obtained, mainly from equipment located at basements or ground floors of relatively small buildings. A uniform digitalization and correction procedure was applied to all the records in order to reduce noise in the high and low frequency range before being used in the study and whose principal characteristics are given in Table 1.

The available database of uniformly processed earthquake records was classified in function of the following characteristics of earthquake ground motions: Magnitude (M), Epicentral Distance (DE), Focal Depth (H), Acceleration (AM), Velocity (VM) and Maximum Displacement of the ground (DM), Fundamental Periods of vibration (TP) and Duration for AM $\geq$ 5% of acceleration of the gravity (D). The first three parameters were obtained from published values by Catalogues and the other ones from the digitalized and adjusted versions of the accelerograms.

In the selection of the magnitude to be employed in this work, a hybrid plan in which M=MS if ML and MS are greater to 6 or otherwise M=ML was adopted.

To calculate the source size, the expression $\log S = MS+8.13-0.6667 \log (\sigma\Delta\sigma/\mu)$ was used. It is obtained by combining the expression of energy of the seismic waves considering the earthquake as an elastic rebound phenomenon and the given by Gutenberg and Richter, being S = area of fault; σ = average stress; $\Delta\sigma$ = stress drop and μ = rigidity of the medium.

According to the parameters selected in this classification, most of the database records corresponding to the seismic movements with intermediate magnitude between the range of 5.5 to 6.0 can be observed, being 7.4 the greater one. These were obtained from stations located at distances smaller than 100 Km from the epicenter and with a Focal Depth less than 40 Km (Figure 1).

Most of these records has peak ground accelerations smaller than 20% of the gravity acceleration (g), though some of them has values higher than 40% of g. When these not so high ground acceleration values are integrated, very high values of peak velocity and peak ground displacement are obtained as a result of their frequency content and duration. (Fig. N° 2).

The natural period of the ground, which has a great influence on the vibrations produced in the structures during an earthquake, was estimated by the Spectra of Fourier of the shaking ground record. It must be considered the fact that the predominant period in this kind of study depends on the scale of the earthquake and the focal distance to the record site. In the case of relatively great earthquakes, the predominant period of the vibration is approximately equal to the ground natural period, while for relatively small earthquake, secondary or higher order vibrations predominate.

This type of analysis showed that the predominant periods of the ground obtained from the places of the registering stations vary from 0.2 to 0.4 sec (Figure 3). As there were not geotechnical data available in these stations, the ground surface layer was considered uniform and the equivalent shear wave velocity was obtained. Such velocity was used to classify the type of soil according to the guidelines of the Seismic Code currently in force in the country. Most of them correspond to the features of Type ll Soil (shear velocity from 100 to 400 m / sec and allowable stresses between 0.1 to 0.3 MN/ m^2).

The duration of the records for levels of acceleration of ground greater to 5% g (limit of engineering significance), is less than 10 sec, though some have values as large as of 50 sec. (Fig N° 3).

INTERDEPENDENCE OF THE PARAMETERS

Most of the basic parameters of the movement of the ground produced by earthquakes show a statistics interdependence between them, which can be measured by a correlation coefficient. This coefficient can take values between - 1.0 and +1.0, each one representing a perfect negative or positive correlation. Zero represented a total lack of correlation.

One of the most widely used types of correlation coefficients is the "r" due to Bravais and Pearson, also called product – moment correlation, which does not depend on the specific measurement units used. The coefficient "r" assumes that the two variables are measured on least interval scales and determines to which values of the two variables are “proportional to each other”. Proportionality means linear relationship, that is, the correlation is high if a straight line can express it. This line is called the regression or least squares line, because it is determined on such a way that the sum of the squares of the distances of all the data points to the regression rectum will be a minimum. The coefficient r^2, called coefficient of determination, represents the proportion of the common variation in the two variables.

Figure N° 4 shows a matrix of two-way scatter- plots relating AM, VM, DM vs DH and M. In this figure a certain relationship between M and DH (r=0.35) is observed, although it is small can introduce mistakes when they are used as independent explanatory variables in a multiple regression. To reduce these mistakes, some of the following two solutions can be adopted:

1. Homogenise the database to give a weight to each record so that the impact of the intervening parameters is the same.

2. Regression in two stages (Joyner and Boore), that leads to disconnect the dependency of the independent variables.

In this work the first method was adopted, using the following expressions to calculate of the weight each record is affected.

Let

- ncat: number of the total adopted intervals, so that for the interval n_i it is fulfilled for the Magnitude M and DH

$$M \in [\, M(n_i) \,;\, M(n_i)+\Delta M(n_i)] \quad ; \quad \log DH \in [\, \log DH(n_i) \,;\, \log DH(n_i)+ \Delta \log DH(n_i)]$$

- $ne(n_i\ i_S)$: number of record located in the interval n_i and that were registered in a site with soil type i_S.

- ns: total number of records for the sites with soil type i_S

then

$$\omega_M= n_s(i_s)\ \Delta M(n_i)\ n_e(n_i,i_s)\ \Delta M_T / n_{cat} \quad ; \quad \omega_{DH}= n_s(i_s)\ )\log DH(n_i)\ n_e(n_i,i_s)\ \Delta \log DH_T / n_{cat}$$

being

$$\Delta M_T= \sum \Delta M(n_i)/n_{cat} \quad ; \quad \Delta \log DH_T= \sum \Delta \log DH(n_i)/n_{cat}$$

As total weight for each record the mean arithmetic of the two previous weights is adopted

$$\omega_i = (\omega_M+\omega_{DH})/2.$$

Two types of different soil, three categories for the magnitude and four for the epicentral distance were considered in this calculation.

FREQUENCY DEPENDANT ATTENUATION OF THE SPECTRAL AMPLITUDE

The ground movement produced by an earthquake consists of waves, which in an elastic medium attenuate like $1/R^4$, $1/R^2$, $1/R$, $1/R^{1/2}$. Considering that the range in which these attenuation rates dominate depends, in addition to other conditions on its inelastic attenuation properties, the representative frequencies content changes with the distance.

According to the aforesaid, the shape of the attenuation curves with the distance should change with the seismic origin and be dependent of the frequencies content. Generally in this type of analysis, the experimental relationship proposed by Richter(1958) to obtain the local magnitude M_L, as the amplitude attenuation function versus distance to estimate the size and the shape of the spectrum is adopted. This Richter's relationship that was found with data registered in Southern California, which conditions its application to other parts of the world, has the disadvantages and limitations that its shape does not depend neither on the magnitude, dimensions of the seismic origin, focal depth, of the geological environment on the registering station, nor on the actual amplitudes of recorded motions.

To determinate this function from the earthquake records occurred in the western region of Argentina the following empirical model was used. It considers the geometric and inelastic attenuation with the distance, the effects of the magnitude, direction of the registered component and the type of soil in the record site, for which a very general classification is adopted in accordance with the Seismic Code in force in the country.

$$A(DE,H,S,T)= A_0(T)\ \log \Delta(DE,H,M)$$

being: A = attenuation function with the distance proposed, $A_0(T)$ = dependent Function of the Period, empirically determined, $\Delta=(DE^2+H^2+S^2)^{1/2}$,T= Period and S = size of the fault.

An iterative procedure to calculate the function proposed was used, employing adjustments by regression analyses in 200 discrete values of periods ranging from 0.1 to 6 of the Fourier spectrum amplitude of the database. These spectra are the ones that best describe the relative contribution of each frequency to the total movement. Figure N° 5 shows the variation of the function properly dependent of the frequency in which the more fast attenuation of the components of the short periods of the waves to greater distance of the area is observed.

EMPIRICAL MODELS FOR SCALING ACCELERATION SPECTRA

The laws of spectral attenuation in function of the characteristic parameters of the seismic movements can, as a rule, be characterized by expressions of the type:

$$\log AE(T)= A(R,H,M,T)- \log AE_0(T,M,s,v,e_p)$$

being: AE(T)= amplitudes spectral to determine; $AE_0(T,M,s,v,e_p)$ = represents a correction function which incorporates the effects of the magnitude, distribution of the observations with respect to the assumed empirical model, as represented by the confidence level "p", geological site conditions, direction of the ground records and e_P = residuals assuming that can be described by a normal distribution function

In this paper the attenuation equation of the spectral amplitude used is as follows:

$$\log S_A(T)=A(\Delta,T)+M+b_1(T)+b_2(T)\ M+b_3(T)\ s+b_4(T)\ v+b_5(T)\ M^2+e_p \quad \text{(i)}$$

Being $A(\Delta,T)$ the attenuation function with the distance dependant of the frequency previously found. The values bi for regression analysis are obtained using the method of the least squares in 200 discrete values of periods in the same range that the previously used.

Figure N° 6 shows bi in function of the period (T). The relative contribution of each term to the least squares of the spectral amplitude $\log S_A$ (T) in each T period can be observed.

The previous equation can be applied only in the Mmin≤ M ≤Mmax range because $\log S_A(T)$ represents a parabola in function of M, for fixed values of T, Δ, v , s, being Mmax= -(1+b2(T))/2 b5(T) and Mmin= -b2(T)/2 b5(T).

For M ≤Mmin in the previous equation M is used in the second terms and Mmin in the other ones. For Mmax ≤ M, Mmax is used in all the terms of (i). It gives as a result a linear variation in (i) for M ≤Mmín, parabolic for Mmin≤ M ≤Mmax and constant for Mmax≤ M.

Figure N° 7 shows the limit values in function of the period. The magnitudes of the available records seismic in the database are within the range defined by these two extreme values for practically all periods. The maximum amplitudes in the range of the high frequencies are reached for average magnitudes of approximately 8.

The residues ε(T)=log S(T) - log S'(T) describe the distribution of the observed amplitudes in relation to the estimates. Assuming that the residue can be described by a normal distribution function with mean μ(t) and standard deviation σ(t).

$$p(\varepsilon,T)= \int \exp [-(x-\mu(T)/ \sigma(T)]^2 /\sigma (T) \sqrt{2\pi} \quad \text{(ii)}$$

It represents the probability that Sa(T)-log Sa'(T)≤ε(T). For a given value of the residue ε(T) in a particular period, the actual probability (p*(ε,T)) that ε(T) will not be exceeded, can be evaluated by finding the fraction of residues which are smaller than the given value. To fit (ii) the real probability values in the discrete values of considerate periods, the mean and the standard deviation of the assumed normal distribution function can be evaluated. Substituting these values in (ii) ε(T) can be calculated for different probability levels. Figure Nº 8 shows these residues for five probability levels.

To test the quality of fitting the real probabilities to a normal distribution function the following two statistic, χ^2 and KS, were used, previously verifying that the sum of all the residues in each period is null.

Figures N° 9 and 10 show the calculated: χ^2 and KS versus T and also the acceptance criteria for their 95% cut-off levels. According to these results, it can be considered that the adopted theoretical probability distribution represents a good approximation of the real at a level of 5 % of acceptance.

The empirically estimated Pseudo Acceleration Spectra (PSA) with probabilities from 50% to the 90% of non exceedence are compared in the figure Nº11 for an earthquake of magnitude 7.4 and hypocentral distance of 83 Km. These values that correspond to the city of San Juan during the Caucete earthquake (23/11/ 77), with the average PSA of the four horizontal records obtained during this earthquake in this city. The very good concordance between the shape and amplitudes for all the periods between the spectrum estimated with probability of the 50% and the calculated average is observed in the figure.

Figure N° 12 shows a comparison between the estimated spectra and the design spectra given by the codes actually in force in the Provinces of San Juan and Mendoza, the most important provinces of western Argentina, for this earthquake but with a hipocentral distance corresponding to the Caucete city.

This figure shows that for intensities such as those occurred during the November 23, 1977 Caucete earthquake, similar to the ones observed in San Juan city during the January 1944 earthquake, both codes in force in Argentina (INPRES-CIRSOC and Mendoza) underestimate the excitation in the periods within the range of 0.25sec and 0.75 sec., and overestimate it in the periods higher than 0.75 sec.

This same effect is observed in form more clearly when is considered for the estimate PSA the values of magnitude and hypocentral distance corresponding to the earthquake of the 20 of March of 1861 that destroy the city of Mendoza.

RESULT AND CONCLUSIONS

The above analysis shows that it is now possible to extract directly from the database, same general trends of the spectral amplitude attenuation in function of the Magnitude, frequency contents, Epicentral Distance and soil condition.

In the adopted model it was assumed that the attenuation function should depend on the epicentral Distance, Focal Depth and on size of the fault. Since the “fault size” was not available for the seism of the database a theoretical formula was introduced.

The magnitudes employed in this work correspond to the published M_L or M_S.

Among all the variables term of the attenuation function the most important one that has an effect on spectral amplitude is the magnitude. Its greater influence is in the range of intermediate periods, which correspond to the tallest building of the zone.

It proves that the design spectra given in the codes in force in the country underestimate the seismic effects in the short and intermediate period rank and overestimates them for long periods, without giving a uniform seismic protection to the different types of structures. So, it is necessary to adjust the design spectrum considering the different seismic characteristic parameters for the region.

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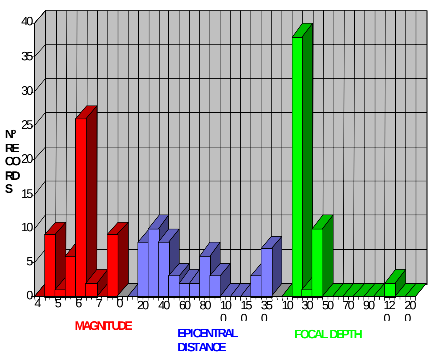

Figure: 1

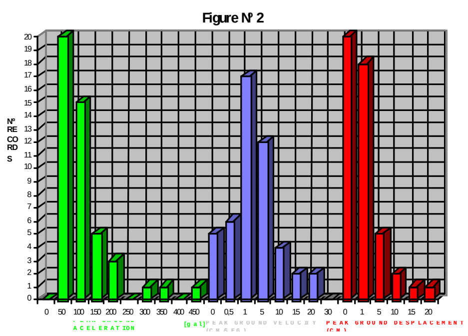

Figure: 2

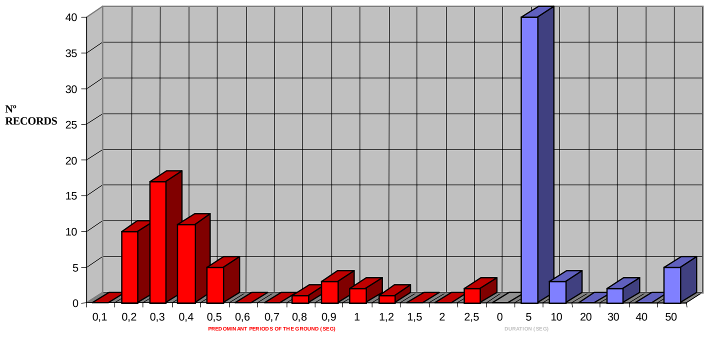

Figure: 3

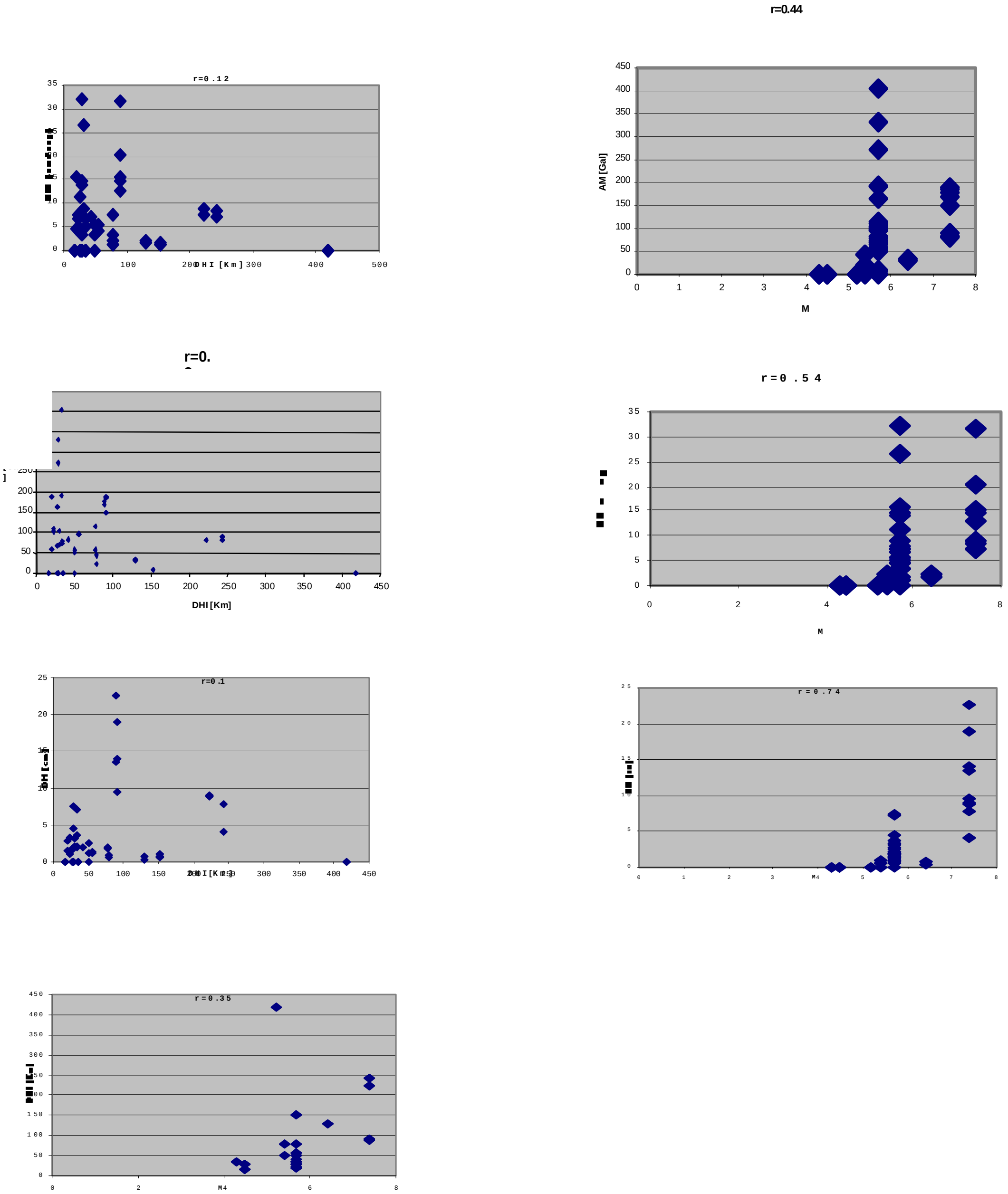

Figure Nº 4   Matrix of two-way scateter

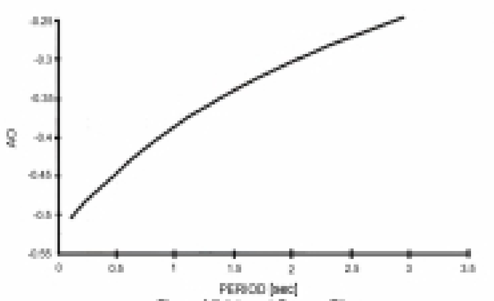

Figura N° 5 Least Square Fit

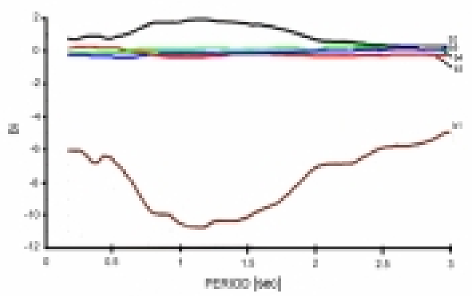

Fig. N° 6 Regression coeficents

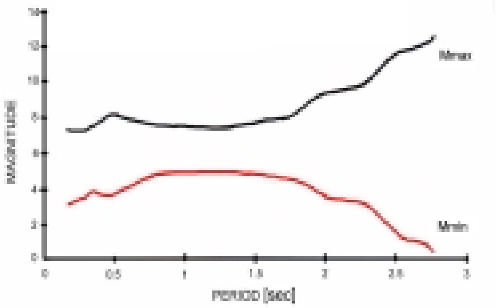

Fig. N° 7 Range of the magnitude of the Regression

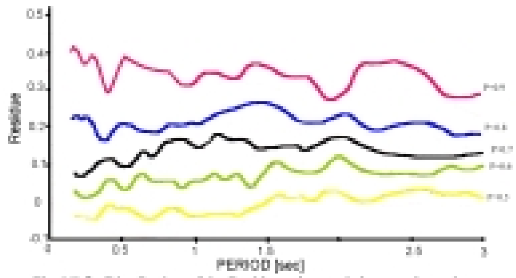

Fig. N° 8 Distribution of the Residues observed about to the estimates

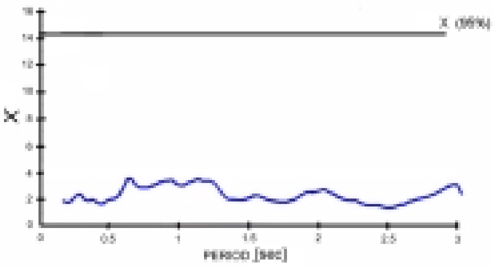

Fig. N° 9 Statistical Parameter of the residuals

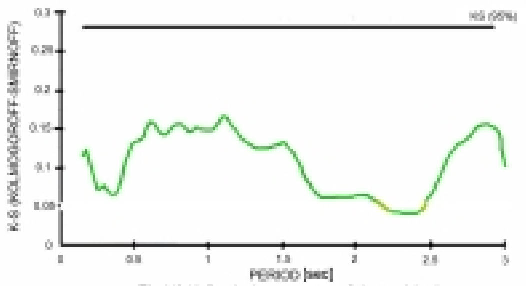

Fig N° 10 Statical parameter of the residuals

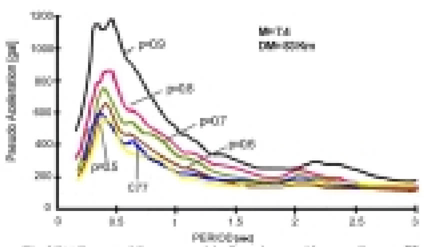
Fig. N° 11 Compared Spectra empirically estimate with mean Caucete 77

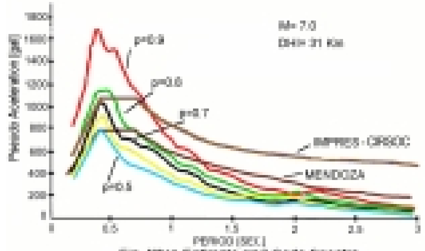

Fig. N° 12 Estimate and Code Spectra

TABLE Nº 1

TE	Madop	EPI(Km)	H(Km)
19/10/1976	5,2	350	230
19/10/1976	5,2	350	230
19/10/1976	5,2	350	230
23/11/1977	7,4	80	40
23/11/1977	7,4	80	40
23/11/1977	7,4	81,7	40
23/11/1977	7,4	81,7	40
23/11/1977	7,4	81,7	40
23/11/1977	7,4	240	40
23/11/1977	7,4	240	40
23/11/1977	7,4	219	40
23/11/1977	7,4	219	40
09/12/1977	4.6	219	24,01
30/08/1979	5,4	38,5	32
10/11/1980	5,4	78,3	13
10/11/1980	5,4	78,3	13
28/12/1983	5.5	60	12
26/01/1985	5,7	76,7	12
26/01/1985	5,7	76,7	12
26/01/1985	5,7	40,4	12
26/01/1985	5,7	32,1	12
26/01/1985	5,7	32,1	12
26/01/1985	5,7	54,6	12
26/01/1985	5,7	54,6	12
26/01/1985	5,7	30,8	12
26/01/1985	5,7	30,8	12
26/01/1985	5,7	16	12
26/01/1985	5,7	16	12
26/01/1985	5,7	48,7	12
26/01/1985	5,7	48,7	12
26/01/1985	5,7	25,5	12
26/01/1985	5,7	25,5	12
26/01/1985	5,7	27,2	12
26/01/1985	5,7	27,2	12
26/01/1985	5,7	24,4	12
26/01/1985	5,7	24,4	12
26/01/1985	5,7	24,4	12
26/01/1985	5,7	19,4	12
26/01/1985	5,7	19,4	12
26/01/1985	5,7	19,4	12
26/01/1985	5,7	152	12
26/01/1985	5,7	152	12
26/01/1985	5,7	152	12
26/01/1985	4,3	32,7	12
26/01/1985	4,3	32,7	12
26/01/1985	4,3	32,7	12
26/01/1985	4,5	25,4	12
26/01/1985	4,5	25,4	12
26/01/1985	4,5	25,4	12
26/01/1985	4,5	11	12
26/01/1985	4,5	11	12
26/01/1985	4,5	11	12
08/06/1993	6,4	64,3	113
08/06/1993	6,4	64,3	113