RELATIONSHIPS BETWEEN BASIC GROUND MOTION PARAMETERS FOR EARTHQUAKES OF THE ARGENTINE WESTERN REGION

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

SUMMARY

The central western region of the Argentine Republic is the more active seismic zone in this Country. From the strong motion accelerograph network installation in this area in the decade of the 60`s, a set of data was obtained. It is mostly about the movements produced by surface earthquakes with intermediate magnitude and epicentral distances smaller than 100 Km. It let to develop statistic studies and to obtain empirical relationships among basic ground motion parameters, which are very used in various types of studies as in geotechnics, seismic risk, dynamics of structures etc.

The interrelated parameters were: peak acceleration (AM), peak velocity (VM) and peak ground displacement (VM), effective peak acceleration (EMA) and effective peak velocity (VME), epicentral distance (DE), focal depth and fault dimension.

The obtained relationships cover an empty space in the seismic risk studies accomplished in the country, since they are obtained from registered seismic movement in a zone with its characteristics, and demonstrate, again, the problems and limitations in using empirical relationships obtained in other parts of the world.

SCOPE OF STUDY

The systematic classification of the instrumental and spectral parameters of such large number of earthquake records obtained in the centre west region of the Argentine Republic, gives the opportunity to explore the possible correlation which might exist among various design ground motion parameters. The validity of the interdependence of such parameters in geotechnics, seismic risk and structural dynamics is examined by this classification.

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.

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 of 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.

[1] *Universidad Nacional de San Juan - Argentina Email: cmonguilner@iinfo.unsj.edu.ar*
[2] *Universidad Nacional de San Juan - Argentina*
[3] *Universidad Nacional de San Juan - Argentina*

The parameters usually used to characterise the severity and the damage potential of an earthquake, which were used to classify the database, can be grouped in the following categories:

1. Values published by Catalogues such as the different magnitudes obtained.

2. Instrumental values obtained either directly or with some simple calculations from the digitalized and corrected version of the accelerograms, such as the peak ground acceleration (AM), peak ground velocity (VM) and peak ground displacement (DM), the duration of the input ground motion taken between the extreme values of AM> 5% of g.

3. Spectral values obtained from the decomposition of the movements in its harmonic or in the parametric integration of the equation of motion of elastic and inelastic single-degree-of-freedom systems, such as the effective peak acceleration (AME) and the effective peak velocity (VME) such which defines it ATC 3-06 and the predominant period of the ground (Tp).

4. Spectral values obtained considering the energy balance equations for elastic and inelastic systems, such as input energies spectra and hysteretic energy spectra.

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 epicentre 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 velocity and peak ground displacement are obtained as a result of their frequency content and duration. (Fig. N° 2).

The peak ground acceleration is the most widely used attribute of earthquake ground motion in engineering design applications, due to its direct relationship with the inertial forces that are induced within a structure (2° law of Newton). In spite of its great use, it corresponds to the high frequencies which are out of range of the natural frequencies of most of the structures of our interest and therefore, large values of AM alone can seldom initiate resonance in the elastic range, or be responsible for large-scale damages in inelastic range. Many attempts have been made to formulate a refined interpretation of peak ground acceleration, which would be more sensible from an engineering point of view. In the development of the seismic design code ATC 3-06, two new parameters to characterize the intensity of design ground shakings were introduced. These parameters are called the Effective Peak Acceleration (AME) and Effective Peak Velocity (VME).

These parameters which do not present a definition specify in physical terms, that are proportional to the spectral ordinates of periods in the range of 0.1 to 0.5 seconds (AME), while the VME is proportional to the spectral ordinates at a period of about 1 sec. The AME and VME are not necessarily equal to the peak acceleration and velocity, being able to be greater or smaller than they are. While it is admitted that these definitions are somewhat arbitrary, they show the great importance of the frequency content, velocity and strong ground motion duration, as important factors to be used in the classification of design ground motion.

The AME for the records of the database shows a distribution more uniform that the AM in the intermediate and high acceleration ranges, having the majority smaller values than the 20% g (Figure N°3). Figure N°4 shows the distribution of the VME. It can be appreciated that, when it is compared with the VM, the number of records for low speeds, without showing large variations for high and intermediate values is increased.

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 5). 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° 5).

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° 9 shows a matrix of two-way scatter- plots relating AM, VM, DM, AME and VME vs DH and M, and the Table N°2 a matrix of the its corresponding correlation coefficients. In both figures 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.

On establishing empirical relationships of peak ground acceleration, peak ground velocity and peak ground displacement with the magnitude and focal distance of an earthquake, the following must be satisfied: the attenuation by internal damping in the rock must be equal to the multiplication of the wave component that has a frequency ω by the factor $e^{-\beta\omega DE}$, where β does not depend on ω, therefore the movement of the ground and the distance tend to a harmonic oscillation of growing period, with values of the relationship $AM\times DM/VM^2=1$. On the other hand, when DE tends to zero, the movement of the ground differs from the harmonic movement, being approaching a white noise, which the previous relationship tends to infinite. Typical values recommended for this relationship, those which are used in Dynamics of structure for the construction of Elastic Design spectra in hard ground, are from 5 to 15, together with the value of VM/AM»120 cm/sec /g.

Figure N° 6 show plots of these relationships for earthquakes occurred in the region. It can be observed that the relationship $AM\times DM/VM^2$ for the earthquake of the region falls within the values band usually used for earthquakes of large and mean epicentral distance, though are very different from small and intermediate distances of the deduced theoretical relationship. For the VM/AM ratios to epicentral distance, data shows no significant relationship, the normally adopted values are no confirmed (Figure N° 7). For a harmonic movement, the relationship VM/AM is equal to $T_p / 2.\pi$, being T_p the predominant period of the ground. Figure N° 8 compares the values from periods obtained for this relationship, considering that the movement is harmonic with

the values obtained by spectral analysis. These values are similar for large epicentral distances (greater to 200 Km) which confirm the filtered of the waves of low periods with the distance to the place of record.
The relationships AME = 0.65 ÷0.85 AM and AME/AM ratios to epicentral distance are widely used in geothecnics. This practice usually suggests ratios of 0.65 ÷ 0.85 for near-fault events and ratio of 1 for distant sites. These relationships are not fulfilled for the studied database that contains occurred earthquake records solely in the Cuyo zone of the Argentina Republic, since a relationship in acceleration units from the gravity (g) of AME» 0.96AM and between VME and VM of approximately 2 it is obtained (figures N°10 and 11). The AME/AM ratios do not show trend for the earthquakes included in this database (figure N° 12)
A common approach used in the Seismic Codes, the one which is applied currently in the Argentina to obtain design spectra, it 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.
For the application of this type of methodology it is necessary to know the attenuation of AM with the M and DE. To this purpose a linearly scaled model in magnitude is adopted. It includes terms, which take into account the inelastic and geometric attenuation with the distance according to the following equation:

$$\log a_i = C_0 + C_1 M + C_2\,\Delta + C_3\,\log \Delta \qquad (1)$$

The ground movement produced by an earthquake consists of waves, which in an elastic medium are attenuated inversely proportional to a power of the distance. The distance range where these attenuation rates dominate depends on the source mechanism, source size and depth, complexity of the surround geological medium and its inelastic attenuation properties. At a distance less than about 100 Km, the size and the shape of the fault surface influence the shape of the whole attenuation law of wave amplitudes.
For sites very close to the causative fault, the strong motion amplitudes will primarily depend on the stress released during faulting and the resulting permanent displacement in short and large periods motions respectively. While the entire source size will not be significant when it exceeds certain characteristic source dimension, tending therefore to reduce the attenuation of the waves for large fault. At comparable distances the small dislocation surfaces will progressively look more like point source and thus will lead to more rapid attenuation of wave amplitudes with distance. Thus the shape of the strong motion attenuation curves will change with source dimensions.
Assuming that the attenuation function depends, in addition to other conditions, on the epicentral distance, focal depth and source size, the following expression for the distance used in the formula (1) is adopted.

$$\Delta = f(DE, H, M) = (DE^2 + H^2 + S^2)^{1/2}$$

being

Δ = Source distance adopted
DE= Epicentral Distance
H = focal depth
S =f(M)= Fault length
M = Magnitude
Although the conditions under which site geology may amplify or de-amplify the peak ground motion have not been conclusively established, it is clear that the local site conditions play an important role in influencing both the shape and amplitude of the typical earthquake values as are the attenuation curves of the peak ground motion. Obtaining the residues for each value peak acceleration of the ground from the equation:

$$\varepsilon = \log a_{mi} - (C_0 + C_1 M + C_2\,\Delta + C_3\,\log \Delta)$$

Then a regression is performed on the following equation

$$\varepsilon = C_4 S_r + C_5 S_{al}$$

where S_r takes the value 1 if the site is classified as stiff soil (II_A) and 0 otherwise. S_{al} is similarly defined for intermediate stiff soil (II_B). Taking into account that most of the records are obtained on-site II_B, the equation (1) was modified as follows:

$$\log a_m = C_0' + C_1 M + C_2\,\Delta + C_3\,\log \Delta + C_4'\,S_r$$

being:

$$C_0'=C_0+C_5 \quad ; \quad C_4'=C_4+C_5$$

For the database of seismic motion records obtained in the region, the following expression resulted:

$$\log a_m= -1.23+0.068\ M-0.001\Delta-0.043\ \log\Delta-0.04\ S_{al}$$

The figure N° 13 shows this function versus hypocentral distance for different magnitude and soil type II_B.
This equation of the attenuation of the peak horizontal ground accelerations for M=7.4 (Caucete’s Earthquake) and M=5.7(Mendoza’s Earthquake) were compared with the obtained for data from the same studied region, proposed by Bufaliza and with the formulated by Watabe and Okamoto, obtained from the earthquake data occurred in Japan (Figure N° 14, 15). As can be observed, the law proposed agree quite well with the available data, the same does no occurring with the expression found by Bufaliza. The variation of the peak ground acceleration found shows an attenuation with the distance smaller than the proposed in other parts of the world for distances greater than 100 KM. This can be because the records were obtained in less rigid soils, which attenuate in a lower level the peak ground acceleration in large epicentral distances, or due to the few amount of data for this distances. The high acceleration values that are observed in some sites can be due to the waves direction.

RESULTS AND CONCLUSIONS

The preceding work presents the results of a study to determine the correlation that exist among various design ground motion parameters which are usually used in different types of studies in Earthquake Engineering obtained from seisms occurred in the zone. The following conclusions can be outlined:
1- Empirical relationships normally used in geotechnical, for example in seismic verification methods of earth structures as dams or in the dynamical test, between the AM, EMA and DE do not verify the data obtained in the region.
2- Empirical and theoretical relationship proposal made by several authors between the peak ground accelerations, which are frequently used in Dynamics of the Structures for the construction of elastic design spectra, are not verified for this database.
3- Average values of the predominant periods of the soil differ thoroughly from the recommended in different bibliographies, those, which have been used in the structure design of this zone.
4- The proportionality constants recommended by ATC 3-06, when VME and EMA are considered as normalization factors in the construction of the elastic design spectra are different to that found in this work.
5- The variation of the peak ground acceleration shows attenuation with the distance which is less than the proposals in other parts of the world to DE ≥100 KM. This can be due to the fact that the records were obtained in less rigid soils, which attenuate in smaller degree, or due to the scarce data.
6- Except some cases, a great influence of the waves in the earthquakes that compose the used database is not observed.
Though the results obtained should be considered strictly applicable to the conditions shown in this paper, they cover a great emptiness in the risk seismic risk studies for both the application in studies a particular structure and in the seismic codes updating. It demonstrates again, the limitations and problems that could be found when empirical relationships obtained in other part of the world are used.

REFERENCES

1. Monguilner C. (1977),”Análisis y cuantifificación estadística de espectros de respuesta sísmica en la región Cuyo deArgentina”, Universidad Nacional de San Juan
.2. Monguilner C (1978),” Aplicación de Espectros de respuestas en función de parámetros característicos del terremoto al análisis no lineal de edificios reales de la ciudad de San Juan”, Universidad Nacional de San Juan.
3. Ceresis (1982),”Catálogos de terremotos para América del Sur. Volumen 2”
4. Trifunac M, Lee V,”Dependence of Fourier amplitude spectra of strong motion acceleration on the depth of sedimentary deposits”, University of Southern California.

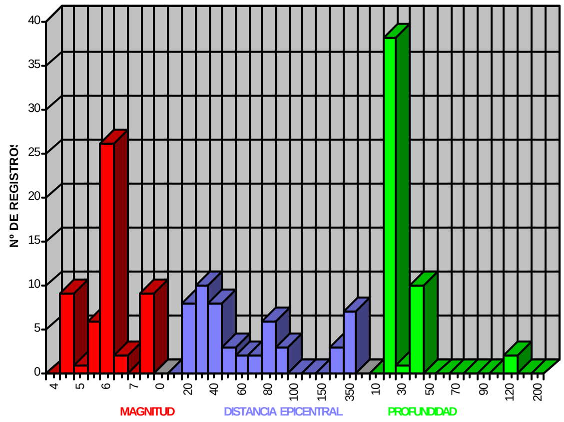


Figure Nº 1

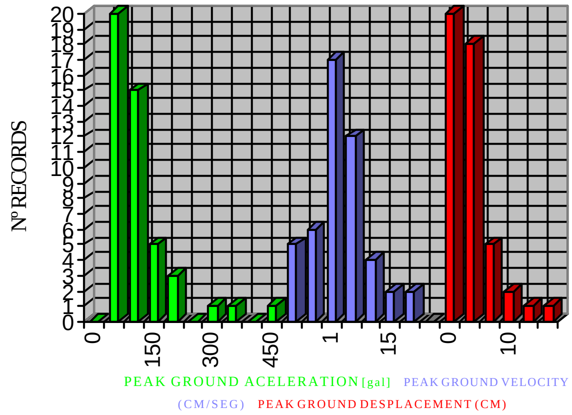


Figure Nº 2

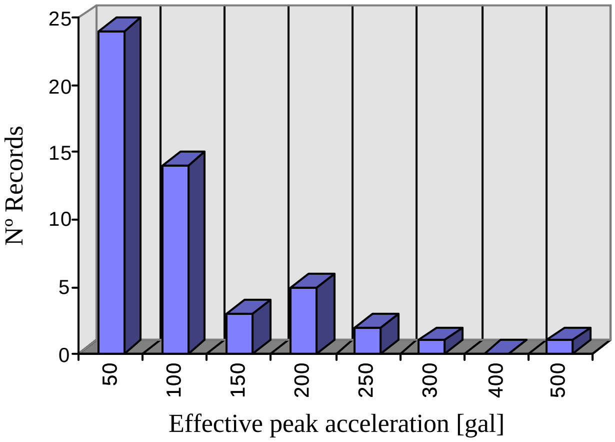


Figure Nº 3

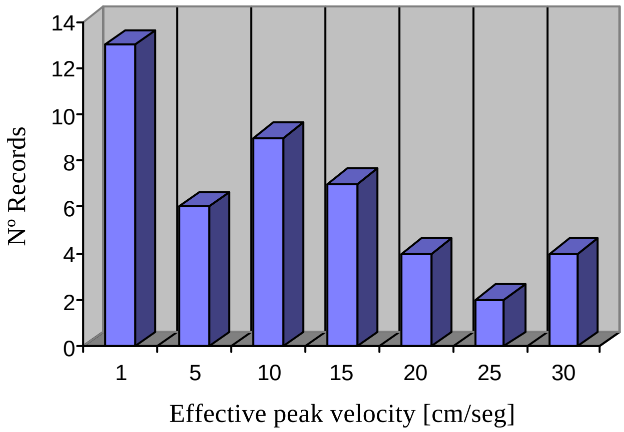
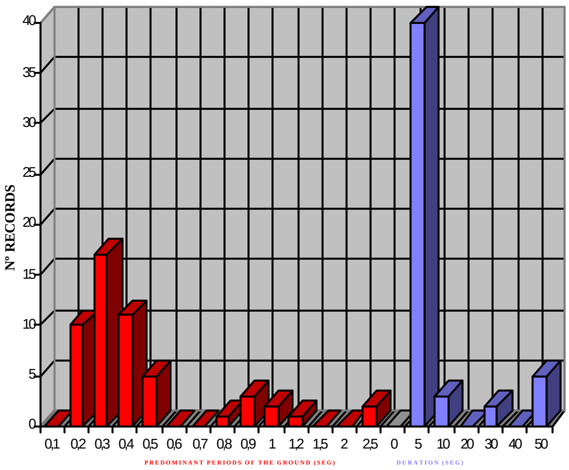


Figure Nº 4



Figere Nº 5

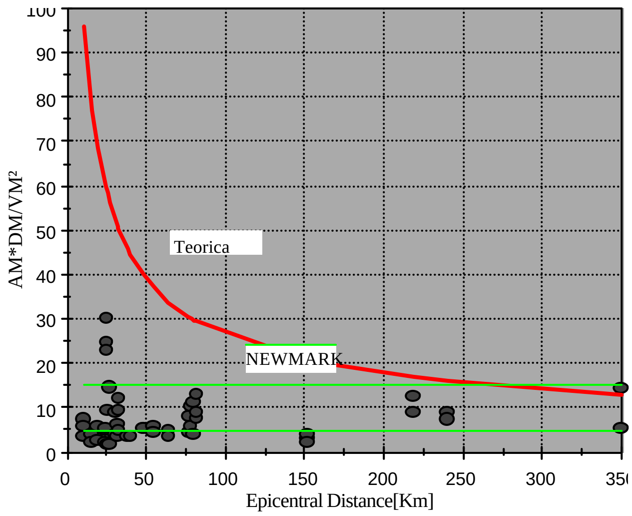


Figure Nº 6

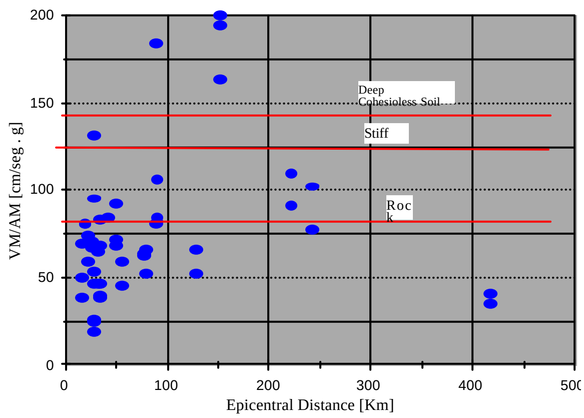


Figure Nº7

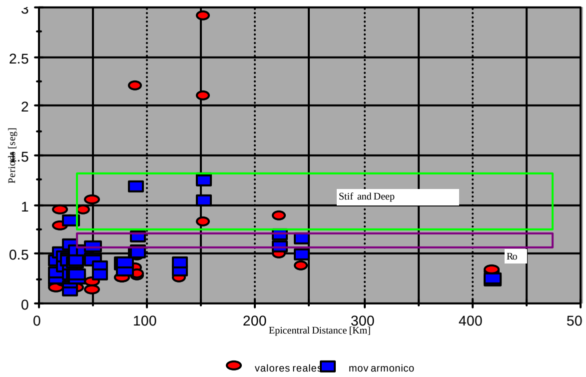


Figure Nº 8

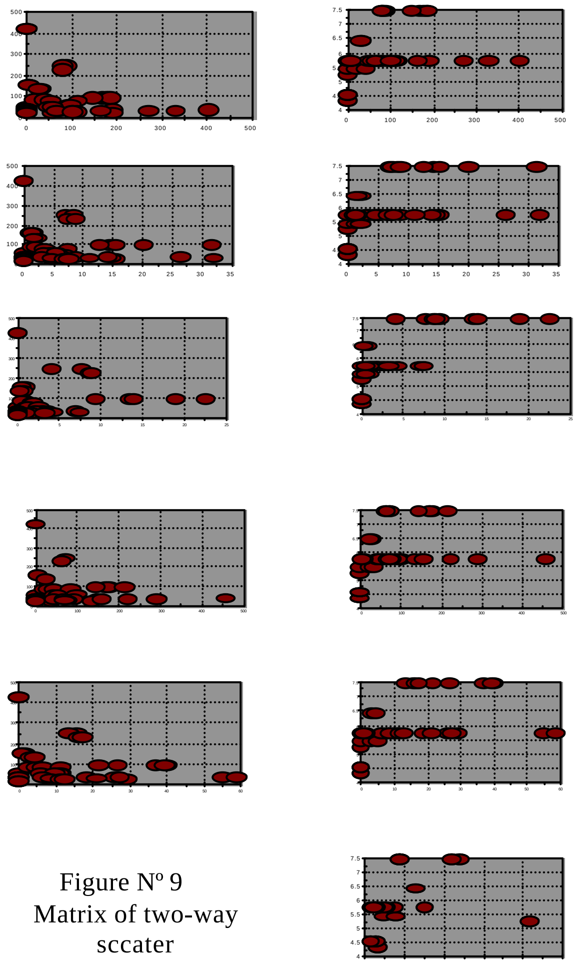


Figure Nº 9
Matrix of two-way sccater

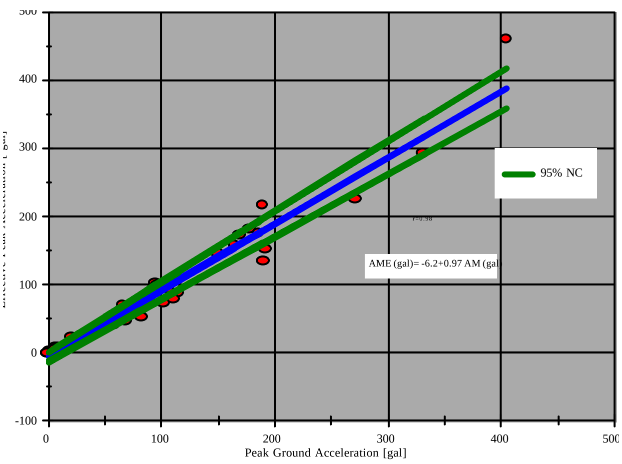


Figure Nº 10

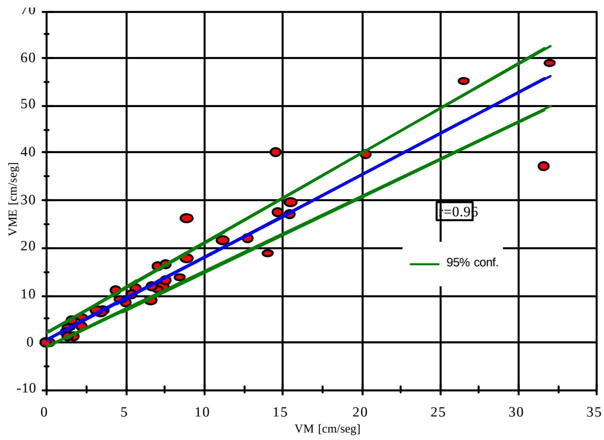


Figure Nº 11

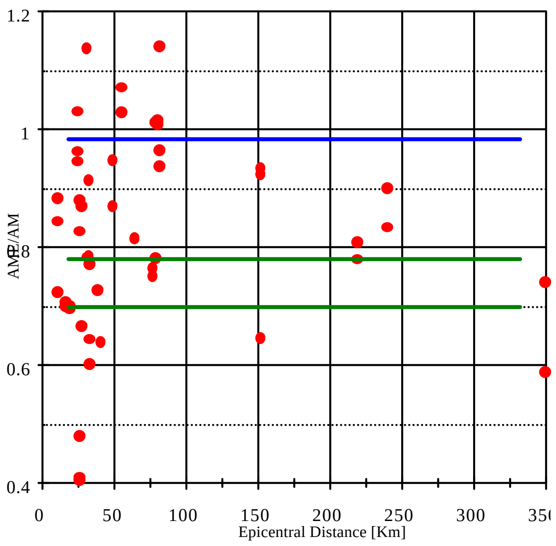


Figure Nº 12

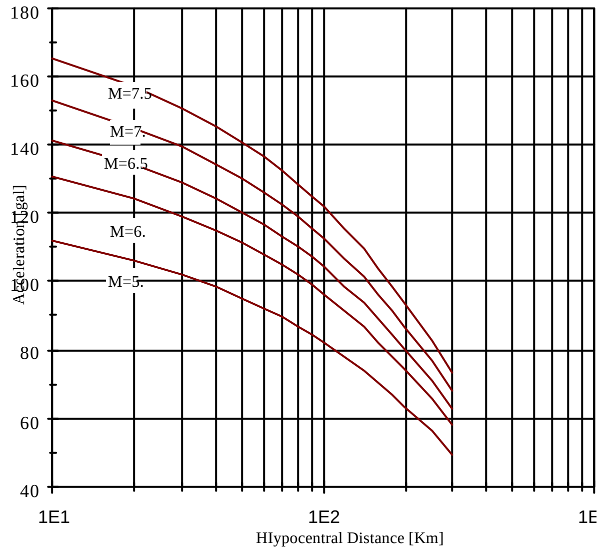


Figure Nº 13

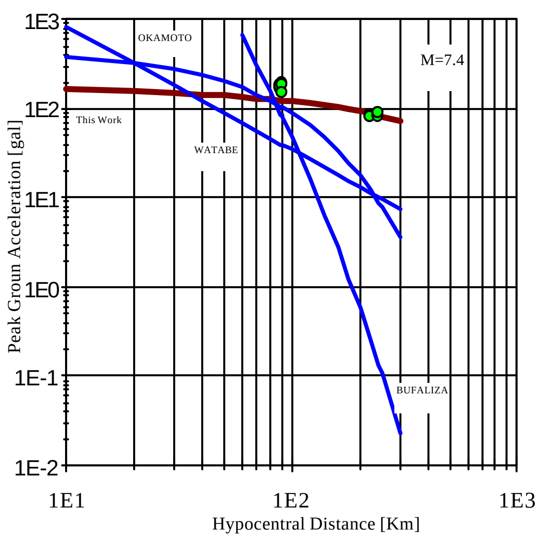


Figure Nº 14

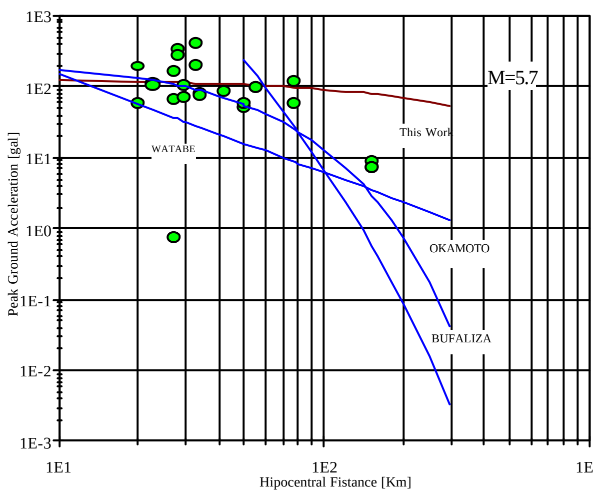


Figure Nº 15