SEISMIC HAZARD ASSESSMENT FOR CUBA AND THE SURROUNDING AREA

Julio A. García Pelaez *(1), Jose Leonardo Alvarez Gomez (1), Dario Slejko (2), Laura Peruzza (3), Alexandro Rebez (2)*

(1) *Centro Nacional de Investigaciones Sismológicas. Filial Occidental. Calle 212 No. 2906, e/ 29 y 31.La Coronela, Cuba.* julio@geoastro.inf.cu
(2) *Osservatorio Geofisico Sperimentale, Trieste, Italy. Borgo Grotta Gigante, Trieste. risk@.risk735.ogs.trieste.it*
(3) *GNDT c/o Osservatorio Geofisico Sperimentale, trieste, Italy. Borgo Grotta Gigante, Trieste. risk@.risk735.ogs.trieste.it*

ABSTRAT

Seimic hazard assessment for the Cuba and the surrounding areas has been performed in view of a possible future revision of the national building code. The hazard assessment has been done according to a standard robust methodology both in terms of maximun expected peak ground acceleration and macroseismic intensity.
Problems of earthquake catalogue treatment, attenuation of peak ground acceleration and macroseismic intensity, and seismic source definition have been faced and deeply analyzed. The final results are reported in two maps: that of the expected peak ground acceleration with 475-year return period and that of macroseismic intensity with 475-year return period.

INTRODUCTION

The 1990's decade is concluding, designed by the General Assembly of the United Nations as International Decade for Natural Disasters Reduction (IDNDR). In this context, the Global Seismic Hazard Assessment Program (GSHAP; Giardini & Basham, 1993) implemented a regionalized strategy for the assessment of seismic hazard based on a mosaic of multinational test-area and regions.
The seismic hazard assessment of our interest area remained out of the GSHAP results; in fact GSHAP cooperated with several bilateral and multinational projects in different continents, and the regional seismic hazard mapping of Mexico, Caribbean, Central and South America has been supported by PAIGH/IDRC.
The results can be considered incomplete, at least for the Cuban region, due to imperfect knowledge of our seismicity, which made the method used insufficient to obtain a real hazard assessment for Cuba; similarly, the analysis does not take into account the diverse seismic hazard studies made in Cuba during last years (Chuy & Alvarez, 1995, Rodriguez et al, 1997).
The general comments on the status of seismic hazard assessment for Cuba may be as follows:

- ✓ the estimates for both the central and the western regions have an implicit certain degree of subjectivity due to the lack of events in "inactive" zones (or zone with very low activity);
- ✓ the source zoning is a problem not yet solved, as each map presents only a partial sight of the kinematics of the area. To improvement this is not trivial, but some methodological examples do exist (Scandone, 1992); here the basic assumption to delineate seismogenetic sources is an adequate kinematics: it means that there must exist a logical link between the areas under stress conditions and the balance of space (the consumed one has to be compensated by the created one),under some established boundary conditions.
- ✓ a contradictory aspects of the DSZ studies is the use of diverse acceleration attenuation relationships in seismic hazard assessment and engineering calculations, which are obtained from synthetic accelerografic method.

✓ the computation of acceleration values from intensity by using a linear relation (Trifunar & Brady, 1975) instead of local acceleration attenuation law makes the calculated hazard interms of this parameter less realiable. Moreover recently Alvarez et al (in press) obtained evidence that the cited Trifunac and Brady relationships overstimate the groundmotion values.

The aim of this project was obtain new probabilistic seismic hazard assessments using the approach proposed by Cornell (Cornell, 1968), with the algorithm developed by Bender (1984) and of the Italian experience matured in the frame of the Gruppo Nazionale per la Difesa dai Terremoti (GNDT) activities (Slejko et al., 1998). Moreover, a special task of this study is the complete revision of attenuation relationships for macroseismic intensity, in order to obtain some other usefull results in seismic hazard analyses.

SEISMOGENIC ZONING FOR SEISMIC HAZARD PURPOSES

The delineation of active faults and earthquake sources in the region is one of the most important inputs of a seismic hazard analysis.

Taking into account the complexity of the Cuban geology (Iturralde -Vinent, 1996), the poor knowledge about the kinematic evolution of the principal faults system, and the uncertainty in the hypocentral determination of events give a minimum uncertainty of 15-20 km in the horizontal coordinates, it is impossible to address the individual faults responsible of the earthquake occurrences. This is truer in the intraplate region where both the geologic and tectonic qualitative knowledge are sometimes even bigger than the seismicity ones.

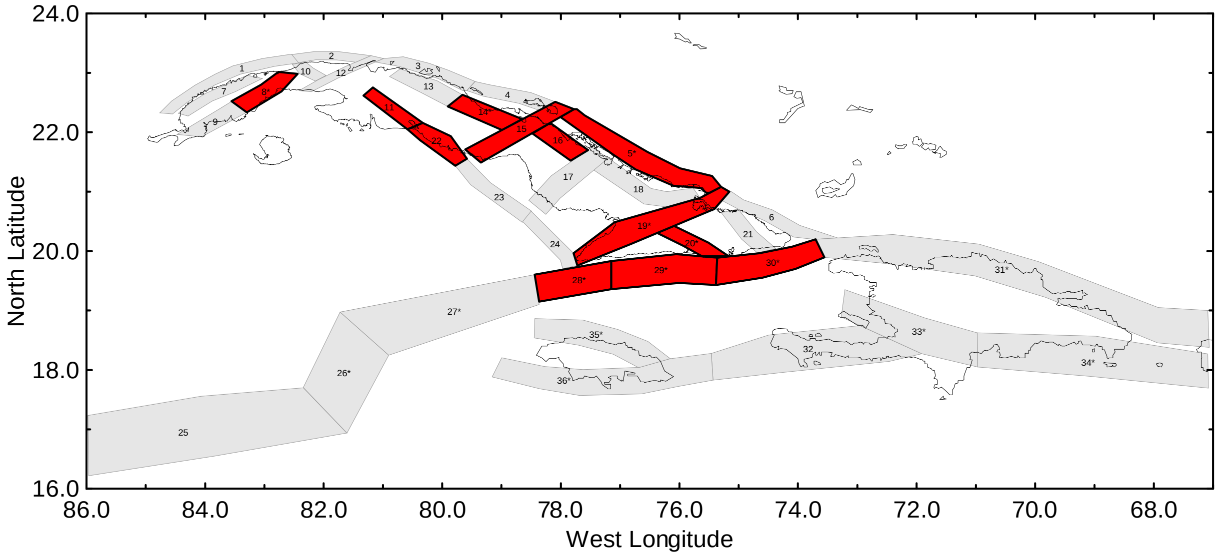

Fig.-1 Seismic Source zones used, the zones with higher border uncertainties are marked with a thicker border and background in red.

In source zoning presented here (see Fig. 1), each zone represents the superficial projection of one or more seismogenic structures (faults, fault systems, and alignments) supposed to have similar kinematic behavior and rupture mechanisms.

Uncertainties in the source location are taken into account and used later in the computation of seismic hazard (this is one of the advantages of used algorithm); as most of the sources are adjacent polygons, the mislocation of the boundaries is applied inwards, leaving a source of similar shape but smaller in size. In the figure 1 the sources with higher border uncertainties are marked with a thicker border and background in red.

The seismicity that remains outside of the proposed zonation has been collected into three background zone for hazard computation

THE CUBAN CATALOGUE

An earthquake catalogue for seismic zoning purposes of Cuba and neighboring areas was prepared. It covers from the XVI Century until December 1995. In the catalogue is present several kinds of data: historic-macroseismic for Centuries XVI-XIX and part of XX Century, Instrumental from international seismological services (ISS, ISC, USCGS-NEIS), during this Century and instrumental from Cuban local network since 1964.
For a systematic storage and processing of data it was decided to create a database in which each earthquake can be characterized by several entries, one for each source of data available. The database was prepared by joining all previous catalogues of different kinds and adding entries for additional available data. This " main base" was used to prepare a generalized by only one entry, formed by selecting the more reliable data on each considered input source. This transformation was done in two steps, the first with the aim of the computer program EDCAT (International Institute of earthquake Prediction Theory and Computational Geophysics, Moscow) with allowed us to discard the more evident duplicated information, retaining the maximum non duplicated one for each earthquake. The second with a visual checking and analysis case by case. The final catalogue (see, table I), contains 9241 earthquakes from 1502 until 1995.

Table I. General characteristics of catalogue.

TimeWindows:	1502	to	1995/12/30	(y/m/d)
Latitude:	16.00 N	to	24.00 N	(degrees)
Longitude:	67.00 W	to	86.00 W	(degrees)
Depth:	0	to	300	(km)
Intensity:	II	to	X	(MSK scale)

HAZARD ASSESSMENT

The methodology used in most probabilistic seismic hazard analyses, was originally defined by Cornell (1968), and translated into computer codes by Algermissen et al. (1976). The basic steps of the Cornell approach are:
Step 1 is the definition of the earthquake sources. The sources are explicitly defined as being of uniform earthquake potential and may range from small planar faults to large seismotectonic provinces.
Step 2 is the definition of seismicity recurrence characteristics for each zone, which is characterized by an earthquake probability distribution or recurrence relationship.
Step 3 is the estimation of the earthquake effect, where the range of earthquake sizes considered requires a family of earthquake attenuation or "*ground motion"* curves, each relating a ground motion parameter, such as PGA, to distance for an earthquake of given size.
Step 4 consists in determining the hazard at the site: the effects of all the earthquakes of different sizes occurring at different locations in different earthquake sources at different probabilities of occurrence are integrated into one curve that shows the probability of exceeding different levels of ground motion (i.e. PGA,) levels at the site during a specified period of time.

The engineers as physical quantity in building projects frequently use PGA, when a more complete hazard parameter is not available. It is important to note that PGA cannot be expected to represent the damage potential of strong-motion, being a single point which does not consider important factors such as the number of cycles, duration, frequency and energy content. Nevertheless, PGA is a useful parameter to fix design criteria in the absence of frequency-dependent attenuation relations, which predict spectral ordinates.
A difference from the traditional use of PGA and intensity exits and consist in the seismicity rates expressed in epicentral intensity, and attenuation relationships. This implies the adoption of earthquake epicentral parameters derived directly from original macroseismic data sets in conjunction with the attenuation relationship to reproduce the damage distribution; but for other hand, the macroseismic intensity as a seismic hazard parameter predominates internationally, more than 60 % of the countries have hazard assessment exclusively expressed in term of maximum observed intensity or intensity at a given probability level (Mc Guire, 1993).
Thus, it is evident the need of a simplified indicator of seismic risk, as macroseismic intensity can be considered. This approximation is valid from Cuba if we take into account that highly populated areas and

low quality buildings are present throughout the country, so the present building vulnerability can be considered comparable to that for the strongest earthquakes of the past.

SEISMICITY RATES

The definition of seismicity recurrence characteristics for each source zone is given by an earthquake probability distribution or recurrence relationship, which indicates the chance of an earthquake of a given size occurring anywhere inside the source during a specified period of time.
The specific seismicity of every source is then given as the number of earthquakes, in each magnitude class, counted on the basis of the completeness of the interval previously calculated. The possibility to use interval seismic rates, avoiding interpolation of the data with the Gutenberg-Richter relation, leads to two main advantages:

1) if different return periods are considered the hazard assessment really change in function of different seismic energy release in time while if a Gutenberg-Richter approach is adopted different return periods produced only a homogeneous raising (or lowering) of values;
2) it is so possible to describe adequately those source zones with a "characteristic earthquake" behavior.

A study about catalogue completeness was made, dividing it, in three sub-catalogues (Zone A: central-eastern Cuban region, Zone B: Jamaica and the Hispanola region and Zone C: western Cuban region, see figure 16). The difference between the three zones are not significant in the magnitude interval 3.0 - 4.5, but from Ms=5.0 zone A has a different behavior, while the B and C maintain almost the same.
For every sub-catalogue, the completeness periods were defined and the results are shown in table II.

Table. II Completeness periods by sub-catalogue, the periods in italics represent their rounded values chosen for sake of simplicity.

Ms	**all**	Zone_A		Zone_B		Zone_C	
2.0	**1980**	**1985**	*1980*	**1973**	*1970*	**1980**	
2.5	**1973**	**1980**		**1970**		**1980**	
3.0	**1970**	**1940**		**1950**	*1940*	**1960**	*1970*
3.5	**1965**	**1940**		**1930**	*1940*	**1960**	*1970*
4.0	**1950**	**1940**		**1927**	*1900*	**1955**	*1940*
4.5	**1950**	**1910**	*1900*	**1900**		**1910**	*1900*
5.0	**1872**	**1900**		**1880**	*1850*	**1775**	*1800*
5.5	**1800**	**1900**	*1850*	**1760**	*1700*	**1775**	*1800*
6.0	**1760**	**1880**		**1760**	*1700*	**1680**	*1700*
6.5	**1760**			**1500**		**1650**	*1600*
7.0	**1500**			**1500**		**1500**	
7.5	**1500**			**1500**		**1500**	
8.0	**1500**			**1500**			

For each magnitude value the period computed by the test of completeness is presented, which were used for obtaining the seismicity rates by counting the earthquake number in each magnitude class during those time periods, and then normalizing the number to 100 years.
The procedure for adequately determining the seismicity rate has been established on an objective basis. In fact, the completeness period of each magnitude class identifies the seismicity rate and, consequently, the related return period (T=100 years/seismicity rate). The highest seismicity rate related to a time period not shorter than the return period computed with respect to the completeness interval is chosen. This procedure warrants a caution choice based on the analysis of the whole catalogue (Slejko et al, 1998).
An example is given in figure 2, source zone 34 (sz34), where the rates computed for nine different time periods are marked with different symbols, the rates suggested by the stationarity/completeness test are marked by arrows, and the final choices are marked by large open squares. On the right side of the plot, the indicative return periods are reported.
For the magnitudes classes from 3.5 to 6.0 (see fig. 2), the suggested number of events has been changed in favour of a rate related to a shorter (but more complete) period in agreement with the return period indicated by the stationariness/completeness test.

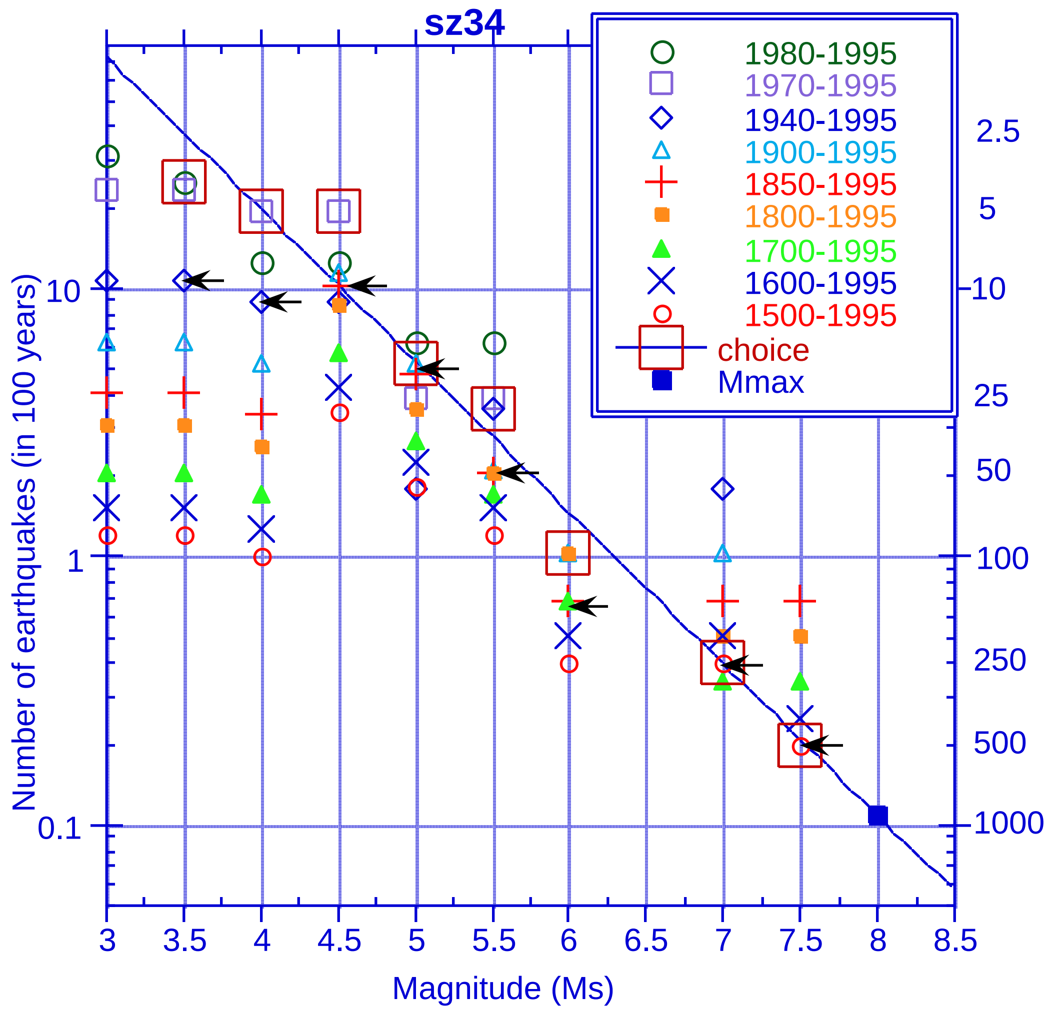

Figure-2 Seismicity rate from southern Hispanola source zone.

For example, the suggested period for the class 5.0 was 1850-1995 and the number of events reported in this period is 4.79 which corresponds to a return period of about 21 years. According to this return period it is possible to choose the shorter period 1900-1995 (longer than 25 years) but it is impossible to select the too short 1980-1995 (15 years) period. The 1940-1995 and 1970-1995 periods are longer than 21 years but have a number of events lower than the 1900-1995 period, which reports a high number of events.

The adjustments, always conservative, are related to the particular seismic behavior of the source zone, while the suggested completeness period was computed by grouping several zones and cannot be adapted to every case.

Another important point for the seismicity definition is the maximum magnitude value considered as input. The geological complexity of the Caribbean region and the incomplete knowledge of the seismotectonic processes prevent a clear assignment of seismicity to specific tectonic structures. For these reasons it was decided to introduce a maximum magnitude for some sources zones on the basis of the catalogue seismicity only. But, it was impossible for low seismicity areas where the present seismicity knowledge is insufficient to support the idea that most/all the maximum magnitudes (possible maximum earthquake), occurred during the time covered by the catalogue.

Thus, it was decided to follow due procedures.

The chosen rates (large open squares in figure 2) were fitted by the Gutenber-Richter relationship (line in figure 2.), and the extrapolated rate for a magnitude greater by one step unit (0.5 in our case) was

consider if it involved a mean return period between 500 and 1,500 years (solid square in the same figure at magnitude 8.0), i. e., larger than the time window of the catalogue and, therefore, possibly involving events missing in it, but not too long to account for events with a very low rate. It was possible to assign the maximum magnitude rate to 15 source zones. An asterisk in figure 2 indicates these zones.
For the other ones, in which it was not possible to obtain a maximum magnitude by the way cited before: the value suggested by seismotectonic/geologic evidence was taken.
The assignment is not easy, if we take into account the wide variation of this parameter in previous works (Cotilla et al, 1991; Orbera et al., 1987, 1989, 1990; Cotilla and Alvarez, unpublished; Gonzalez et al., 1993; Chuy et al., 1992), although the source zones contained the same tectonic structures and their drawing are almost identical.
We decided then: to assign the maximum magnitude proposed by seismotectonic evidence when it does not exceed two intervals of the maximum observed magnitude, and the return period for this value was longer than 500 and shorter than 2500 years.

SEISMICITY RATES

The same procedure used for defining the Source Zone seismicity rates in terms of magnitude was followed for defining the seismicity rates in intensity. As for magnitude, the catalogue also has an intensity value for each event (I_{max}), when an intensity value was not available, a “virtual” value of Io was calculated from magnitude using an empirical relation (Fedootov and Shumilina, 1971).
A stationarity analysis similar to that adopted for magnitude was applied to intensities by grouping the catalogue into three megazones (northern-central; southern of Cuba and Jamaica-Hispanola).
The choice of intensity rates was driven by the same criteria used for magnitude: the values were suggested by the stationarity test and sometimes changed cautiously by choosing a longer and more seismic period them the complete one, or a shorter one but always longer than the return period suggested by the completeness test.
In general, the Source Zone seismicity rates give an idea of the contribution of medium to low intensity data to seismic hazard assessment for each SZ. There is a general agreement between these rates with those for magnitude. Nevertheless, some differences mainly in the medium and high intensity clearly arise. In some case they are due to magnitude estimates not in agreement with the intensity derived from the magnitude/ intensity relation (Fedootov and Shumilina, 1971); for instance in 31, 35, 36 SZ’s medium and high magnitude can produces very high intensities not reported in the past. All these aspects produce intensity maps, which are not a simple transformation of the PGA maps, since they derive from completely separate elaboration.

PGA ATTENUATION RELATIONS

The strong-motion relationships to use in seismic hazard assessment form an essential input and have a great influence on the resulting earthquake design loads. These can be chosen among those of existing, when local relations are not available.
In our case PGA attenuation relationships of Caribbean validity do no exist as well as Cuiban attenuation ones. For these reasons we decided to prove with four PGA attenuation relationships (Ambraseys, 1995; Ojeda, 1998; Abrahamson and Litehiser, 1989 and Joyner and Boore 1981).
Considerations about the applicability range of these relations determined the final choice.

- ***Ambraseys(1995)*** used an extensive data set (1260 records for 619 European earthquakes) obtained in the free-field or from the base of structures with no more than three storeys, from Albania, Algeria, Bulgaria, Greece, Iceland, Iran, Israel, Italy, Pakistan, Portugal, Romania, Spain, Turkey, former USSR and former Yugoslavia. Calibrating different relations in the magnitude (Ms) range 2.0 - 7.3. Also, it is defined for distance from the fault and applies to an average soil.

$$\mathrm{Log}\ (a) = -1.43 + 0.245\ M - 0.786\log(R^2 + 2.7)^{1/2} - 0.0010(R^2 + 2.7)^{1/2}$$

- By other hand, ***Ojeda (1998)*** based his study on recordings from earthquakes in Colombia. He divided the Colombian region into three different tectonic provinces. *A-tectonically stabile*: conformed by the Continental plains and the Amazonia, with lower seismicity and poor quality of the data. *B-tectonically* *active:* contained the main fault system of the Andes region, which presents a higher and shallow seismicity and *C-subduction zones*: conformed by the Offshore Pacific seismicity and the Benioff zone with focal-depths of more than 100 km.. Attenuation relations were derived for the three different zones, in the magnitude (Ms) range 3.1 - 6.6 and epicentral distance between 20 - 400 km, and refer to rock. In this study the relation obtained for the second zone was used, as the tectonic environment is fairly similar to the Caribbean region.

- ***Abrahamson & Litehiser (1989)*** used a very large data set from all around the world. The equation included a variable F which takes a value 1 for faults with a reverse component and 0 otherwise, and another variable E which is equal to 1 for interplate and 0 for intraplate regions. It is defined for Ms.

  $\mathrm{Log}(a) = -0.62 + 0.177M - 0.982\log(R + e^{0.284M}) + 0.132F - 0.0008ER$

- ***Joyner & Boore (1981)*** derived an equation using recordings generated by earthquakes in the western North America, in spite of the other this relation is defined for moment magnitude (Mw) in a range 5.0 - 7.7, thus, the standard (Ms) magnitude of the catalogue was transformed to Mw using the relations obtained by Giardini from a global data set.

  $\mathrm{Log}(a) = -1.02 + 0.249M - \log(R^2 + 7.3)^{½} - 0.00255(R^2 + 7.3^2)^{½}$

All the relations are azimuth independent and do not consider the intrinsic differences of the source zone tectonic regime (compresional, tensile, transcurrent, etc) and were extrapolated to lower or higher values than their threshold when necessary.
The behavior of the attenuation relations used present PGA higher values in all magnitude classes by the Joyner and Boore relation, while for the medium magnitude the Abrahamson and Litehiser equation present a slightly increase with respect to the Ambraseys. The Ojeda relation obtains the poorest results, the PGA reached higher values upon 10 km and then drop strongly to lower values.

INTENSITY ATTENUATION RELATIONS

In the frame of the seismic hazard assessment for Cuba, attenuation relationships were developed for macroseismic intensity. The attenuation curves were derived from the datasets of the most important earthquakes. Following the Italian experience, we adopted some different well-known formulation and a semi-automatic procedure in order to derive the unknown coefficients of each relationship.
The selected models are:
the relationship proposed by Grandori et al. (1985) as in eqn.(1)

$$I_0 - I_i = \frac{1}{\ln \psi} \ln\left[1 + \frac{\psi - 1}{\psi_0}\left(\frac{D_i}{D_0} - 1 \right) \right] \qquad (1)$$

where Io indicates the epicentral intensity, Ii the intensity at the ith-site, Di the distance of the site from the epicenter, and y, yo and Do are unknown coefficients;
the formula proposed by Berardi et al. (cit.) as

$$I_0 - I_i = \alpha + \beta \sqrt[3]{D_i} \qquad (2)$$

where α and β are unknown coefficients, Io, Ii and Di have the same meanings of eqn.(1);
the Blake (1941) model

$$I_o - I_i = M_1 \log(D^2 + M^2) / M_2 \qquad (3)$$

where ..

and the Koveslighety relationships given in eqn (4)

$$I_o - I_i = a_1 + b_1 \log D_i + c_1 D_i \qquad (4)$$

where 2 or 3 parameter have been allowed to be estimated from experiemental data.

The procedure to obtain the unknown coefficients from the macroseismic dataset does not utilize isoseismal maps, but the effective data points distribution. It follows four main steps:
1) to compute the distance of each locality with observed intensity from the epicenter reported in the earthquake catalogue;
2) to construct the sample cumulative curve of distances corresponding to the same macroseismic degreee; a weight factor distinguishes certain from uncertain observations;
3) to select the empirical sample percentiles (distances expected not to be exceeded at 50% probability level) for each intensity class, associated with its proper intensity decay;
4) to apply a non linear least squares method to the couples distance-intensity decay, in order to derive the unknown coefficients of eqn (1) to eqn (4).
The methodology is widely presented and commented in Peruzza (1996); this application utilizes the empirical samples and do not superimposes probabilistic models to the data.
The choice of 50% fractile distance is consistent with the use of ordinary rounding algorithm of real into integer conversion: as no intermediate degree are considered (e.g. an intensity assessment reported as VI-VII is splitted into two samples of the same coordinates, and half weight, in classes VI and VII), the 50% probability level separates the two intensity classes leaving "not consistent" observations in equal number on both sides.
More than 85 earthquakes have been treated following the previously described methodology. Table III lists the main information of the selected events.
In Table III, the 'N_{sam}' column indicates the total number of samples: it derives from the total number of points having the macroseismic intensity, after that uncertain data have been splitted into different intensity classes. The more 'N_{sam}' differ from 'N' value, the more the dataset is characterized by uncertain evaluation of the intensity degree; on average, datasets have 30% of uncertain data points. Uncertain samples are properly weighted in the cumulative frequency curve. The distance corresponding to the 50% percentile is computed only if we dispose at least of three samples in that intensity class.
The final attenuation relaiontships are linked to the seismogenic zonation proposed, and reported in figure 1, here red areas indicate sources that have a characteristic attenuation relaionship for the macroseismic intensity. Figure 3 shows the curve fitting for some events.
The one-source-one-attenuation-relationship was the ultimate solucion, after the failure of homogeneous propagationproperties of macroseismic intensity.

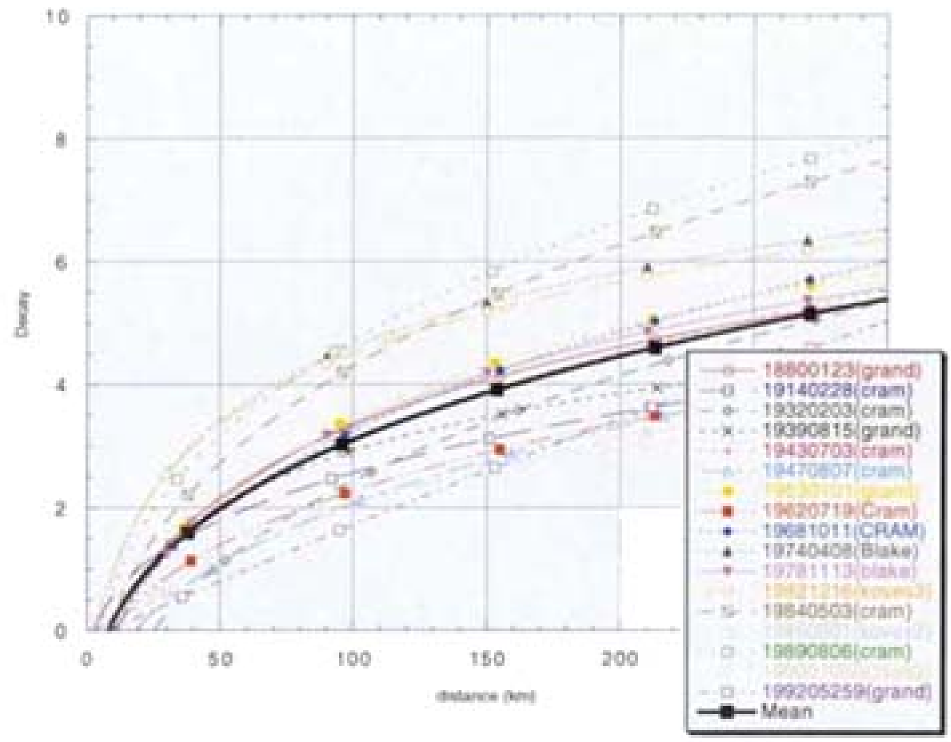

Figure 3- Curve fitting for representative earthquakes by seismogenic sources,

RESULTS

As final results, some of the seismic hazard maps in terms of PGA and maximum intensity calculated for 475 year return period are presented. Similar maps were computed for the 100 and 1000 year return period too. The 475 year return period is conventionally used to represent the seismic loads for ordinary buildings: it corresponds to 90% non-exceedance probability in 50 years, reference generally used in the Cuban building code.

Computation of the final maps was done over an approximately 0.1^0 x 0.1^0 grid, taken into account the accuracy of the earthquake-localization of the catalogue. PGA is given in g (gravity acceleration), the contouring interval being 0.04 g.

The seismic hazard maps for a 475-year return period were prepared for each attenuation relationship cited before, using the same source map and the seismicity rates. The results when using the Ambraseys (1995) present higher values (larger than 0.36 g) in southern Cuba (near Santiago de Cuba city) and northern Hispanola. The Cuban south-eastern region continues under the influence of these main source zones (sz28, sz29, sz30, sz31), reaching PGA values from 0.3 g to 0.12 g. In the Cuban western region the PGA values do not exceeded 0.24 g and the central one is under the 0.16 g.

In generally, the same behavior show the Abrahamson & Litehiser (1989) approach, maintain the same thresholds in the PGA values for zones described above with fair differences due to the fact that this attenuation relationship presents an slightly increasing with respect to the Ambraiseys for the medium magnitude, while for the highest magnitudes the Ambraseys relationship is bigger.

The results obtained from the use of Ojeda (1998) equation are fairly different from the other ones used, the PGA reached higher values upon 10 km and then drop strongly to lower values. We think that this map should be treated only as an input to a "weighted" map and cannot be considered itself as a final one.

The highest PGA values are reached when using the Joyner and Boore relation in the whole region; PGA values higher than 0.4 g are present in entire sz30, sz32 and sz37 zones, for the Cuban western zones the increment is larger than 0.1 g as mean value.

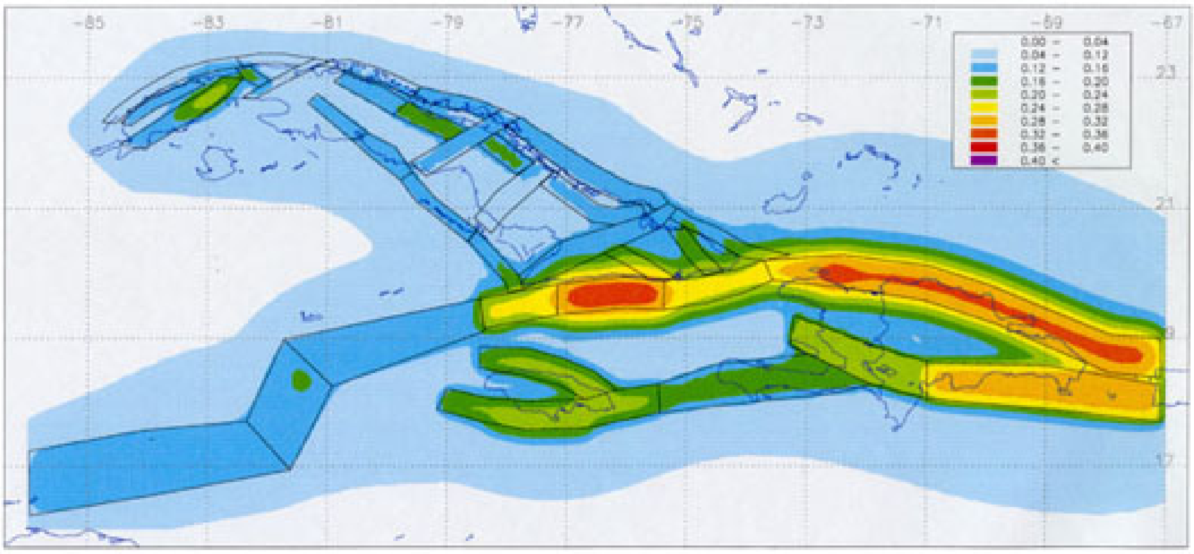

Figure 4- Weighting Seismic hazard map for 475-year return period for PGA.

Following the idea of a "logic tree" approach, a robust map (figure 4) was done weighting adequately the previous PGA results with the exception of those obtained by the Joyner and Boore relation. The probability 0.4 was associated both to the Ambraseys and the Abrahamson relations while probability 0.2 was given to the Ojeda relation. The obtained map is obviously an average value of those presented before and is considered robust as is less dependent on the choice of the attenuation relation as a local one is not available for the Caribbean region. It is interesting to note that some peculiarities of the previous maps are present in this final map and it does not represent simply a smoothed value.
The seismic hazard result, using intensity (see figure 5), depend critically on the chosen attenuation relationship, the propagation characteristics derived from this study shown that the better solution is a one-source-one attenuation solution.
For about 40% of the SZ's, we selected characteristic relationships, usually derived from the strongest earthquake which had occurred in the source. The other SZ a mean attenuation relationship was computed.

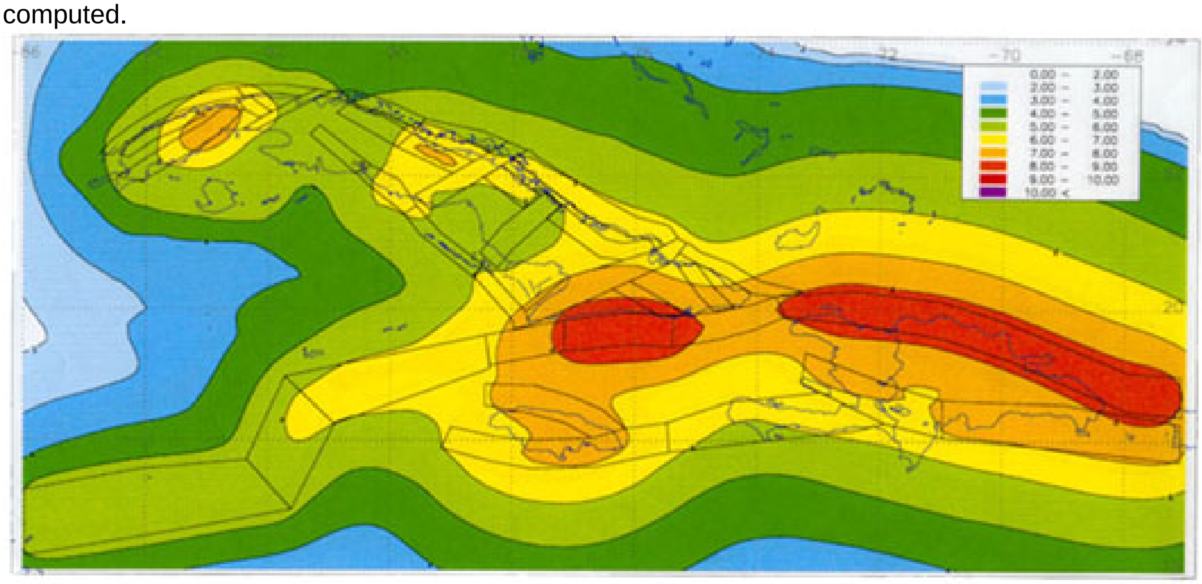

Figure 5- Seismic hazard map for 475-year return period for intensity.

CONCLUSIONS

1. For a systematic storage and processing of data was created a database in which each earthquake can be characterized by several entries, one for each source of data available. As a result, an earthquake catalogue of Cuba a neighboring area was prepared for seismic zoning purposes.
2. Four different attenuation relationships was used due the choice of the local attenuation relation is not available for the Caribbean region. The maps in term of PGA shown the possibility to use this way as a variant of the logic tree to quantify the uncertainties in PGA attenuation relationships. For other hands is evident a possible overestimation in the traditionally used of Trifunac and Brady, 1975 relationships to obtain Ah from intensity values.
3. For each attenuation relationship, using the same source map and the seismicity rates a set of seismic hazard maps in terms of PGA calculated for 100, 475 and 1000 year return period are presented. The Ambraseys (1995) and Abrahamson & Litehiser (1989) relationships described with a good approximation the attenuation of this parameter from Cuba, using the Ojeda (1998) relationship the PGA drop strongly to lower values after reach the 10 km and cannot be considered as “characteristic”. The high PGA values reached when using the Joyner and Boore (1981) relationship in the whole region; make this map a maximum threshold for this parameter. The final map is obviously an average value of those presented before and is considered robust. It is interesting to note that some peculiarities of the previous maps are present in this final map and it does not represent simply a smoothed value.
4. A newer macroseismic database was used in order to make a revision of attenuation relationships for intensity, in order to obtain a local attenuation relationship in term to intensity. Four approach was used including the Koveslligethy formulation traditionally used in Cuba. The seismic hazard result, using intensity, depend critically on the chosen attenuation relationship, the propagation characteristics derived from this study shown that the better solution is a one-source-one attenuation solution.

BIBLIOGRAFIA.

ABRAHAMSON, N. A. & J. J. LITEHISER (1989) Attenuation of vertical peak acceleration. Bull. Seis. Soc. Am., 79, pp. 549-580.

ALVAREZ, L.; T. CHUY, M. COTILLA (1991): Peligrosidad sísmica de Cuba. Una aproximación a la regionalización sísmica del territorio nacional. Revista Geofísica del Instituto Panamericano de Geografiá e Historia, vol 35, pp. 125-150.

AMBRASEYS, N. N. (1995): Reappraisal of the prediction of ground accelerations in Europe – EAEE Working Group report. In: Duma (ed), 10th European Conference on Earthquake Engineering, Balkema, Rotterdam, pp. 3041 – 3048.

BENDER, B. (1984): Incorporating acceleration variability into seimic hazard analysis. Bull. Seism. Soc. of America, vol. 74, No. 4, pp. 1451- 1462.

BENDER, B.; D. M. PERKINS (1987):Seisrisk III: A computer program for seismic hazard estimation. U. S. Geological Survey Bulletin 1772, 48 pp.

CORNELL, C. A. (1968): Engineering seismic risk analysis. Bull. Seism. Soc. Am., 58, 1583 – 1606.

COTILLA,M.; et al (1991): Mapa sismotectónico de Cuba. Escala 1:1000000. Comunicaciones Científicas sobre Geofísica y Astronomía, No. 23, 49 p., 1er anexo.

CHUY, T.and L. ALVAREZ (1995): Seismic Hazard Map of Cuba for the New Building Code of the Republic of Cuba. Ministry of Construction, Habana, Cuba.

FEDOTOV, S. A.; L. S. SHUMILINA (1971): Seismic shakeability of Kamchatka (in Russian). Izv. Akad. Naukk S.S.S.R. Fizika Zemli, No. 9, pp. 3-15.

GIARDINI, D., P. BASHAM (1993): The Global Seismic Hazard Assessment Program (GSHAP). Annali di Geofisica, Vol. XXXVI, No 3-4, pp 3-13.

GONZALEZ, B.E.; et al (1993): Estudios Sismológicos Complejos de Cuba centro oriental para el emplazamiento de Objetivos Nucleares. Reporte de Investigación, Fondos del CENAIS, de la SEAN y del MINBAS.

ITURRALDE-VINENT, M. A. et al (1996): Project 364 “Geological Correlation of Ophiolites and Volcanic Arc Terrains in the Circum Caribbean Region”. Miami, U.S.A. Museo Nacional de Historia Natural, Havana, Cuba.

JOYNER, W. B. & D. M. BOORE (1981): Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California, earthquake. Bull. Seis. Soc. Am., 71, 2011-2038.

McGUIRE, R. K (1993): Computations of seismic hazard. Annali di Geofísica, vol XXXVI, No 3-4, pp 181-200.

ORBERA, L.; et al (1990): Investigación sísmica en la región de emplazamiento del Centro de Investigaciones Nucleares. Reporte de Investigación, 344 p. Anexos gráficos, Fondos del CENAIS.

ORBERA, L.; et al (1989): Estudio sismotectónico para el emplazamiento del Complejo Hidroenergético Toa-Duaba. Reporte de Investigación. E.I.P.I.B., MINBAS.

ORBERA, L.; et al (1987): Las investigaciones sismotectónicas y la estabilidad de las construcciones energéticas en Cuba. En: Primer Congreso Internacional sobre Desastres Naturales, Habana.

RODRIGUEZ, M.; L. ALVAREZ & J. GARCIA (1997): Estimaciones probabilísticas de la peligrosidad sísmica en Cuba. Submitted to: Revista Geofísica del Instituto Panamericano de Geografía e Historia.

SCANDONE, P. et al (1992): Struttura geologica, evoluzione cinematica e schema sismotettonico della penisola italiana. In: GNDT, Atti del Convegno 1990 Vol. 1 Zonazione e riclassificazione sismica, Ed. Ambiente, Bologna, pp. 119-135.

SLEJKO, D.; L. PERUZZA; A. REBEZ (1998): Seismic hazard maps of Italy. Submitted to: Annali di Geofisica.

TRIFUNAC, M. D. & A. G. BRADY (1975): On the correlation of Seismic Intensity Scales with the peaks of Ground Motion records. BSSA. Vol. 65. No. 1.

Table III- Results of the procedure to derive the unknown coefficients of each relationship.

SZ	DATE	I_0	Lat	Long	N_{sam}	Ψ	Ψ_0	D_0	α	β	M_1	M_2	a_1	b_1	c_1
SZ5	1914 08 25	7.0	21.22	76.17	54	2.140	1.753	12.987	-1.65	0.802	3.012	19.209	3.0	19.18	0.0
SZ8	1880 01 23	8.0	22.70	83.00	110	1.655	1.491	9.112	-2.616	1.277	4.311	16.968	3.0	13.018	7.0
SZ11	1982 12 16	6.0	22.60	81.40	84	3.359	0.182	11.865	-3.126	1.69	4.68	11.132	4.019	10.04	0.0007
SZ14	1939 08 15	7.0	22.51	79.58	56	2.13	1.038	11.796	-2.582	1.202	3.805	16.835	3.0	14.21	4.00
SZ15	1953 01 01	6.0	22.15	78.60	81	1.445	2.305	6.766	-2.507	1.278	4.50	17.211	3.0	14.104	1.20
SZ16	1974 04 08	6.5	21.82	77.10	65	1.528	2.848	2.645	-2.421	1.591	3.997	7.039	3.0	5.831	0.0014
SZ19	1962 07 19	6.0	20.52	77.20	17				-1.968	0.916	2.965	17.762	3.0	17.482	0.0
SZ20	1985 09 01	5.5	19.86	75.39	65				-2.273	0.934	3.563	27.11	3.0	24.48	0.0007
SZ22	1943 07 30	6.0	21.85	80.10	39	1.233	3.336	6.547	-2.469	1.198	4.525	20.645	3.0	17.654	0.001
SZ28	1992 05 25	8.0	19.93	77.51	132	1.046	7.458	7.122	-4.759	1.42	8.839	86.48	3.0	48.86	0.001
SZ29	1932 02 03	8.0	19.50	75.50	93	1.288	1.466	18.974	-4.148	1.420	6.689	48.586	3.0	28.053	---
SZ30	1947 08 07	8.0	19.75	75.70	41	1.134	6.168	5.928	-3.783	1.348	6.391	45.84	3.0	29.795	0.001
mean									-2.303	1.174	1.790	3.080			