Maximum expected ground motions in eastern Cuba

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ABSTRAC

A deterministic seismic zoning of Cuba is performed by modelling, with modal summation, the complete P-SV and SH waves fields generated by point-source earthquakes buried in flat layered anelastic media. The results of the computation, performed for periods greater than 1 second, are presented in two sets of maps of maximum displacement (d_{max}), maximum velocity (v_{max}) and design ground acceleration (DGA), obtained using two different criteria in the definition of the input magnitude: (1) values reported in the earthquake catalogue (M_{obs}) and (2) values determined from seismotectonic considerations (M_{max}). A comparison with the results of a previous probabilistic seismic zoning is made to test the possibility of making intensity – ground motion conversion with the aid of log-linear regressions.

INTRODUCTION

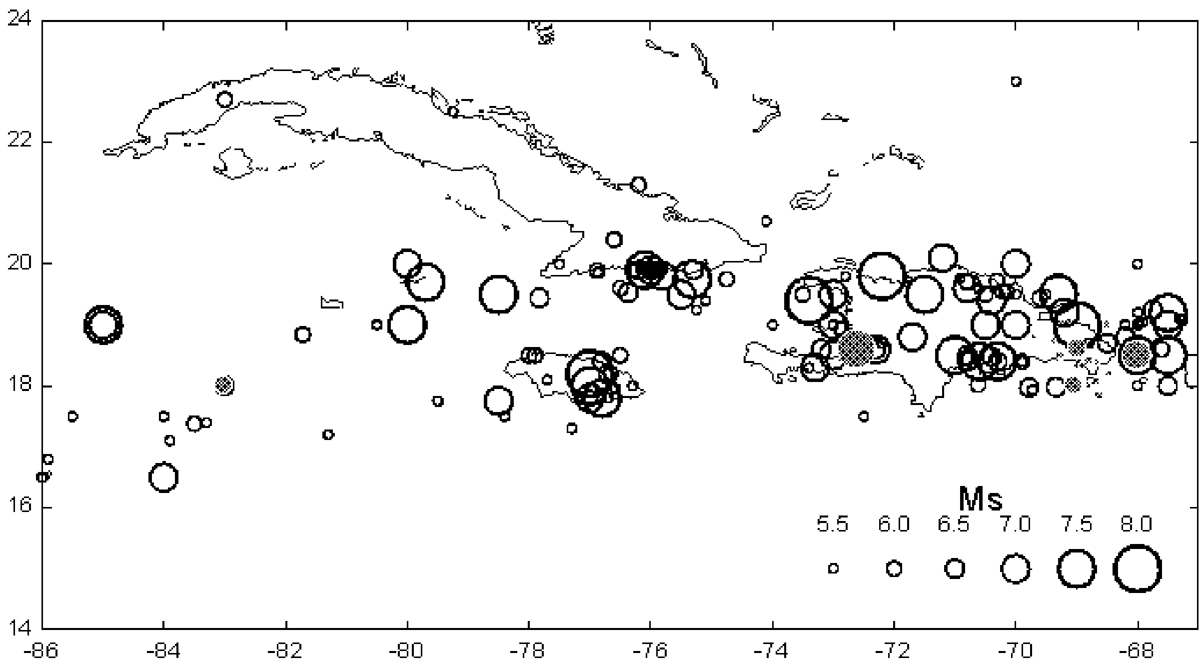
Seismic zoning in Cuba began with a deterministic approach based on felt intensities (Alvarez, 1970, Chuy et al., 1983). In the middle of the 80's a qualitative change is due to the introduction of probabilistic approaches (Rubio, 1985, Alvarez and Bune, 1985). The detailed seismic zoning for the sitting of nuclear power plants, radioactive waste deposits and hydroelectric complexes, was summarised in the new proposal for the seismic building code (Chuy and Alvarez, 1995). Finally, a new probabilistic investigation has been performed (Rodríguez et al., 1999). The parameter commonly used in Cuba for hazard description is the macroseismic intensity because there are not records of acceleration or any other ground motion parameter during strong or felt earthquakes. A way to estimate seismic ground motion parameters is complete waveform modelling. In this paper we formulate a new deterministic seismic zoning of eastern Cuba, made by modelling P-SV and SH wave fields with the modal summation method (Panza, 1985; Panza and Suhadolc, 1987; Florsch et al., 1991).

The procedure for the deterministic seismic zoning, developed by Costa et al. (1993), is based on the use of the available information on the Earth's structure, seismic sources and the level of seismicity of the investigated area to generate synthetic seismograms, from which parameters representative of the ground motion are then obtained.

The validity of the use of log-linear transformations between ground motion parameters and intensity for Cuban conditions is controlled by studying the relationships between our results, based on ground motion modelling and the results of Rodríguez et al. (1999) based on calculated intensity.

SEISMICITY DATA

We use an earthquake catalogue for the period from 1502 to 1994 for the region between 67°-85°W and 16°-24°N. The magnitudes of earthquakes in the catalogue are Ms, m_b, M_I (estimated from macroseismic data), M_D (estimated from signal duration) and K_r - energetic class (Rautian, 1964). The conversion relationships to Ms are: $M_I \cong M_D \cong Ms$, $Ms=1.51m_b-3.69$, $Ms=0.48K_r-2.11$ (Alvarez et al., 1999). In Fig. 1 the map of epicenters for $Ms \geq 5$ is presented: the seismicity of the region is mainly shallow ($h \leq 70$Km) with the



presence of deeper foci ($70<h\leq 220$Km) only in the eastern part of Hispaniola island.

Fig. 1. Map of epicenters from 1502 until present in Cuba and neighbouring territories. Open circles - shallow events, full circles - intermediate depth events.

The studied region is divided into cells of 0.2° x 0.2° and the maximum observed magnitudes M_{obs} of the earthquakes occurred within each cell is determined. These data are smoothed following the procedure described in Costa et al. (1993). The obtained smoothed seismicity is intersected with the seismic source zones (SSZ) derived from the map of seismogenetic zones of Cuba and its surroundings, shown in Fig. 2. Taking into account the great difference between the space distribution of M_{obs} and of M_{max}, the maximum possible magnitude expected from seismotectonic considerations took from Fig. 2, it has been decided to make the calculation both considering M_{obs} and M_{max}.

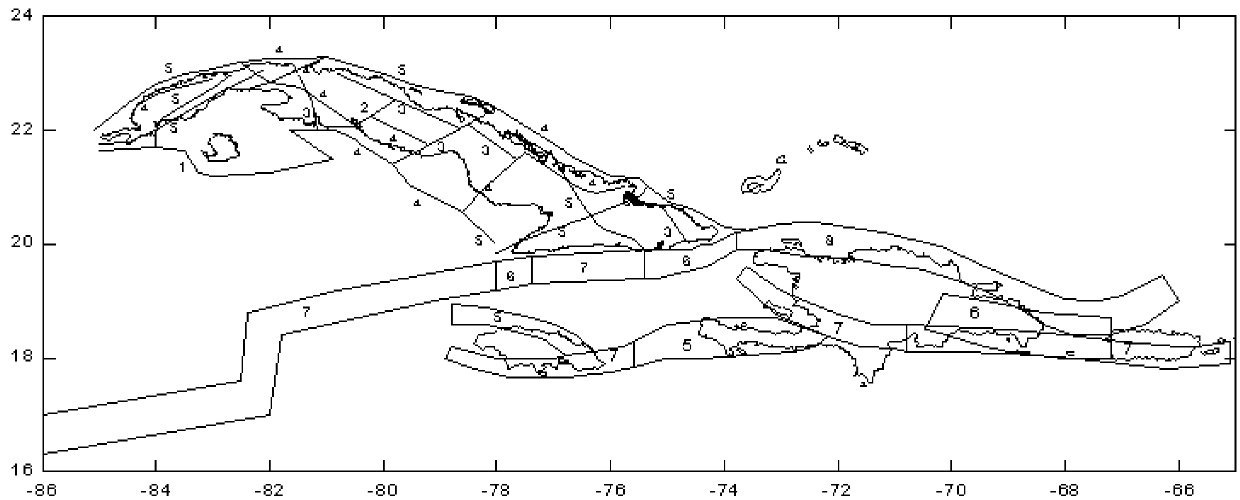


Fig. 2. Map of seismogenetic zones with M_{max} values [modified from Cotilla et al. (1996)]. The seismic source zones represented by lines in the Cuban Island are of 10 Km wide. 1.- $4.5<M_{max}\leq 5$, 2.- $5<M_{max}\leq 5.5$, 3.- $5.5<M_{max}\leq 6$; 4.- $6<M_{max}\leq 6{,}5$; 5.- $6.5<M_{max}\leq 7$, 6.- $7<M_{max}\leq 7.5$, 7.- $7.5<M_{max}\leq 8$, 8.- $8<M_{max}$

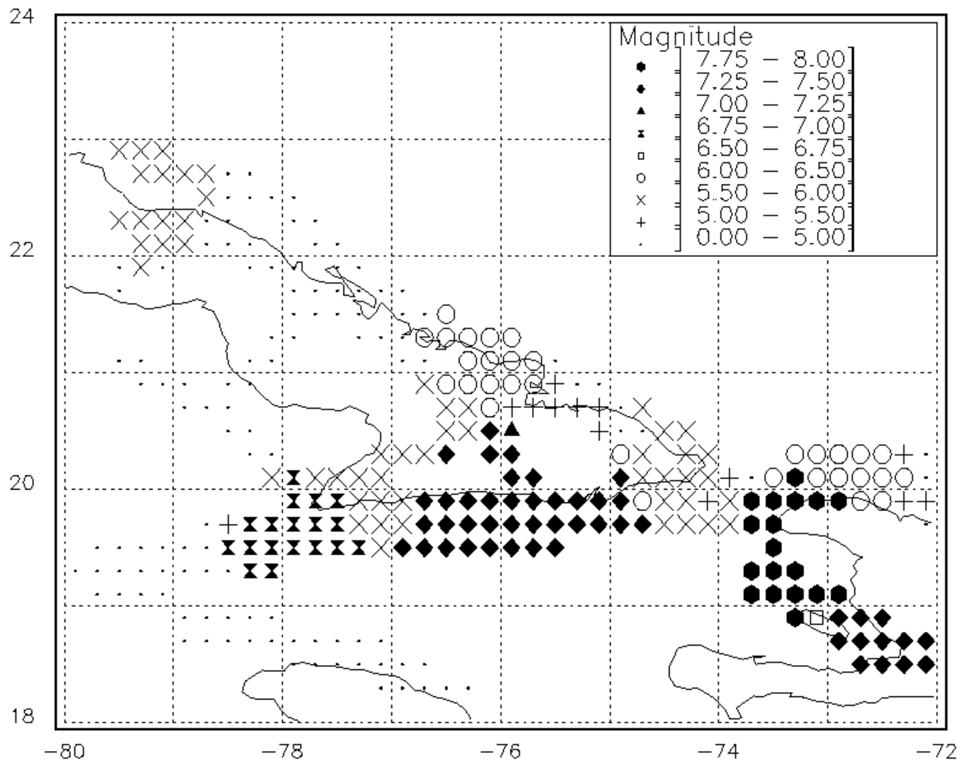


Fig. 3. Map obtained by smoothing the maximum observed magnitudes $M_{obs.}$

FOCAL MECHANISM IN THE REGION

For the definition of the focal mechanism of each SSZ, we have collected all the available data about fault plane solutions and CMT determinations for the region. For each SSZ we select the more reliable solution as the typical mechanism to be used in the modelling of the seismic motion. Nevertheless, for the intraplate SSZ no focal mechanism or CMT solutions are available, and the expected mechanisms has been chosen only on the base of general considerations on the geodynamics of the region.

STRUCTURAL MODEL

The uppermost 150 Km of the structural model are shown in Fig. 4 and represent a modification of the P and S waves velocities model used for earthquake hypocenter's location (MINBAS, 1989). The density values are adapted from those proposed by Orihuela and Cuevas (1993). Since Q values are not available in the literature we assumed standard values of Q_α=400 and Q_β=200 for all the layers.

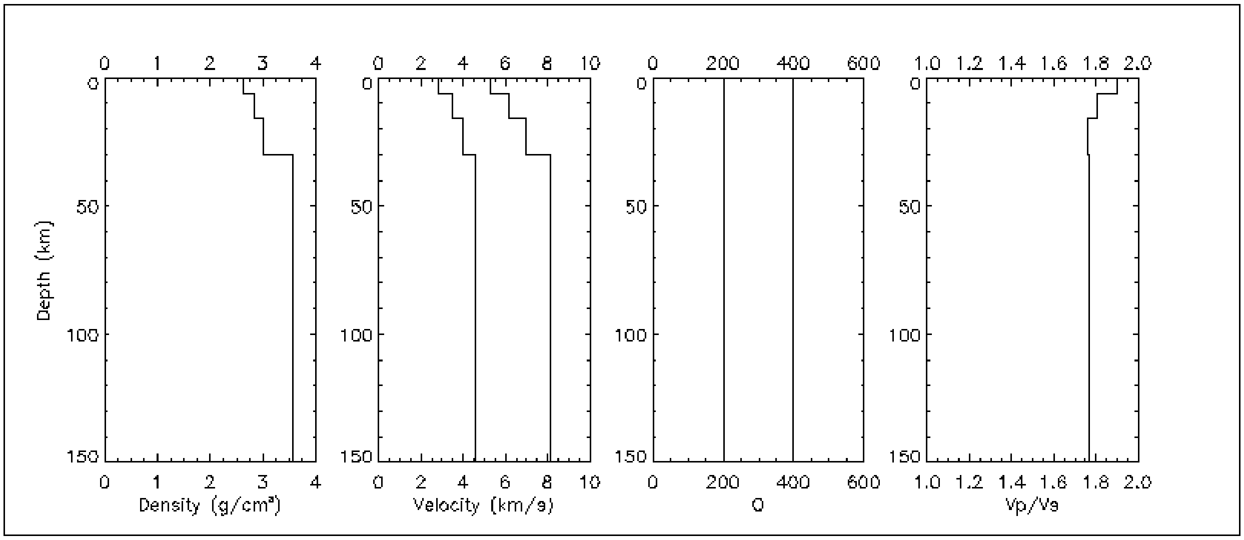


Fig. 4. Uppermost 150 Km of the structural model used for the computation of synthetic signals.

RESULTS

The calculation of synthetic signals has been performed following the procedure described by Costa et al. (1993). The maximum frequency used is 1 Hz, because the available details about input structure and source properties don't warrant the computation of synthetic signals at higher frequencies. All seismograms are scaled to the magnitude associated to the relevant cell using the scaling law of Gusev (1983) as reported by Aki (1987). For each point of the 0.2°x0.2° grid we select the maximum values of displacement (d_{max}) and velocity (v_{max}), and we draw a set of maps of d_{max} (Fig. 5) and v_{max} (Fig. 6).

Fig. 5. Maximum expected displacement d_{max}: (a) from M_{obs}, (b) from M_{max}.

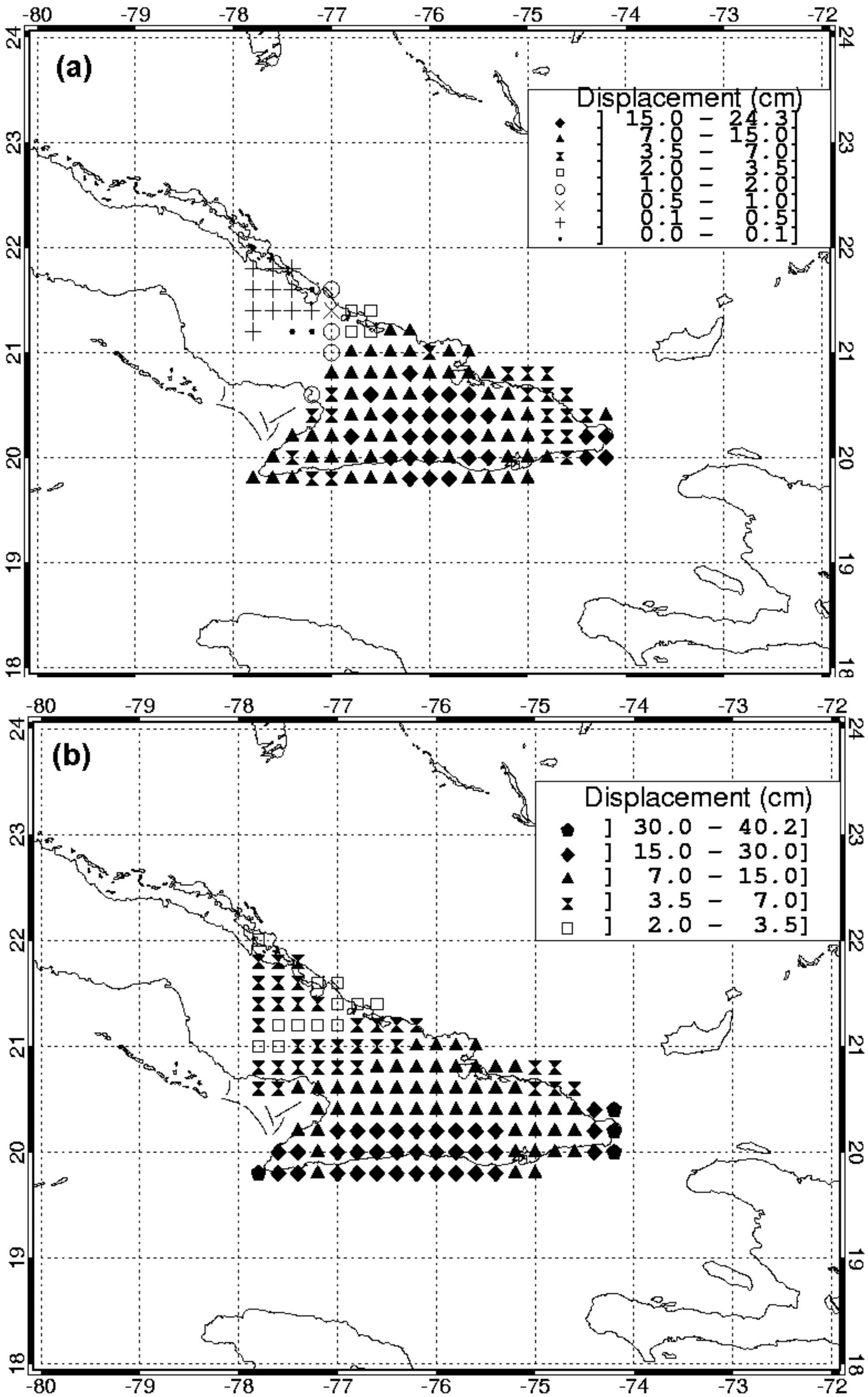
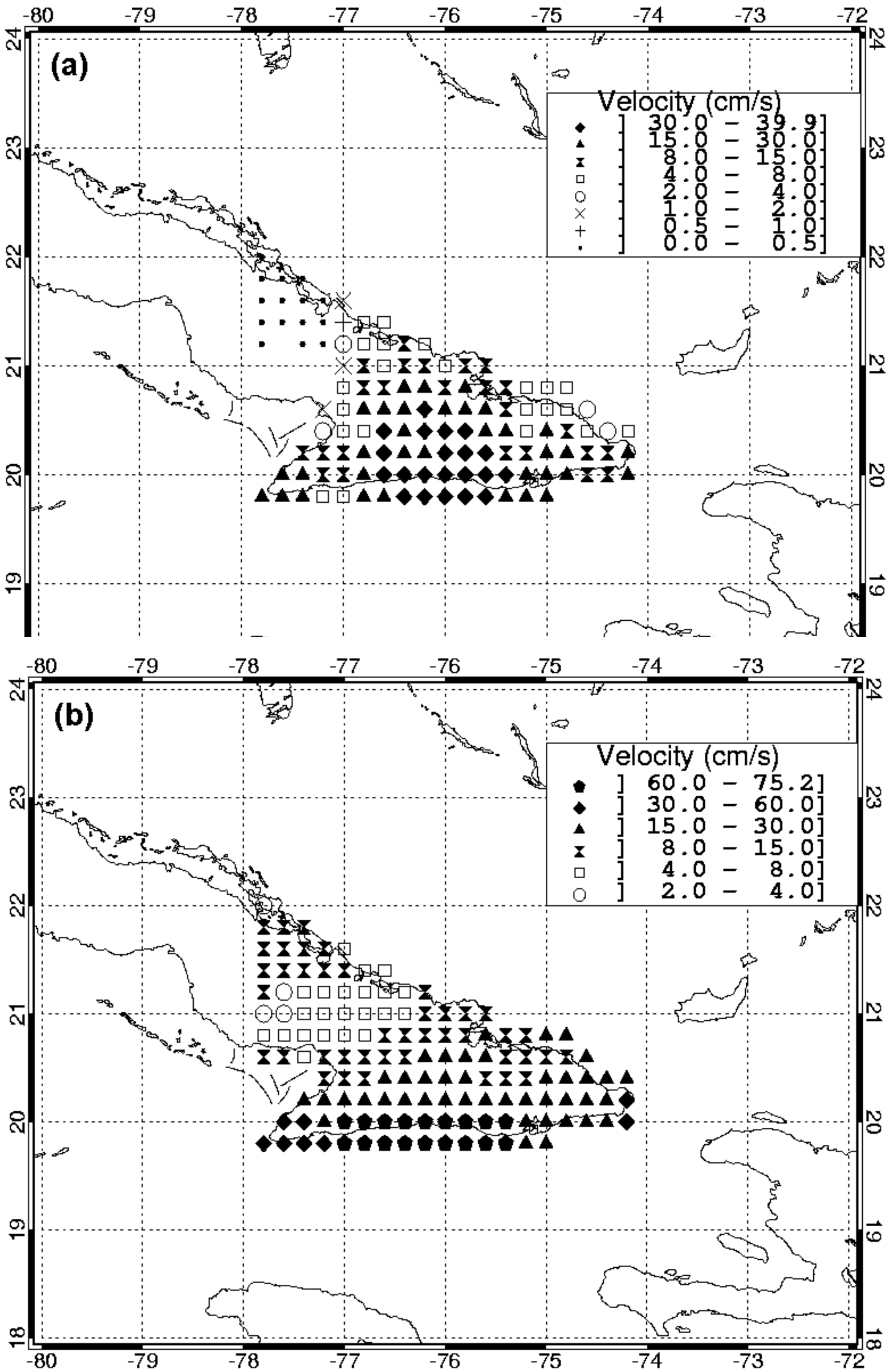


Fig. 6. Maximum expected velocity v_{max}: (a) from M_{obs}, (b) from M_{max}.



The maximum ground accelerations are observed for frequencies greater than 1 Hz, i.e. outside of the range considered; but the extension to larger frequencies can be made using standard or, if available, local response spectra (Panza et al., 1996).This suggestion is supported by the results obtained by Youngs et al. (1997) for subduction earthquakes (50-200 Km, M=6.5-8.5) and Sadigh et al. (1997) for shallow earthquakes (10-50 Km, M=5.5-7.5), on the dependence of the ratio MSV/PGA (MSV - maximum spectral value of response spectra and PGA – peak ground acceleration) with respect to magnitude and distance. These authors obtain values of MSV/PGA between 1 and 2 for periods from 0.1 to about 1 second, with an abrupt fall to values of 0.1-0.2 for periods of the order of 3 seconds. For periods between 0.8-1.2 seconds the ratio MSV/PGA varies in the range (0.7-1.2), which means that in the period range in which we compute the a_{max} values the peak ground acceleration is comparable to the maximum of the response spectra. The results obtained with the use of the design ground acceleration (DGA) as defined by new proposal of seismic building code (unpublished) are presented in Fig. 7.

DISCUSSION

As it can be seen from Fig. (5-7), there is a big difference in the estimations made for the two considered variants. This is a normal problem in low seismic activity zones. In high seismic activity regions, for which the input earthquake catalogue can be considered representative of the seismic regime, the differences between the observed seismicity and the one expected by seismotectonical considerations is generally small, sometimes of the order of the error in magnitude determination. In low activity zones, as a rule, the earthquake catalogue does not contain a good characterisation of seismicity, and for zoning purposes it is necessary to consider the possibility of activating faults that until present didn’t show any activity. Therefore our results should be considered as interval estimations: expected ground motion parameters will lie between the values obtained with the two variants, based on M_{obs} and M_{max} respectively.

We cannot obtain an empirical "first hand" correlation between maximum felt intensity, I_{max}, and "calculated by modelling" ground motion parameters, since there is not an updated map of I_{max} for the region. Nevertheless, for the studied part of Cuba, there is a recent probabilistic seismic hazard assessment (Rodríguez et al., 1999) made using the same seismic source zones and seismotectonical, M_{max}, values that we used in this paper. Rodríguez et al., (1999) processed the data with two methods, the well-known Cornell's and McGuire's approaches. From their original data, we have prepared two maps of I_{max}. For both data sets of expected I_{max}, and the ground motion parameters determined for the case of M_{max}, [I_{max}(Cornell) vs. (d_{max}, v_{max}, DGA)] (data set 1) and [I_{max}(McGuire) vs. (d_{max}, v_{max}, DGA)] (data set 2), we calculate the logarithmic average value of the ground motion corresponding to each value of the macroseismic intensity, and from these data, the regression lines **{lg(y)= a + b * I}** by least squares method. The obtained values for the parameters a and b are presented in table I. These relationships can be applied for the prediction of mean ground motion values in the intensity range from VII to X, in alternative to the Trifunac and Bradys’s (1975) ones that were applied before (e.g. Chuy and Alvarez, 1995)

Fig.7. Expected design ground acceleration (DGA) according to the new proposal of seismic building code of Cuba: (a) from M_{obs}, (b) from M_{max}.

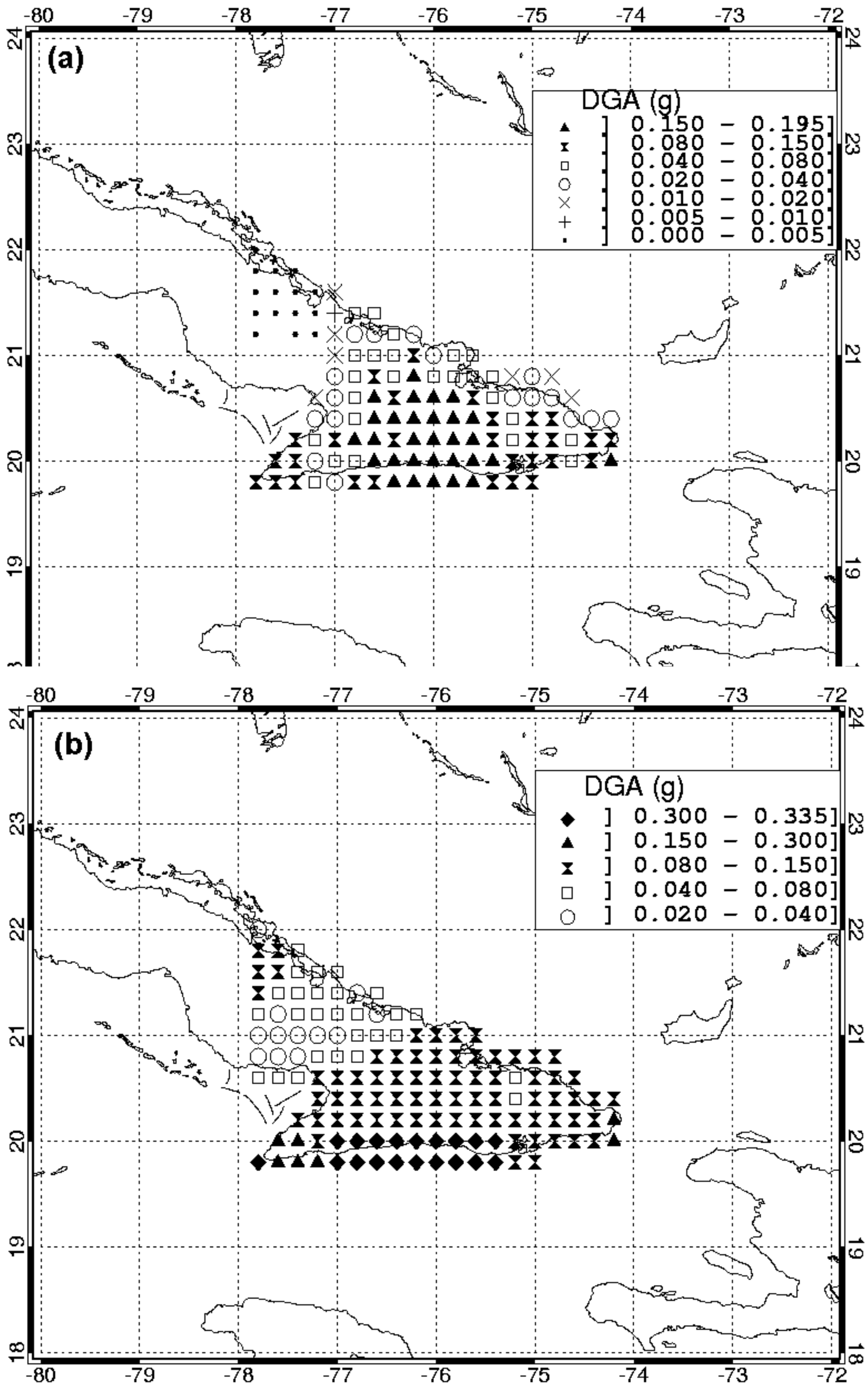


Table I. Parameters of the regression lines (d_{max}, v_{max}, DGA) vs. I_{max} for both cases.

Parameter	Data set 1		Data set 2	
	a	b	a	b
d_{max}(cm)	-1.889	0.308	-1.451	0.237
v_{max}(cm/seg)	-2.204	0.364	-2.134	0.376
DGA(cm/seg^2)	-0.980	0.365	-0.856	0.338

CONCLUSIONS

The deterministic seismic zonation of eastern Cuba is made under two alternative hypotheses:

(a) The maximum possible magnitudes of earthquakes in each seismic zone are determined by the known seismic history (M_{obs}).

(b) The maximum possible magnitudes of earthquakes in each seismic zone are determined from seismotectonical criteria (M_{max}).

The results are presented in a set of maps giving the space distribution of important mean ground motion values (d_{max}, v_{max} and DGA). Expected ground motion values will lie in the intervals defined by means of the two variants.

The ground motion values obtained in the hypothesis (b) are compared with the results of a previous probabilistic study to obtain the parameters of log-linear regressions ground motion (d_{max}, v_{max}, DGA) – intensity (I_{max}). These regressions may be used for the estimation of ground motion parameters in the intensity range from VII to X.

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