Proceedings of the 3rd International Symposium on the Analysis of Seismicity and Seismic Risk
Liblice Castle, Czchoslovakia, June 17-22, 1985

A COMPUTER PROGRAM FOR SEISMIC HAZARD ESTIMATION

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ABSTRACT

A computer program for seismic hazard estimation is described. Seismic hazard is estimated in terms of shakeability B_I and probabilistic measures of seismic shakes occurrence. The program considers an elliptical model of earthquake's isoseismal curves and a cummulative magnitude-frequency relation for earthquakes downcurved in the region of maximal magnitudes. Examples are presented for the Crimea peninsula, Eastern Carpatian Region and Eastern Cuba.

SEISMIC SHAKEABILITY AND PROBABILISTIC ESTIMATES OF SEISMIC HAZARD

The concept of seismic shakeability was introduced in seismological practice by Riznichenko (1965,1966) as an average frequency B_I of occurrence, in a given point, of seismic vibrations of any given intensity $\geq$ I. The inverse value $T_I=1/B_I$ is the return period of vibrations of intensity $\geq$I. This period may be considered equal to the mathematical expectation of the distribution of time between consecutive earthquakes of intensity $\geq$I (Riznichenko, 1979).

The seismic shakeability is calculated by means of the integral

$$B_I = \int_V N_\Sigma(M_I)dxdydz \qquad (1)$$

where: M_I - minimum magnitude of earthquakes capable to produce shakes in a given point with intensity $\geq$ I, N (M_I) - cummulative frequency of earthquake's occurrence, V - region in which are located all the seismic source zones that influence the region of interest.

For computer calculations, the depth is considered as a parameter and the integral is transformed into a summation

$$B_I = \sum_{ij} N_\Sigma(M_I)_{ij}\Delta s_{ij} \qquad (2)$$

For seismic hazard estimation a very good aproach is to evaluate the seismic shakeability integral, which gives us the average seismic hazard, and then, from these estimates, to obtain the probabilistic ones which correspond to the distribution function of time intervals between consecutive earthquakes with intensity $\geq$I, founded for this particular region.

MODEL OF ELLIPTICAL ISOSEISMALS

The estimation of M_I depends on the model used to describe the macroseismic field, i.e., the law of spatial attenuation of intensity. We used a model of elliptical isoseismals. The characteristics of that model are discussed in another paper of these proceedings (Alvarez, Chuy, these proceedings).

MAGNITUDE-FREQUENCY RELATION

A very useful representation of magnitude-frequency relation is the continuous function of distribution (Riznichenko,1960)

$$N_*(M) = 10^{a-b(M-M_o)} \qquad M_{min} \leq M \leq M_{max}$$
$$N_*(M) = 0 \qquad M > M_{max} \qquad (3)$$

where $N_*(M)dM$ is the number of earthquakes in the interval $(M,M+dM)$ normalized in time (year). By using the density function $N_*(M)$ may be obtained any integral representation of frequency of earthquake occurrence.

The frequency of earthquakes in an interval of wide M_i $(M_i-\Delta M_i/2, M_i+\Delta M_i/2)$ is the following:

$$N_i = \int_{M_i-\Delta M_i/2}^{M_i+\Delta M_i/2} N_*(M)dM = 10^{a-b(M_i-M_o)}.F(b,\Delta M_i) \qquad (4)$$

where $\qquad F(b, M_i) = (10^{b\ M_i/2} - 10^{-b\ M_i/2})/(b.\ln 10)$

Function $F(b,\Delta M)$, in a first aproximation, may be changed by ΔM.

The cummulative-frequency of earthquake occurrence is the earthquake's occurrence frequency in the interval $(M_i-\Delta M_i/2,\ M_{max}+\Delta M_{max})$

$$N_\Sigma(M_i) = \int_{M_i-\Delta M_i/2}^{M_{max}+\Delta M_{max}} N_*(M)dM = 10^{a-b(M_i-M_o)} \frac{10^{b\ M_i/2}}{b.\ln 10}(1-10^{-b(M_{max}-M_i+\Delta M_{max}+\Delta M_i/2)}) \qquad (5)$$

which represents, in a semilogarithmic scale, a downcurved line in the region of maximal magnitudes.

The normal magnitude-frequency graphic is constructed by plotting the values $(\lg(N/\Delta M),M)$, and the cummulative one by plotting the values (N_Σ,M). An example of these graphics is presented in Fig. 1.

PROGRAM SACUDIDA

Program SACUDIDA calculates the return periods T_I for elementary cells of a chart. Then, making use of the distribution function of time intervals between consecutive earthquakes with intensity $\geq I$, calculates the probability that the value I will not be exceeded in different waiting times. As a result, five kinds of seismic hazard maps may be constructed:

- maps of return periods for intensity $\geq I$
- maps of intensities for different return periods
- maps of the probability that the value of I will not be exceeded in a given waiting time
- maps of waiting times for which there is a probability p that the intensity I will not be exceeded
- maps of intrnsities that will not be exceeded with a probability p for a given waiting time

The input data are:

- map of seismic source zones (SSZ)

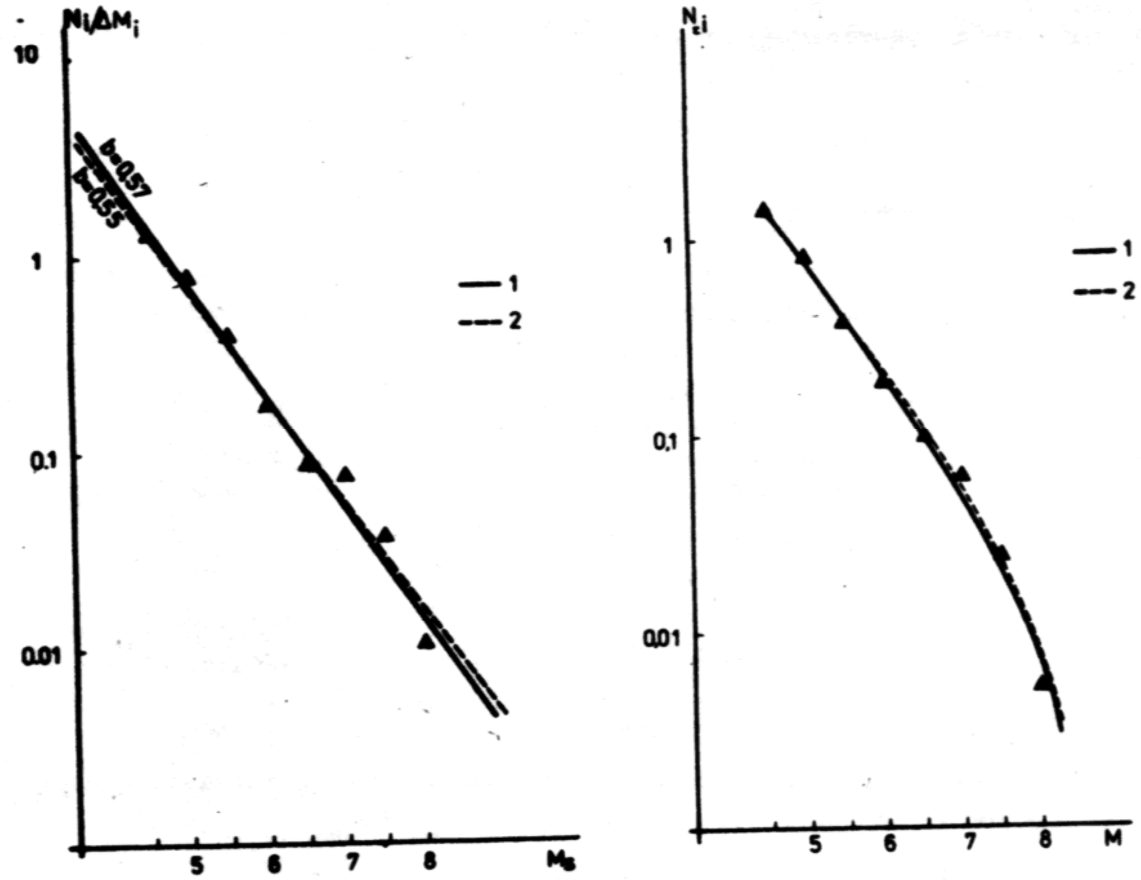


Fig. 1. Normal and cummulative magnitude-frequency graphics for the region (16°-24°N, 71°-81°W). 1 - least square fitting, 2 - maximum likelihood fitting.

- seismic regime's parameters for every SSZ: a, b and M_{max}; parameters a and b are determined from formula (4), and M_{max} should be determined by seismological, geophysical and geological considerations
- parameters of the isoseismals model for every SSZ: semiaxis relation A/B, parameters b, k, p and d from Kövesligethy's attenuation formula, direction along which is measured the effective radius in that formula, and the angle between the orientation of the SSZ and EW direction
- distribution function for time intervals between consecutive earthquakes with intensity ≥I

The program acts in the following way: All the region is divided into elementary cells. After reading initial data the value of I is fixed. For every cell of the zone of interest (ZI) the corresponding return period is calculated. The process consists in looking for the SSZ cells that may influence the given ZI cell, and to calculate the effective radius for that relative position of the cells with the corresponding value of M_I. If $M_I \leq M_{max} + \Delta M_{max}$, the cummulative frequency $N_{\Sigma}(M_I)$ is calculated. After calculation of the matrix of return periods the probabilistic estimates are performed. The process is repeated for all I values. A block-scheme of the program is presented in Fig. 2.

EXAMPLES OF PROGRAM USE

Crimea peninsula

A seismic source zone south of the peninsula with seismic regime's parame-

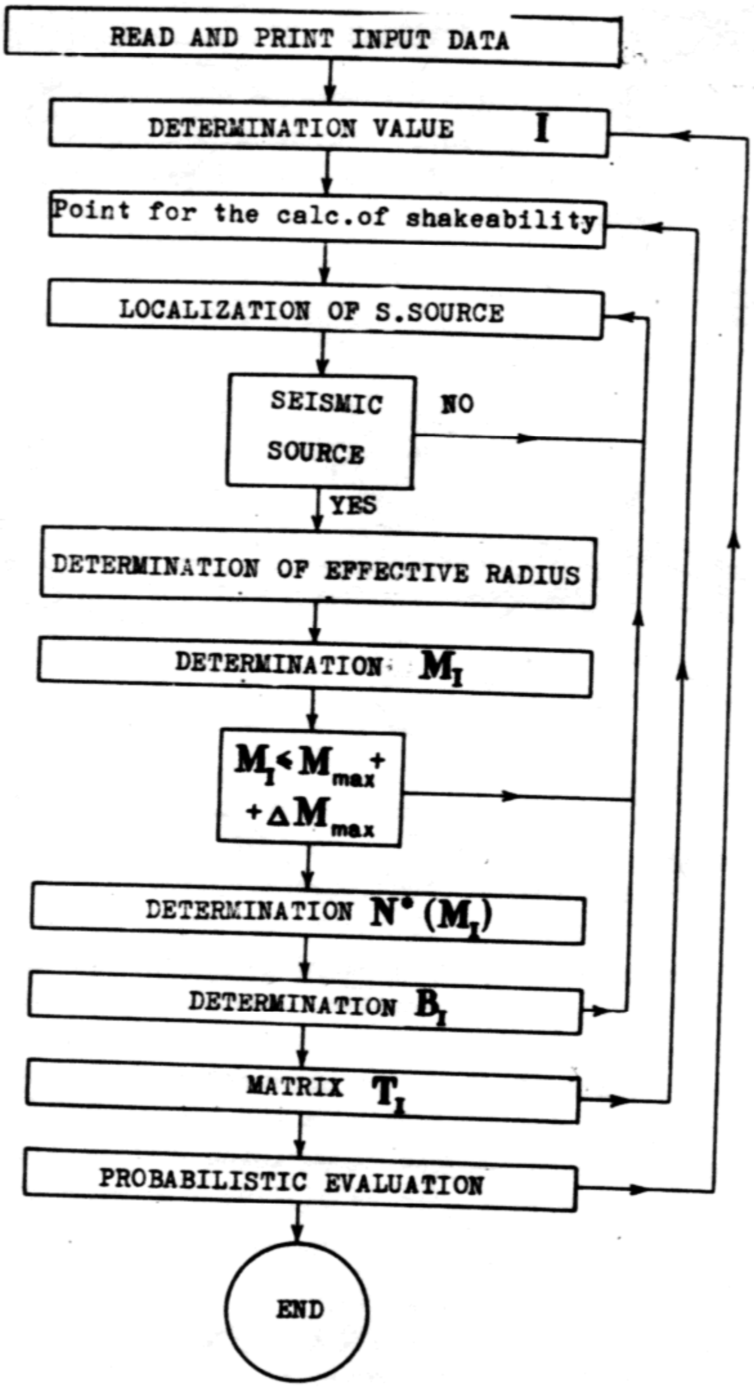


Fig. 2. Block-scheme of the program SACUDIDA.

ters N_5=0.067, b=0.59, M_{max}=7 and h=15km was only considered (Bune,Gorshkov, 1980). Circular isoseismals with parameters b=1.5, k=3.5, p=0 and d=3.0 in Kövesligethy's attenuation formula were used (Kondorskaya,Shebalin,1977). In Fig. 3 are shown the obtained maps of return periods for intensities 6, 7 and 8 with the map of seismic zoning of the USSR for this region. A good agreement was obtained between our estimates and the map of seismic zoning of the USSR.

Eastern Carpatian region.

The Vrancea deep seismic source zone with parameters N_5=0.8, b=0.87, M_{max}=7.5 and h=150km was only considered (Bune,Gorshkov,1980). A model of ellip-

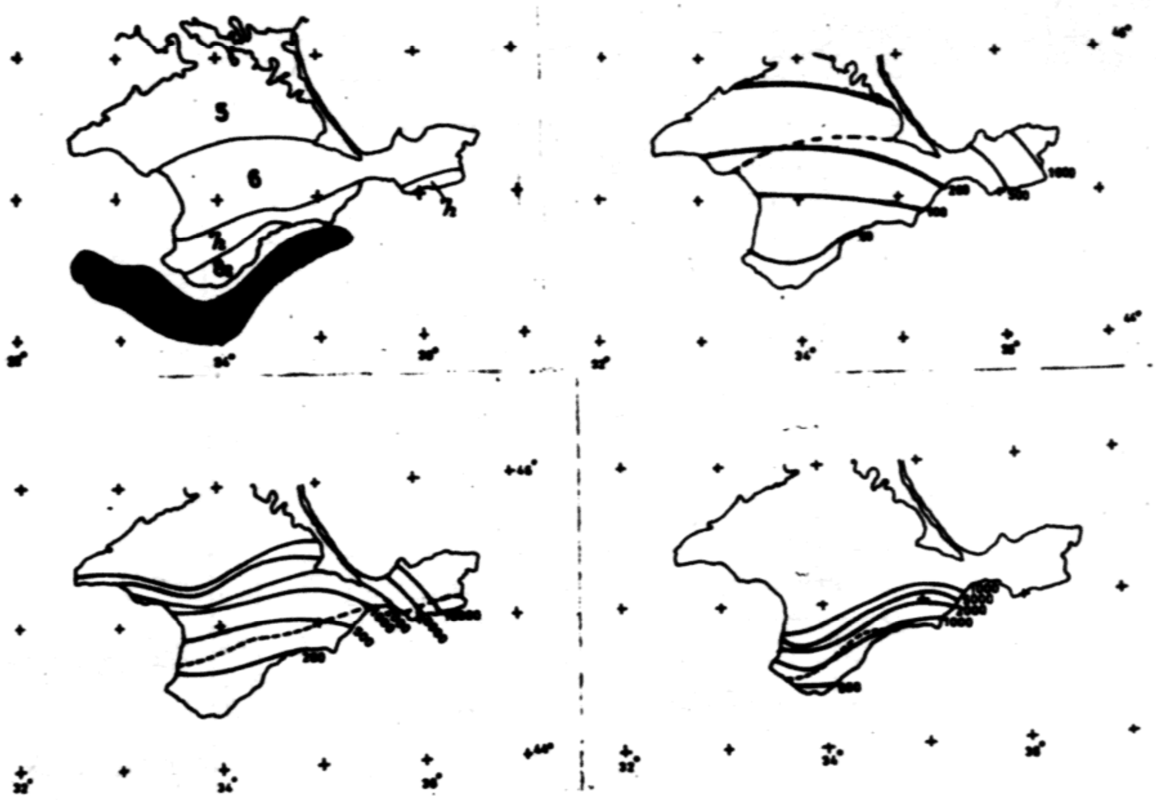


Fig. 3. Maps of calculated return periods for Crimea peninsula. For comparision is presented the map of seismic zoning of the USSR for this region (Bune,Gorshkov,1980).

tical isoseismals was used. It was obtained by reprocessing the results of Radu and Apopei (1978) for Vrancea earthquakes. Obtained model parameters are: semi-axis relation A/B=1.9, parameters of Köveligethy's attenuation formula b=1.5, k=7.4, p=0 and d=14.1, effective radius measured along great semiaxis, and direction of this semiaxis N32E. In Fig. 4 the maps of return periods for intensities 6, 7,and 8 are presented. The comparision with observed intensities in Kishiniev and Bucharest (Riznichenko et al.,1976) shows a good agreement.

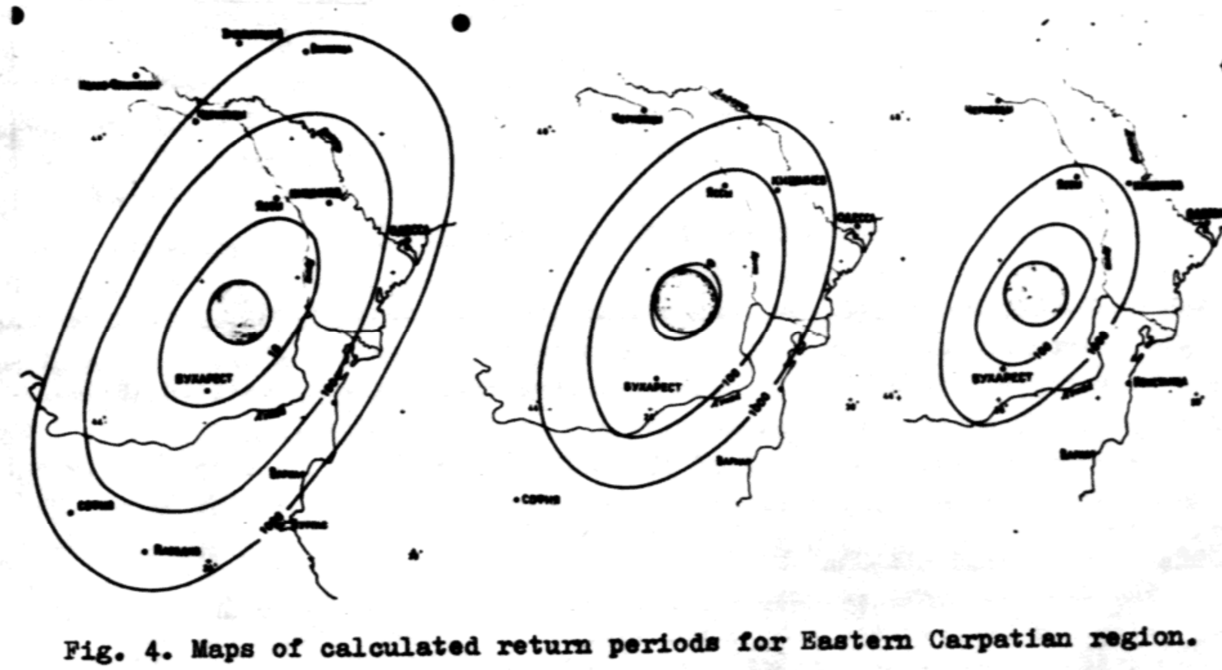


Fig. 4. Maps of calculated return periods for Eastern Carpatian region.

Eastern Cuba.

For a region limited by 16°-24° N. Lat. and 71°-81° W. Long. a catalogue of earthquakes for 1551-1981 was prepared. On a basis of epicenter maps and with the aim of some geological and geophysical information, 6 seismic source zones were delimited (Fig. 5). The parameters of seismic regime and of isoseismals model were determined for each one. It was shown that the time intervals between felt earthquakes with I 7 in Santiago de Cuba city obeys an exponential law of distribution, which corresponds to a Poissonian process of seismic shake occurrence.

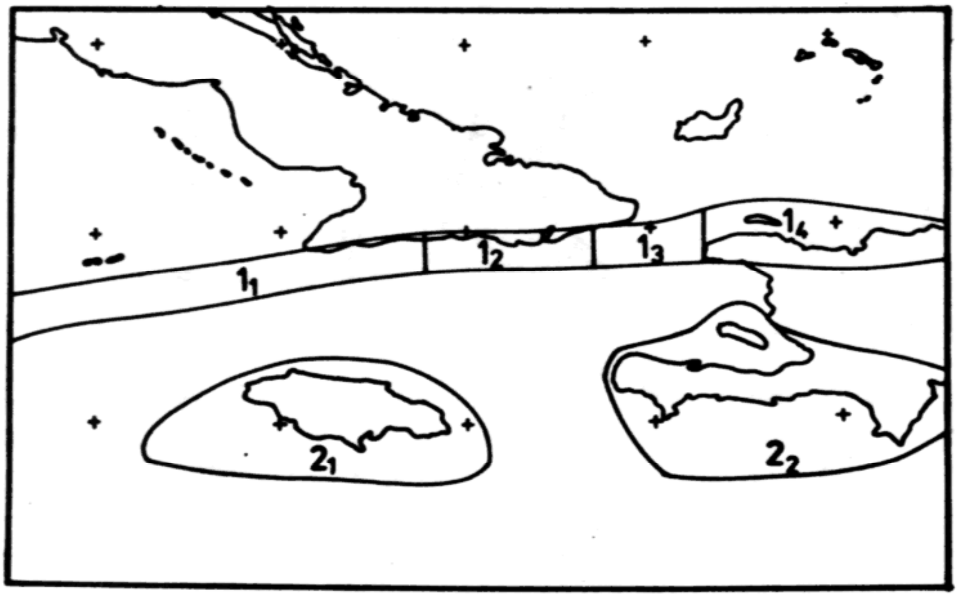


Fig. 5. Seismic source regions that affect Eastern Cuba.

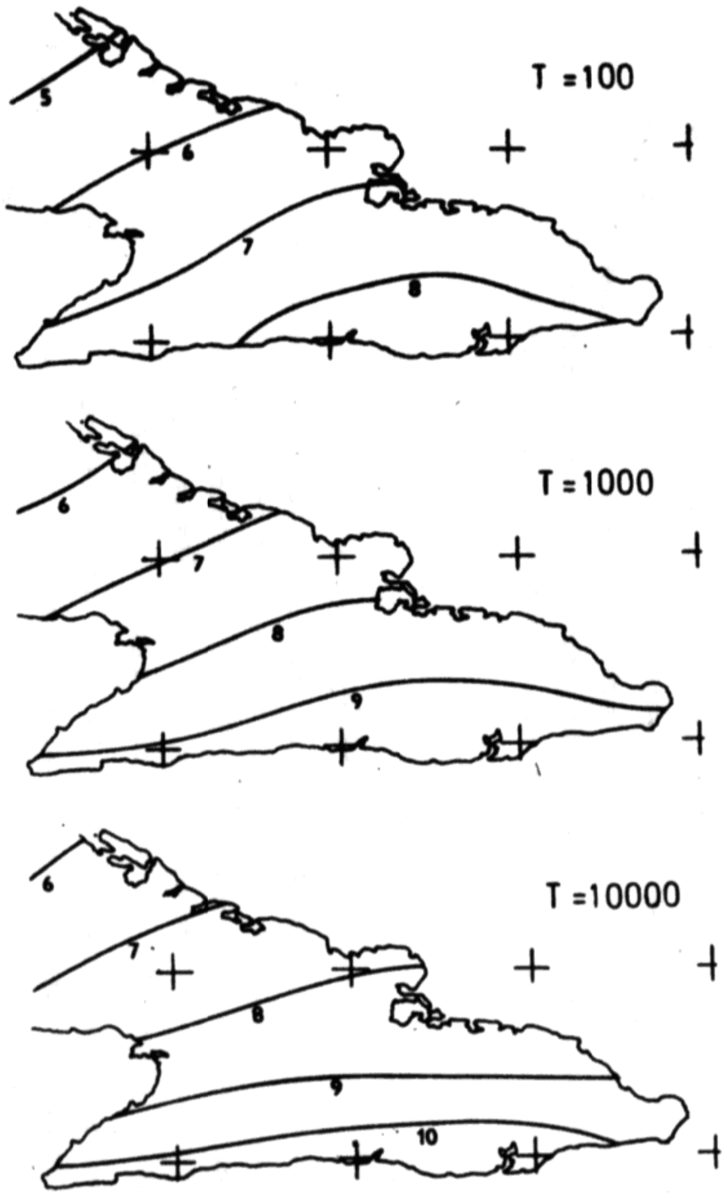
The shakeability estimates and the probabilistic ones (with the use of a Poisson's distribution) were obtained for the eastern Cuba region. In Fig. 6 maps of intensities for diferent return periods (100, 1000 and 10000 years), and maps of intensities that will not be exceeded with a probability 0.9 for different waiting times (20 and 50 years) are shown. Obtained return periods are in very good agreement with the observed ones in Santiago de Cuba City:

I	6	7	8	9	10
T_I obs.	4.5	20	72	215	-
T_I cal.	8	20	55	200	3650

FINAL CONSIDERATIONS

The described program was successfully proved in three different seismic regions. It should be very useful for regions characterized by occurrence of earthquakes with elongated elliptical isoseismals. In actual version the probabilistic estimates are made only with the Poisson's distribution, but the structure of program allows us to change easily that distribution.

Calculations were performed in terms of macroseismic intensity. But the concept of shakeability may be extended to other parameters, like the ground motinn's ones (acceleration, velocity and displacement), or, in a more complicated case, the spectral characteristics of ground oscillations (Riznichenko, Seiduzova,1984). By estimating the seismic shakeability in terms of any of these parameters it is necessary to have the corresponding spatial attenuation



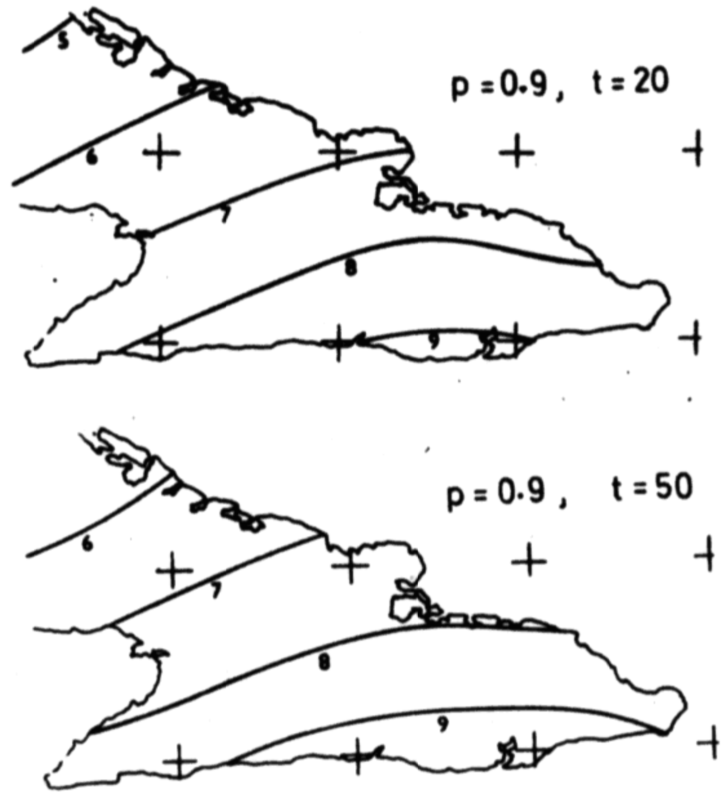


Fig. 6. Eastern Cuba. Maps of intensities for return periods of 100,1000 and 10000 years, and maps of intensities that will not be exceeded with a probability of 0.9 in waiting times of 20 and 50 years.

law. For studied by us regions there were no data to estimate the regional behaviour of attenuation laws for anyother parameter that the macroseismic intensity. Nevertheless in program is considered the shakeability estimation in terms of ground motion's parameters.

In conclussion we may affirm that the discussed characteristics of program SACUDIDA garantize its wide applicability in seismic hazard's estimation practice.

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