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Estimation of Seismicity Parameters Using a Computer

[*Raschet Parametrov Seismicheskogo Rezhima na E'VM*]

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This monograph presents the methodology for machine calculations of the main seismicity indices. It is suitable for seismic zoning and for a study of the regularity of earthquakes. The current methods of determining and plotting seismic parameters are analyzed and the rationale of switching over to machine calculation justified. A number of computer programs are included for evaluating graphs of recurring earthquakes, mapping seismic activity and maximum possible earthquakes. Also included are the examples of the use of these programs to study seismicity in Uzbekistan.

The monograph is intended for seismologists and geophysicists.

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Foreword

The quantitative indices and parameters of seismicity—the recurrence $N(K)$ of earthquakes of various magnitudes $K = \log E$ (where E—seismic energy of the focus), the spatial distribution of seismic activity A, and the maximum possible earthquake $K_{\max}$—are determined for two purposes: first, to solve problems of the general theory of the seismic process as an integral part of geodynamics; second, to qualitatively evaluate the seismic dangers for seismic zoning (delimitation) and the forecast of earthquakes.

In the present state of the development of seismology, however, seismic zoning and the establishment of long-time average indices of seismic danger happen to be the main applications of seismicity indices. This is now done not only on the basis of the old maxmium possible points but also on the new, more complete, seismic shocks—the average recurrence frequency of seismic tremors of various intensities at any given place, to the maximum possible. The intensity may be expressed in macro-seismic points, which are already considered obsolete, or in more modern spectral and time indices. The point is that knowledge of the characteristics of seismicity, $N(K)$, A and $K_{\max}$, is necessary to approximately calculate shocks whether the intensity is expressed in points or in spectral and time indices.

This book illustrates a method for the machine calculations of seismicity indices—$N(K)$, A and $K_{\max}$. The advantages of machine calculations over manual methods are well known; agitation against automation is out of place. The most important thing was to place the determination of $K_{\max}$ within the scope of machine calculation. This had been the most difficult task for manual calculation. Machine calculation also gives interpreters optimum conditions for the stable determination of this quantity where the parameters are variable. Using manual calculations the interpreters rarely had the energy or patience.

Machine calculation of seismicity indices has become especially important in view of programs developed by the Commission for the Elaboration of Qualitatively New Methods of Evaluating Seismic Danger (CESD) by the Interdepartmental Committee for Seismology and Seismological Construction (ICSSC) of the Presidium of the Academy of Sciences, USSR. This work is being done by a number of central and state organizations engaged in the problems of seismic zoning and related work in all the main seismic zones of the Soviet Union. The volume of these calculations and the necessity to standardize operations have increased recently, with the development of a new quantitative basis for seismic zoning of the USSR, and the development of seismic research during the construction of large hydroprojects in earthquake prone areas.

Programs for the machine calculation of seismic shocks have already been published. References to them are given in this monograph. However, the task of this book is to determine the feasibility of using machine calculations while interpreting actual seismological material to calculate the shocks. Since programs to determine the hypocenters and other parameters of earthquakes already exist, this book fills the last remaining gap in mechanizing seismic risk calculations arising from earthquake annals.

Besides programs for the machine calculation of seismic indices, this book provides an introduction to this problem and its study in the USSR and abroad.

It is hoped that the book will be useful to a wide range of specialists in the problems of seismicity and seismic risk. Engineers may also be interested in reading it to use the rich seismology data to design earthquake-proof structures and equipments.

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Introduction

Quantitative indices of seismicity—the so-called seismic regime parameters of one territory or another, which are necessary to delimit seismic regions—are redetermined periodically in our country using the constantly gathered data. The distribution map of expected seismic effects on the earth's surface is more accurately established in this manner. This is necessary to evaluate possible earthquake dangers for buildings and installations. Average long-term values of seismicity indices are important for seismic delimitations.

Computation of the qualitative characteristics determining the seismicity of a territory over relatively short time is necessary to reveal the temporal regularity of the seismic process. This knowledge is necessary to forecast earthquakes. Besides, investigation of the change in seismicity with time is also necessary to evaluate the correctness of the seismic delimitations map since reliable determination of the average, long-term parameters of seismicity directly depends on the seismic regime.

Recently, because of an increased volume and variety of actual data, it became necessary to use the computer in seismology. Seismologists of the USSR have written numerous programs to determine the coordinates of earthquake epicenters and hypocenters and have used them successfully. Before, the computation and areawise plotting of the qualitative characteristics of seismicity were done mainly by hand and demanded considerable time.

Programs are proposed to compute graphs of the repeatability of earthquakes, seismic activity maps, and maximum possible earthquakes. The application of these programs to determine seismic parameters in Uzbekistan shows that the computation of seismic activity maps is 5–10 times faster and that of the maximum possible earthquake is more than 10 times faster than hand calculations.

The work is divided into two parts. In the first are described the main directions of the quantitative investigation of seismicity and developments in the USSR and abroad with a short survey of the application of machine methods. In the second part, computer programs are presented which can calculate seismicity characteristics for any given period of earthquake observation. Examples are given of the calculation of seismic activity maps and maximum possible earthquakes for Uzbekistan.

The author is greatly indebted to Yu.V. Riznichenko and S.D. Vinogradov for their friendly discussions of the materials in this work; to E.M. Butovskaya and Y.U. Saatov for careful scrutiny; to L.M. Matasovaya, N.A. Ovechkinaya, and L.P. Kazachenko for help in the computation and formulation of the text.

Quantitative Investigation of Seismicity

A qualitative description of specific features of seismicity indices, particularly in relation to the geological structure and other factors, must precede the estimation of values of these indices (Riznichenko, 1960). The works of Yu.V. Riznichenko and I.L. Nersesova (1960a, b) present a history of the development of quantitative seismicity criteria and describe the main literature before 1960. Later works are partially reviewed by Yu.V. Riznichenko (1969).

This part reviews publications on the subject, mainly between 1961–1970. Special attention is given to the use of computers.

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Chapter I

Formulation of the Problem

Attempts to qualitatively express seismicity were made at the beginning of this century (Ballor, 1900). As a measure of seismicity the quantity

$$\sigma = \sqrt{F/i}, \qquad (1)$$

where i—average yearly repeatability of the earthquakes;
F—area of the region under study, was used.

The quantity σ is the length of the side of the square, in which, with uniform distribution, one earthquake would have taken place in one year. However, in such determinations, the force of the earthquakes is not considered, which leads to non-comparable results for the regions in which the earthquake's frequency and force are not even approximately proportional (Toperczer, 1953). Besides, the lower limit of the acceptable earthquake force in quantity σ remains unclear (Riznichenko, 1961).

L. Koning proposed using magnitude as the measure of seismicity (Koning, 1952).

To map seismicity many investigators used the quantity of seismic energy or its modifications. Thus M. Bath determined seismicity as the general energy emitted in unit area in unit time (Bath, 1953) and used this characteristic for Phennoskandia. V. Sponheuer determined the seismicity of the GDR using the quantity of seismic energy of earthquakes (Sponheuer, 1953). M. Toperczer (1953) chose the average sum of seismic energy S brought to the unit area as a measure of seismicity

$$S = \frac{\sum l_i}{F \cdot P}, \qquad (2)$$

where l_i—the so-called "surface energy" of earthquakes, i.e., the part of the actual energy available for observation;
F—area of the region;
P—time.

The value l_i was calculated according to the magnitude M on Richter scale in accordance with the expression:

$$1.8\, M = \log l_i/l_0, \qquad (3)$$

where l_0—the seismic energy of the standard earthquake.

Trapp (1954) used the logarithm of the surface energy as a measure of seismicity to simplify the computations and construction of maps. P. Amand (1954) expressed seismic activity of the region under study by a specific seismicity S:

$$S = \frac{K_1}{AT} \sum_A \sum_T E_i, \tag{4}$$

where A—the chosen area;

T—time of observation;

K_1—a constant depending on unit of measurement;

E_i—summation of seismic energy of all earthquake centers in the given time.

It is clear that expression (4) is very similar to (2) proposed by M. Toperczer.

W. Ullman and R. Maaz (1967) define seismicity as the density of seismic energy emitted in the region under investigation for the entire observation period. It is true that the authors complicate their definition of seismicity by proposing that it be determined in timespace points by summing the various tremors. We prefer to compute tremors of the earth's surface brought about by earthquakes at a later stage.

G.A. Shenkareva (1967) proposed to compute a map of specific seismic energy E_m (or the power of the energy flow N_m), which is understood as the energy emitted in 1 cm^3 of the earth's crust or mantle in 1 second, i.e.,

$$E_m = \frac{\sum E_i}{VT}, \tag{5}$$

where E_i—the sum of the quantity of energy (in ergs) of all earthquakes, whose centers are included in the given volume V of the core or mantle;

T—time of observation, second.

A map of specific seismic energy has been built for the USSR (Gorshkov, Shenkareva, 1970). The volume V in this is computed as the volume of a cylinder with radius $r = 50$ km and height H equal to the thickness of the earth's crust; whereas, for the focal zones in the mantles, considering the depths of the centers of the earthquakes, the value of E_m varies from 0 to 10^{-4} erg/cm$^3\cdot$sec.

I.A. Sokolova (1969, 1971) found a way to compute a map of seismic energy with a prior division of equal density zones. A graph of the dependence of the linear dimensions of the focus on the quantity K of the corresponding earthquake is built for the region under investigation. Thereafter, for each K a zone of average energy S_K is chosen, the radius of which is equal to:

$$R_K = r_K + a, \tag{6}$$

where r_K—linear dimensions of the focus;

a—the accuracy of epicenter determination at the reliability level 0.9.

The energy of each earthquake E_i is converted into density $E_K = \frac{E_i}{S_K}$, which is normalized according to time. For each K a repeatability period T_K is chosen in accordance with the graph of earthquake repeatability. Due to the small number of strong earthquakes the empirical repeatability graph is constructed theoretically. Its basis is a proposition about the normal logarithmic distribution of the linear dimensions of the focus. The energy density at any point of the map for Chatkal'skii Khrebet (spinal column) is calculated according to the formula:

$$E = \sum_{K=10}^{17} E_K,$$

where

$$E_K = \frac{10^{K-10} \cdot 1000}{S_K \cdot T_K}. \tag{7}$$

The zones of equal energy density E_K are separated by statistical methods. It is suggested that the density of seismic energy map be used to delimit the seismic region, along with maps of the seismic activity and intensity of modern tectonic movements.

H. Benioff (1951) proposed, as a measure of the temporary seismic changes, a quantity related to the released elastic strain expressed as $\sum\sqrt{E_i}$, where E_i—earthquake energy. Some investigators used it to study the spatial distribution of seismic activity. Thus, A. Ritzema (1954) related the quantity $\sum\sqrt{E_i}$ to the unit area and unit time while investigating the seismicity of Sunda-Arc, whereas, P. Amand (1956), using the Benioff's terms, proposed to measure seismicity by tectonic flow F_f from the expression

$$F_f = \frac{1}{AT} \int_A \int_T E^{1/2}\, dA dT, \tag{8}$$

entirely analogous to the application by Benioff and Ritzema.

The quantitative characteristics of seismicity most widespread in the USSR were worked out by Yu.V. Riznichenko in 1958 to understand the seismic regime, which, according to his definition, is the distribution of any region's earthquakes in space and in time. In recent years Riznichenko, Nersesov, and others have worked out methods to investigate seismic regime parameters based mainly on the instrumental observations of TKSE* (Nersesov, Riznichenko, 1959; Riznichenko, Nersesov, 1960a; Riznichenko, ed., 1960).

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The main point of the investigation of the seismic regime of any region is to explain the law of the repeatability of earthquake, i.e., the dependence between the number N of earthquakes and their seismic energy E. This dependence is expressed usually in biologarithmic scale as a linear curve:

$$\log N = \log N_0 + \gamma (K - K_0), \tag{9}$$

here $K = \log E$—the class of the earthquake energy;

$\log N_0$ and γ—coefficients of the curve (9), its level and inclination, respectively;

$(K\text{–}K_0)$—argument of the function $\log N$, its present coordinate;

K_0—the constant part of argument, representing the fixed class of energy.

It may be noticed that the first investigation about the distribution of earthquake repeatability was done by Japanese (Kawasumi, 1952, a, b; Tsuboi, 1952), seismologists using the dependence of the number of earthquakes N on their magnitude M in a form similar to (9):

$$\log N = a + bM. \tag{10}$$

V.N. Gaiskii (1970) observes that only in TKSE was the dependence between the repeatability of earthquakes of different energies subsequently used to describe and compare the seismic regimes of various areas of the seismo-active region. This was further promoted to a large extent by the earthquake energetics classification introduced by T.G. Rautian (1960, 1964) which made possible the objective construction of seismic regime. This classification uses instrumental data recordings of earthquakes, according to which energy fluxes are evaluated, which pass through the sphere of a given radius—the so-called reference sphere. This method of evaluating earthquake quantities using the energy flux of seismic waves, first proposed in 1911 by B.B. Golitsyn (1960), was adopted for the mass determination of foci energy by V.I. Bune (1955, 1956, a, b, c; 1957), who built nomograms which simplified the computations considerably. T.G. Rautian investigated methods to compute the density of the energy flux at the observation point —the relation between the total seismic energy radiated by the focus of the earthquake and the energy flux through the reference sphere, damping the density of the energy flux with distance. On this basis she worked out a practical system to determine the energetics class K of the earthquake, presenting a logarithm of the seismic energy E. T.G. Rautian's classification is now used in many seismic regions of the Soviet Union.

If in the formula of the repeatability law (9) the number of earthquakes N is normalized according to area and time, then we get $N^* \equiv A$, i.e., an expression for the seismic activity (Riznichenko, 1958). According to the definition, the seismic activity is the average number of earthquakes of a particular class of energy K which occur in unit area in unit time. The value of the seismic activity A_K may be found for any class K of earthquake energy according to the formula

$$A_K = N^*_K = 10^{-\gamma\,(K-K_0)} \cdot N_0, \tag{11}$$

which immediately arises out of (9).

Most widespread is the determination of seismic activity A according to the energy class $K = 10$, since in most seismically dangerous regions, these earthquakes are most numerous (Riznichenko, Gorbunova, 1968) and give the most promising values of A_{10}. Substituting the actual value for K in the expression (11), one gets the earthquake repeatability of various classes of seismic energy up to $K = K_{\max}$, i.e., the maximum energy class in the region of investigation. Maps of seismic activity give substantially more stable pictures of seismicity distribution along the area, than maps of totaled or specific energies, which are mainly dependent on powerful but rare earthquakes. From seismic activity maps one may pass on to the maps of the repeatability of earthquakes of any class K, even the greatest possible. Thus the maps of earthquake repeatability are constructed from $K = 15$ for Fergana valley and the River Narin basin (Nersesov and others, 1960, Butovskaya and others, 1961).

The repeatability period T_K is computed in accordance with the expression

$$T_K = \frac{S_1 \cdot 10^{(K-K_0)}}{S \cdot 10^{-\gamma} A_K}, \tag{12}$$

where S—area of the territory investigated;

S_1—unit of area, for which the seismic activity A_K is normalized.

The law of earthquake repeatability (9) is defined by three main parameters of the seismic regime, which may be used to quantitatively describe the seismicity of any territory: the inclination γ of the curve of repeatability, seismic activity A, and the maximum earthquake $K_{\max}$. The determination of these parameters of the seismic regions of the Soviet Union and its other isolated areas have been logged by many investigators, e.g., while conducting experiments on the seismic region delimitation of the USSR (Medvedev, ed., 1968).

While studying the seismicity of active zones of the Soviet Union, a tendency was noticed toward associating epicenters of strong earthquakes with zones of increased seismic activity (Riznichenko, 1962, 1964b). A correlation was made showing a dependence between the value observed in strong earthquakes and the value of activity computed at the peaks of its epicenters (Yu.V. Riznichenko, 1966, 1967a). Establishing the correlational dependence shows it is possible to estimate the quantity of maximum earthquakes $K_{\max}$ at any point under investigation according to the level of seismicity, independent of whether or not any strong earthquake had occurred there.

Distribution of the quantity $K_{\max}$ according to the territory may be shown as a map of the maximum possible earthquakes, first prepared for Eastern Sayan and Jungariya (Riznichenko, 1966) according to the relation:

$$\log \bar{A} = \alpha + \beta\,(K_{\max} - K_\alpha), \tag{13}$$

where $\bar{A}$—average seismic activity;

K_α—15;

α and β—numerical coefficients in which $\alpha = 2.84$; $\beta = 0.21$.

The quantity $\bar{A}$ in the formula (13) is calculated for some area responsible for the generation of strong earthquakes. Its dimensions are in accordance with the quantity of energy $E_{\max}$ emitted in the focus and are proportional to the volume of the region and its formation

$$E_{\max} = 10^{K_{\max}} = cr^3, \tag{14}$$

where r—radius of this region;

c—proportionality coefficient $= 3 \times 10^{10}$ J/km^3.

Later maps of $K_{\max}$ by the Riznichenko's method were compiled for many areas of the USSR and beyond its boundaries (see Chapter IV).

Thus, until the present time, the quantitative evaluation of seismicity took two main directions (Riznichenko, 1969). In the USSR, Europe, China, and India, the seismicity of isolated regions, and often of an entire territory under consideration, was mapped by seismic activity A. Earthquake repeatability was investigated in space as well as time. In many regions of the Soviet Union, a new method of compiling a maximum possible earthquakes $K_{\max}$ map, as proposed by Riznichenko, is now being successfully assimilated (1962, 1964b, 1967a).

Foreign authors, particularly in America and Japan, formerly expressed seismicity either as a summation of the quantity of seismic energy $\sum E$ emitted by the foci in unit area of the region in unit time or as the quantity of Benioff stress release, presented as the sum of the square roots from the seismic energy of the foci $\sum E^{1/2}$. Besides, here is investigated the spatial distribution of the number of earthquakes along the magnitude M (Miyamura, 1969). Mapping the quantities $\sum E$ and $\sum E^{1/2}$ and often also the earthquake distribution along M is carried out by computer. We present here one of the investigations on the law of the repeatability of earthquakes, carried out by H. Neunhöfer without a computer.

The representation of the law of distribution of the number of earthquakes according to their energies in the double logarithmic scale for an approximation of a straight line is being practiced in the USSR (Riznichenko, 1958). H. Neunhöfer (1970) considers that such a representation does not give a true picture of the seismic process and suggests a logarithmic distribution normal for its representation. This representation has the form:

$$n_i = \frac{N}{\varphi E_0 \sigma \sqrt{2\pi}} \exp \left\{ - \frac{\ln^2 E_i/E_0}{2\sigma^2} \right\}, \tag{15}$$

where n_i—frequency of representation of energy $E_i \pm 1/2\ (\Delta E_i)$;

$\ln E_0$—indirect measure of the application of maximum repetition frequency of these earthquakes;

N—common energy in ergs of all earthquakes in the theoretical distribution (here the elementary volume in 10^5 km^3 and time of 1 year is connected);

φ—normalized factor for conducting the quantity of energetic classes and observation times in the corresponding units;

σ—parameter of distribution.

The distribution of earthquakes in the various epicentral zones for various time periods is calculated according to formula (15). In all cases, it is established that the form of the distribution curve depends on the parameter N, which is the common sum of the energies of all earthquakes taking place in the epicentral region under investigation in unit volume and unit time. Thus, the law of the distribution of earthquakes according to their energies can be reduced to obtain specific energy. The quantity of the total energy of earthquakes is insufficiently stable to represent long-term or transient maps of earthquake distribution in the region under study. It depends on rare, strong earthquakes and is entirely determined by their energies.

In all probability the quantity of seismic activity A happens to be the most promising index of the long-term mean distribution of seismicity. As compared to $\sum E$ or $\sum E^{1/2}$, it changes to a lesser extent with time. According to Riznichenko's data (1969) obtained from investigations of the mean yearly values of the quantities A, $\sum E$, and $\sum E^{1/2}$ for the crustal foci of the Baikal Rift region during 1961–1966, Tajikistan during 1956–1966, and also the deep foci of Pamir-Hindukush, 1956–1965, the quantity of $\sum E^{1/2}$ fluctuates about the mean 2–3 times and $\sum E$—10 times more than A.

Until now the discussion was on the spatial distribution of seismicity, although along with it also developed the time aspect of the investigation of earthquakes. V.N. Gaiskii (1970), using probability theory and mathematical statistics, investigated the general properties of the seismic field and established necessary parameters or functions for its quasi uniformity. These are the temporal and quantitative distribution of earthquakes and maps of seismic activity. The seismic regime of crust and deep-focus earthquakes was investigated by instrumental observations in Tajikistan and Pamir-Hindukush.

Quantitative methods to evaluate seismic danger according to data of focal seismicity are now being widely used in the USSR (Riznichenko). The basis of this evaluation is to calculate the frequency of seismic tremor repetitions (Riznichenko, 1965, 1966, 1968, 1969, 1970, 1971). The problems of the distribution of tremors at a point under investigation as functions of earthquake energy and on the earth's surface depending on epicentral distance and damping of seismic waves were investigated long ago. Thus, Ishimoto and Iida (1939) established the law of the distribution of the number of tremors according to the maximum amplitude of recording in the form:

$$N(a)\,da = k\cdot a^{-m}\,da, \tag{16}$$

where a—amplitude of recording;

$N(a)$—number of earthquakes with the amplitudes of recording between a and da;

m and k—constant values.

S.V. Medvedev, remembering the surface effect, proposed that seismic delimitation should consider not only the earthquake's possible maximum force but also the frequency of its repetition. For this purpose, the seismic region was divided into different activity zones for different points—high, medium, and low—according to the expected repeatability through 10–15, 40–60 and 120–150 years (Medvedev, 1947). According to this classification, buildings, in terms of their longevity, are classified as temporary, massive and monumental. It may be noted here that the understanding of seismic activity expresses the repeatability effect of earthquakes of a certain force independent of its energies. Somewhat later (Riznichenko, 1958) seismic activity was called the frequency of earthquake repetitions of a certain energy class independent of their surface effect, referred to unit area. This definition was accepted by seismologists of the Soviet Union. In 1948–1949, S.V. Medvedev (1949) used his method to evaluate seismic danger in Moldavia. For this purpose, separate seismo-statistical maps were compiled for 6-, 7-, 8-, and 9-point earthquakes, on which were superimposed isoseists of the same point value, referring to all known earthquakes. Each isoline on the map represented one earthquake, e.g., an area limited by this 6th-point earthquake isoline was considered a 6th-point type, independent of the presence here of higher seismic point values (7, 8, 9 points). Thus, for the specific region the frequency of earthquakes with the intensity under consideration or higher was estimated. To determine the frequency of earthquakes of nth point, at a given point a summation was given of the number of earthquakes of nth as well as higher point values occurring here. The delimitation map of Moldavia prepared by Medvedev had three isolines for each point, e.g., 6H, 6M, and 6L (the letters mean high, medium, and low activity, expressing the repeatability of 6-point earthquakes through 10–15, 40–60 and 120–150 years). Thus, Medvedev attempted a direct computation of Moldavia's shakeability according to the number of tremors of various forces, depending on strong earthquakes taking place there. Computing the repeatability of tremors allows a differentiated evaluation of the seismic danger; whereas, in the usual delimiting practically all points of the area transferred to one point are considered equally dangerous. Besides, it is possible to determine more correctly the necessary and minimum degree of seismic protection for various classes of constructions and to consider repeated seismic actions. It is regrettable that the application of Medvedev's method is limited due to its use of data about strong but rare earthquakes; their limited data does not permit the necessary detailed, direct calculations of shocks in large areas (Riznichenko, 1969). Apparently, therefore, seismostatistical maps which used the frequency of previous earthquakes of different forces did not develop. Thus, on the seismic delimitation map of the USSR for 1957 (Medvedev, 1960) only the boundaries of regions with expected surface tremors are shown in points. It is true that Medvedev indicated the limitations of his method: (1) the absence of the time factor and the evaluation of the probability of earthquakes of a given force for each point; (2) the absence of regional differentiation according to the spectral condition of the earth's oscillations and also along the depth of the foci bedding and the mechanism of the earthquake. However, the repetition periods of corresponding tremors and other necessary characteristics were also not shown on the latest seismic delimitation map (Medvedev, ed., 1968).

M. Toperczer (1953) made one of the first attempts to evaluate the probability of the appearance of destructive earthquakes in a region under consideration. He proposed a measure, the so-called relative seismicity S of the region, connected it with the seismic action W, equal to the product of the scale points I in the epicenter by the area f_j of the region undergoing tremors:

$$W = I f_j. \tag{17}$$

If during the observation period P on the surface F, n earthquakes took place, then the relative seismicity S is expressed by the formula:

$$S = \frac{\sum_1^n W}{F \cdot P}. \tag{18}$$

If an area F is sectioned into basic areas f_{ik}, a quantity S_{ik} can be defined for each—the surface density of the seismicity. Besides, it is possible to compute the frequency of tremors n_{ik} for angular points for the period under observation and the sum $\sum f_{ik}$ which shows the intensity of each separate tremor and the distribution of its force in the area. Toperczer also proposes to evaluate seismic danger by the probability that a destructive earthquake may take place in a given region during a given time interval. Thus, since the main values of the region's seismicity are only strong earthquake foci, all surrounding territories with no strong earthquakes would be considered non-seismic, irrespective of whether or not tremors of various strengths reach there. Seismic danger here would seem minimal, according to the calculation. This may not be the actual condition of the area, as regions without their own foci may have very strong tremors due to the seismic activity of adjoining territories.

V.I. Keilis-Borok, I.L. Nersesov and A.M. Yaglom (1962) considered the economical problems connected to shocks. First, they computed the number of tremors of different values released by the earthquakes with epicenters beyond its limits for each basic area and then added tremors from the foci within it. Such an approximate computation of the number of tremors, it appears, is actually not correct, since shocks are related not to the area but to each separate point (Riznichenko, 1969).

The first general solution to the computation of shocks was found by Riznichenko (1965) who later (1968) described it in detail.

Shocks B_I is the mean frequency of the repetition of tremors of a given intensity I at a given point, to the maximum possible intensity. These tremors result from activity from close and far earthquake foci, i.e., all foci producing tremors with the intensity I at the point under investigation. Thus, when calculating the shocks, it is necessary to consider the total action of the tremors, and therefore, the mention of the total shock B_I, representing the seismic effect on the surface. Its computation is carried out on the basis of given earthquake foci in accordance with the expression:

$$B_{\Sigma_I} = \iiint\limits_{V} N_{\Sigma_I}\, dx \cdot dy \cdot dz, \tag{19}$$

where N_{Σ_I}—transferred to the unit time and volume, the total number of earthquakes with hypocenters in the elementary volume $V = dx \cdot dy \cdot dz$, which at this point cause tremors of intensity I and above. Integration is extended to the entire volume of the region where the earthquake foci are met (Riznichenko, 1966).

When the law of earthquake repeatability is established in the following form:

$$N = A \cdot 10^{-\gamma\,(K-K_0)}, \tag{20}$$

where N—mean number of earthquakes in the energy class $K \pm 0.5$ and on the unit space and time;
A—seismic activity, i.e., spatial density of the earthquakes of a given class of energy;
γ—inclination of the curve of repeatability;
K_0—fixed quantity of the energy class of the earthquake to which the seismic activity definition is related.

In formula (19), the following expression is obtained for the total shocks

$$B_{\Sigma_I} = \frac{1}{10^{0\cdot5\gamma} - 10^{-0\cdot5\gamma}} \iint\limits_S A \left[10^{-\gamma(K_1 - K_0)} - 10^{-\gamma(K_{\max} - K_0)} \right] dS, \tag{21}$$

where S—area surrounding the point of the region with epicenters in all basic areas—$dS = r_0\, dr \cdot d\alpha$, existing on the various hypocentral distances $r = \sqrt{r_0^2 + h^2}$ and in various azimuths α from this point;

r_0—epicentral distance;

h—mean foci depth which explains the change in formula (19) from triple to double integral;

K_I—index of the seismic energy degree emitted in the focus, resulting in tremors of the given intensity I and higher at the point under consideration;

$K_{\max}$—maximum possible earthquake on area dS.

Shocks may be computed for seismic tremor intensity expressed in any form, e.g., in the density of earthquake energy flux (Riznichenko and others, 1967, 1971a), or in points of standard seismic scale (Riznichenko and others, 1969, 1970). In both cases formula (21) may be used initially, in which the quantity K_I is expressed in accordance with the accepted intensity. [If tremor intensity I is expressed by the density Ξ of the seismic energy flux then the law of damping of Ξ with distance r, is used in the form

$$\log \Xi = \log \Xi_R - n\,(\log r - \log R), \tag{22}$$

where Ξ_R—density of the energy flux on the reference sphere with radius R;

n—damping coefficient of the energy flux density with the hypocentral distance r;

Ξ—density of the seismic energy flux, i.e., the energy flux arriving on 1 km² at the observation point.

For K_I, in the formula (22), the following expression may be brought in:

$$10^{K_1} = 4\pi R^2 \left(\frac{r}{R}\right)^n \cdot \Xi. \tag{23}$$

Putting in expression (21), the value of K_I from (23), and changing the integration to machine summation, one gets the computed shakeability formula B_{Σ_Ξ} in the final form

$$B_{\Sigma_\Xi} = \sum_S A \frac{\left\{ \left[4\pi R^2 \left(\frac{r}{R}\right)^n \cdot \Xi \right]^{-\gamma} - \left(10^{K_{\max}}\right)^{-\gamma} \right\} \cdot 10^{\gamma \cdot K_0}}{10^{0\cdot5\gamma} - 10^{-0\cdot5\gamma}}\, \Delta S. \tag{24}$$

The double integral along variable r and α is replaced by one summation, since the change in the tremor intensity is now considered dependent on distance only.

The given value of the density Ξ of the seismic energy flux during calculations for a shock map of Eastern Uzbekistan (Riznichenko and others, 1967; Zakharova, Seiduzova, 1969) was changed to approximate points. For this was used the relation between the energy flux density and value of points obtained by Nersesov and others (1960). Here, the term point value means the point value I_0 in the epicenters of strong earthquakes.

It is evident, that it is not entirely correct to use the relations between the quantities Ξ and I_0 to evaluate tremors according to point values at observation points any distance from the epicenter. Therefore, it was important to construct maps of shocks of the same intensity territory expressed immediately in points.

To determine the value K_1 in formula (21), one may use the law of damping point values with distance, as obtained by N.V. Shebalin (1968):

$$bM - I = S \log r - C, \tag{25}$$

where b, S, and C are coefficients.

Expressing the magnitude M through the energy class K_1 according to the formula

$$K_1 = pM + q, \tag{26}$$

where p and q—coefficeints, one gets the following expression for K_1:

$$10^{K_1} = r^{\frac{SP}{b}} \cdot 10^{q - \frac{cP}{b}} \cdot 10^{\frac{P}{b} \cdot I}. \tag{27}$$

Putting the value of K_1 from (27) in (21) one gets the computed formula for shocks B_{Ξ_I}:

$$B_{\Xi_I} = \sum A \frac{\left\{ \left[10^{q - \frac{cP}{b}} \cdot r^{\frac{SP}{b}} \cdot 10^{\frac{P}{b} \cdot I} \right]^{-\gamma} - (10^{K_{\max}})^{-\gamma} \right\} 10^{\gamma \cdot K_0}}{10^{0.5\gamma} - 10^{-0.5\gamma}} \cdot \Delta S. \tag{28}$$

With the given formulas one may compute the shocks for any earthquake distribution according to quantity and for any distribution of intensity around the epicenter (Riznichenko, 1966). At the present time maps of shock waves are computed by assuming the linearity of the curve of earthquake repeatability and the circular form of isoseists. The initial material for the computations are: the map of seismic activity A, the mean depth h of the foci of earthquakes, the inclination of the curve of repeatability γ, the map of maximum possible earthquakes $K_{\max}$, and the law of damping seismic intensity with distance. Since maps of shock waves are computed by computer, proofs about the computer programs and their results in the territory investigated are given in the next part.

The illustrated method of computing maps of seismic shocks makes it possible to quantitatively evaluate seismic danger, having added to the determined intensity of the tremors in the studied zone, e.g., in points and also the frequency of their repetition. While transferring the map of shocks to a given interval of time it may be possible to compute the probability of seismic dangers. Thus the main deficiency of existing seismic delimitation methods noticed by Medvedev (1960) is avoided—the absence of a time factor and the evaluation for each point of the probability of earthquakes of a given force.

Further development of the Riznichenko's method suggests that the intensity of the seismic effect be expressed in spectral-temporal frame (Riznichenko, 1970, 1971). Then one may also remove the other deficiency of the existing method of seismic delimitation—the absence of regional differentiation according to the spectral nature of the earth's oscillations.

Chapter II

Use of the Computer to Quantitatively Investigate Seismicity

All the above methods use as initial data information about the occurrence of earthquakes of various energies in the region under investigation to determine quantitative seismicity features. To construct a repeatability curve, one should limit the information about earthquake energy and its effect in the territory. Also, to construct a map of seismic activity or the maximum possible earthquakes, it is necessary to know their spatial or area distribution, i.e., to have a map of epicenters. This is related also to the methods of registering seismicity accepted abroad. Mapping either as units of the density of total seismic energy or as stress release (seismic flow) demands knowledge about the places of the emission of earthquake's energy.

Thus the quantitative investigation of seismicity in any region should begin by establishing the foci coordinates of local earthquakes. Because of the necessity of this step, it seems, computer methods in seismology were developed.

One of the first programs was for a IBM-704 (Bolt, 1960 a, b), to correct the hypocenter coordinates and times of emergence, which were computed by hand and stated as first estimates. The problem was solved with information about the minimum differences between the observed times of the appearance of waves P, PKP, and ρP (for deep points) and calculated by the Jeffreys-Bullen hodograph. The least squares method was used, along with right-angled coordinates and observations from more than 50 seismic stations, each of which was weighted in accordance with the seismic wave time discrepancies. In the final results, corrections were introduced for the earth's ellipticity. In 1961 B. Bolt wrote a new program for the IBM-709 and IBM-7090 in which, besides finding the location of the epicenters, the seismic wave hodograph was corrected (Bolt, 1961). To Bolt's program, accepted for assessing earthquake parameters by the Coast and Geodetic Survey of the USA, was added an initial search for the hypocenter coordinates according to data from five seismic stations. The program was written for the IBM-650 (Gunst, Brazee, 1962) and envisaged eliminating transit times of seismic stations with large discrepancies from further computations.

The subsequent program (Gunst, Engdahl, 1962) was divided in two parts. First the data was grouped by hand to determine the hypocenters and about 15% of the descriptive data was discarded; two-fifths of the stations were chosen along two initial hypocenter approximations, one of which was usually required for further computations. The second part of the program automatically found the hypocenter coordinates as well as the emergence time of the focus and station residual. The depth of the focus was located without confidence, especially when no data existed closer than 20°. With observations from not less than 50 stations the accuracy of the epicenters was 0.1° whereas, the focus depth was ± 25 km. Later, the first part of the program was also automated (Engdahl, Gunst, 1966). To select coordinated data, the times were compared by pairs to get the arrival of the longitudinal waves at various stations. If their difference was more than the time of run between them, they were considered nonconcurrent and discarded by the computer. As a theoretical base the Jeffreys-Bullen hodograph was used, the experimental data were presented by the arrival time of the *P* and *PKP* waves. The first approximation was determined from five stations and corrections were introduced concerning the height of each and the ellipticity of earth. Besides the hypocenter coordinates, the program determined azimuths, epicentral distances, magnitudes, and corrections to the hodograph.

In 1962, a program was written to determine earthquake hypocenters on the UNIVAC 1103 (Herrin, Taggart, Brown, 1962) according to data from 200 seismic stations. Its main difference from the Bolt program was the determination of time discrepancies, in which corrections are introduced for the absolute height of the station and ellipticity of earth. The accuracy of the epicenter determination found from four nuclear explosions, was 2.5–7 km and that of the focus depth from waves was 3–16 km. According to nuclear explosion and earthquake data in the USA, the regional changes in the velocities of *Pn* waves were investigated and, as a result, a map was constructed showing *Pn* velocities from 7.6–8.1 km/sec for the western part of the country and 8.1–8.4 km/sec for the eastern. This *Pn* velocities map was used to prepare a new program to determine earthquake epicenters, increasing the computation accuracy considerably (Herrin, Taggart, 1962). For example, the calculation of the focus location of a nuclear explosion (Herrin, Taggart, 1966) showed that, using data from 91 stations, taking into account regional and station corrections, the coordinates were determined ten times more accurately.

A program to determine the epicenter coordinates of remote earthquakes by an analytical method was written for the IBM-704 (Ullmann, Maaz, 1964). It was a solution of the spherical triangles system. Each determines one possible value of the epicenter coordinates, whereas, the most probable of their values is found by computing the weighted mean (average).

The above programs were meant for analyzing remote earthquakes. The method to determine epicenter coordinates of close earthquakes was first proposed by Flinn (1960). The program to determine coordinates of hypocenter and time of emergence of the focus of close earthquakes was worked out for a station network at a Pasadena laboratory (Nordquist, 1962). The arrival time of the direct and two head waves, recorded by not more than 24 stations, was entered in the computers. Hodographs were computed for a three-layer model of the earth's crust with the focus lying above a basalt layer. The hypocenter was found by the least squares method, in which the observation weight depended on the residual. Uniform distribution of stations in the azimuth relative to its position is necessary to accurately determine the epicenter; whereas, for the focus depth each quadrant of stations must be sufficiently distant to record the direct and head waves. The main drawback of the program is the absence of a hodograph for foci below the Konrad boundary and the limited initial data (not more than 24 stations).

The program (Nordquist, Gardner, 1963) was meant to determine the epicentral coordinates and emergence time of the focus of southern California earthquakes. Approximate epicenter coordinates, emergence of the focus, and the arrival time of not less than six phases of longitudinal and transverse waves for the closer stations were entered in the computer. This program proposed a two-layer section of the earth's crust. Corrections to the first estimates were made by the method of least squares.

The Cisternas program (1963) was designed for the Benuiks G-15. It used a two-layer section and longitudinal wave travel time, corrected for the structure of the earth's crust. The accuracy of the coordinates determination was 1–3 km.

Arrival times of the direct longitudinal and transverse waves not more than 200 km from the epicenter, were used as initial data in the program to determine close earthquakes in southeast Australia (Cleary, Doyle, 1962). The depth of the focus was not determined—the main drawback of this program. The program to analyze local earthquakes recorded by eight seismic stations in Nevada (Ryall, Jones, 1964) was prepared for the IBM-1620. The arrival times of P and S waves were entered in chronological order. Here the arrival of the transverse wave was used only to eliminate earthquakes taking place outside the area under investigation. The program also excluded earthquake data registered by less than three stations. The choice of the initial estimate of the epicentral coordinates was made by comparing the observed differences of the P waves and the timings for three pairs of stations with tables stored in the computer memory. These were then computed for the given model of the earth's crust for epicenters at the corners of a right-angled grid for every 50 km. Thereafter the position of the epicenter was made more accurate by the method of least squares according to all available data about the arrival times of the P waves. This correction used a model of the crust with a layer boundary inclination found by the refracted waves method. In this program as in the previous one, the depth of the focus was not established.

A program to determine the hypocenters of Japanese local earthquakes (Aki, 1965a) gives the time the *P* and *S* waves first arrive at the station and an initial estimate of the focus. These are corrected by the least squares method, in which the theoretical time of arrival is computed along the two-layer section. Inside the section layer the propagation velocity of the elastic waves is varied according to Bullen's step rule. After determining the hypocenter, the emission angles of the seismic rays from the focus are computed. These are necessary to study the earthquake's dynamic parameters. A computer evaluation of the accuracy of the hypocenter positions (Aki, 1965b) showed that there were many errors in the times of emergence of the focus and its depth. With a sufficient number of observational stations these errors are insignificant when determining the coordinates of epicenters.

Seismic observations were automated by the Japanese meteorological agency in the following manner (Ichikawa, 1965): using the hand measured times of the first arrivals of *P* and *S* wave groups, recorded by agency stations, a first estimate of the coordinates of the epicenter and time of emergence of the focus were determined by computers. Thereafter, using the method of least squares the epicenter and the time in the focus were found by successive estimates leading to the minimum mean square residual time of the arrival of *P* and *S*. The magnitude of the earthquake *M* is determined on the computer first for each station from the hand calculated maximum amplitudes of *P* and *S* waves (using Tsuboi's formula) and then the average value of *M* is found from the data of all stations. Also introduced are the relative weights of the arrival times of the *P* and *S* waves. If necessary, the output gives, besides coordinates of epicenter and *M*, the discrepancies of travel time in the function of epicentral distance. An important drawback of the program is the absence of data on the depth of the earthquakes foci.

In the USSR, the first program for the machine search for the coordinates of focus (EPI-1) appeared in 1963 (Pyatetskii-Shapiro, Jelankina, Keilis-Borok, and others, 1963). This program, different from the abovementioned ones, does not require a first estimate. It uses the arrival times of *P* and *PKP* waves and the Jeffreys-Bullen hodograph. Calculating the focus position and the time of emergence of the focus leads to a search of the minimum mean square discrepancies of the arrival times of longitudinal waves in the space of the hypocentral coordinates. Observations with large discrepancies are excluded; since the earth is non-spherical the geographical coordinates are changed to geocentral. Later this program was improved, (the new model—EPI-2); use of *pP* and *sP* wave data gave a more accurate focus depth and epicenter position (Vartanova, Jelankina, Keilis-Borok and others, 1966).

The EPI-1 and EPI-2 programs were mainly for analyzing remote earthquakes with epicentral distances higher than 20°. The final computations include the earthquake dates, time of emergence of the focus in hours, minutes, and seconds, the epicenter coordinates in degrees and minutes, focus depth in kilometers, and the mean-square error of the coordinates in seconds.

Closer earthquakes are analyzed by a program for the M-20 (Abutaliev, Butovskaya and others, 1967a). It uses a right-angled system of *P* wave coordinates and regional hodographs; the time of emergence of the focus is given by the difference *S–P*. The epicenter is obtained iteratively for various fixed depths of the focus. Coordinates for the minimum mean-square deviations of theoretical and observed travel times are used as solutions. The accuracy of the determined coordinates is evaluated, as a result a principal ellipse may be constructed for each epicenter (Abutaliev, Butovskaya and others, 1967b). The result is rectangular coordinates which are very inconvenient, since spherical coordinates are usually used to prepare a catalog of earthquakes. They are considerably distorted in the double transfer process, when the spherical coordinates from the stations under observation are changed to rectangular and later these rectangular epicenter coordinates are again converted back to spherical coordinates. The program to determine the earthquake hypocenters in Uzbekistan (Pavlovskaya, 1968), written for the Minsk-2, does not have this drawback. It uses special coordinates, the first arrival times of longitudinal waves at stations, the time of emergence of the focus, and regional hodographs. As initial estimates the coordinates of the nearest-to-the-epicenter stations are chosen; they are determined by the method of least squares on some fixed depths of the hypocenter; data are excluded from stations with large discrepancies. For the final result are chosen coordinates of the focus with the least mean square residual of the observed and the theoretical travel time. Another version of this program (Fadina, 1971), besides the focus coordinates, their mean square error, and epicentral distances, considers the direction of the epicenter—station azimuth, apparent velocities, and the deviation of the travel time from that tabulated.

Programs not requiring the velocity cross section of the region under investigation (Pomerantseva and others, 1971; Abutaliev, Ikramov, 1970) propose the distribution of direct waves in a uniform medium and are meant for assessing closer earthquakes, only a few hundred kilometers, thus limiting their application considerably.

One version of the azimuth method to determine the earthquake epicenter by computer according to equations of the epicentrals type $A_i x + y + B_i = 0$ is described in the program by M.B. Vertlib (1968). The coefficients A_i and B_i are found from the differences of wave arrival times at four stations. On the surface *AB*, points A_i B_i should lie in a straight line, on the parameters of which the coordinates of epicenters *x*, *y* are determined. For its construction by the composition method, the initial points are converted to others with fewer points also forming a straight line. The epicenters on Pribaikal were determined by this program. Its application is considerably limited due to the use of the arrival times of strictly identical phases of elastic waves. The program does not determine the earthquake's depth of the focus, which somewhat depreciates the calculated results. The program by F.V. Novomaiskaya and G.I. Perevalova (1968) may be a possible addendum to this program. It determines the foci depths of Pribaikal earthquakes by a differential method. In this method the observed arrival times of waves are corrected to agree with the hyperbolic hodograph for the given velocity distribution of the transverse waves, close to 3.5 km/sec.

The coordinates of the epicenters and foci depths of closer earthquakes are simultaneously computed from the observations of Pribaikal's seismic stations using a program by S.I. Golenetskii and G.I. Perevalova (1971), designed for BSEM-2. The arrival times of the direct transverse *S* waves at the registering stations and their geographical coordinates are used as initial data. The solution is found by estimates in several steps. In the first step the time of emergence of the focus or the nearest-to-the-epicenter station is computed from the *S–P* values and, with the given value of the velocity *V*, the first estimate of the epicentral coordinates is computed. In the second, according to the obtained coordinates with given values of *V* and focus depth *h*, the sum of the residual squares of the travel times and the variation direction of the coordinates is determined for the epicenter. In the third and final step the solution is corrected and the focus depth and velocity are varied with the given step. The minimum sum of residual squares is considered the solution. In the next stage the accuracy of the solution is evaluated with the introduction of unknown weights and their confidence limits, which are calculated on the basis of the student's distribution criterion. The program also determines the propagation velocity of seismic waves (if not given earlier) and the coordinates of earthquakes' foci, not only by observations of direct waves, but also according to their collection from head waves ($\bar{P}$, *P*, $\bar{S}$, *S*) during the minimization of the general sum of the residual squares of all utilized travel times. On an average, it takes two minutes of machine time to get one solution with an evaluation of the errors of the results.

A number of review works discuss the results of machine computation of foci coordinates of earthquakes. A computer was used in the seismological laboratory of California Institute of Technology to find the position of the hypocenters and to solve other seismological problems (Phinney, 1963). Studies on the computer of the 191st underwater earthquake on the Galapagos Islands during 1935–1961 with the superimposition of the distribution of epicenters were conducted by N.K. Acharya (1965). L.R. Sykes and M. Ewing (1965) present a vertical section map through the epicentral zones in the Greater and Lesser Antilles. To construct this map the foci of five hundred earthquakes during 1950–1964 were redetermined by computer, using $M = 3.5$–6.7. N.V. Kondorskaya and others (1966) described the results of using a computer to generalize the seismic observations. In the USSR, using the EPI-1 program to determine epicenters according to the data from a network of stations of the Unitary System of Seismic Observation (USSO), more than five thousand earthquakes were assessed by 1964. This analysis provided greater computation speed and accuracy when compared to hand determination. The possibilities for solving other problems were also made clear, and influenced improvements in the system to interpret seismic observation. Thus a mean law of the distribution of residuals (inclination from the standard Jeffreys-Bullen hodograph) was found for seismic stations in the USSR, the accuracy of determining epicenters in various parts of the earth's sphere was evaluated, and so on.

While selecting the proper method of machine processing the earthquakes in Uzbekistan and writing a corresponding program, M.P. Pavlovskaya (1968, 1971) reviewed works which also describe some of our programs.

Combining automatic computer operations, which use programs to determine coordinates of the foci of earthquakes, with some initial manual seismogram operations, enables us to develop entire systems to treat seismological data in individual regions and on a global scale. The USA's system of automated bulletins and the establishment of seismic data (Rackets, 1963) is related to it. It consists of a number of programs which guarantee seismic bulletins and determine the minimum correct information to investigate seismicity with the fewest changes of computer magnetic tapes. The operations include the manual determination of the seismic wave arrivals, and the verification of their arrivals as forecast by computer from Coast and Geodetic Survey of USA (CGS) information on the hypocenters and according to hodographs. Seismic bulletins are hand done only after that, as the CGS information becomes useful during the choice of arrivals. This makes the bulletin more complete especially when the interpreter is not very experienced.

To place the seismic wave arrivals from a number of stations, with epicenters that are determined by the CGS, a FORTRAN program was written (Fletcher, Wellen and others, 1966). Thus it is possible to identify up to 23 phases of elastic waves using data from monthly bulletins on earthquakes from five USA seismic observatories working on the VELA-UNIFORM project.

A computerized system at the International Seismological Center in Edinburgh is described by P.L. Willmore (1966) and D. Fluendy, D. McGregor and P.L. Willmore (1966). Data from separate seismic stations on the arrival time of the elastic wave phases and their amplitude are carried on special cards, with pencil notations. The franking installation converts these data into punch cards. The computer analyzes the information on the punch cards by a special correction program, which excludes erroneous records. Next the data from various stations is unified and recorded on magnetic tape in order of arrival. They are now the initial data to determine the epicenter coordinates and are used in the following manner: 110 angular, approximately uniformly distributed points are chosen. The computer figures the travel time of the waves from each point to each station registering the earthquake. The difference between the observed transit times at the stations and those calculated to the nodal point gives an estimate of the emergence time of the focus with the epicenter placed at the points. The best agreement of the differences is obtained for points at the least distance from the actual epicenter as compared to the other nodal points. This point is the initial estimate for the following accurate computation of the epicenter position using the CGS USA program (Bolt, 1960, a, b). The algorithm of the automatic identification of the seismic wave phase, reproducing the corresponding manual work, is done in FORTRAN-IV in A.L. Levshin's program for the International Seismological Center in Edinburgh (Keilis-Borok, ed., 1968).

It may be noted that the initial data to determine earthquake coordinates by computer may not be available only on punch cards which contain codified information from seismological bulletins. In modern times there are methods to directly enter information on the kinematics and dynamics of seismic waves from seismo-receivers. For this purpose systems of signals from the so-called large seismic groups (LASA) have been formed, as described by R.V. Wood and others (1965), H.W. Briscol and P.L. Fleck (1965), C.B. Forbes and others (1965), P.E. Green and others (1965), G. Dorman (1967), G. Dorman and others (1969). The work of T.I. Sokolowski and G.R. Miller (1967) discusses an automated method to quickly determine (in a few minutes after registration of longitudinal P waves) an earthquake's epicenter on a specialized computer according to the difference of the P run to the four seismic stations. These stations are 35–40 kilometers from each other on the Hawaiian Islands. This method insures the transmission of the obtained information to the forecasting service by seismic sea waves in the USA. D.H. Weichert and E.B. Manchee (1968) described a computer method to make recordings from seismic stations in Yellowknife to obtain the automatic emission of seismic signals, the determination of epicenter coordinates, and earthquake sizes according to short period P waves.

The next step to prepare computations for quantitative seismicity indices, after determining earthquake epicenters and their dynamics, is the orderly and systematic arrangement of information. For this purpose earthquake catalogs are made and they are entered in the order of their data processing.

A catalog of punch cards with data from more than 9,000 southern California earthquakes with magnitudes $M > 3$ between 1934 and 1963 was made in 1964 (Nordquist, 1964). The punch cards may be analyzed by an IMB-

7090. The available enumeration of their information is varied regarding the accurate determination of the magnitude, focus timing, and earthquake coordinates. As a result there are four accuracy gradations—A, B, C, D. To increase the speed of computation the data are initially transferred to paper punch ribbon, suitable for the Bendix-G-150. J. Nordquist (1964) illustrates examples of using a catalog of punch cards and tapes for computing seismicity and its distribution in southern California. The disposition of the data is also shown and a scheme is suggested for the most economical computation (least punching time) from punch cards.

The catalog of Nevada earthquakes between 1852 and 1961 was prepared on punch cards for an IBM computer (Slemmons, 1966). Its data can be easily converted into quantitative parameters—specific seismicity and tectonic flow—to show stress release during earthquakes. The maps on stress release during Nevada earthquakes so obtained confirm the comparability of local regional seismicity values on an area with the seismicity of western states of the USA.

V. Karnik prepared a catalog enumerating more than 10,000 European and mediterranean earthquakes with $M \geqslant 3.5$ between 1901 and 1955 (Karnik, 1965 a). In the first section of the catalog information is given in chronological order; in the second it is given according to the coordinates of separate regions through 0.5° lat. × 0.5° long.; the third lists strong earthquakes, mainly from macroseismic data beginning in 1829. All these sections maintain a uniform order of material distribution—each line is related to one earthquake, and along the more than 40 columns, are noted the date and time of appearance, coordinates of focus, value of M, region number, number of stations to determine M macroseismic information, and so on. Each column has one figure for ease in entering data in the computer, (e.g., columns 1–4—the year of the earthquake—1901).

In the KSE IFZ* AN USSR codification of the earthquake catalog of the Garmsk seismoactive region has been completed and holds information about more than 20,000 earthquakes which permits the simultaneous use, for thematic machine working, of a large quantity of uniform material (Sadovskii, ed., 1971).

Information on the immediate computerization of quantitative seismicity indices appeared in literature only recently. Thus, J. Nordquist (1964) introduces the program algorithm to construct a seismicity map of southern California. In it, as a measure of seismicity, the sums of the square roots of earthquake energy has been accepted; they are normalized about the area. The author thinks that his map shows the density of the release of elastic pressures. This viewpoint is supported by P. Amand (1956), and Richter

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*Complex Seismological Expedition of the Institute of Physics of the Earth—General Editor.

and Allen (1958), who conducted similar hand calculations earlier.

With a computer, D. Slemmons (1966) calculated maps of the release of elastic pressures in Nevada, using the terms specific seismicity and tectonic flow. To determine these terms earthquake energy was totaled. In the first case, it was emitted on the unit area in the unit time, and in the second as square roots from the seismic energy of the foci.

In 1966–1967, a program was prepared in the USSR for the M-20 computer and for the first time, maps of seismic shocks B_{Σ}—mean repetition frequency of tremors of given intensity at a point on the earth, were computed (Riznichenko and others, 1967). Computations were made for Eastern Uzbekistan based on hand constructed maps of seismic activity and maximum possible earthquakes and on the dependence of seismic intensity I on the epicentral distance. In Riznichenko's works (1967, 1969) algorithms of B_{Σ} are introduced and maps of two values of I, expressed in units of the density of seismic energy flow, are shown, viz., $\Xi_1 = 10^{12}$ J/km^2 and $\Xi_2 = 10^{13}$ J/km^2. Later seismic shock maps were computed for the intensity given as standard points. A.I. Zakharova and S.S. Seiduzova (1971) compiled shock maps for Eastern Uzbekistan for tremor intensities of $I = 6, 7, 8$ and 9 points.

An algorithm of the shocks map program and its block-diagram is explained by S.S. Seiduzova and A.I. Zakharova (1969, 1971). This program computes the value of shocks B_{Σ_I}—the total frequency of seismic impulse repetitions of given intensity and higher—as well as value, inverse of B_{Σ_I}—mean period T. In algorithmic form the relation (24) is used with the tremor intensity I expressed by the density of the seismic energy flow or (28) with the values of standard seismic scale given in points. In both cases the maps of maximum possible earthquakes $K_{\max}$ and seismic activity A, curves of damping of intensity with distance (22) or (25) constants of the formula (24) or (28) are initial computation data. A version of the computation of B_{Σ_I} maps for which the value of A is not entered in the data set of initial data is also available. The value of A is computer calculated according to the correlated equation (A, $K_{\max}$) in formula (13). The initial map $K_{\max}$ should be made from two parts—the central part represents the territory on which shocks are computed; the peripheral is the territory of which the earthquake foci call for given tremor effects in the central part. The depth h of the earthquake foci is considered a constant for the first estimate, i.e., its mean value is used for the region under investigation. For largely different depths of seismogenic layers of the earth's crust, all computations of shocks B_{Σ_I} may be conducted layerwise, beginning from maps A and $K_{\max}$ and the results B_{Σ_I} for each point on the earth should be superimposed (Riznichenko and others, 1970). The final stage of the program is to assign the number of the point, B_{Σ_I}, and T in years.

Vel'kner (1969), analyzing the spatial distribution of seismic parameters in North Chile, described the results of the IBM-360 investigations of coefficients a and b in the Gutenberg-Richter statistical formula

$$\log n\,(M) = a + b\,(M), \tag{10'}$$

where $n\,(M)$—number of earthquakes with the magnitude between M and $(M + dM)$.

While normalizing the quantity a along the area and timing, as conducted by Vel'kner, this coefficient happens to be analogous to the quantity of seismic activity accepted in the USSR. Coefficient b on its own is similar to the inclination γ of the repeatability curve of earthquakes taking into account the transfer from magnitude M to energy class K. The values of the coefficients a and b were calculated for an overlapping 1° × 1° section where the mean depth of focus h was also determined. In this the following formula of Aki (1965 c) was used:

$$\bar{b} = \frac{\log l}{\overline{M} - M_0}, \tag{29}$$

where $\bar{b}$—most probable value of b for the group of earthquakes submitting to the statistical relation of Gutenberg-Richter;

$\overline{M}$—mean;

M_0—lower limit of magnitude for this group so that

$$\overline{M} = \frac{\sum(\overline{M} \cdot n)}{\sum n}, \quad M \geqslant M_0. \tag{29'}$$

To calculate the normalized value $a = \tilde{a}$ (mean yearly number of earthquakes with $M \geqslant 3.5$ in area (10^4 km) the expression used was

$$\tilde{a} = \log N_{\Sigma}\,(M_0) + \bar{b}\,M_0 \log T, \tag{30}$$

where $N_{\Sigma}(M_0)$—total number of earthquakes with magnitude M_0 and higher;

T—period of observation.

Statistical parameters a, b, and h correspond to each section, smoothed by dual filters, the coefficients of which are proportional to the areas of the neighboring sections which are exceeded:

$$A_{ij} = \frac{a_{ij} + 0.5\,[a_{ij\pm1};\ a_{ji\pm1}] + 0.25\,[a_{i\pm1,\ j\pm1}]}{n_{ij} + 0.5\,[n_{ij\pm1};\ n_{i\pm1,j}] + 0.25\,[n_{i\pm1;\ j\pm1}]} \tag{31}$$

where

$$n_{ij} = 1, \text{ if } a_{ij} \neq 0;\ n_{ij} = 0, \text{ if } a_{ij} = 0.$$

Parameters a, b, and h were calculated from earthquake observations during 1963–1966. The corresponding isoline maps were constructed according to their smoothed values. Besides, for each 1° × 1° section the values of the logarithm of the mean annual quantity of the released energy E were found on the basis of these parameters, i.e., according to Utsv's formula (1961):

$$E_{\Sigma} = \frac{bE}{(\beta - b)\, B\,(\beta/b,\, N)}, \tag{32}$$

where E—energy of earthquake with magnitude M;

β—coefficient in the equation

$$\log E = \alpha + \beta\, M; \tag{26'}$$

B—beta-function.

Further, the isoline maps of the quantities $\log E_{\Sigma}$, are constructed on the distribution of extremes which appeared similar to those for seismic activity.

The curve for the distribution of earthquake magnitude was converted into the curve for the distribution of the value of tremors (intensity) using V. Karnik's equation (1965b):

$$M = \frac{2}{3} I_0 + 1.7 \log h - 1.4, \tag{33}$$

from the smoothed values a, b, and h. Here I_0 is the epicentral seismic intensity value. The curve for tremor distribution was used to calculate the mean yearly number of destructive earthquakes (with intensity $I \geqslant 7\frac{1}{2}$ points) in each section and determine the so-called seismic risk, the probability of the appearance of at least one earthquake with $I = 7\frac{1}{2}$ during the period $T = 100$, 50, 30, and 10 years using Poisson's timing interval distribution. Maps of seismic risk isolines for the first three periods are constructed according to the calculated values of probability. A comparison of these maps with the map of curve inclination b of earthquake repeatability shows an inverse correlation of the values brought in them—the b minimum corresponds to the maximum probability of an earthquake appearance and vice-versa. It may be noted that if the statistical seismicity parameters a and b are analogous to the seismic region parameters introduced by Riznichenko (1958), then the seismic risk value here considers the influence of an earthquake occurring on the 1° × 1° section to which the point under investigation is related. Also the probable seismic dangers, according to Riznichenko (1966b, 1971), are based on the frequency of tremors from close and far earthquake foci, at the point under investigation, i.e., from all foci which are capable of forming tremors of given intensity.

W. Sponheuer, R. Maaz and W. Ullmann (1970) introduced computer seismicity maps of central Europe. The density $S(Z)$ of seismic energy at the point Z under investigation was considered a measure of seismicity between 1900 and 1967 and was calculated according to the formula:

$$S(Z) = \frac{E}{4\pi h^2} \exp\left[- \left(\frac{\Delta}{2R} \right)^2 \right], \tag{34}$$

where E—earthquake energy in ergs;
h—focus depth;
Δ—epicentral distance;
R—radius of earth.

For instrumentally registered earthquakes the values of the energy were determined from the expression:

$$\log E = 1.6\,M + 11. \tag{26'}$$

When only macroseismic data were present the magnitude M was obtained by Karnik's formula (33).

Computations of the value $S(Z)$ were made from the data of 374 earthquakes with $M \geqslant 4$ taking place between 1900 and 1967. Isolines of similar values of seismic energy density are differentiated on the map in tenfold and carried out through the corners of a square ten minute wide grid. During these 67 years the maximum seismicity level $S(Z) = 9 \cdot 10^{17}$ erg/km^2 and maximum intensity were observed in the Swabian Alps.

Recently, using statistical methods, computer calculations were made on the probability indices of a seismic regime. Thus E.P. Tsvetkov (1969) using a BSEM-3M computer analyzed the synchronous nature of seismic regimes of various parts of the Garmsk region of Tajikistan from a combination of earthquakes between 1955 and 1965 in the energy interval classes $K = 7$–11. Maps were constructed of the distribution of epicenter densities with different sizes of areas of averaging—126 and 63 km^2. For each the corresponding sum of earthquakes was converted into a timely order. These timely orders were paired with each other and a matrix was constructed, in which the members i and j reflect the coefficient of correlation r between the regimes i and j of the area. Since the fluctuation of the regimes in different areas may have various periods and contacts between the regimes may develop at different times, depending on the energy of earthquakes and the specific seismic life of the region, the investigated timing intervals were partitioned. As a result of this the following average time intervals were chosen: 0.25; 0.5; 1; 2 and 3 years. In each interval 104 timing orders were formed for the 126 km^2 area and 208 for the 63 km^2 area, in which from 9 to 44 members were enumerated in each order. The value of the coefficient of correlation r was determined from the expression:

$$r_{i,j} = \frac{\sum\limits_k (N_i^k - \overline{N}_i)(N_j^k - \overline{N}_j)}{\sqrt{\sum\limits_k (\overline{N}_i^k - N_i)^2 \cdot \sum\limits_k (N_j^k - \overline{N}_j)^2}}, \tag{35}$$

where N_i^k and N_j^k—quantity of earthquakes in ith and jth areas correspondingly in kth interval of time;
$\overline{N}_i$ and $\overline{N}_j$—average number of earthquakes in these areas occurring in each time interval during the entire observation period.

Besides the coefficient of correlation of the paired orders, the signs of the inclinations were also established for 2- and 3-yearly intervals. The timing orders of 0.25 and 0.5 years, were grouped and correlated with the coefficient $r \geqslant 0.6$. For one year intervals chosen level r was 0.8. According to the calculated coefficients of correlation along with compact groups of contiguous sections, groups were divided into sections far from each other. To interpret these connections, a model of the actual earthquake catalog was made so that the earthquakes were distributed regionally with uniform density. The construction used a special adjunct to the computer—a random numbers sensor. It was explained that this model reflects a chaotic field of similar separate area connections in which group identification is not possible. When the actual results for the catalog and for the model were compared, it was noticed that with a decrease in the timing step, i.e., shorter periods, the differences between them are smoothed and with the smallest timing interval (0.25 year) they are practically absent. The maximum differences mentioned are clearly expressed in histograms of the distribution of the number of groups depending on their length. For collected variations of activity (density of epicenters) between blocks, that is, the unified section areas with positive connection at the level of given coefficients of correlation, the differences between the actual version and the model are also maximum for the large time intervals. It happens when longer correlative section groups exist as compared to the model. E.P. Tsvetkov explains the random connection field between separate regional sections by a general decrease in activity between 1955 and 1960 and then a general increase during 1961–1964. While analyzing the spontaneous correlation between neighboring areas for relatively longer times, it was established that the actual and the model connections differ by the total absence of a counter-phase model. In the shorter periods, there also is no connection with the negative coefficient of correlation in the actual version, i.e., during earthquake analysis. The author proposes that the negative correlations between the regions of adjacent sections may be formed by local changes in the pressure fields of the region. This is supported by the results of a comparison of the spatial distribution of positive and negative connections between neighboring sections with the strong earthquake map ($K = 12$–13), the epicenters of which are actually at those places where regional counter-phases are established between the connected areas. Inside the synchronous regions there are no strong earthquakes, their epicenters for $K = 16$–17 seemed timed to the contact zones of synchronous blocks.

E.V. Vil'kovich, V.I. Keilis-Borok and others (1970) used statistical methods on the computer to investigate the contact between earthquakes and the random changes of seismic activity with time, that is, the nonstationariness of the seismic region. To limit the number of observations of nearby earthquakes, two local statistics $\hat{F}(d_{\text{int}})$ and $\hat{d}(F_{\text{int}})$ were introduced.

The first indicates the time interval between the initial earthquake and the next one occurring not farther than d_{int} from it. The second is the distance between the epicenters of the initial and the next closest one to occur during the interval F_{int} after it. The thresholds (d_{int} and F_{int}) were chosen to achieve maximum statistical sensitivity. Later the distribution of these introduced statistics was shown along the factual and random earthquake catalogs, which may be obtained by reshuffling the factual. The random catalog corresponds to the theoretical distribution. The comparison of the histograms of the distributions of these local statistics was done with nonparametrical criteria.

To introduce the influence of the initial earthquake on each successive one, the following relation was used:

$$R = KP_f - P_r, \tag{36}$$

where P_f and P_r—are histograms constructed according to factual and random catalogs;

$K = \int_A^\infty P_r\,(S)\ dS \int_A^\infty P_f\,(S)\ dS$—coefficient smoothing out the histograms on the section (A, ∞).

Here A is made sufficiently large, so that the influence of the initial earthquake is already damped and the conditional distributions $P_r\,(S) S \geqslant A$ and $P_f\,(S) S \geqslant A$ are in agreement.

The mutual correlation of the earthquakes is based on data obtained from the eastern part of Central Asia between 1952 and 1956 in the interval M from 3-4¼. About 2,000 earthquakes in the core ($H < 75$ km) and with intermediate focus depth ($H = 80$–250 km) were analyzed separately. For normal earthquakes an analysis of curves $R\,(d)$ on the 95% reliability level shows that the initial earthquake is related to a next one farther than 50 km. The after shock of a strong earthquake has influence at a smaller distance—35 km. The curves $R\,(F)$ show (99% reliability level) that after the initial earthquake there is an enhanced probability of another within 20–40 days. The construction of curves $R\,(F)$ for the Presurkhoba, Pridarvaza, Eastern Tien-Shan, and Fergana regions of Central Asia testifies about the significantly different, positive influence of the initial earthquakes on the following, and negative on the next two (99% reliability level). For intermediate earthquakes, according to curves $R\,(d)$ and $R\,(F)$ at the 99.8% level, significant positive influence has been established of the initial earthquake on the successive one; but this influence is considerably smaller than in smaller ones. No negative influence was noticed.

Earthquake catalogs of eastern Central Asia between 1952 and 1956 show a random variation of their intensity with time. The reliability of the difference of earthquake intensities in 1952 and 1956 is very high—99.9%. The randomness of the variations of the spatial distribution of epicenters with time was also verified. For this purpose, the epicenter distributions for different durations (for example, of 5 years and of 3 months or 1 quarter) were compared using statistical criteria. In 11 of 20 quarters the distribution matched less than 5% which, according to A.I. Kolmogorov's criteria on the 99% reliability level, shows the randomness of the spatial distribution of epicenters with time. This established the nonstationariness of the temporal seismic process (variation of intensity), as well as spatial (random migration of epicenters).

A short survey of the methods to quantitatively describe seismicity and the use of the computer leads to the following conclusions. Presently in our country, a number of programs, other than those to determine the coordinates of the foci, have been written mainly to evaluate the stationariness of the seismic process in space and time. The programs to compute the values of the total seismic energy and stress release, as well as the coefficients of the Guttenberg-Richter statistical formula available abroad, belong to the seismicity characteristics which, in their physical concept, cannot fully describe the seismicity of any region, and cannot be used directly.

Programs are not available for computing and more so mapping the parameters of the seismic regime, determined by Yu.V. Riznichenko's method—a method most popular in the USSR. Subsequent chapters, therefore, are devoted to the development of such programs.

Computer Programs to Compute Main Seismicity Parameters

Seismic regions for any territory are determined mainly by three parameters: inclination of the curves of earthquake repeatability, seismic activity A, and the maximum possible earthquake $K_{\max}$. The mean long-term values of these parameters for the entire territory may be obtained by constructing a curve of earthquake repeatability, i.e., the distribution of the number of earthquakes according to their energies. For this, many years' instrumental observations of earthquakes which had a considerable range of energies are usually used as initial data. The inclination γ of the repeatability curve and the mean errors—σ_j and σ_A—are determined by the method of least squares. This requires considerable time just to find the average long-term parameter values for the entire territory. The time requirement in manual work increases several fold during compilation of areawise maps for obtaining the spatial distribution of γ, seismic activity and the maximum possible earthquakes, increasing the amount of the manual work many more times. Therefore, it becomes necessary, from the point of view of time, to engage many technical personnel for these computations.

The above considerations and the need to calculate the maps and seismicity curves of Uzbekistan to study the special features of the seismic regime of separate regions, and problems of quantitatively evaluating seismic danger led us to write programs to accelerate the automatic calculation of the seismic regime parameters. While determining the seismic delimitation of the USSR in 1961–1962, and also during the recent preparation of the following seismic delimitation maps, we often came across unreliable uses of Yu.V. Riznichenko's main formulas to construct repeatability curves and seismic activity maps. The results were mainly distorted by the absence of calculations of return periods of the earthquakes of various energies. Computing the main characteristics of seismicity on the computer by standard programs averts, it seems, many errors which usually arise while comparing a seismic activity map with considerably more complex maps of maximum possible earthquakes in separate seismoactive zones. This comparison becomes necessary when constructing maps of seismic shocks for the USSR, a quantitative base for evaluating seismic danger.

In this work, programs are introduced whose aim is the computation of the main parameters of the seismic regime, curves of repeatability, maps of seismic activity, and maps of maximum possible earthquakes. The nomenclature of all programs begins with letters SP (seismic parameters), that is, SP-1 is the first program for computing seismic parameters, SP-2 is the second, etc. In all, there are seven programs. One is meant for computing the characteristics of the rule of earthquake repeatability, four are for maps of seismic activity, and two are for maps of maximum possible earthquakes. All the programs are for M-20, M-220, or BESM-4 computers and use the library of standard programs.

Chapter III

Programs to Compute Seismic Activity Maps and Curves of Earthquake Recurrence

Seismic activity—the quantitative characteristics of seismicity—represents in itself the number of earthquakes of a particular class of energy occurring in a particular area in unit time. The first seismic activity maps were constructed by Riznichenko and Nersesov during 1958–1960. During the last twelve years, the seismicity of all seismically dangerous regions of the USSR has been evaluated using this most important parameter (Medvedev, ed., 1968, Riznichenko, ed., 1971). For this purpose seismic activity maps were prepared to present an objective distribution of the density of the epicenters of earthquakes in the region under study brought to one energy level. The mapping of seismic activity is a necessary step in the quantitative evaluation of the seismicity of any territory.

While computing the seismic delimitation of the USSR in 1961–1962, maps of the seismic activity *A* were compared with maps of the vertical gradients of the velocity of tectonic movements to specify the boundaries of zones of various intensities (Medvedev, ed., 1968). Currently, the computation of *A* is also necessary to prepare maps of the possible maximum earthquakes and seismic shocks (Riznichenko, ed., 1971).

Map *A* computations for large territories are very difficult and require considerable manual work and time. Therefore, it is necessary to use fast computers.

Nowadays, seismologists generally use several methods to compute seismic activity. The most widespread is the summation of earthquakes in a zone of averaging (Riznichenko, 1964a). In some seismoactive zones the classwise distribution of earthquakes method is most used (Butovskaya and others, 1966; Flenova, 1969). Seismic activity maps are constructed depending on the specific problems of studying one or another seismicity aspect with given details or accuracy by the distribution or summation method (Riznichenko, Gorbunova, 1968). There are several programs for computing seismic activity maps—SP-1; SP-2; SP-3, and SP-4.

PROGRAM SP-1 FOR COMPUTING *A* MAPS WITH CONSTANT RESOLUTION BY THE SUMMATION METHOD

The constant resolution of the computation of seismic activity maps is insured by maintaining constant the areas of the zone of averaging. To construct such a map, the zone of averaging is usually split around each node of the given grid. In the zones the number of epicenters are totaled and later converted to unit area and time. The obtained activity A value is related to the nodes of the map grid in this method.

While writing the SP-1 program Zakharova (1970) proposed to define for the zone of averaging the activity by the computation interval a, i.e., the distance between two neighboring nodes of the given grid.

The catalogs of earthquake epicenters are usually published in spherical coordinates. For convenience of computation, we use these coordinates to compile maps of the established earthquake epicenters and during the actual computation of seismic activity maps—during transit from one node of the grid to another. Therefore, this computation interval is in fractions of geographical degrees; whereas the zone of averaging is right-angled, almost trapezoidal and its area is $S = 2a \times 2a$, km².

The Riznichenko formula (1964a) was used to determine quantity A by the summation method in algorithmic form. It has the following form to normalize the number of earthquakes in 1,000 km² and for one year:

$$A = N_{\Sigma} \frac{1 - 10^{-\gamma}}{10^{-\gamma}(K_{\min} - K_0)} \cdot \frac{1000}{S \cdot T}, \tag{37}$$

where N_{Σ}—number of earthquake epicenters in zone of averaging with area S km², in the period T of the establishment of earthquakes of energy class $K_{\min}$;

$K_{\min}$—the least energy class of earthquakes in the region;

K_0—Energy class, about which the seismic activity is determined;

γ—inclination of the repeatability curve.

The SP-1 program is standard: with suitable built-in instructions based on the above formulas, it may be used to compute A in any territory, with any computation interval and any dimensions of averaging zones, with two initial data sets. These data sets fully determine the amount of machine computation.

The first set of the initial map of epicenters, M_1, is given as matrix A_{mn}. The number of lines of the matrix m is equal to the number of earthquake epicenters on the map. The number of columns n is the number of parameters determining each epicenter. In principle, m may be any number (to the limit of the computer memory), i.e., map A may be computed for any sufficiently large area. The number n in the computation of map A for the earth is limited by three parameters for each earthquake: the spherical

PROGRAM SP-1

Address	Command	A_1	A_2	A_3
		0500 A		
0500	055	0624	0770	0624
1	013	0624	1042	0624
2	000	0000	0000	0000
3	055	0710	0770	0710
4	013	0710	1043	0710
5	000	0000	0000	0000
6	055	0714	0770	0714
7	013	0714	1014	0714
0510	000	0000	00000	0000
1	055	0521	0771	0521
2	013	0521	1041	0521
		0513 A		
0513	000	0000	0000	0000
4	075	0000	0000	6053
5	000	0000	0000	0000
6	000	0000	0000	0000
7	000	0000	0000	0000
0520	016	0522	7741	0007
1	000	1100	1100	0000
2	0000	0000	0000	0000
3	016	0524	7741	0007
4	000	1000	1000	1040
5	000	0000	0000	0000
		0526 A		
0526	052	0000	0000	0000
7	075	0000	1026	6026
0530	075	0000	1027	6027
1	452	0000	0000	0731
2	000	0000	0000	0000
3	452	0000	0000	0630
4	056	0535	0536	0604
5	075	0000	1013	6013
6	056	0537	0540	0606
7	075	0000	6030	6000
0540	056	0541	0542	0560
		0541 A		
0541	075	1101	1101	6032
2	056	0543	0544	0561
3	075	0000	1102	6033
4	056	0545	0553	0576
5	075	0000	1100	6031
6	000	0000	0000	0000
7	013	0576	1045	0576
0550	013	0561	1045	0561

(Contd.)

Address	Command	A_1	A_2	A_3
		551		
1	013	0560	1045	0560
2	056	0000	0560	0000
3	001	6026	1030	6034
		0554 A		
0554	002	6026	1030	6035
5	001	6027	1030	6036
6	002	6027	1030	6037
7	075	0	0	6040
0560	077	0	0	0
1	077	0	0	0
2	002	6034	6032	0
3	076	0	0565	0
4	056	0	0624	0
5	002	6032	6035	0
6	076	0	0570	0
		0567 A		
0567	056	0	0624	0
0570	002	6036	6033	0
1	076	0	0573	0
2	056	0	0624	0
3	002	6033	6037	0
4	076	0	0576	0
5	056	0	0624	0
6	077	0	0	0
7	001	6040	0101	6040
0600	0	0	0	0
1	0	0	0	0
		0602 A		
0602	075	0	1040	6041
3	056	0604	0605	0620
4	077	0	0	0
5	056	0606	0607	0621
6	077	0	0	0
7	056	0610	0613	0613
0610	075	0	1000	6030
1	013	0620	0772	0620
2	013	0613	0772	0613
3	077	0	0	0
4	002	6030	6031	0
		0615 A		
0615	076	0	0620	0
6	002	6041	0101	6041
7	076	0	0611	0
0620	077	0	0	0
1	077	0	0	0
2	013	0604	0773	0604

Address	Command	A$_1$	A$_2$	A$_3$
3	013	0606	0773	0606
4	112	0	0547	0001
5	075	0	6040	6056
6	0	0	0	0
7	075	0	1037	6057
		0630 A		
0630	077	0	0	0
1	002	6040	1031	0
2	076	0	0640	0
3	002	6040	0101	0
4	076	0	0637	0
5	075	0	0	6054
6	056	0	0723	0
7	0	0	0	0
0640	075	0	1011	6044
1	002	6040	1033	6043
2	075	0	1025	6045
		0643 A		
0643	075	0	0	6046
4	056	0645	0647	0647
5	004	6045	6113	6050
6	013	0647	0772	0647
7	077	0	0	0
0650	001	6046	6050	6046
0651	002	6043	0101	6043
2	076	0	0646	0
3	075	0	6046	6056
4	075	0	1035	0140
5	016	0656	7714	0007
		0656 A		
0656	075	0	0160	6047
7	075	0	0101	6050
0660	075	0	1034	6051
1	005	6051	6047	0140
662	016	0663	7711	0007
3	002	6050	0160	6050
4	075	0	6044	6052
5	002	6052	012	6052
6	005	6051	6052	6052
7	005	6052	6047	0140
0670	016	0671	7711	0007
		0671 A		
0671	075	0	0160	6052
2	005	6046	6050	6050
3	004	6050	6052	6050
4	005	6050	1036	6050

(Contd.)

Address	Command	A_1	A_2	A_3
5	005	6057	1025	6051
6	004	6050	6051	6054
0677	044	6046	0	6050
0700	004	1036	1035	6051
1	004	6051	6050	6055
2	056	0	0724	0
3	075	0	6051	6055
		0704 A		
0704	001	6053	0101	6053
5	016	0707	7751	0007
6	000	6053	4000	6056
7	075	0	6034	6026
0710	112	0000	0533	0001
1	077	0	0	0
2	075	0	1026	6026
3	075	0	6036	6027
4	112	0000	0531	0001
5	077	0	0	0
		0770 A		
0770	777	0	7777	7777
1	777	7777	7777	0
2	0	0	0001	0
3	0	0	0	0001

coordinates of its epicenter, latitude φ_i and longitude λ_i in degrees, and the energy class K_i.

The second data set of the constants M_2 includes coordinates of the initial point of computation—φ_0, λ_0, computation step latitudinally—a_{φ_i} and longitudinally—a_{λ_i}, area of the averaging zone $S = 2a_{\varphi_i} \times 2a_{\lambda_i}$, the value of the inclination of the repeatability curve γ, and the establishment period of earthquakes of class $K_{\min}$—7. Besides, included here are the number of lines m and columns n of the initial matrix, the corresponding numbers q and r of the resulting matrix (maps of activity of the region under investigation), a set of fixed classes of energies K_{f_i} (about which A is computed) and their corresponding periods of presentation T_{f_j}; and the number P of these classes (here and further $j = 1, 2, \ldots p$). In the set K_{f_j} are included the classes of energies presented by the earthquakes of the region, beginning from $K_{\min}$—least of them, therefore, $K_{f_1} = K_{\min}$; $K_{f_2} = K_{\min} + 1$; $K_{f_3} = K_{\min} + 2 \ldots$; $K_{f_p} = K_{\min} + (P-1)$.

The SP-1 program occupies memory cells 0500–0773; the data sets of constant and informational lines—1000–1045; the initial data sets of epicenters are in the machine memory from cell 1100. The remaining memory cells are operational and contain the intermediate results.

Block Diagram SP-1 (see p. 49)

The SP-1 program moves in accordance with the block diagram and begins with loading the actual program and data sets of initial data in the machine. The control is in block 1, where the command address is given depending on the information. In block 2, data sets M_1 and M_2 are converted from the decimal system to the binary. Here the printer lists data sets M_1 and M_2 to control the numerical information entered in the machine. Further control is on blocks 3 and 4 to load the instruction addresses necessary for successive blocks, and further to block 5.

Block 5 contains the choice of epicenters with the coordinates of averaging zones—the coordinates φ_i, λ_i of all epicenters of the first data sets M_1 are sorted and only those falling within the limits of this zone are retained. For example, for the beginning point of the computation with coordinates φ_0, λ_0 these limits are limited by the lat. $\varphi_0 \pm a_\alpha$ and long. $\lambda_0 \pm a_\lambda$. The choice of each epicenter in the averaging zone is fixed by a special counter. The energy class K_i, corresponding to each chosen epicenter, is transferred to block 7, i.e., identification K, where it is determined by comparing with K_{f_i} stored in the memory. The transfer of control from block 5 to 7 takes place through block 6 where the instruction addresses of block 7 are loaded. Thereafter control is transferred to block 8, where the instruction addresses for block 9 are loaded, and further to block 9. Here for the energy class K_i of each epicenter in the averaging zone a corresponding presentation period T_{f_i} is chosen, which is necessary during unequal observation periods of earthquakes of various energy classes. Further, the number of earthquakes of various energy classes in the averaging zone are brought to the presentation period T of earthquakes of class K, and the control is transferred to block 10, where the total number N_Σ of earthquakes in the averaging zone is computed according to the expression:

$$N_\Sigma = \sum_{j=1}^{l} \frac{T_{\min}}{T_{f_j}}, \tag{38}$$

where l—number of epicenters in the averaging zones.

Here, the numbers N_Σ are compared with the given N_σ, determining the number of epicenters in the averaging zones, necessary to calculate seismic activity with the desired accuracy. When $N_\Sigma \geqslant N_\sigma$ the control is transferred to block 11 to compute seismic activity A and error σ_A in the averaging zone. The computation of A is carried out according to formula (37). The quantity σ_A is inversely proportional to the square-root of the number of earthquake epicenters of various energy classes in the averaging zone, brought to one observation period T. It is computed according to the following formula (Riznichenko, ed., 1960).

$$\sigma_A = \frac{100}{\sqrt{N_\Sigma}} \%. \tag{39}$$

If, as a result of the work in block 10 it appears that $N_\Sigma \leqslant N_\sigma$, the control is transferred directly to printing block 12, bypassing 11. In this case, $A = 0$. As a result of the work in block 12, the point number and the values A and σ_A (%) are printed.

After printing the results of computation A for the first point of the activity map (the first averaging zone) control is transferred to block 13—preparation for computation at the next point. Here crossing to the next averaging zone of activity is achieved with step a, if the point number $N_T < qr$. If $N_T = qr$ the computation stops.

Application of the above-described program to compute seismic activity maps considerably saves time. The automatic computation of value A according to formula (37) requires much less time than the manual method. Besides, here constructing the epicenter map is excluded, since for machine computation lists of epicenters are sufficient initial material. Using the SP-1 program a seismic activity map of a thousand points can be computed in 40 min. During this time the initial epicenter list enumerates these points not less than 500 times.

One more important feature is automatically done when computing the seismic activity map using the SP-1 program. Determining the computation errors A–σ_A, considered in the program, permits accurate computations for each point, separately for its section and for the map as a whole. It is necessary to compare these maps with the tectonics of the territory under investigation to compute the more complex quantitative evaluations of seismic danger—seismic shock maps.

Illustrative Example

The SP-1 program is standard and remains unchanged for any region. Only the contents of the initial data M_1 and M_2 sets and the control information may change. In this illustrative example, which may be used as a concurrent version of the program to verify that it works, the form to record initial data on standard blanks is shown, as well as the results of seismic activity computation using SP-1.

The set of epicenters M_1 (Table 1) holds the data of seven earthquakes and is recorded in decimal code along triads, beginning from cell 1100. The characteristic of each earthquake uses three cells: in the first the energy class K is placed, in the second—latitude φ, and in the third the longitude λ of epicenter in degrees.

The data set of the constant M_2 (Table 2) is placed in cells 1000–1041.

The control information lines (Table 3) is written in octal code along note-books, beginning from cell 1042 to 1046, and holds the following data: line number of matrix A_{mn} less one $(m-1)$; number of columns of this matrix (n); corresponding numbers for the resulting matrix A_{qr} $(q-1)$ and $(r-1)$; address of the last cell of the data set M_1 (A_{mn}).

Further the results of computing the seismic activity of two columns of the map are placed by SP-1 for the initial data sets M_1 and M_2 and groups of control information (Tables 1–3) are placed (Table 4). N_T—serial number of the map point; A_{10}—value of the seismic activity about $K_0 = 10$; σ_A—error of the computation A_{10} (%); n—number of epicenters in the averaging zone.

The placement of the epicenters relative to the computation points A_{10} conditions the value $A_{10} > 0$ only at four points: 1, 2, 10 and 11. At the remaining points $A_{10} = 0$ and $\sigma_A = 100\%$, since either $N_\Sigma < N_\sigma$, or $n = 0$ at those points.

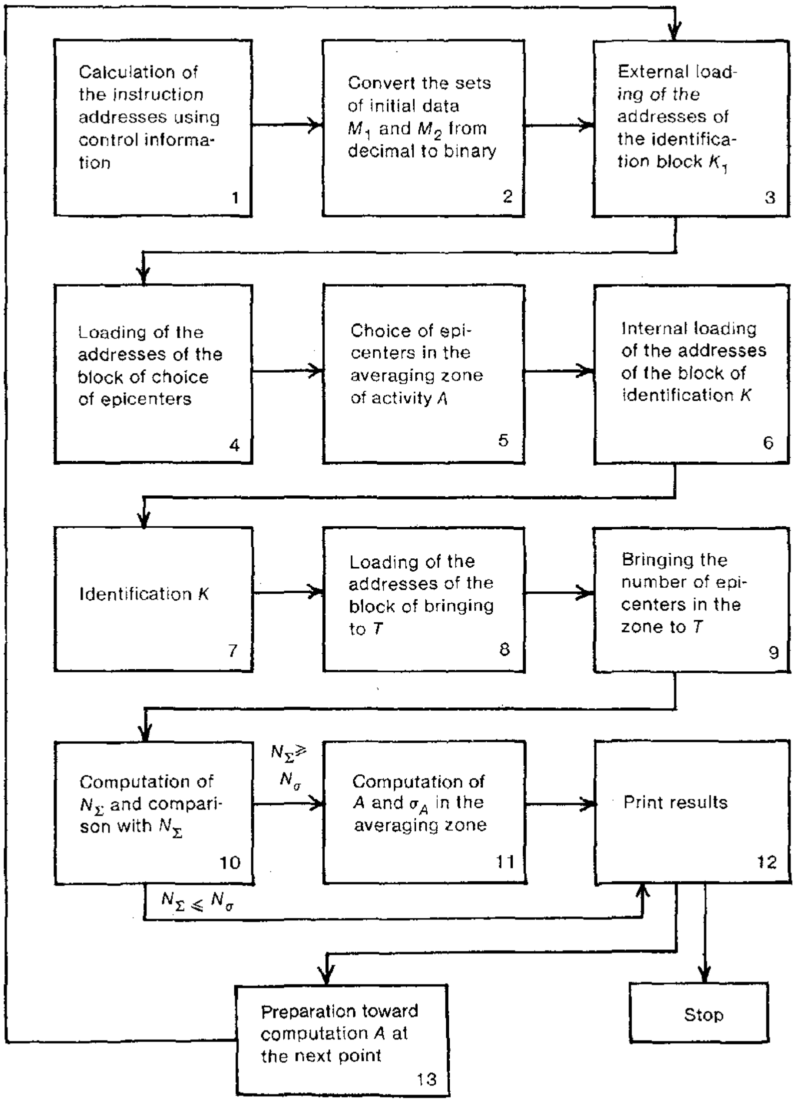
TABLE 1. DATA SET M_1 FOR SP-1

Address	Commands and number						Remarks
	Sign of		Order	A₁	A₂	A₃	
	No.	Order					
			1100 A				
1100	++	+	02	130	000	000	$K_1 = 13$
1	++	+	02	400	100	000	$\varphi_1 = 40.01$
2	++	+	02	700	100	000	$\lambda_1 = 70.01$
3	++	+	02	130	000	000	$K_2 = 13$
4	++	+	02	401	100	000	$\varphi_2 = 40.11$
5	++	+	02	700	100	000	$\lambda_2 = 70.01$
6	++	+	02	100	000	000	$K_3 = 10$
7	++	+	02	401	500	000	$\varphi_3 = 40.15$
1110	++	+	02	702	1000	000	$\lambda_3 = 70.21$
1	++	+	02	110	000	000	$K_4 = 11$
2	++	+	02	402	120	000	$\varphi_4 = 40.21$
			1113 A				
1113	++	+	02	701	800	000	$\lambda_4 = 70.18$
4	++	+	02	120	000	000	$K_5 = 12$
5	++	+	02	400	500	000	$\varphi_5 = 40.05$
6	++	+	02	701	200	000	$\lambda_5 = 70.12$
7	++	+	02	100	000	000	$K_6 = 10$
1120	++	+	02	401	100	000	$\varphi_6 = 40.11$
1	++	+	02	698	100	000	$\lambda_6 = 69.81$
2	++	+	02	120	000	000	$K_7 = 12$
3	++	+	02	401	100	000	$\varphi_7 = 40.11$
4	++	+	02	701	100	000	$\lambda_7 = 70.11$

TABLE 2. DATA SET M_2 FOR SP-1

Address	Commands and number						Remarks
	Sign of		Order	A₁	A₂	A₃	
	No.	Order					
			1000 A				
1000	++	+	02	100	000	000	$K_{t_1}=10$
1	++	+	02	110	000	000	$K_{f_1}=11$
2	++	+	02	120	000	000	$K_{t_3}=12$
3	++	+	02	130	000	000	$K_{t_4}=13$
4	++	+	00	000	000	000	
5	++	+	00	000	000	000	
6	++	+	00	000	000	000	
7	++	+	00	000	000	000	
1110	++	+	00	000	000	000	
1	++	+	02	100	000	000	$K_{\text{rep}}=10$
2	++	+	02	100	000	000	$K_0=10$
			1013 A				
1013	++	+	02	160	000	000	$T_{t_1}=16$
4	++	+	02	160	000	000	$T_{t_2}=16$
5	++	+	02	160	000	000	$T_{t_3}=16$
6	++	+	02	380	000	000	$T_{t_4}=38$
7	++	+	00	000	000	000	
1020	++	+	00	000	000	000	
1	++	+	00	000	000	000	
2	++	+	00	000	000	000	
3	++	+	00	000	000	000	
4	++	+	00	000	000	000	
5	++	+	02	160	000	000	$T_{\text{rep}}=16$
			1026 A				
1026	++	+	02	401	000	000	$\varphi_0=40.1$
7	++	+	02	701	000	000	$\lambda_0=70.1$
1030	++	+	00	100	000	000	$Q=0.1$
1	++	+	01	300	000	000	$N_6=3$
2	++	+	01	150	000	000	const=1.5
3	++	+	00	500	000	000	const=0.5
4	++	+	00	430	000	000	$\gamma=0.43$
5	++	+	02	100	000	000	const=10
6	++	+	04	100	000	000	$S_0=1000$
7	++	+	03	352	000	000	$S=352$
1040	++	+	01	350	000	000	$P-0.5=3.5$

BLOCK DIAGRAM OF PROGRAM SP-1



BLOCK DIAGRAM OF PROGRAM SP-2

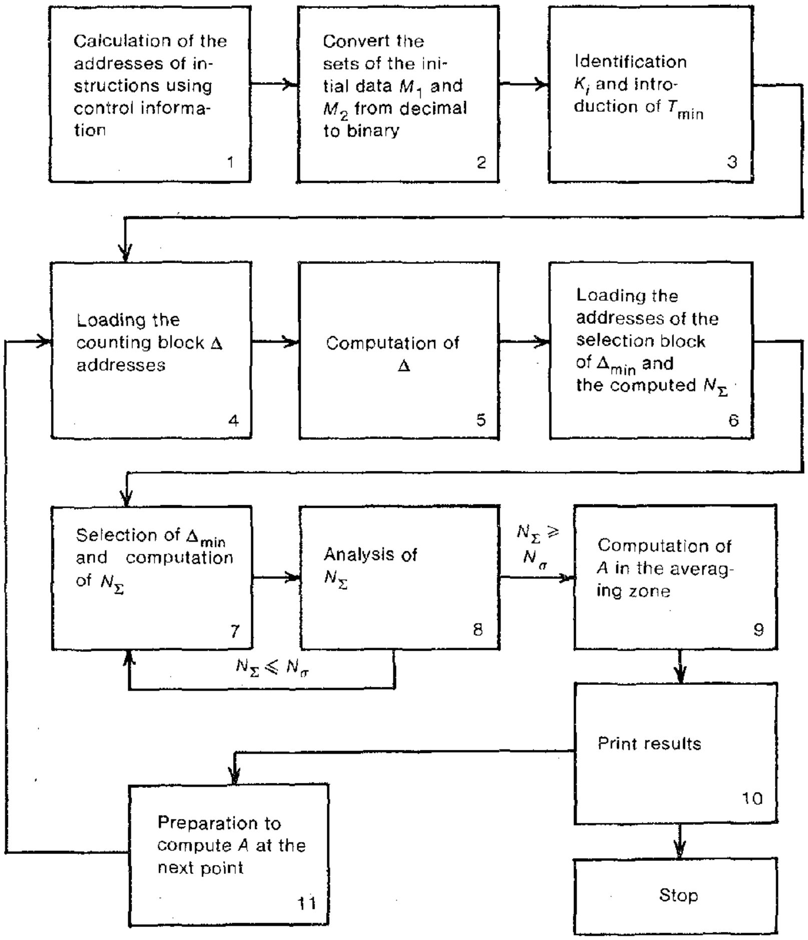


TABLE 3. CONTROL INFORMATION FOR SP-1

Address	Commands and number				Remarks
	Command	A_1	A_2	A_3	
		1042 A			
1042	000	0006	0000	0000	$(m-1, 0, 0)$
3	000	0010	0000	0000	$(q-1, 0, 0)$
4	000	0010	0000	0000	$(r-1, 0, 0)$
5	000	0000	0003	0000	$(0, n, 0)$
6	000	0000	0000	1124	$(0, 0, A_{mn})$

Different values of A_{10} at points 2, 10, and 11 with an identical number n of epicenters in the averaging zones is explained thus: earthquakes, corresponding to these epicenters, differ in energy class K and, therefore, in the presentation period T. As a result, different numbers N_Σ in the averaging zone and different values of A_{10} are obtained in accordance with expressions (37) and (38).

PROGRAM SP-2 OF THE COMPUTATION OF *A* MAPS WITH CONSTANT ACCURACY BY THE SUMMATION METHOD

In the SP-2 program, the value of seismic activity at each point of the resulting map is computed by averaging around the circular varying area zone (Zakharova, 1971) unlike SP-1, where it was trapezoidal. In this the area of the averaging zone of activity A was left unchanged, which, with the usual heterogeneous distribution of epicenters, leads to unequal accuracy in computing A at various map points. A different number of epicenters fall on area S whereas the error of computing seismic activity σ_A, according to (39), is inversely proportional to the sum of epicenters N_Σ in the averaging zone.

While studying the seismic region it is often important to get a seismic activity map with uniform accuracy of all values of A (Riznichenko, Gorbunova, 1968).

The method of computing the map of seismic activity A with uniform accuracy (Gorbunova, 1964) suggests of an equal number of earthquake epicenters N_Σ at each averaging zone A. The number N_Σ represents a certain error σ_A of the computation of A according to (39). Then, after calculating the seismic activity A according to formula (37) by the earthquake summation method (Riznichenko, 1964a), one may compute the number of epicenters N_σ according to (39) and search it around each point, given the certain error σ_A. The larger the area S to contain N_σ, the lesser the level of seismic activity A.

TABLE 4. RESULTS OF COMPUTATION OF A_{10} ACCORDING TO SP-1

N_T	A_{10}	σ_A %	n
+++ 01 100000000	++− 00 372117298	+++ 02 593171014	+++ 01 400000000
+++ 01 200000000	++− 00 316988809	+++ 02 642684586	+++ 01 300000000
+++ 01 300000000	+++ 00 000000000	+++ 03 100000000	+++ 01 100000000
+++ 01 400000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 01 500000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 01 600000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 01 700000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 01 800000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 01 900000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 100000000	++− 00 392790481	+++ 02 577350269	+++ 01 300000000
+++ 02 110000000	++− 00 392790481	+++ 02 577350269	+++ 01 300000000
+++ 02 120000000	+++ 00 000000000	+++ 03 100000000	+++ 01 100000000
+++ 02 130000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 140000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 150000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 160000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 170000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 180000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000

PROGRAM SP-2

Address	Command	A_1	A_2	A_3
		0500 A		
0500	055	0545	0770	0545
1	013	0545	1051	0545
2	055	0665	0770	0665
3	013	0665	1051	0665
4	055	0633	0770	0633
5	013	0633	1052	0633
6	055	0615	0770	0615
7	013	0615	1051	0615
0510	055	0730	0770	0730
1	013	0730	1043	0730
2	055	0734	0770	0734
		0513 A		
0513	013	0734	1044	0734
4	055	0520	0774	0520
5	013	0520	1041	0520
6	000	0000	0000	0000
7	016	0521	7741	0007
0520	000	1100	1100	0000
1	016	0523	7741	0007
2	000	1000	1000	1040
3	016	0525	7741	0007
4	000	1054	1054	1066
5	056	0000	0656	0000
		0526 A		
0526	052	0000	0000	0000
7	275	0000	1100	6031
0530	056	0531	0532	0535
1	002	1000	6031	0000
2	056	0533	0534	0543
3	075	0000	1013	6045
4	075	0000	1040	6041
5	077	0000	0000	0000
6	076	0000	0543	0000
7	013	0535	0771	0535
0540	013	0543	0772	0543
		0541 A		
0541	002	6041	0101	6041
2	076	0000	0535	0000
3	017	0000	0000	0000
4	104	1025	6045	1100
5	112	0000	0527	0003
6	052	0000	0000	0000
7	075	0000	1027	6027
0550	075	0000	1026	6026
1	452	0000	0000	0731

(*Contd.*)

Address	Command	A_1	A_2	A_3
		0552 A		
2	452	0000	0000	0654
3	004	6026	6070	6032
		0554 A		
0554	004	6027	6070	6033
5	056	0556	0557	0613
6	005	1065	6050	4550
7	075	0000	6032	0140
0560	016	0561	7712	0007
1	075	0000	0161	6060
2	075	0000	0160	6061
3	075	0000	6033	0140
4	016	0565	7712	0007
5	075	0000	0161	6062
6	075	0000	0160	6063
		0567 A		
0567	275	0000	1101	0140
0570	016	0571	7712	0007
1	075	0000	0161	6064
2	075	0000	0160	6065
3	275	0000	1102	0140
4	016	0575	7712	0007
5	075	0000	0161	6066
6	075	0000	0160	6067
7	005	6060	6064	6050
0600	005	6061	6063	6051
1	005	6051	6065	6051
		0602 A		
0602	005	6051	6067	6051
3	001	6050	6051	6050
4	005	6061	6062	6051
5	005	6051	6065	6051
6	005	6051	6066	6051
7	001	6050	6051	6050
0610	075	0000	6050	0140
1	016	0612	7716	0007
2	005	0160	6070	6050
3	017	0000	0000	0000
4	013	0613	0773	0613
		0615 A		
0615	112	0000	0567	0003
6	075	0000	0000	6017
7	075	0000	0000	6046
0620	052	0000	0000	0000
		0621 A		
1	075	0000	0000	6072

Address	Command	A_1	A_2	A_3
2	075	0000	0000	6073
3	075	0000	4550	6074
4	013	6072	1045	6072
5	013	6073	0773	6073
6	402	4551	6074	0000
7	076	0000	0633	0000
		0630 A		
0630	075	0000	6072	6075
1	075	0000	6073	6076
2	275	0000	4551	6074
3	112	0000	0624	0001
4	056	0635	0636	0643
5	001	6046	1100	6046
6	056	0637	0640	0644
7	075	0000	1036	4550
0640	075	0000	6074	6057
1	013	0643	6075	0643
2	013	0644	6076	0644
		0643 A		
0643	077	0000	0000	0000
4	077	0000	0000	0000
5	001	6077	0101	6077
6	002	6077	1066	0000
7	036	0000	0620	0000
0650	005	6057	6057	6050
1	005	6050	1064	6057
2	075	0000	6046	6056
3	075	0000	1011	6044
4	077	0000	0000	0000
5	056	0000	0671	0000
		0656 A		
0656	0000	0000	0000	0000
7	0000	0000	0000	0000
0660	0000	0000	0000	0000
1	004	1062	1063	6070
2	052	0000	0000	0000
3	504	1101	6070	1101
4	504	1102	6070	1102
5	112	0000	0663	0003
6	0000	0000	0000	0000
7	075	0000	0000	6053
0670	056	0000	0526	0000
		0671 A		
0671	0000	0000	0000	0000
2	0000	0000	0000	0000

(Contd.)

Address	Command	A_1	A_2	A_3
3	0000	0000	0000	0000
		0674 A		
4	075	0000	1035	0140
5	016	0676	7714	0007
6	075	0000	0160	6047
7	075	0000	0101	6050
0700	075	0000	1034	6051
1	005	6051	6047	0140
2	016	0703	7711	0007
3	002	6050	0160	6050
		0704 A		
0704	075	0000	6044	6052
5	002	6052	1012	6052
6	005	6051	6052	6052
7	005	6052	6047	0140
0710	016	0711	7711	0007
1	075	0000	0160	6052
2	005	6046	6050	6050
3	004	6050	6052	6050
4	005	6050	1036	6050
5	005	6057	1025	6051
6	004	6050	6051	6054
		0717 A		
0717	044	6046	0000	6050
0720	004	1036	1035	6051
1	004	6051	6050	6055
2	000	0000	0000	0000
3	000	0000	0000	0000
4	001	6053	0101	6053
5	016	0727	7751	0007
6	000	6053	4000	6056
7	001	6026	1030	6026
0730	112	0000	0552	0001
1	077	0000	0000	0000
		0732 A		
0732	075	0000	1026	6026
3	001	6027	1030	6027
4	112	0000	0551	0001
5	077	0000	0000	0000
		0770 A		
0770	777	0000	7777	7777
1	000	0001	0000	0000
2	000	0000	0001	0000
3	000	0000	0000	0001
4	777	7777	7777	0000

To compile map A by the uniform accuracy method, the averaging zone S is usually considered circular. Therefore, $S = \pi r^2$ where r is the radius of the averaging zone.

In the SP-2 program, two sets of data are used as initial material. The first, M_1, as in SP-1, is given by the matrix A_{mn}, the number of lines m for which equals the number of epicenters of represented earthquakes in the region under investigation; whereas, the number of columns n is the number of parameters of each epicenter. When computing map A for the earth's surface, these parameters would be as follows: the coordinates of earthquake epicenters φ and λ in degrees and its energy class K_i. The second set of initial data M_2 includes the seismic regime characteristics of the region under investigation according to (37), γ, $K_{\min}$, K_0, $T_{\min}$, set of fixed classes of energy K_{f_j}, and their periods of presentation T_{f_j}, the computation interval —latitudinally—a_φ and longitudinally—a_λ, the number of lines m and columns n of initial matrices, and the corresponding numbers q and r of the resulting matrices (the product $q \cdot r$ gives the number of points of the activity map).

Unlike the data sets of parameters M_2 for the SP-1 program, the area of the averaging zone is not given, but rather the number of epicenters in it—N_σ. While using the program for each point of the map beginning from the first, the coordinates of which φ_0, λ_0 are also fixed in the data sets M_2, the epicenter N_σ is found. The distance to the farthest epicenter of the number N_σ is taken as the radius r of the averaging zone of activity. Besides, constants are added to data sets M_2 which are necessary to convert the scale from degrees to radians: size of the surrounding area in degrees, number 2π and π; to change radians into kilometers, while measuring the epicentral distances—$\hat{r} = 111.199$; and the value $\Delta_{\max} = 1{,}000$ km. The SP-2 program is stored in cells 0500–0735 of MOZV, constants M_2 set and control information engage cells 0770–1066, initial set M_1 of the epicenters is written in the memory, from cell 1100. The remaining MOZV cells are used for the working area in which the intermediate results are written.

Block Diagram SP-2 (see p. 50)

SP-2 flows in a block diagram and begins with entering the actual program and the data sets of initial data into the machine. After control is given to block 1 the addresses of the commands are formed, depending on the control information. In block 2 the sets of initial data are converted from the decimal system to binary. Further control is transferred to block 3 (combined). In it the operations related to the two blocks of the program SP-1 are carried out: identification of the energy class K_i and introduction of the representative time T_i of the class K_i of each earthquake of the initial set to the period $T_{\min}$. For this purpose the energy classes K_i of all earthquakes are successively compared with a set of fixed energy classes K_{f_j} ($j = 1, 2, 3, \ldots p$). If $K_i = K_{f_j}$, the earthquake is written as the corresponding period T_{f_j}. Thereafter with the division of $T_{\min}$ by T_{f_j} the number of earthquakes of energy class K_{f_j} during the period $T_{\min}$ is obtained, corresponding to earthquakes during the period T_{f_j}:

$$N_j = \frac{T_{\min}}{T_{f_j}}.$$

Thus, the work of blocks 1–3 ends with the preparation of the first set of initial data M_1 toward the computation of seismic activity A. In blocks 4–11 A is automatically computed at each point of the map. From block 3 control is transferred to block 4, where the addresses of the block 5 cells are loaded to compute epicentral distances.

Block 5 calculates the distances Δ between the computation point of activity and the epicenters of all the earthquakes of initial data set M_1. The calculation of Δ is carried out according to the formula:

$$\cos \Delta = \sin \varphi_i \cdot \sin \varphi_0 + \cos \varphi_i \cdot \cos \varphi_0 \cdot \cos (\lambda_i - \lambda_0), \tag{40}$$

where φ_i, λ_i—coordinates of the epicenter;

φ_0, λ_0—coordinates of the point in which the seismic activity is counted.

Formula (40) was used by P. Pavlovaskaya (1968) while programing the determination of the foci coordinates Uzbekistan earthquakes.

Control is then transferred to block 6, where are loaded the addresses of the instructions of the selection block of least epicentral distances $\Delta_{\min}$ and the computation of summated number N_Σ of the epicenters in the averaging zone of activity. Thereafter control is transferred to block 7.

In block 7, the least distance—$\Delta_{\min}$ is chosen from those measured in block 5. For this, all the m distances of λ are compared successively with each other. Selection of the least $\Delta = \Delta_{\min_1}$, is accompanied by the computation of the number N_{Σ_1}, corresponding to this $\Delta_{\min_1}$, and by its storage in the cell where the number of epicenters N_{Σ_1} in the averaging zone is formed, which is brought to one observation period $T_{\min}$. The number N_Σ is shifted to block 8, where it is analyzed by comparison with N_σ, representing the number of earthquake epicenters in accordance with the error of determining seismic activity σ_A, according to the formula (39).

When $N_\Sigma \geqslant N_\sigma$ control is shifted to block 9 and is returned to block 7 when $N_\Sigma \leqslant N_\sigma$, where the next least Δ is chosen from those remaining.

For this purpose, in place of the previous $\Delta_{\min} = \Delta_{\min_1}$, $\Delta_{\max}$ is selected; in most cases its previously known value is used (e.g., in Uzbekistan when epicentral distance did not exceed 500–700 km on an average, $\Delta_{\max} = 1{,}000$ km). All the remaining values of Δ are again compared with each other until the selection of the least of them $\Delta_{\min_2}$. Then follows again the computation of N_Σ and transfer of control to block 8. If the comparison of the new number N_Σ again shows the inequality $N_\Sigma < N_\sigma$, control is returned to block 7 and $\Delta_{\max}$ is dispatched in place of $\Delta_{\min_2}$. The process is repeated until $N_\Sigma \geqslant N_\sigma$.

TABLE 5. ADDITIONAL CONSTANTS M_2 FOR SP-2

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				1061 A			
1061	++	+	04	100	000	000	$\Delta_{\max}=1000$
2	++	+	03	360	000	000	$2\pi=360°$
3	++	+	01	628	318	600	$2\pi=6.283186$
4	++	+	01	314	150	300	$\pi=3.141593$
5	++	+	03	111	199	000	1°=111.199 km
6	++	+	01	300	000	000	$N_\sigma=3$

TABLE 6. CONTROL INFORMATION FOR SP-2

Address	Commands and numbers				Remarks
	Command	A_1	A_2	A_3	
		1041 A			
1041	000	000	000	1124	$(0, 0, A_{mn})$
2	000	0006	000	000	$(m-1, 0, 0)$
3	000	0010	000	000	$(q-1, 0, 0)$
4	000	0010	000	000	$(z-1, 0, 0)$
5	000	000	0003	000	$(0, n, 0)$
6	000	000	0001	000	$(0, 1, 0)$
7	000	000	000	0001	$(0, 0, 1)$
1050	000	0001	000	000	$(1, 0, 0)$
1	000	0022	000	000	$[3(m-1), 0, 0]$
2	000	0005	000	000	$(m-2, 0, 0)$

As a result of block 7, a series of distances Δ is chosen answering the condition: $\Delta_{\min_1} < \Delta_{\min_2} < \Delta_{\min_3} \dots < \Delta_{\min_{N_\sigma}}$, the number of these Δ would be $N_\Sigma \geqslant N_\sigma$. After the choice of the least $\Delta = \Delta_{\min_{N_\sigma}}$, control is transferred to block 8 where $N_\Sigma \geqslant N_\sigma$. Further, control is transferred to block 9.

The computation of seismic activity A according to formula (37) is carried out in block 9. The area of the averaging zone S was found before from the expression $S=\pi r^2$, where $r=\Delta_{\min_{N_\sigma}}$.

TABLE 7. RESULTS OF COMPUTATION OF A_{10} ACCORDING TO SP-2

N_T	A_{10}	σ_A	N_Σ
+++ 01 100000000	++− 00 505839551	+++ 02 642684586	+++ 01 242106268
+++ 01 200000000	++− 00 317147752	+++ 02 577350269	+++ 01 300000000
+++ 01 300000000	++− 01 838902168	+++ 02 577350269	+++ 01 300000000
+++ 01 400000000	++− 01 360430929	+++ 02 577350269	+++ 01 300000000
+++ 01 500000000	++− 01 199357111	+++ 02 577350269	+++ 01 300000000
+++ 01 600000000	++− 01 126308151	+++ 02 577350269	+++ 01 300000000
+++ 01 700000000	++− 02 871270444	+++ 02 577350269	+++ 01 300000000
+++ 01 800000000	++− 02 637057144	+++ 02 577350269	+++ 01 300000000
+++ 01 900000000	++− 02 485999108	+++ 02 577350269	+++ 01 300000000
+++ 01 100000000	++− 00 486605219	+++ 02 577350269	+++ 01 300000000
+++ 01 110000000	++− 00 236393739	+++ 02 577350269	+++ 01 300000000
+++ 01 120000000	++− 01 743027819	+++ 02 577350269	+++ 01 300000000
+++ 01 130000000	++− 01 341530739	+++ 02 577350269	+++ 01 300000000
+++ 01 140000000	++− 01 193443057	+++ 02 577350269	+++ 01 300000000
+++ 01 150000000	++− 01 123911577	+++ 02 577350269	+++ 01 300000000
+++ 01 160000000	++− 02 859813598	+++ 02 577350269	+++ 01 300000000
+++ 01 170000000	++− 02 630920910	+++ 02 577350269	+++ 01 300000000
+++ 01 180000000	++− 02 482425038	+++ 02 577350269	+++ 01 300000000

In block 10, the results from the binary representation system are converted to decimal and value A at the point is printed. With the serial number of point $N_T = qr$ the computation is complete; when $N_T < qr$ the control is transferred to block 11 where the preparation goes on to compute A at the next point, and further in block 5.

As a result of SP-2, the serial number of the map point N_T and the value of its seismic activity A is printed. This program accelerates the construction of seismic activity maps with several times greater accuracy when compared with manual computation.

Illustrative Example

The illustrative example for computing seismic activity maps according to the SP-2 program is meant mainly for the same initial data as in SP-1. Therefore, the Table 1 data may be used for loading SP-2 also. The change is related to data set M_2 and the control information group. The set M_2 consists of two parts. The first occupies cells 1000–1040 and fully duplicates Table 2; in the second, additional constants are introduced (Table 5), which are placed in cells 1061–1065.

The control information begins in cell 1041 in the same manner as in SP-1, but with the addition of other lines (Table 6).

In Table 7, where the results of the seismic activity computation are placed, unlike Table 4, the number of epicenters in the averaging zones N_Σ brought to the period of observation, $T_{\min}$ is placed in the last column. The computation data are given for two map columns A_{10}, i.e., for 18 points.

While discussing the results of the computation of A_{10} according to the SP-1 program (Table 4) the differences in the activity values with similar n in the averaging zones of the same area were given different values of N_Σ. Different values of A_{10} for point numbers 2–18 (Table 7) with similar numbers of N_Σ are explained by the variable value of the averaging zone of activity, depending on the distance Δ between the computation point and the last epicenter, fulfilling the condition $N_\Sigma \nless N_\sigma$.

PROGRAM SP-3 FOR COMPUTING A MAPS BY THE COMBINATIONAL METHOD

While calculating the seismic activity A of any territory by the uniform resolution method in each averaging zone of activity, a different number of earthquake epicenters appears, depending on the density of their distribution in the area. With small computation intervals in detailed investigations, not a single epicenter may be seen in certain zones and then a zero value of A is written at that point—the averaging zone center. This leads to a large variation in the activity map, which is, seemingly, less true with the existing

PROGRAM SP-3

Address	Command	A_1	A_2	A_3
		0500 A		
0500	055	0521	1102	0521
1	013	0521	1117	0521
2	055	0545	1103	0545
3	013	0545	1116	0545
4	055	0620	1103	0620
5	013	0620	1112	0620
6	055	0661	1103	0661
7	013	0661	1114	0661
0510	055	0665	1103	0665
1	013	0665	1115	0665
2	0	0	0	0
		0513 A		
0513	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
0520	016	0522	7741	0007
1	000	2361	2361	0
2	016	0524	7741	0007
3	000	1021	1021	1074
4	0	0	0	0
5	0	0	0	0
		0526 A		
0526	052	0	0	0
7	275	0	2361	1120
0530	056	0531	0532	0535
1	002	1021	1120	0
2	056	0533	0534	0543
3	075	0	1034	1122
4	002	1047	1062	1121
5	077	0	0	0
6	076	0	0543	0
7	013	0535	1075	0535
0540	013	0543	1076	0543
		0541 A		
0541	002	1121	0101	1121
2	076	0	0535	0
3	077	0	0	0
4	104	1052	1122	2361
5	112	0	0527	0003
6	0	0	0	0
7	0	0	0	0
0550	075	0	0	1115
1	052	0	0	0

Address	Command	A₁	A₂	A₃
		0552 A		
2	075	0	1050	1124
3	075	0	1051	1125
		0554 A		
0554	0	0	0	0
5	452	0	0	0662
6	452	0	0	0627
7	056	0560	0561	0600
0560	075	0	2362	1126
1	056	0562	0563	0601
2	075	0	2363	1127
3	056	0564	0565	0616
4	001	1130	2361	1130
5	075	0	0	1157
6	056	0	0573	0
		0567 A		
0567	013	0600	1100	0600
0570	013	0601	1100	0601
1	013	0616	1100	0616
2	056	0	0600	0
3	001	1124	1060	1133
4	002	1124	1060	1134
5	001	1125	1061	1135
6	002	1125	1061	1136
7	075	0	0	1130
0600	077	0	0	0
1	077	0	0	0
		0602 A		
0602	002	1133	1126	0
0603	076	0	0605	0
4	056	0	0620	0
5	002	1126	1134	0
6	076	0	0610	0
7	056	0	0620	0
0610	002	1135	1127	0
1	076	0	0613	0
2	056	0	0620	0
3	002	1127	1136	0
4	076	0	0616	0
		0615 A		
0615	056	0	0620	0
6	077	0	0	0
7	001	1157	0101	1157
0620	112	0	0567	0001

(Contd.)

Address	Command	A₁	A₂	A₃
		0621 A		
1	002	1157	1053	0
2	076	0	0624	0
3	056	0	0671	0
4	075	0	1157	1167
5	075	0	1130	1132
6	075	0	1054	1137
7	077	0	0	0
		0630 A		
0630	075	0	1063	0140
1	016	0632	7714	0007
2	075	0	0160	1160
3	075	0	0101	1161
4	075	0	1055	1162
5	005	1162	1160	0140
6	016	0637	7711	0007
7	002	1161	0160	1161
0640	002	1056	1057	1163
0641	005	1162	1163	1163
2	005	1163	1160	0140
		0643 A		
0643	016	0644	7711	0007
4	075	0	0160	1163
5	005	1132	1161	1161
6	004	1161	1163	1161
7	005	1161	1064	1161
0650	005	1137	1052	1162
1	004	1161	1162	1165
2	004	1157	0	1161
3	004	1064	1063	1162
4	004	1162	1161	1166
5	001	1164	0101	1164
		0656 A		
0656	016	0660	7751	0007
7	000	1164	4000	1167
0660	075	0	1133	1124
1	112	0	0556	0001
2	077	0	0	0
3	075	0	1050	1124
4	075	0	1135	1125
5	112	0	0555	0001
6	077	0	0	0
7	0	0	0	0
0670	0	0	0	0
		0671 A		
0671	055	0751	1103	0751

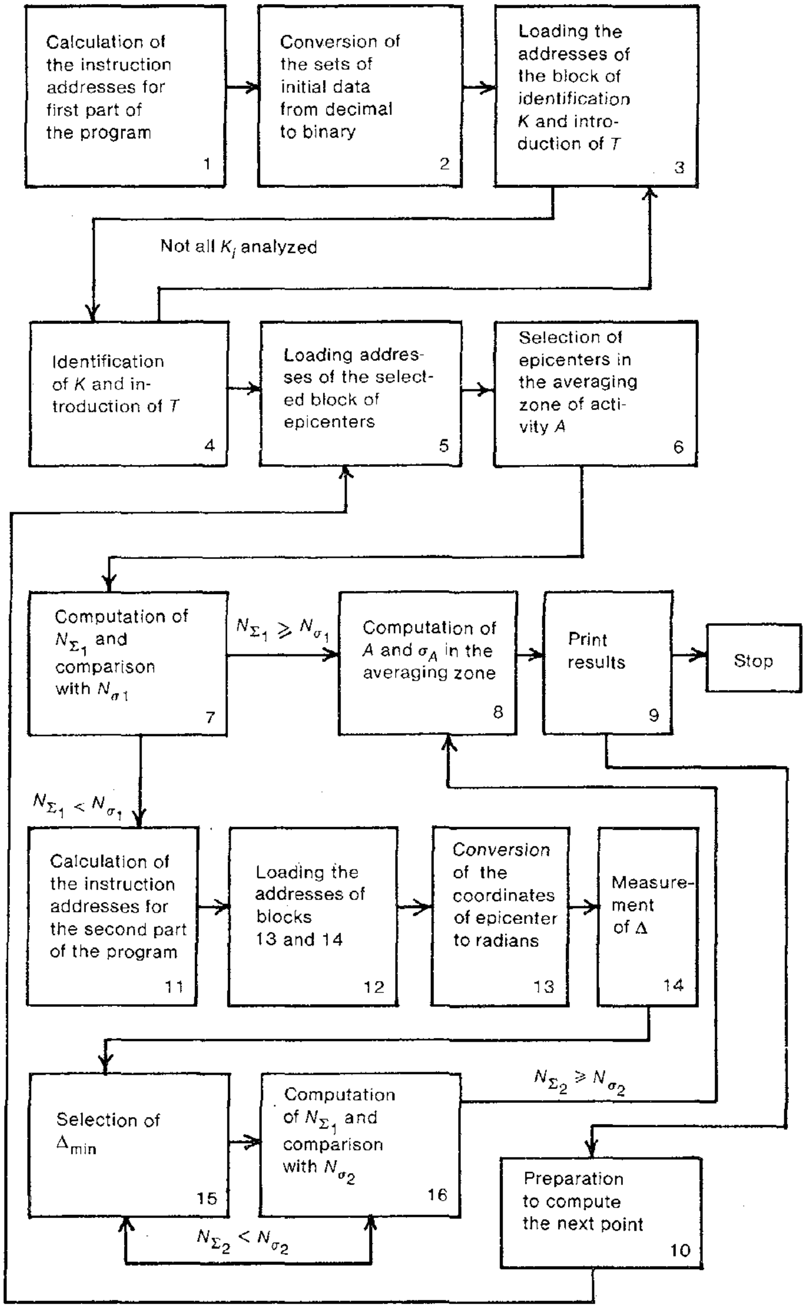
Address	Command	A_1	A_2	A_3
2	013	0751	1116	0751
3	055	0770	1103	0770
4	013	0770	1113	0770
5	056	0676	0677	0707
6	004	2362	1140	1141
7	056	0700	0701	0710
0700	004	2363	1140	1142
1	004	1066	1067	1040
2	004	1124	1140	1126
3	004	1125	1140	1127
		0704 A		
0704	052	0	0	0
5	056	0706	0707	0745
6	005	1065	1161	1171
7	077	0	0	0
0710	077	0	0	0
1	075	0	1126	0140
2	016	0713	7712	0007
3	075	0	0161	1143
4	075	0	0160	1144
5	075	0	1127	0140
6	016	0717	7712	0007
		0717 A		
0717	045	0	0161	1145
0720	075	0	0160	1146
1	075	0	1141	0140
2	016	0723	7712	0007
3	075	0	0161	1147
4	075	0	0160	1150
5	075	0	1142	0140
6	016	0727	7712	0007
7	075	0	0161	1151
0730	075	0	0160	1152
1	005	1143	1147	1161
		0732 A		
0732	005	1144	1146	1162
3	005	1162	1150	1162
4	005	1162	1152	1162
5	001	1161	1162	1161
6	005	1144	1145	1162
7	005	1162	1150	1162
0740	005	1162	1151	1162
1	001	1161	1162	1161
2	075	0	1161	0140

(Contd.)

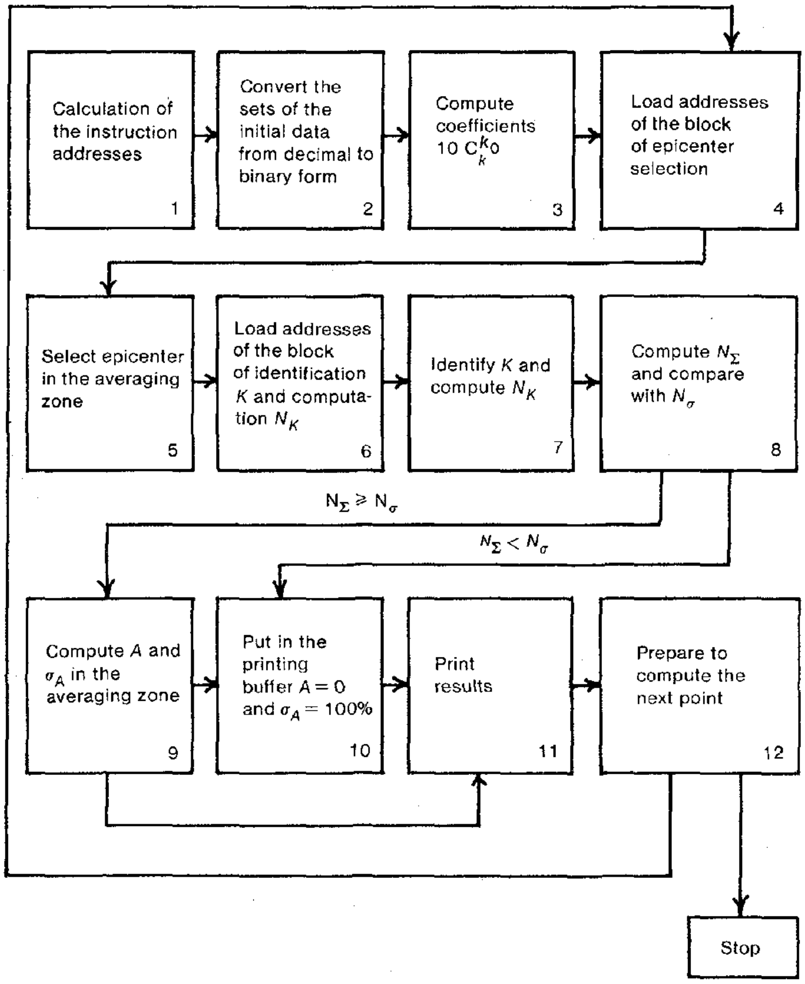
Address	Command	A_1	A_2	A_3
		0743 A		
3	016	0744	7716	0007
4	005	0160	1140	1161
		0745 A		
0745	077	0	0	0
6	013	0745	1077	0745
7	013	0707	1101	0707
0750	013	0710	1101	0710
1	112	3272	0707	0003
2	0	0	0	0
3	075	0	0	1170
4	075	0	0	1131
5	052	0	0	0
6	075	0	0	1153
7	075	0	0	1154
		0760 A		
0760	075	0	1171	1123
1	013	1153	1100	1153
2	013	1154	1077	1154
3	402	1172	1123	0
4	076	0	0770	0
5	075	0	1153	1155
6	075	0	1154	1156
7	275	0	1172	1123
0770	112	1075	0761	0001
1	0	0	0	0
2	0	0	0	0
		0773 A		
0773	056	0774	0775	1003
4	001	1131	2361	1131
		0775 A		
5	056	0776	0777	1004
6	075	0	1064	1171
7	005	1123	1123	1160
1000	005	1070	1160	1137
1	013	1003	1155	1003
2	013	1004	1156	1004
3	077	0	0	0
4	077	0	0	0
5	0	0	0	0
		1006 A		
1006	001	1170	0101	1170
7	002	1170	1053	0
1010	036	0	0755	0
1	075	0	1170	1167
2	075	0	1170	1157

(Contd. on p. 69)

BLOCK DIAGRAM OF PROGRAM SP-3



BLOCK DIAGRAM OF PROGRAM SP-4



PROGRAM SP-3 (*Contd.*)

Address	Command	A_1	A_2	A_3
3	075	0	1131	1132
4	056	0	0627	0
		1075 A		
1075	000	0001	0	0
6	000	0000	0001	0
7	000	0	0	0001
1100	000	0	0003	0
1	000	0003	0	0
2	777	7777	7777	0
3	777	0	7777	7777
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0

accuracy of determining the epicenter coordinates ("Earthquakes in the USSR", 1962–1967). Therefore, I.V. Gorbunova's method (1964) is used when it is necessary to use the constant resolution method, i.e., the constant value of averaging zone A at low activity places, where in each zone less than a given minimum number of epicenters may fall (e.g., less than 3). This is connected with the change of averaging zone A and an increase in the computation accuracy, although, it is true, at the cost of its detailing (Riznichenko, Gorbunova, 1968).

To compute activity maps on the computer by the methods described above, taking into account, if necessary, the constant resolution and constant accuracy methods, we formed a combination program—SP-3, unifying certain blocks of the earlier SP-1 and SP-2 programs. As in SP-1 and SP-2, it uses the method of totaling earthquake epicenters in the averaging zone of activity (Riznichenko, 1964a). The initial information for computing A is given by two sets. The first M_1 is formed by the matrix of epicenters A_{mn}, similar to SP-1 and SP-2.

The second set M_2 mainly holds the constants necessary to compute the seismic activity in the region under investigation: viz., a list of presented energy classes of earthquakes K_{f_j}; number K_{f_j} equal to P; schedule of presentation periods T_{f_j} corresponding to K_{f_j}; value of the zone S_1 of averaging the seismic activity during its calculation with constant detailing; N_{σ_2} is the least number of earthquakes in zone S_1, giving the value A with given reliability; N_{σ_2} is the least number of earthquakes in the averaging zone, corresponding to given error σ_A of computing activity with constant accuracy; φ_0, λ_0—coordinates of the initial point of computation A; a_φ, a_λ is the step of computing activity latitudinally and longitudinally, in this, the product $2a_\varphi \cdot 2a_\lambda$ determines the area of averaging zone S_1; some numerical constants, e.g., the numbers 2π and 360 to change from degree scale to radians and so on. Besides, control information is available with data about the volume of the initial matrix A_{mn} and the volume of the resulting matrix A_{qr}. Here, also are situated data about some concrete cell numbers of memory necessary to calculate the construction sequence. Control information standardizes the program, which may be accepted unchanged to compute seismic activity with any stipulated accuracy for any region with any computation interval and with any averaging zone dimensions. Only the contents of the data sets of the initial data are changed.

The SP-3 program uses the library of standard programs, which is in cells 0–0477 and 6200–7777 of the memory. The SP-3 program itself engages cells 0500–1020 of the memory; the data set of constants and control information is in 1021–1117, the data set of epicenters in 2361–6177, the remaining cells are used for recording intermediate computation results.

Block Diagram SP-3 (see p. 67)

The work flows through blocks 1–16 of the SP-3 program as seen in the block diagram. After the introduction of the actual program and initial data sets to the memory, control is given to block 1. Here the addresses of the first part of the program are calculated for the instructions sequence to compute seismic activity with a constant resolution using the control information. Control is transferred to block 2, where the initial data is converted from decimal to binary. Next control is shifted to block 3 where the addresses of the instructions for block 4 are loaded.

In this block the representative periods T_i, corresponding to the energy class K_i of each earthquake given in M_1, are brought to the period $T_{\min}$ in accordance with the least energy classes of the representative earthquake of the region under investigation. Then control is shifted to block 5 where the addresses of instructions of block 6 are loaded. Computation A begins from the point using the given coordinates φ_0, λ_0. For this, the averaging zone of activity $S_1 = 2a_\varphi \cdot 2a_\lambda$ is taken around the initial point (φ_0, λ_0) and from data set M_1 all earthquake epicenters are chosen, whose coordinates are included in S_1. In block 7, the number of these earthquakes N_{Σ_1} is calculated, which is then compared with the given minimum N_{σ_1} that is necessary to obtain a reliable value of activity at the point (φ_0, λ_0). If $N_{\Sigma_1} \geqslant N_{\sigma_1}$ then control is shifted to block 8, where the values of A and σ_A are automatically computed according to formulas (37) and (39). If $N_{\Sigma_1} < N_{\sigma_1}$, then the number of earthquakes inside the averaging zone is insufficient to obtain a reliable value of activity at point (φ_0, λ_0) in the calculations with constant resolution and it becomes necessary to increase the area of the averaging zone so that $N_{\Sigma_1} = N_{\sigma_1}$. For this purpose control is shifted from block 7 o block 11 which begins the second part of the program. The addresses of he commands for the blocks of the second part of the program are autonatically formed in block 11, after which control is shifted to block 12. The ddresses of the cells of the next two blocks—13 and 14—are loaded there.

Computation of the epicentral distances Δ from the point with coordiiates φ_0, λ_0 to all epicenters (φ_i, λ_i) as in the first data set of initial data, akes place in block 14. The computation of Δ is carried out according to ormula (40), which needs all the arguments to be expressed in radians. The onversion of degrees to radians for the corresponding coordinates of the omputation points (φ_0, λ_0) and epicenters (φ_i, λ_i) is carried out in block 13. Control is shifted from block 14 to block 15 where the computed Δ, the number m of which is equal to the number of epicenters in the first data set of initial data, are compared with one another and the least distant $\Delta_{\min_1}$ from the computation point of activity (φ_0, λ_0) to the nearest earthquake epicenter of the initial set, is selected from among them. In block 16 the selection of $\Delta_{\min_1}$ is accompanied by the selection of the corresponding value of N_{Σ_2}, i.e., the total number of earthquakes in the averaging zone with area $S_1 = \pi\Delta^2_{\min_1}$, brought to the observation period $T_{\min}$. Here, it is compared with the earlier given value N_{σ_2}, defining the accuracy of the seismic activity computation according to expression (39). If $N_{\Sigma_1} \geqslant N_\sigma$ control is shifted to block 8 to compute activity; if $N_{\Sigma_2} > N_{\sigma_2}$ control goes to block 15. Here again all the remaining Δ are compared with each other without the chosen $\Delta_{\min_1}$, which is replaced by number $\Delta_{\max}$ larger than all possible in the region under study. As a result of the comparison, a new $\Delta_{\min_2}$ is selected. The procedure of selecting the least epicentral distances $\Delta_{\min}$ in block 15 is accompanied by the selection and summation of the corresponding N_i in block 16 and this is repeated as long as $\sum N_i = N_\Sigma$ does not equal N_σ—the number of earthquakes in the averaging zone. This insures the given accuracy of the activity computation. (In this case, the last $\Delta_{\min}$ among the values chosen in block 15 is taken to be the radius r of the zone S_2 of averaging activity.) After the computation of S_2 control is shifted to block 8, where, according to the summation formula of earthquakes (37) the activity and the error of computation σ_A—according to (39)—are calculated.

From block 8, control is shifted to block 9 where the results of computation are printed. The print-out gives the point number (N_T) and values A and σ_A. The number N_T is analyzed in the same block and if $N_T = q \cdot r$ (the number of points of the resulting matrix A_{qr}) then the computation is finished. If $N_T < qr$ then control is shifted to block 10 where the computation for seismic activity is made ready for the successive point, for which its coordinates are formed using constants a_φ and a_λ. Further, control is shifted to block 5 and the entire process is fully repeated for each point of the seismic activity map.

Illustrative Example

The initial data of sets M_1, M_2 and the control information may be used to test the SP-3 program. Set M_1 is similar to that in the SP-1 and SP-2 programs (see Table 1), but here the entry address is changed from 1100 to 2361. The set of the constants M_2 includes the contents of the same-named sets for SP-1 and SP-2 and engages cells 1021–1074. The recording of the constants M_2 for the concurrent version of the program is on standard tabulation sheets (Table 8). Here cells 1021–1033 are meant for the energy classes K_{f_j} of the representative earthquakes in set M_1. The illustrative example uses only the first four cells (1021–1024) of the nine put forth in accordance with the number $P = 4$ of the class K_{f_j} of the set M_1 (Table 1). In accordance with the class K_{f_j}; for the placement of the presentation

TABLE 8. DATA SET M_2 FOR SP-3

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				1021 A			
1021	++	+	02	100	000	000	$K_{t_1}=10$
2	++	+	02	110	000	000	$K_{t_2}=11$
3	++	+	02	120	000	000	$K_{t_3}=12$
4	++	+	02	130	000	000	$K_{t_4}=13$
5	++	+	00	000	000	000	
6	++	+	00	000	000	000	
7	++	+	00	000	000	000	
1030	++	+	00	000	000	000	
1	++	+	00	000	000	000	
2	++	+	00	000	000	000	
3	++	+	00	000	000	000	
				1034 A			
1034	++	+	02	160	000	000	$T_{t_1}=16$
5	++	+	02	160	000	000	$T_{t_2}=16$
6	++	+	02	160	000	000	$T_{t_3}=16$
7	++	+	02	380	000	000	$T_{t_4}=38$
1040	++	+	00	000	000	000	
1	++	+	00	000	000	000	
2	++	+	00	000	000	000	
3	++	+	00	000	000	000	
4	++	+	00	000	000	000	
5	++	+	00	000	000	000	
6	++	+	00	000	000	000	

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				1047 A			
1047	++	+	01	400	000	000	$P=4$
1050	++	+	02	401	000	000	$\varphi_0=40.1$
1	++	+	02	701	000	000	$\lambda_0=70.1$
2	++	+	02	160	000	000	$T_{\text{rep}}=16$
3	++	+	01	300	000	000	$N_\sigma=3$
4	++	+	03	352	000	000	$S=352$
5	++	+	00	500	000	000	$\gamma=0.5$
6	++	+	02	100	000	000	$K_{\text{rep}}=10$
7	++	+	02	100	000	000	$K_0=10$
1060	++	+	00	100	000	000	$a_\varphi=0.1$
1	++	+	00	100	000	000	$a_\lambda=0.1$
				1062 A			
1062	++	+	00	500	000	000	const=0.5
3	++	+	02	100	000	000	const=10
4	++	+	04	100	000	000	$\Delta_{\max}=1000$
5	++	+	03	111	199	000	$1°=111.199$
6	++	+	03	360	000	000	$2\pi=360$
7	++	+	01	629	318	600	$2\pi=6.283186$
1070	++	+	01	314	159	300	$\pi=3.141593$
1	++	+	04	100	000	000	$S_0=1000$
2	++	+	01	150	000	000	const=1.5
3	++	+	00	000	000	000	
4	++	+	00	000	000	000	

TABLE 9. CONTROL INFORMATION FOR SP-3

Address	Commands and numbers				Remarks
	Command	A_1	A_2	A_3	
			1112 A		
1112	000	0006	0000	0000	$(m-1, 0, 0)$
3	000	0005	0000	0000	$(m-2, 0, 0)$
4	000	0010	0000	0000	$(q-1, 0, 0)$
5	000	0010	0000	0000	$(r-1, 0, 0)$
6	000	0022	0000	0000	$[(3(m-1), 0, 0]$
7	000	0000	0000	2406	$(0, 0, A_{mn})$

TABLE 10. RESULTS OF COMPUTATION OF A_{10} ACCORDING TO SP-3

N_T	A_{10}	σ_A	n
+++ 01 100000000	++− 00 37217298	+++ 02 593171014	+++ 01 400000000
+++ 01 2000000000	++− 00 316988809	+++ 02 642684586	+++ 01 300000000
+++ 01 300000000	++− 01 838902168	+++ 02 577350269	+++ 01 300000000
+++ 01 400000000	++− 01 360430929	+++ 02 577350269	+++ 01 300000000
+++ 01 500000000	++− 01 199357111	+++ 02 577350269	+++ 01 300000000
+++ 01 600000000	++− 01 126308151	+++ 02 577350269	+++ 01 300000000
+++ 01 700000000	++− 02 871270444	+++ 02 577350269	+++ 01 300000000
+++ 01 800000000	++− 02 637057144	+++ 02 577350269	+++ 01 300000000
+++ 01 900000000	++− 02 485999108	+++ 02 577350269	+++ 01 300000000
+++ 02 100000000	++− 00 392790481	+++ 02 577350269	+++ 01 300000000
+++ 02 110000000	++− 00 392790481	+++ 02 577350269	+++ 01 300000000
+++ 02 120000000	++− 01 743027819	+++ 02 577350269	+++ 01 300000000
+++ 02 130000000	++− 01 341530739	+++ 02 577350269	+++ 01 300000000
+++ 02 140000000	++− 01 193443057	+++ 02 577350269	+++ 01 300000000
+++ 02 150000000	++− 01 123911577	+++ 02 577350269	+++ 01 300000000
+++ 02 160000000	++− 02 859813598	+++ 02 577350269	+++ 01 300000000
+++ 02 170000000	++− 02 690920910	+++ 02 577350269	+++ 01 300000000
+++ 02 180000000	++− 02 482425038	+++ 02 577350269	+++ 01 300000000

periods T_{t_j}, cells 1034–1046 are set aside; whereas, only four (1034–1037) are engaged in our example. In general, without changing the program, the activity computation may be carried out even with $P = 9$, i.e., in a wider range of earthquake energy classes. In cells 1047–1072 the remaining constants of M_2 are recorded, the values of which are shown in the remarks. If data set M_2 (Table 8) is enumerated in decimal code, then the next table containing control information to the illustrative example is given in octal code (Table 9), as in the SP-1 and SP-2 programs, where m—number of lines of the matrix A_{mn} of the initial set M_1, q—number of lines, and r—number of columns of the resulting matrix A_{qr}; A_{mn}—the last cell of the set M_1. The control information engages cells 1112–1117.

Table 10 shows the results of the seismic activity computations of the SP-3 program for the initial data given in Tables 1, 8 and 9. Here the values of activity A_{10} are found for two columns of the map; N_T—serial number of the computational point; σ_A—computation error of A_{10} (%); n—number of epicenters in the averaging zone of activity.

PROGRAM SP-4 FOR COMPUTING *A* MAPS BY THE DISTRIBUTION METHOD

The distribution method (Nersesov, Riznichenko, 1959; Riznichenko, Nersesov, 1960b) was applied during the construction of the first seismic activity maps, and also during the attempts to quantitatively evaluate seismic dangers for the seismic zoning of Uzbekistan in 1962 (Atabaev and others, 1968). The computation was conducted by the expression

$$A = \frac{\sum_{k=10}^{13} n_k^2 c_k^{10} \frac{1000}{T \cdot S}}{\sum_{k=10}^{13} n_k}, \tag{41}$$

where n_k—number of energy class K earthquakes during T years in the area S, km^2;

c_k^{10}—coefficient of transition from the activity according to class K to the activity of energy class 10.

The computation of the activity maps of many seismic zones is conducted by the earthquake summation method (Riznichenko, 1964a; Gorbunova, Riznichenko, 1965; Zakharova, Seiduzova, 1969; Riznichenko, Bune and others, 1969; Riznichenko, Zakharova, Seiduzova, 1970; Drumya and others, 1969, 1971a, b; Kallaur, 1971; Jibladze, 1971 and others). There is a commutative function in the basic construction by the summation method used in the SP-1, 2, and 3 programs, which presents itself as a dependence

PROGRAM SP-4

Address	Command	A_1	A_2	A_3
		0500 A		
0500	055	0522	0764	0522
1	013	0522	0777	0522
2	055	0537	0765	0537
3	013	0537	1000	0537
4	055	0621	0765	0621
5	013	0621	1003	0621
6	055	0671	0765	0671
7	013	0671	1001	0671
0510	055	0675	0765	0675
1	013	0675	1002	0675
2	000	0000	0000	0000
		0513 A		
0513	000	0000	0000	0000
4	000	0000	0000	0000
5	000	0000	0000	0000
6	000	0000	0000	0000
7	055	0701	0765	0701
0520	013	0701	1000	0701
1	016	0523	7741	0007
2	000	1100	1100	0000
3	016	0525	7741	0007
4	000	0710	0710	0763
5	075	0000	0743	1010
		0526 A		
0526	000	0000	0000	0000
7	075	0000	0000	1063
0530	052	0000	0000	0000
1	402	0710	0744	1011
2	005	1010	1011	1011
3	004	1011	0752	1011
4	075	0000	1011	0140
5	016	0536	7710	0007
6	175	0000	0160	1021
7	112	0000	0531	0001
0540	052	0000	0000	0000
		0541 A		
0541	075	0000	0737	1013
2	075	0000	0740	1014
3	452	0000	0000	0672
4	452	0000	0000	0622
5	056	0000	0677	0000
6	056	0547	0550	0565
7	075	0000	1102	1015
0550	056	0551	0552	0566
1	075	0000	1103	1016

Address	Command	A₁	A₂	A₃
		0552 A		
2	056	0553	0560	0603
3	075	0000	1101	1017
		0554 A		
0554	013	0565	0766	0565
5	013	0566	0766	0566
6	013	0603	0766	0603
7	056	0	0565	0
0560	001	1013	0745	1034
1	002	1013	0745	1035
2	001	1014	0746	1036
3	002	1014	0746	1037
4	045	0	0	1020
5	077	0	0	0
6	077	0	0	0
		0567 A		
0567	002	1034	1015	0
0570	076	0	0572	0
1	056	0	0621	0
2	002	1015	1035	0
3	076	0	0575	0
4	056	0	0621	0
5	002	1036	1016	0
6	076	0	0600	0
7	056	0	0621	0
0600	002	1016	1037	0
1	076	0	0603	0
		0602 A		
0602	056	0	0621	0
3	077	0	0	0
4	001	1020	0101	1020
5	002	0736	0747	1040
6	056	0607	0610	0614
7	002	0710	1017	0
0610	056	0611	0614	0620
1	001	1041	0101	1041
2	013	0614	0767	0614
3	013	0620	0770	0620
4	077	0	0	0
		0615 A		
0615	076	0	0620	0
6	002	1040	0101	1040
7	076	0	0612	0
0620	077	0	0	0

(*Contd.*)

Address	Command	A_1	A_2	A_3
		0621 A		
1	112	0	0554	0001
2	077	0	0	0
3	075	0	1020	1066
4	002	1020	0753	0
5	076	0	0631	0
6	075	0	0	1064
7	075	0	0750	1065
		0630 A		
0630	056	0	0665	0
1	002	0736	0747	1054
2	075	0	0	1061
3	075	0	0	1062
4	056	0635	0636	0645
5	004	1041	0723	1011
6	056	0637	0645	0650
7	005	1012	1021	1012
8				
0640	0	0	0	0
1	0	0	0	0
2	0	0	0	0
		0643 A		
0643	013	0645	0771	0645
4	013	0650	0772	0650
5	077	0	0	0
6	001	1061	1011	1061
7	005	1011	1011	1012
0650	077	0	0	0
1	001	1062	1012	1062
2	002	1054	0101	1054
3	076	0	0643	0
4	0	0	0	0
5	0	0	0	0
		0656 A		
0656	004	0751	0742	1012
7	0	0	0	0
0660	005	1062	1012	1012
		0661 A		
1	004	1012	1061	1064
2	045	0	0750	1012
3	044	1020	0	1011
4	004	1012	1011	1065
5	001	1063	0101	1063
6	016	0670	7051	0007
7	000	1063	4000	1066
0670	075	0	1034	1013

Address	Command	A_1	A_2	A_3
		0671 A		
0671	112	0	0544	0001
2	077	0	0	0
3	075	0	0737	1013
4	075	0	1036	1014
5	112	0	0543	0001
6	077	0	0	0
7	002	0736	0747	1055
0700	056	0701	0702	0703
1	075	0	0	1041
2	013	0703	0773	0703
3	077	0	0	0
		0704 A		
0704	002	1055	0101	1055
5	076	0	0702	0
6	056	0	0546	0
		0764 A		
0764	777	7777	7777	0
5	777	0	7777	7777
6	0	0	0003	0
7	0	0001	0	0
0770	0	0001	0	0001
1	0	0001	0001	0
2	0	0	0001	0
3	0	0	0	0001

between energy E and the summated number N_E of earthquakes, exceeding a given value $E_{\min}$ according to energy. To compute the quantity A in each averaging zone the common number of earthquakes is totaled independent of their energy level, i.e., all the earthquakes are given identical weight during summation. The summation method, compared to the distribution method, has some great advantages from the technological angle as well as of principle (Riznichenko, 1964; Riznichenko, Gorbunova, 1968). However, the experiment of computing a seismic activity map of Uzbekistan's interior (Zakhanova, Seiduzova, 1969) as well as outside its boundary (Riznichenko and others, 1969, 1970) shows that these advantages are realized only if there is uniform material of several years of instrumental observations. Its adoptation for small time intervals causes the main advantage of the summation method to almost vanish, that advantage is the possibility of computing strong earthquakes along with the numerous weak ones which are usually taken into account when computing activity by the distribution method. Strong earthquakes take place rarely, therefore, they are usually estimated by individual units on the epicenter maps during short periods of instrumental observations. If it is attempted to use all or, depending on the presentation, almost all known strong earthquakes in the region under investigation, then it is necessary to consider them during various time intervals, that is, in accordance with the presentation periods of earthquakes of each energy class. In this case, the first step to compute the activity map becomes very difficult—viz., to determine the number of epicenters in the averaging zones. This itself does not lead to the technical advantage of the summation method, which appears mainly in the simplicity of fulfilling this particular step of constructing the activity map.

As shown in the literature (Gorbunova, Riznichenko, 1965; Riznichenko, Gorbunova, 1968), the activity maps computed by the distribution and summation methods, are identical, at least within the limits of computation errors.

But this situation may be correct only for the uniform distribution of earthquake epicenters of all representative energy classes along the area, which is usually noticed in long-term instrumental observations. The maps of earthquake epicenters during short periods often have a peculiarity, which is expressed in the advantageous timing of earthquakes of large and small K in the particular region. In several regions, e.g., Pritashkent, and according to materials from relatively long-term observations, weak earthquakes are associated with one geological structure, whereas stronger ones are related to others, depending on the history of their tectonic development.

In similar cases, seismic activity maps would differ in the level as well as in the configuration of isolines A depending on the construction method. Besides, the use of the summation method gives here a distorted picture of the activity of different zones, partly of different geological structures. Actually, if earthquake epicenters with $K \geqslant 8$ correspond to one structure and with $K \geqslant 10$ to another and their total numbers N_{Σ} are somewhat identical, then other conditions remaining the same and the values of γ, T and S, $K_{\min}$, K_0 remaining the same in expression (37), the seismic activity value in the limits of both structures would be identical. The classwise distribution method, however, would give considerably higher activity level on the second structure, which seems physically to be more correct. It seems that the distribution method is more correctly used here, rather than the summation method.

Computing the activity map by the distribution method is a very difficult operation. In accordance with expression (41), it demands a partial computation of the number of earthquakes of each energy class for each point of the map. Therefore, it seems, machine computation makes a sense here. The SP-4 program makes it possible to compute a seismic activity map by the classwise earthquake distribution method with constant resolution.

Initial data of the program are given by two sets M_1 and M_2 and a row of control information, the contents of which are analogous to those of SP-1, 2, and 3. The SP-4 program itself engages 177 memory cells—from 0500 through 0677. Cells 0700–1000 are used for the second set of initial data M_2 and control information. Cells 1010–1100 are a working scratch area and in them are recorded intermediate results while the program is running. Cells 1101–6152 store the main set of initial data, i.e., the set of epicenters M_1.

Block Diagram SP-4 (see p. 68)

The work of the program takes place according to the block diagram and begins with the entry of the initial data to the memory. Thereafter control is given to the beginning of the computation—block 1, where the row of instructions is formed using control information. In block 2 the initial data are converted from the decimal system to the binary. In blocks 3–12 the values of seismic activity A_{K_0} according to energy class K_0 are computed for the corresponding map.

The formula for the computation is similar to (41) and in general is expressed in the following manner:

$$A_{K_0} = \frac{\sum\limits_{K=K_{\min}}^{K_{\max}} N_K^2 \cdot C_K^{K_0} \cdot \frac{1000}{S \cdot T_{\min}}}{\sum\limits_{K=K_{\min}}^{K_{\max}} N_K}, \tag{42}$$

where N_K—number of class K earthquakes taking place during $T_{\min}$ years in the area S km^2;

$C_K^{K_0}$—coefficient of activity transfer from class K to the activity according to class K_0, where K may change from the value $K_{\min}$ to $K_{\max}$ from the number of earthquake energy classes presented in the region under study.

In block 3 the coefficients $C_K^{K_0}$ are computed, that is, using the SP-4 program to determine the seismic activity for any energy class K_0, with any interval of the energy classes K of the initial sets of epicenters—K_{f_j} ($j = 1, 2, 3, \ldots p$). The computation of coefficients $C_K^{K_0}$ is carried out in accordance with the curve of earthquake repeatability according to the formula:

$$C_K^{K_0} = \frac{n_{K_0}}{n_K} = 10^{\gamma (K-K_0)}. \tag{43}$$

The computed coefficients $C_K^{K_0}$, the number P of which are put into the working cell, are stored up to the automatic computation of seismic activity.

With the work of first three blocks the preparatory operations are completed; these are common for all points of the future map. Beginning from block 4, all succeeding operations are carried out for each point.

In block 4 the addresses of the cells are loaded to select the epicenters. Control is then given to block 5 where the coordinates of the initial points of computation are entered and coordinates are formed limiting the averaging zone of activity around this point. Further the coordinates of all epicenters of the initial sets are analyzed for their affiliation to the averaging zone and only those which are inside it are selected. In block 6 the addresses of the identification block for earthquakes of energy class K_i of the initial sets are loaded. Construction of this block considers the variation of the epicenter addresses, since all the m epicenters of the initial data set are analyzed. The subsequent loading of the initial addresses is needed to repeat the operation for each computation point.

Control is shifted from block 6 to block 7, which analyzes or rectifies the energy class K of each earthquake, the epicenter of which is in the averaging zone. The value K_i is compared, for this purpose, with the values of each K_{f_j} from the list of energy classes of the representative earthquake as given in the second set of initial data. When $K_i = K_{f_j}$ the number of earthquakes of each energy class is summated from the set of those presented—K_{f_j}, i.e., the number N_K of the numerator in formula (42) is formed and is related to the corresponding K.

Since the periods of the representative earthquakes of the various classes of seismic energy may not be uniform, they are brought to a single observation period $T_{\min}$ in block 7, which is the least of the representative classes $K_{\min}$ for the earthquakes of the region, in accordance with the expression:

$$N_K = n_{K_{f_j}} \frac{T_{\min}}{T_{f_j}},$$

where $n_{K_{f_j}}$—total earthquakes of energy class K_{f_j} in the averaging zone during the observation period T_{f_j},

N_K—total earthquakes of energy class $K = K_{f_j}$ in the averaging zone during the observation period T.

Next control is shifted to block 8 where the number of chosen epicenters of various K are summated to form the denominator N_Σ in formula (42)

$$N_\Sigma = \sum_{K=K_{\min}}^{K_{\max}} \cdot N_K.$$

Here, of course, the number N_Σ is the total of earthquake epicenters of any K within the averaging zone of activity, the number of which is brought to the observation period $T_{\min}$, and is compared with the already given number N_σ, which defines the required accuracy of the computation of A.

When N_Σ is less than N_σ control is shifted from block 8 to printing block 10, wherein printing buffer $N_{T_{\text{pri}}}$, A_{pri} and $\sigma_{A_{\text{pri}}}$ are input with the following values: N of the point, 0 and 100%, respectively. In this case, the number of epicenters N_Σ appears to be very small for computing activity with the desired accuracy, therefore, A is considered equal to 0, whereas the error $\sigma_A = 100\%$. When $N_\Sigma \geqslant N_\sigma$ control is shifted from block 8 to block 9, where A_{K_0} and σ_A are computed for the point under study in accordance with (42) and (39) and control is shifted to printing block 11, where the computation results are printed. Thereafter control is shifted to block 12, to prepare for the computation of A in the next point. Here its coordinates are formed and control is again shifted to block 4, etc. The computation process is repeated $q \cdot r$ times and the program is stopped.

The SP-4 program is standard—it may be used to compute seismic activity A by the distribution method on any territory, with any step of computations, dimensions of the averaging zones of any earthquake energy class and with any specified accuracy of the computation of A.

Illustrative Eaxmple

To test the SP-4 program an example is formed with sets of the initial data M_1, M_2, group of control information and computation results. It may be used as a check-out version of SP-4. The set M_1 includes the parameters of 20 earthquakes and occupies cells 1100–1173 (Table 11). These parameters are the same as for the sets M_1 of the previous SP-1, 2, and 3 programs.

Set M_2 is meant for the seismic region parameters of the region under investigation and constants of the computation (Table 12). Here eleven cells 0710–0722 are kept for the energy classes of the representative earthquakes K_{f_j}, out of which only the first five are engaged in this example—0710–0714. In accordance with the number K_{f_j}; five successive cells 0723–0727 are used by the numbers T_{f_j}. The parameters in cells 0736–0753 are normally the same (see Tables 2, 6 and 8). The control information (Table 13) uses cells 0777–1003 where A_{mn} is the number of the last cell of the set M_1; P—number of presented earthquake classes, and q and r—number of lines and columns of the resulting matrix A_{qr}, m—number of lines of the initial matrix. Table 14 shows the results of the computation of seismic activity.

Here the values A_{10} for two columns of the maps are brought; N_T—serial number of the point; σ_A—error of computation of A (%); n—number of epicenters in the averaging zone of activity.

PROGRAM SP-5 FOR COMPUTING CURVES OF EARTHQUAKE REPEATABILITY

The law of earthquake repeatability expressing the dependence between the number of earthquakes and their seismic energies is described by a linear

TABLE 11. DATA SET M_1 FOR SP-4

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				1100 A			
1100	++	+	02	110	000	000	$K_1=11$
1	++	+	02	400	100	000	$\varphi_1=40.01$
2	++	+	02	690	510	000	$\lambda_1=69.51$
3	++	+	02	100	000	000	$K_2=10$
4	++	+	02	407	100	000	$\varphi_2=40.71$
5	++	+	02	695	100	000	$\lambda_2=69.51$
6	++	+	02	107	000	000	$K_3=10$
7	++	+	02	406	100	000	$\varphi_3=40.71$
1110	++	+	02	695	100	000	$\lambda_3=69.51$
1	++	+	02	100	000	000	$K_4=10$
2	++	+	02	400	100	000	$\varphi_4=40.01$
				1113 A			
1113	++	+	02	696	100	000	$\lambda_4=69.61$
4	++	+	02	110	000	000	$K_5=11$
5	++	+	02	401	100	000	$\varphi_5=40.11$
6	++	+	02	695	100	000	$\lambda_5=69.51$
7	++	+	02	120	000	000	$K_6=12$
1120	++	+	02	401	100	000	$\varphi_6=40.11$
1	++	+	02	695	100	000	$\lambda_6=69.51$
2	++	+	02	110	000	000	$K_7=11$
3	++	+	02	401	100	000	$\varphi_7=40.11$
4	++	+	02	697	100	000	$\lambda_7=69.71$
5	++	+	01	900	000	000	$K_8=9$
				1126 A			
1126	++	+	02	407	100	000	$\varphi_8=40.71$
7	++	+	02	695	100	000	$\lambda_8=69.51$
1130	++	+	01	900	000	000	$K_9=9$
1	++	+	02	400	100	000	$\varphi_9=40.01$
2	++	+	02	695	100	000	$\lambda_9=69.51$
3	++	+	02	100	000	000	$K_{10}=10$
4	++	+	02	401	500	000	$\varphi_{10}=40.15$
5	++	+	02	696	100	000	$\lambda_{10}=69.61$
6	++	+	01	900	000	000	$K_{11}=9$
7	++	+	02	401	500	000	$\varphi_{11}=40.15$
1140	++	+	02	698	700	000	$\lambda_{11}=69.87$
				1141 A			
1141	++	+	02	100	000	000	$K_{12}=10$
2	++	+	02	401	500	000	$\varphi_{12}=40.15$
3	++	+	02	697	500	000	$\lambda_{12}=69.75$
4	++	+	02	100	000	000	$K_{13}=10$
5	++	+	02	400	100	000	$\varphi_{13}=40.01$
6	++	+	02	695	800	000	$\lambda_{13}=69.58$

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				1147 A			
7	++	+	01	900	000	000	$K_{14}=9$
1150	++	+	02	409	500	000	$\varphi_{14}=40.95$
1	++	+	02	695	100	000	$\lambda_{14}=69.51$
2	++	+	01	900	000	000	$K_{15}=9$
3	++	+	02	400	100	000	$\varphi_{15}=40.01$
1154	++	+	02	695	700	000	$\lambda_{15}=69.57$
5	++	+	01	900	000	000	$K_{16}=9$
6	++	+	02	408	100	000	$\varphi_{16}=40.81$
7	++	+	02	695	800	000	$\lambda_{16}=69.58$
1160	++	+	01	900	000	000	$K_{17}=9$
1	++	+	02	409	300	000	$\varphi_{17}=40.93$
2	++	+	02	693	100	000	$\lambda_{17}=69.31$
3	++	+	01	900	000	000	$K_{18}=9$
4	++	+	02	406	100	000	$\varphi_{18}=40.61$
5	++	+	02	696	100	000	$\lambda_{18}=69.61$
6	++	+	02	100	000	000	$K_{19}=10$
				1167 A			
1167	++	+	02	401	500	000	$\varphi_{19}=40.15$
1170	++	+	02	697	700	000	$\lambda_{19}=69.77$
1	++	+	01	900	000	000	$K_{20}=9$
2	++	+	02	402	200	000	$\varphi_{20}=40.22$
3	++	+	02	697	700	000	$\lambda_{20}=69.77$

TABLE 12. DATA SET M_2 FOR SP-4

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				0710 A			
0710	++	+	01	900	000	000	$K_{t_1}=9$
1	++	+	02	100	000	000	$K_{t_2}=10$
2	++	+	02	110	000	000	$K_{t_3}=11$
3	++	+	02	120	000	000	$K_{t_4}=12$
4	++	+	02	130	000	000	$K_{t_5}=13$
5	++	+	00	000	000	000	
6	++	+	00	000	000	000	
7	++	+	00	000	000	000	

(Contd.)

TABLE 12 (*Contd.*)

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
0720	++	+	00	000	000	000	
1	++	+	00	000	000	000	
2	++	+	00	000	000	000	
				0723 A			
0723	++	+	01	850	000	000	$Tt_1=8.5$
4	++	+	02	180	000	000	$Tt_2=18$
5	++	+	02	180	000	000	$Tt_3=18$
6	++	+	02	180	000	000	$Tt_4=18$
7	++	+	02	400	000	000	$Tt_5=40$
0730	++	+	00	000	000	000	
1	++	+	00	000	000	000	
2	++	+	00	000	000	000	
3	++	+	00	000	000	000	
4	++	+	00	000	000	000	
5	++	+	00	000	000	000	
				0736 A			
0736	++	+	01	500	000	000	$P=5$
7	++	+	02	401	000	000	$\varphi_0=40.1$
0740	++	+	02	696	000	000	$\lambda_0=69.6$
1	++	+	01	850	000	000	$T_{pr}=8.5$
2	++	+	03	352	000	000	$S=352$
3	++	+	00	500	000	000	const=0.5
4	++	+	02	100	000	000	const=10
5	++	+	00	100	000	000	$a_\varphi=0.1$
6	++	+	00	100	000	000	$a_\lambda=0.1$
7	++	+	00	500	000	000	const=0.5
0750	++	+	03	100	000	000	const=100
				0751 A			
0751	++	+	04	100	000	000	$S_0=1000$
2	++	+	00	434	290	000	1=0.43429
3	++	+	01	100	000	000	$N_\sigma=1$

TABLE 13. CONTROL INFORMATION FOR SP-4

Address	Commands and numbers				Remarks
	Command	A_1	A_2	A_3	
			0777 A		
0777	000	0000	0000	1173	$(0, 0, A_{mn})$
1000	000	0004	0000	0000	$(p-1, 0, 0)$
1	000	0010	0000	0000	$(q-1, 0, 0)$
2	000	0010	0000	0000	$(r-1, 0, 0)$
3	000	0023	0000	0000	$(m-1, 0, 0)$

TABLE 14. RESULTS OF COMPUTATION OF A_{10} ACCORDING TO SP-4

N_T	A_{10}	σ_A	n
+++ 01 100000000	+++ 01 131071840	+++ 02 454858826	+++ 01 800000000
+++ 01 200000000	+++ 00 935143140	+++ 02 643267520	+++ 01 400000000
+++ 01 300000000	++− 00 105689842	+++ 03 100000000	+++ 01 100000000
+++ 01 400000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 01 500000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 01 600000000	++− 00 105689842	+++ 03 100000000	+++ 01 100000000
+++ 01 700000000	++− 00 357986887	+++ 02 582771517	+++ 01 400000000
+++ 01 800000000	++− 00 357986887	+++ 02 582771517	+++ 01 400000000
+++ 01 900000000	++− 00 211379685	+++ 02 707106781	+++ 01 200000000
+++ 02 100000000	++− 00 105689842	+++ 03 100000000	+++ 01 100000000
+++ 02 110000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 120000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 130000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 140000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 150000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 160000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 170000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000
+++ 02 180000000	+++ 00 000000000	+++ 03 100000000	+++ 00 000000000

repeatability graph in formulas (9 and 10) as a first estimate. Seismologists in the USSR used the dependence of the number of earthquakes N_K from seismic energy class K according to formula (9). While normalizing the number of earthquakes N_K around the area and time an expression is obtained for the seismic activity of class K, i.e., A_K (11). Then $N_0 \equiv A_0$, i.e., seismic activity, corresponding to class $K = K_0$. The parameters of the repeatability curve A_0 and γ signify its level and inclination and are obtained by the method of least squares. The mean square errors of these values—σ_A and σ_γ—are also computed in the same manner.

Arising out of the proposed linearity of the curves of earthquake repeatability, the quantity γ is computed as a tangent of inclination angle to the axis of abscissa, built in the coordinates $K = \log E$ and $\log N^*$:

$$\log N^* = A_0 + \gamma K. \tag{44}$$

Here N^*—number of earthquakes of a particular K brought to the unit area and time. Having a system of linear equations (44), the coefficients of the straight line γ and A_0 are found using determinants

$$\gamma = \frac{\begin{vmatrix} \sum (K \log N^*) & \sum K \\ \sum \log N^* & d \end{vmatrix}}{\begin{vmatrix} \sum K^2 & \sum K \\ \sum K & d \end{vmatrix}}. \tag{45}$$

$$A_0 = \frac{\begin{vmatrix} \sum K^2 & \sum (K \cdot \log N^*) \\ \sum K & \sum \log N^* \end{vmatrix}}{\begin{vmatrix} \sum K^2 & \sum K \\ \sum K & d \end{vmatrix}}. \tag{46}$$

Here d is the number of equations used to construct the repeatability curve and determined by the range of presented energy classes—the so-called fixed classes K_{f_j}.

The intercept of the straight line (44) on the axis of ordinate, is characterized by the values A_0, and on the axis abscissa—by value $b = A_0/\gamma$, obtained from equation (44) with $\log N^* = 0$. This value is convenient for the computation, although it may be devoid of physical sense (Butovskaya and others, 1966).

To compute the mean error of the points from the straight line equation (44) the following formula is used:

$$\sigma_\gamma = \sqrt{\frac{\{\sum [\log N^* - K \cdot \gamma + A_0]^2\}\, d}{\begin{vmatrix} \sum K^2 & \sum K \\ \sum K & d \end{vmatrix} (d-2)}}. \tag{47}$$

The computation of the unknown quantities using formulas (45–47) by hand is very time consuming and difficult even if done only once. If these computations are repeated to establish temporal dependence, there is a

PROGRAM SP-5

Address	Command	A_1	A_2	A_3
		0500 A		
0500	055	0553	1054	0553
1	013	0553	1055	0502
2	055	0602	1054	0602
3	013	0602	1055	0602
4	055	0515	1060	0515
5	013	0515	1061	0515
6	055	0517	1060	0517
7	013	0517	1062	0517
0510	055	0521	1060	0521
1	013	0521	1063	0521
2	055	0523	1060	0523
		0513 A		
0513	013	0523	1064	0523
4	0	0	0	0
5	016	0517	7741	0007
6	0	1000	1000	0
7	016	0521	7741	0007
0520	0	1013	1013	0
1	016	0523	7741	0007
2	0	1026	1026	0
3	016	0525	7741	0007
4	0	1041	1041	0
5	0	0	0	0
		0526 A		
0526	052	0	0	0
7	075	0	0	6000
0530	075	0	0	6001
1	075	0	0	6002
2	075	0	0	6003
3	075	0	0	6004
4	0	0	0	0
5	405	1041	1000	6010
6	004	1003	6010	6010
7	275	0	1026	6005
0540	105	6005	6010	6026
		0541 A		
0541	275	0	6026	0146
2	016	0543	7714	0007
3	0	0	0	0
4	105	0160	1004	604
5	605	1013	6041	6011
6	001	6001	6011	6011
7	201	6002	6041	6002

(Contd.)

Address	Command	A_1	A_2	A_3
0550	201	6003	1013	6003
1	605	1013	1013	6012
		0552 A		
2	001	6004	6012	6004
3	112	0	0535	0001
		0554 A		
0554	005	6001	1001	6013
5	005	6002	6003	6014
6	005	6004	1001	6015
7	005	6003	6003	6016
0560	002	6013	6014	6013
1	002	6015	6016	6011
2	004	6013	6011	6013
3	075	0	6013	6021
4	005	6004	6002	5002
5	005	6001	6003	6001
6	002	6002	6001	6002
		0567 A		
0567	004	6002	6011	6012
0570	075	0	6012	6022
1	004	6022	6013	6012
2	075	0	6012	6023
3	052	0	0	0
4	075	0	0	6001
5	405	1013	6013	6017
6	001	6017	6022	6017
7	202	6017	6041	6017
0600	005	6017	6017	6017
1	001	6001	6017	6001
		0602 A		
0602	112	0	0575	0001
3	005	6001	1001	6001
4	002	1001	1002	6020
5	005	6001	6020	6011
6	004	6001	6011	6011
7	044	6011	0	6011
0610	075	0	6011	6024
1	005	6023	1005	6006
2	005	6022	1005	6007
3	005	6007	1006	6054
4	005	6006	6007	6007
		0615 A		
0615	002	6054	6007	6007
6	004	6007	6006	6025
7	016	0621	7751	0007
0620	0	6021	4000	6025

Address	Command	A_1	A_2	A_3
		0621 A		
1	077	0	0	0
2	0	0	0	0
3	0	0	0001	0
4	0	0001	0	0001
5	777	0	7777	7777
6	777	7777	7777	0
7	0	0001	0	0
		0630 A		
0630	002	1056	0101	0
1	076	0	0635	0
2	002	1057	0101	0
3	016	0700	0500	0525
4	056	0	0500	0
5	055	0642	0626	0642
6	013	0642	1054	0642
7	055	0673	0625	0673
0640	013	0673	1060	0673
1	016	0643	7741	0007
2	000	1000	1100	0
		0643 A		
0643	016	0645	7741	0007
4	000	1000	1000	1053
5	056	0646	0652	0652
6	075	0	1100	1077
7	0	0	0	0
0650	013	0652	1066	0652
1	0	0	0	0
2	077	0	0	0
3	052	0	0	0
4	175	0	0	1026
5	112	0012	0667	0001
		0656 A		
0656	002	1011	1007	1076
7	056	0660	0661	0666
0660	002	1077	1013	0
1	056	0662	0666	0672
2	001	1026	0101	1026
3	0	0	0	0
		0664 A		
4	013	0701	0623	0701
5	013	0705	0624	0705
6	077	0	0	0
7	076	0	672	0
0670	002	1076	0101	1076

(Contd.)

Address	Command	A_1	A_2	A_3
		0671 A		
0671	076	0	0666	0
2	077	0	0	0
3	112	0	0650	0001
4	016	0675	0500	0514
5	002	1067	0101	0
6	076	0	0700	0
7	056	0	0526	0
0700	052	0	0	0
1	075	0	0	0
2	075	0	0	6001
3	075	0	0	6002
		0704 A		
0704	075	0	0	6003
5	075	0	0	6004
6	401	1026	6000	6000
7	405	1041	1000	6010
0710	004	1003	6010	6010
1	075	0	6000	6005
2	105	6005	6010	6026
3	275	0	6026	0140
4	016	0543	7714	0007
5	0	0	0	0
6	105	0160	1004	6041
		0717 A		
0717	605	1013	6041	6011
0720	001	6001	6011	6001
1	201	6002	6041	6002
2	201	6003	1013	6003
3	605	1013	1013	6012
4	001	6004	6012	6004
5	112	0	0534	0001
6	056	0	0554	0

considerable waste of time and labor. This work is considerably simplified with a computer. The SP-5 program computes the parameters of the earthquake repeatability and evaluates their errors on the basis of earlier computed numbers of earthquakes N_K, corresponding to various classes K, as usually done in long-hand calculations. It may also compute these numbers earlier, using as initial data the map or list of earthquake epicenters in the form of matrix A_{mn} (see SP-1, 2, 3, and 4). The use of the matrix A_{mn} is convenient even in the cases when, before the computation of the seismic activity map, it is necessary to fix the already existing value γ or compute it again for the same observation period as for map A. SP-5 program can compute the level of the repeatability curve A_{K_0} for any given class K_0 of seismic energy and the values of γ, A_0 and σ_γ. Partially, with $K = 10$ one may find the average level of seismic activity A_{10} for the region under investigation, which, along with γ, is a main parameter for the seismic region.

For this purpose, the program records the equations of the repeatability curve in a straight line form, passing through two points with coordinates $(0, A_0)$ and $(b, 0)$:

$$\frac{K}{b} = \frac{\log N_K^* - A_0}{-A_0}. \tag{48}$$

Entering the values of $K = K_0$ in equation (48), one gets the value $\log N_K^* = \log A_{K_0}$ and further A_{K_0}.

The initial data for SP-5 are given by sets—mainly the same as for the previous program—and the row of control information. The first set M_1—matrix A_{mn}—formed automatically from the earthquake epicenters map, m—number of matrix lines determined by the number of earthquake epicenters of the region under study, n—number of characteristics of each epicenter, its geographical coordinates φ_i and λ_i, and K_i—earthquake energy class. It may be noted that only data about classes K_i are used in the SP-5 program, the coordinates φ_i and λ_i of the epicenters are not required. Therefore, in principle, the initial set may be given with $n = 1$, i.e., with information only about K_i. However, here arguments continue about the uses of the already codified and perforated matrix of epicenters A_{mn}, prepared for computing the repeatability curve and considerably reducing preparations for machine computation.

The second set of initial data M_2 includes values needed to normalize the numbers N_K temporarily and spatially. Here, mainly are included parameters similar to those shown in previous programs. If it is necessary to compute the parameters of repeatability curves for already known numbers N_K, their values are also entered in the second set of initial data M_2.

Control information is the volume of initial set and some cell addresses necessary to form program instructions. The SP-5 program itself occupies cells 0500–0726 of the memory, set M_2 and control information are in cells 1000–1077.

The set M_1 may occupy memory cells beginning from 1100–5777. Cells 6000–6177 are kept aside for working, printing, and storing the intermediate computation results.

Block Diagram SP-5 (see p. 101)

The SP-5 program takes place as seen in the block diagram. The indexing cell M_1 is analyzed in block 1 which already contains numbers 1 and 0. When $\mu_1 = 1$ control is shifted for the first part of the program (Blocks

2–6), which computes the classwise numbers N_{K_j} of earthquakes based on the initial set of epicenters M_1. In block 2, the addresses of block 3–6 are formed. Control is shifted to block 3, where the parameters of the earthquake epicenters are transformed from decimal to binary system.

In block 4 are loaded the addresses of the instructions for the analysis of epicenter energy classes and the automatic computation of numbers N_{K_j}.

Block 5 analyzes the energy classes of all m earthquakes which are given in the initial matrix A_{mn} (M_1). When $K_i = K_{f_j}$ control is shifted from block 5 to block 6 which computes the classwise number N_{K_j}. From block 6, control is shifted again to block 4 to load the addresses of block 5 and then on to block 5, where the value $K_{i_n} = K_{f_j}$ is chosen for the following analysis. This goes on until all the energy classes of all epicenters of the initial set are identified and the numbers N_{K_j} corresponding to it are summated. Then control is shifted to block 7, where are formed the addresses of some instructions for blocks 8–15.

Block 7 is the first block of second part of the program in which is conducted the automatic computation of the parameters of the repeatability curves. The second part of the program may work independently; in this case, control is shifted straight from block 1 to block 7, if $\mu_1 = 0$—when the earthquake class numbers N_{K_j} are given in the set M_2. After compiling the addresses, control is shifted from block 7 to block 8, where the numbers are converted from decimal to binary, included in the second set M_2 with the numbers N_{K_j}. If control to block 7 is shifted to block 6, i.e., the first part of the program has worked, then the numbers N_{K_j} from the conversion from decimal to binary are bypassed, since these numbers have already been input to the memory in binary-octal code.

Further the control is shifted to block 9 which determines the distribution density of the numbers of earthquakes $N^*_{K_j}$. For this purpose, the number N_K is normalized for 1,000 km^2 area and one year.

In block 10, the index cell μ_2 is analyzed, in which the number 0 or 1 was put earlier, indicating the method of computing the repeatability curve —by distribution ($\mu_2 = 0$) or by summation ($\mu_2 = 1$). When $\mu_2 = 0$, control is shifted to block 11, where the function of the distribution of $N^*_{K_j}$ about K_{f_j} is computed and a system of linear equations (44) is formed. This is equal to P', i.e., the number K_{f_j} in the region under investigation.

When $\mu_2 = 1$ control is shifted from block 10 to block 12 to compute the cumulative function of the number $N^*_{K_j}$ of earthquakes of the entire range of energy classes of representative earthquakes which are given in the initial epicenter map. It is computed by the summation of the normalized numbers of earthquakes $N^*_{K_j}$, which reflect various K beginning from $K_{\max}$, taking part in the construction of the repeatability curve and further increasing the summation up to the formation of the total sum after the computation of $K_{\min}$.

These numbers $\sum N^*_{K_j}$ of earthquakes of each energy class K_{f_j} are put in the same cell as the values $N^*_{K_j}$ of the classwise normalized numbers of earthquakes in the distribution method for constructing the repeatability curve. Further, the systems of linear equations (44) are formed in a manner similar to block 11.

Control is shifted from blocks 11 and 12 to block 13 where are computed the inclination γ and other coefficients of the curve.

Block 14 computes the seismic activity level of the region A_{K_0} according to the seismic energy class K_0 as well as the error of averaging σ_γ. The computation results are printed in block 15. The values γ, A_0, b, A_{K_0} and σ_γ are shown on the printer. When calculating the repeatability curves by the summation method, the values σ_γ and A_{K_0}, apparently, have no significance unlike in the distribution method.

Illustrative Example

To test the SP-5 program, its check-out version may be used, which is written with the already prepared classwise numbers of earthquakes N_{K_j} given in the initial data set M_2. The search of these numbers on the basis of initial set M_1 is not difficult but its volume of M_1 is so large that bringing it here is very difficult. For the illustrative example, data set M_2 has been shown (Table 15) in cells 1000–1053.

In our case, the number $P = 5$, whereas K_{f_j} varies from 13 to 9, but the range of the classes K_{f_j} being used may be increased twice if necessary, since cells 1013–1025 have been left to record K_{f_j}. In accordance with the placement of K_{f_j} the following groups of cells, 1026–1040 and 1041–1053, are meant for recording of the classwise numbers of earthquakes N_{K_j} and presentation periods T_{f_j}.

TABLE 15. DATA SET M_2 FOR SP-5

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				1000 A			
1000	++	+	00	000	000	000	0
1	++	+	00	000	000	000	0
2	++	+	01	200	000	000	const=2
3	++	+	04	100	000	000	$S_0=1000$
4	++	+	00	434	290	000	$l=0.43429$
5	+−	+	01	100	000	000	const=1
6	++	+	02	100	000	000	const=10

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
7	++	+	00	500	000	000	const=0.5
1010	++	+	05	855	000	000	$S=85,500$
1	++	+	01	500	000	000	$P=5$
2	++	+	00	000	000	000	0
				1013 A			
1013	++	+	02	130	000	000	$K_{t_1}=13$
4	++	+	02	120	000	000	$K_{t_2}=12$
5	++	+	02	110	000	000	$K_{t_3}=11$
6	++	+	02	100	000	000	$K_{t_4}=10$
7	++	+	01	900	000	000	$K_{t_5}=9$
1020			00	0	0	0	
1			00	0	0	0	
2			00	0	0	0	
3			00	0	0	0	
4			00	0	0	0	
5			00	0	0	0	
				1026 A			
1026	++	+	02	100	000	000	$N_{K_1}=10$
7	++	+	02	230	000	000	$N_{K_2}=23$
1030	++	+	02	870	000	000	$N_{K_3}=87$
1	++	+	03	224	000	000	$N_{K_4}=224$
2	++	+	03	229	000	000	$N_{K_5}=229$
3			00	0	0	0	
4			00	0	0	0	
5			00	0	0	0	
6			00	0	0	0	
7			00	0	0	0	
1040			00	0	0	0	
				1041 A			
1041	++	+	02	400	000	000	$T_{t_1}=40$
2	++	+	02	180	000	000	$T_{t_2}=18$
3	++	+	02	180	000	000	$T_{t_3}=18$
4	++	+	02	180	000	000	$T_{t_4}=18$
5	++	+	01	850	000	000	$T_{t_5}=8.5$
6			00	0	0	0	
7			00	0	0	0	
1050			00	0	0	0	
1			00	0	0	0	
2			00	0	0	0	
3			00	0	0	0	

TABLE 16. CONTROL INFORMATION FOR SP-5

Address	Commands and numbers				Remarks
	Command	A_1	A_2	A_3	
		1054 A			
1054	000	0000	0000	0000	$(0, 0, A_{mn})=(0, 0, 0)$
5	000	0000	0000	0000	0
6	000	0000	0000	0000	$M_1=0$
7	000	0000	0000	0000	$M_2=0$
1060	000	0000	0000	0000	$(m-1, 0, 0)=(0, 0, 0)$
1	000	0000	0000	1011	$(0, 0, a_e)=(0, 0, 1011)$
2	000	0000	0000	1017	$(0, 0, K_n)=(0, 0, 1017)$
3	000	0000	0000	1032	$(0, 0, N_n)=(0, 0, 1032)$
4	000	0000	0000	1045	$(0, 0, T_n)=(0, 0, 1045)$
5	000	0004	0000	0000	$(p-1, 0, 0)=(4, 0, 0)$
6	000	0000	0000	0000	$(0, n, 0)=(0, 0, 0)$

Control information is recorded in cells 1054–1066 (Table 16). Here A_{mn} is the number of the last cell of the set of epicenters M_1, therefore, in our case the content of the cell 1054 is equal to zero. Index cells 1056 and 1057 are marked for members μ_1 and μ_2; $\mu_1 = 0$ means set M_1 is absent; $\mu_2 = 0$ indicates use of the distribution method to compute the parameters of the repeatability curves; m and n—number of rows and columns of the matrix A_{mn}, consisting of set M_1. Hence, in the cells corresponding to them here, numbers 1060 and 1066 are zero. In the remaining cells, 1061–1064, the numbers of succeeding cells are shown, which are meant to record the following data: a_e—constant of computation, K_n—classes K_{f_j}, N_n—classwise numbers of earthquakes, T_n—representative periods T_{f_j} for the classes K_{f_j}.

Given below are the results of the computation of the parameters of the frequency curve (data Tables 15 and 16) using the SP-5 program while running the distribution method:

γ : ++− 00587957519
A_0 : +++ 01525446148
b : +++ 01893704272
A_{10} : ++− 00125975281
σ_γ : ++− 01426563065.

Chapter IV

Programs to Compute Maps of Maximum Possible Earthquakes (K_{max})

Hand computation of maps of maximum possible earthquakes K_{max} using correlations between K_{max} and seismic activity A has been described by Riznichenko (1966b).

I.V. Gorbunova (1969) uses, for this purpose, seismic activity maps with constant accuracy based on correlations from Northern Tien-Shan.

Value of K_{max} may be found for each node of the map grid thus (Riznichenko, 1966a, 1967a): Based on the correlated dependence (13) for each value of K_{max}, A is found, i.e., the average seismic activity in the area responsible for the strong earthquake K_{max}. In this the radius r of the area is computed with the assumption that the value of energy K_{max}, emitted in the focus of a strong earthquake, is proportional to the volume of the region of its preparation in accordance with (14).

Further, a grid is drawn on the map of earthquake epicenters. It is necessary to establish the values of K_{max} on its points. Each node of the grid becomes the center of concentric areas, whose radius r reflects the values K_{max} of the entire range of earthquakes as in formula (14). The value $\bar{A}$ in each is computed by the summation method. The value K_{max} is assigned to the grid point which corresponds to the value $\bar{A}$ on area $S = \pi r^2$, as in formulas (13) and (14).

The compilation of the K_{max} maps is the same for Eastern Sayan (Riznichenko, 1966b), Eastern Uzbekistan (Zakharova, Seiduzova, 1969), Southern Fergana (Flenova, 1971), certain regions of Turkmenia (Kallaur, 1971), Georgia and its surroundings (Jibladze, 1971), Pribaikal (Uspenskaya, 1971), and others.

Since the described computation of K_{max} was very unwieldy and difficult (Riznichenko and others, 1970), it was simplified in the following manner: At first, the values $\bar{A}$ were computed for each K_{max} value for all earthquakes by formula (13), which should define the appearance of these earthquakes. Then, the total quantity N of epicenters is found by formula (37), taking into account the values of $\bar{A}$ and S, stipulating the given quantity $\bar{A}$. Next the number N_{Σ} of epicenters of concentric areas S is computed, which is done for each grid point. The value $K_{\max}$ is attributed to the point under study, insuring better agreement between the computed value N_{Σ} and the observed one.

The computation of $K_{\max}$ with value N_{Σ} may also be simplified by using the summation method with constant accuracy (Gorbunova, 1964). The values $\bar{A}$ for each $K_{\max}$ are also computed by formulas (13, 14) and are inserted in formula (37) along with the total number of epicenters $N_{\Sigma} = N_{\sigma}$, which is constant for all succeeding calculations and insures the constant accuracy of values $\bar{A}$. The areas S, found from expression (37) for the averaging zone of activity for each $K_{\max}$, are recomputed for r. Then with these r, the concentric areas about the point under study are described: r of each area corresponds to a particular $K_{\max}$, which is attributed to the grid node, if the number of the epicenters N_{Σ} in this area is not less than the given N_{σ}. It is usually convenient to compute the system of grids before.

The summation of earthquakes to compute maps of $K_{\max}$ is difficult with dissimilar periods T_K for earthquakes of various energy classes. In this case the use of formula (37) can only be done after periods T_K are normalized to period $T_{\min}$. Therefore, to compute the numbers N_{Σ} in the averaging zone of activity or to determine its area with given $\bar{A}$ and N_{σ}, it is necessary to establish the relationship of $T_{\min}$ with T_K for each on the map of epicenters. This additional preparation for the initial epicenter map to compute the map of $K_{\max}$ may be avoided if the program analyzes the presentation periods. The great difficulty of hand calculating step $K_{\max}$ equal to the full value K, increases further if this step is further decreased, as is necessary in more detailed investigations. In this case, the computer reduces computation time.

The computation of the map of maximum possible earthquakes is possible when the initial information is entered as maps of earthquake epicenters and as maps of seismic activity. For this two programs—SP-6 and SP-7—have been written.

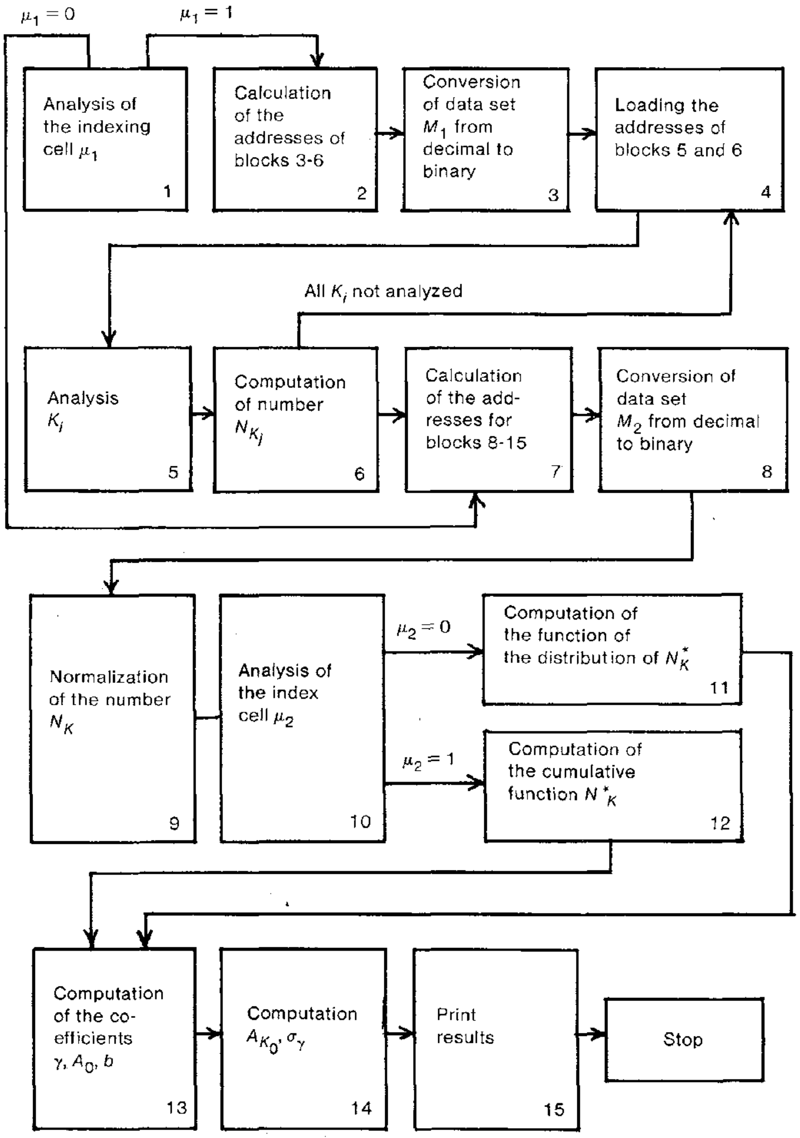
SP-6 PROGRAM TO COMPUTE MAPS OF $K_{\max}$ FROM THE MAP OF EARTHQUAKE EPICENTERS

The SP-6 program works according to an algorithm based on formulas (13), (14) and (37). The main idea behind calculating the $K_{\max}$ map on the computer, as in the manual method, is to compare the values of seismic activity, calculated on one hand from the correlation dependence (13) for the series of values $K_{\max}$ (the so-called tabulated values of activity A_T), and on the other, from the epicenter map in the variable area zones responsible for the emergence of earthquakes of different energy classes (values of activity in the averaging zones—A_z). When $A_T = A_z$ the value $K_{\max}$ is recorded for the point under investigation in accordance with (13). The analysis of the values of activity and transfer to the result, i.e., to determine each member of the resulting matrix $K_{\max}$, is conducted differently for two groups of $K_{\max}$. The first includes values beginning from the maximum proposed in the region to $K = (15-a_K)$, where a_K—step of computation K. In the second are all $K_{\max} \leqslant 15$ to $K_{\min}$. This division is explained as follows: In working with the first group of $K_{\max}$, seismic activity A_z is computed according to formula (13) in the circular variable radius zones with centers at the computation point in which the radius of the zone is reduced by the reduction in $K_{\max}$ according to formula (14). If $K_{\max} = 18r = 314$ km; then $K_{\max} = 15r = 31$ km; and $K_{\max} = 14r = 15$ km, i.e., it decreases. It seems it would be useless to compute seismic activity in radii zones less than $K_{\max} < 14$ since they may not show a single epicenter. This leads to zero values of $K_{\max}$ and the distortion of computation results. To analyze the values of $K_{\max} \leqslant 15$, therefore, a constant number N_σ of the sum of the epicenters in the averaging zone is considered in the program. This number signifies a value of activity, e.g., $N_\sigma \geqslant 3$. According to known N_σ and the value A_T representing the given $K_{\max}$ using relationship (13), the program computes the radius r of the averaging zone by formula (37), where $S = \pi r^2$. Further, the computation is stopped in areas if, corresponding to the series of values r, the total number of epicenters N_Σ is computed and $N_\Sigma = N_\sigma$. The computation of the number N_Σ in the circular zone is replaced by comparing the values r and $\Delta_{\min}$—distance from the point under consideration to the epicenter which, of all N_σ epicenters, is nearest to the point under study. The epicentral distances Δ are measured according to formula (40).

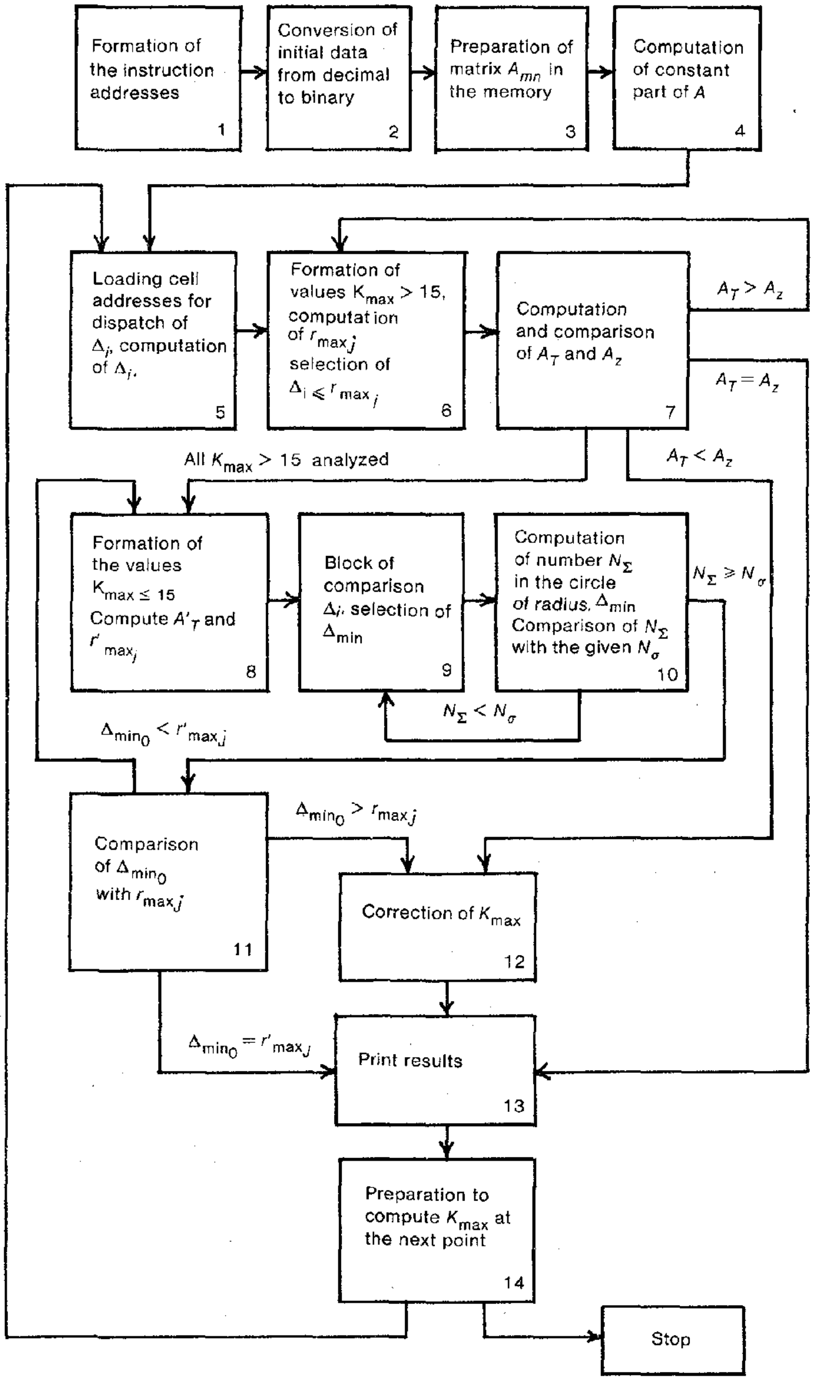
Two sets, M_1 and M_2, are used as initial data with several control data in the program. Set M_1 is presented by a matrix of epicenters A_{mn}, which is compiled directly or automatically from the map of earthquake epicenters or from their catalog, as in the previous programs. Set M_2 presents data about numbers N_σ, seismicity, and computational conditions. These numbers reflect a given accuracy of the computation of activity. It also includes a computation interval along the coordinates—lat. a_φ and long. a_λ and about the value $(K_{\max}-a_K)$; parameters of formula (13)— $\log \alpha$, β, K_α, and values $K_{\max}$ using computation interval A_K, which investigates the activity in the peaks of each computation point and several other data. Program control information holds information about the quantity of elements in each line and column of the initial matrix A_{mn}, about the general quantity and elements, and about the number of rows q and columns r of the resulting matrix $K_{\max}$ in the $K_{\max}$ map being computed.

The addresses of the initial cells for writing the instructions are also stored here. These instructions are to translate of initial data set M_1. Similarly are stored instructions for re-recording the results of the intermediate computation—e.g., values of epicentral distances Δ_i. These distances are measured for each computation point and, during the analysis of the radii

BLOCK DIAGRAM OF PROGRAM SP-5



BLOCK DIAGRAM OF PROGRAM SP-6



PROGRAM SP-6

Address	Command	A_1	A_2	A_3
		0500 A		
0500	055	0523	1021	0523
1	013	0523	1123	0523
2	055	0545	1022	0545
3	013	0545	1124	0545
4	055	0553	1022	0553
5	013	0553	1124	0553
6	055	0643	1022	0643
7	013	0643	1124	0643
0510	055	0750	1022	0750
1	013	0750	1125	0750
2	055	1010	1022	1010
		0513 A		
0513	013	1010	1126	1010
4	055	1014	1022	1014
5	013	1014	1127	1014
6	055	1212	1022	1212
7	013	1212	1131	1212
0520	055	1217	1022	1217
1	013	1217	1131	1217
2	016	0524	7741	0007
3	000	3213	3213	0
4	016	0526	7741	0007
5	000	1034	1034	1122
		0526 A		
0526	052	0	0	0
7	275	0	3213	1140
0530	056	0531	0532	0535
1	002	1047	1140	0
2	056	0533	0534	0543
3	075	0	1062	1141
4	002	1113	1034	1142
5	017	0	0	0
6	076	0	0543	0
7	013	0535	1024	0535
0540	013	0543	1025	0543
		0541 A		
0541	002	1142	0101	1142
2	076	0	0535	0
3	017	0	0	0
4	104	1074	1141	3213
5	112	0	0527	0003
6	075	0	0	1236
7	004	1035	1036	1143

(Contd.)

Address	Command	A_1	A_2	A_3
0550	052	0	0	0
1	504	3214	1143	3214
2	504	3215	1143	3215
3	112	0	0551	0003
		0554 A		
0554	075	0	1040	0140
5	016	0556	7714	0007
6	075	0	0160	1231
7	075	0	0101	1151
0560	075	0	1077	1152
1	005	1231	1152	0140
2	016	0563	7711	0007
3	002	1151	0160	1151
4	002	1060	1061	1153
5	005	1153	1231	0140
6	016	0567	7711	0007
		0567 A		
0567	075	0	0160	1153
0570	005	1037	1074	1152
1	004	1151	1153	1151
2	004	1151	1152	1151
3	005	1151	1111	1232
4	052	0	0	0
5	075	0	1075	1145
6	075	0	1076	1146
7	452	0	0	1011
0600	452	0	0	1006
1	004	1145	1143	1155
		0602 A		
0602	004	1146	1143	1156
3	056	0604	0605	0641
4	005	1041	1151	1241
5	075	0	1155	0140
6	016	0607	7712	0007
7	075	0	0161	1147
0610	075	0	0160	1150
1	075	0	1156	0140
2	016	0613	7712	0007
3	075	0	0161	1157
4	075	0	0160	1160
		0615 A		
0615	275	0	3214	0140
6	016	0617	7712	0007
7	075	0	0161	1161
0620	075	0	0160	1162
1	275	0	3215	0140
2	016	0623	7712	0007

Address	Command	A_1	A_2	A_3
3	075	0	0161	1163
4	075	0	0160	1164
5	005	1147	1161	1151
6	005	1150	1160	1152
7	005	1152	1162	1152
		0630 A		
0630	005	1152	1164	1152
1	001	1151	1152	1151
2	005	1150	1157	1152
3	005	1152	1162	1152
4	005	1152	1163	1152
5	001	1151	1152	1151
6	075	0	1151	0140
7	016	0640	7716	0007
0640	005	0160	1143	1151
1	005	1041	1151	1241
2	013	0641	1026	0641
		0643 A		
0643	112	0	0615	0003
4	056	0	1210	0
5	075	0	0	0710
6	002	1114	1034	1154
7	075	0	1106	1140
0650	005	1231	1140	0140
1	016	0632	7710	0007
2	005	0160	1043	0140
3	016	0654	7714	0007
4	004	0160	1042	0140
5	016	0656	7710	0007
		0656 A		
0656	075	0	0160	1233
7	075	0	1233	1165
0660	002	1112	1034	1166
1	075	0	0	1167
2	056	0663	0664	0670
3	002	1165	1241	0
4	056	0665	0670	0673
5	001	1167	3213	1167
6	013	0670	1025	0670
7	013	0673	1027	0673
0670	017	0	0	0
		0671 A		
0671	076	0	0673	0
2	056	0	0674	0
3	017	0	0	0

(Contd.)

Address	Command	A_1	A_2	A_3
4	002	1166	0101	1166
5	076	0	0666	0
6	0	0	0	0
7	005	1231	1167	1151
0700	005	1233	1233	1152
1	004	1151	1152	1234
2	002	1140	1103	1152
3	005	1152	1105	1152
		0704 A		
0704	001	1104	1152	1152
5	005	1152	1044	0140
6	010	0707	7710	0007
7	075	0	0160	1235
0710	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	002	1235	1234	0
4	076	0	0716	0
5	0	0	1002	0
6	0	0	1235	0
		0717 A		
0717	076	0	1002	0
0720	002	1140	1101	1140
1	002	1154	0101	1154
2	076	0	0650	0
3	002	1115	1034	1170
4	075	0	1107	1140
5	016	0726	0702	0710
6	005	1232	1102	1151
7	004	1151	1235	1151
0730	044	1151	0	1151
1	056	0	1215	0
		0732 A		
0732	0	0	0	0
3	075	0	0	1173
4	075	0	0	1167
5	052	0	0	0
6	075	0	0	1171
7	075	0	0	1172
0740	075	0	1241	1174
1	013	1171	1027	1171
2	013	1172	1026	1172
3	402	1242	1174	0
4	076	0	0750	0
		0745 A		
0745	075	0	1171	1175
6	075	0	1172	1176

Address	Command	A_1	A_2	A_3
7	075	0	1242	1174
0750	112	0	0741	0001
1	056	0752	0753	0760
2	001	1167	3213	1167
3	056	0754	0755	0761
4	075	0	1110	1241
5	075	0	1174	1177
6	013	0760	1175	0760
7	013	0761	1176	0761
		0760 A		
0760	077	0	0	0
1	077	0	0	0
2	001	1173	0101	0
3	002	1173	1102	0
4	036	0	0735	0
5	075	0	1151	1165
6	002	1177	1165	0
7	076	0	0773	0
0770	005	1101	1034	1200
1	001	1140	1200	1237
2	056	0	1003	0
		0773 A		
0773	002	1165	1177	0
4	076	0	1002	0
5	002	1140	1101	1140
6	002	1170	0101	1170
7	076	0	0725	0
1000	075	0	0	1237
1	056	0	1003	0
2	075	0	1140	1237
3	001	1236	0101	1236
4	016	1006	1751	0007
5	000	1236	4000	1240
		1006 A		
1006	077	0	0	0
7	001	1145	1100	1145
1010	112	0	0600	0001
1	077	0	0	0
2	075	0	1075	1145
3	001	1146	1100	1146
4	112	0	0577	0001
5	077	0	0	0
6	777	7777	7777	0
7	777	0	7777	7777
1020	0	0001	0	0
		1021 A		
1021	0	0	0001	0

(*Contd*).

Address	Command	A_1	A_2	A_3
2	0	0	0	0001
3	0	0	0003	0
		1210 A		
1210	052	0	0	0
1	375	0	1241	2226
2	112	0	1211	0001
3	056	0	0645	0
4	0	0	0	0
5	052	0	0	0
6	375	0	2226	1241
7	112	0	1216	0001
1220	056	0	0732	0

of the averaging zones of activity, their order is changed in the memory. Re-recording restores the initial order of the value Δ_i, which is necessary for the multiple analysis of values $K_{\max}$ at each point, in accordance with computation step $(K_{\max}-a_K)$.

The program itself is located in cells 0500–1030 of the memory and set M_2 in cells 1035–1120. Control information engages cells 1123–1135 and set M_1 in 3200–6150. Intermediate results are in cells 1121–3177, the computed Δ_i—epicentral distances—are dispatched to cells 1241–3177 during computation.

Block Diagram SP-6 (see p. 102)

The SP-6 program flows as in the block diagram. First are entered the punch cards of the program itself and the initial data set. Control is then shifted to the four preparational blocks for the main computation. Block 1 handles the instructions and their repetitions (cycles) according to the control information. In block 2, the initial data of sets M_1 and M_2 are converted from the decimal to the binary system. The M_1 data are prepared for computation in block 3, which ends with the introduction of periods T_K of the energy class K_i emergence of each earthquake epicenter of the initial set to the period $T_{\min}$ of the class $K_{\min}$, i.e., the least class from those represented in the region. For this purpose, classes K_i are compared with a set of fixed classes of energy K_{f_j}. When $K_i = K_{f_j}$ the corresponding period T_{f_j} is attributed to the earthquake. By dividing $T_{\min}$ by T_{f_j} the number of earthquakes of the class K_i is found (the emergence time $T_{\min}$), i.e., the number N_i which is dispatched to the initial matrix A_{mn} in place of the corresponding K_i, which represents each earthquake epicenter.

Multiple computations of seismic activity are prepared in block 4 and the constant part of the value $\bar{A}$ is computed from formula (37), depending only on the parameters of the seismic regime, viz:

$$B = \frac{(1-10^{-\gamma})\cdot 1000}{10^{-\gamma}\,(K_{\min}-K_0)\cdot \pi \cdot T_{\min}}. \tag{37'}$$

The value B is dispatched in the working cell and stored until the end of the computation, in the process of which periodic reference is made to it. The preparatory operations are finished in blocks 1–4. In each of the remaining the activity is computed and analyzed for each point under study for the future $K_{\max}$ map. The work of block 5 begins from the first point, situated in its lower left corner. The addresses of the cells are entered to record the intermediate results for the computation of the epicentral distances Δ_i by formula (40). Thereafter their m values are dispatched in two series of cells—working and storage. In block 6 the value $K_{\max_j}$ is given, which at the beginning of the computation is equal to the maximum $K_{\max}$ from those proposed in the region, i.e., $(K_{\max})_1 = (K_{\max})_{\max}$. Later it is reduced by computation interval a_K around $K_{\max}$, i.e., $(K_{\max})_2 = [(K_{\max})_1 - a_K]$ and so on. Next the value of radius $r_{\max_j}$ of the zone responsible for the appearance of the $K_{\max_j}$ earthquake is computed according to formula (14). From the list of epicentral distances Δ_i, obtained from block 5, those compatible with $r_{\max_j}$ are selected, i.e., those for which $\Delta_i \leqslant r_{\max_j}$. After this the sum N_Σ of earthquakes is found, that is, the epicentral distance Δ_i which from the point of computation answers the condition $\Delta_i \leqslant r_{\max_j}$, i.e., $N_\Sigma = \sum N_i$. The value of N_Σ is total number of earthquakes in the circle of radius $r_{\max_j}$ which, after multiplication by the contents of the working cell obtained from formula (37′), gives the value of seismic activity A_z in the averaging zone with $r_{\max_j}$. Activity A_z and its tabulated value A_T are computed in block 7 and later compared. If $A_T = A_z$ then the results are printed. If $A_T < A_z$, then the value $K_{\max}$ for the computation point should be larger than the given $K_{\max}$, but less than the earlier investigated value $K_{\max_{j-1}}$. In the printing cell, therefore, value $K_{\max_j} = [K_{\max_{j-1}} - 0.5 \cdot a_K]$ is dispatched through block 12. If $K_{\max_j} = (K_{\max})_{\max}$ the relationship $A_T < A_z$ signifies the reduction of $(K_{\max})_{\max}$ which may be avoided by making the first value $K_{\max}$ as large as necessary. $A_T > A_z$ signifies that the activity, computed about the earthquake epicenters of the initial set M_1 in the averaging zone $r_{\max_j}$, is less than the tabulated one (13), and it is necessary to reduce the averaging zone $S_{\max_j}$ in accordance with the reduction of $K_{\max_j}$. In this case, $K_{\max_j}$ is reduced by the value of the interval a_K about $K_{\max}$ and control is shifted to the beginning of block 6 where the value $r_{\max_{j+1}}$ is computed—$K_{\max_{j+1}} = [K_{\max_j} - a_K]$. This computation is repeated until the comparison of the activity values A_T and A_z. If they are unequal, computation with the interval a_K is repeated in blocks 6 and 7 for all $K_{\max}$ up to $K_{\max} = 15 + a_K$. When the values $K_{\max}$ in the range $K_{\max} \geqslant 15 + a_K$ are analyzed and all the values A_T from all the

$K_{\max}$ satisfy the value A_z, control is shifted to block 8. Here and further on, in blocks 9–11, are analyzed the values $K_{\max}$ from $K = 15$ to $K = K_{\min}$. In block 8, A_T is computed by formula (13) for the first value $K'_{\max} = 15$. Next the value of the radius $r'_{\max_j}$ of the averaging zone of activity—A'_z—is computed according to formula (37), where $S = \pi r^2$ for $\bar{A} = A'_T$ and $N_\Sigma = N_\sigma$ (N_σ given in the initial computation conditions). Thereafter control is shifted to block 9, where Δ_i—epicentral distances from the computational point to all epicenters of set M_1—are compared with each other.

The comparison ends with the selection of the least Δ_i from those measured; its value is now equal to $\Delta_{\min_1}$. Block 10 computes the number of earthquakes N_Σ which have epicenters inside the circle of radius $\Delta_{\min_1}$ and compares N_Σ with the earlier given N_σ. If $N_\Sigma \geqslant N_\sigma$, the preconsidered accuracy of the computation of the activity in the circle of radius $\Delta_{\min_1} = \Delta_{\min_0}$ is defined and control is shifted to block 11 ($\Delta_{\min_0}$ is the radius of the optimal averaging zone where $N_\Sigma = N_\sigma$). When $N_\Sigma < N_\sigma$ the number of earthquakes in the circle of radius $\Delta_{\min_1}$ is insufficient to compute activity with the given accuracy σ. Therefore, after the dispatch of a very large number in place of $\Delta_{\min_1}$, it is necessary to return to block 9. Here comparing Δ_i is repeated with the selection of a new least distance $\Delta_i = \Delta_{\min_2}$, $\Delta_{\min_2}$ being greater than $\Delta_{\min_1}$. Block 10 repeats the summing of earthquakes and the following comparison of N_Σ with N_σ.

The return from block 10 to 9 is repeated until the relationship $N_\Sigma \geqslant N_\sigma$ is achieved for a particular $\Delta_i = \Delta_{\min_0}$. Then control is shifted to block 11 where the chosen value $\Delta_{\min_0}$ is compared with the $r'_{\max_j}$ computed in block 8. The equality $\Delta_{\min} = r'_{\max_j}$ signifies that the tabulated value A_T, representing the averaging zone with radius $r'_{\max_j}$, agrees with A_z. Then the value $K'_{\max_j}$ corresponds to the point, around which this zone is given; this is insured by the value A_z in accordance with formula (13). Then the results are printed. If $\Delta_{\min_0} > r'_{\max_j}$ then the number of epicenters equal to N_Σ defines the activity A'_T on the area larger than $\pi\,(r'_{\max_j})^2$. In this case $K_{\max}$ of the point under study should be larger than $K'_{\max_j}$, but lesser than the earlier investigated $K_{\max} = K'_{\max_{j-1}}$. Therefore the value $K_{\max} = [K_{\max_{j-1}} + 0.5\,a_K]$ is sent to the printing cell through block 12—to correct $K_{\max}$. Control is shifted then to block 13 to print the results. If $\Delta_{\min_0} < r'_{\max_j}$ the tabulated value of activity A'_T corresponding to the zone radius $r'_{\max_j}$ is insured in the given N_σ only in a much smaller zone, i.e., the point under study answers the relation $K_{\max} < K'_{\max_j}$. The value $K_{\max}$ is lowered by the interval $K_{\max}$ equal to a_K and the control is again shifted to block 8. The number of computation cycles in blocks 8–11 depends on the $K_{\max}$ of the point under study and on the interval computation a_K. If the relation $\Delta_{\min_0} \geqslant r'_{\max_j}$ cannot be made, the process continues up to $K_{\max} = K_{\min}$. Further control is shifted to block 13 to print the results, which fixes the point serial number and value $K_{\min}$. Then follows block 14 which prepares the computation of $K_{\max}$ for the succeeding point. After this computation is stopped if the number of points to study $K_{\max}$ is exhausted. Otherwise control is shifted to block 5, where the epicentral distances from the new computation point are measured and all the above-mentioned operations are repeated.

Illustrative Example

To verify the SP-6 program its check-out version may be used as an illustrative example. It works on the basis of initial data presented by sets M_1 (Table 1), M_2 (Table 18) and a group of control information. The M_1 address entry is changed to 3213 for SP-6.

In cells 1034–1046 the computation constants are kept; 1047–1061—classes K_{f_j} for the region under study; 1062–1074 the periods of presentation T_{f_j} representing K_{f_j}; 1075–1102—coordinates of the initial point computation φ_0, λ_0; computation interval around φ-a_φ and around λ-a_λ; inclination of the repeatability curve γ; least number N_σ of earthquakes in the seismic activity averaging zone A, representing the given error of the computation of A–σ_A. In cells 1103–1105 are the constants of formula (13). In 1106–1107 are the greatest of the proposed earthquakes in the region ($K_{1_{\max}}$) and the value of the earthquake for which the averaging zone A becomes measurable with the epicenter determination errors ($K_{2_{\max}}$).

TABLE 17. RESULTS OF COMPUTATION ON SP-6

N Points	$K_{\max}$
+++ 01 10000000	+++ 02 150500000
+++ 01 20000000	+++ 02 150500000
+++ 01 30000000	+++ 02 150500000
+++ 01 40000000	+++ 02 135499999
+++ 01 50000000	+++ 02 123499999
+++ 01 60000000	+++ 02 114499999
+++ 01 70000000	+++ 02 106499999
+++ 01 80000000	+++ 02 100000000
+++ 01 90000000	+++ 02 100000000
N Points	$K_{\max}$
+++ 02 100000000	+++ 02 100000000
+++ 02 110000000	+++ 02 150500000
+++ 02 120000000	+++ 02 150500000
+++ 02 130000000	+++ 02 144500000
+++ 02 140000000	+++ 02 131499999
+++ 02 150000000	+++ 02 121499999
+++ 02 160000000	+++ 02 113499999
+++ 02 170000000	+++ 02 105499999
+++ 02 180000000	+++ 02 100000000

TABLE 18. DATA SET M_2 FOR SP-6

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				1034 A			
1034	++	+	00	500	0	0	const = 0.5
5	++	+	03	360	0	0	$2\pi = 360$
6	++	+	01	628	318	600	$2\pi = 6.283186$
7	++	+	01	314	159	300	$\pi = 3.141593$
1040	++	+	02	100	0	0	const = 10
1	++	+	03	111	199	0	1° = 111.199
2	++	+	01	300	0	0	const = 3
3	++	−	10	315	0	0	$1/C = 0.315\cdot 10^{-10}$
4	++	+	01	230	259	0	const = 2.30259
5			0	0	0	0	0
6			0	0	0	0	0
				1047 A			
1047	++	+	02	100	0	0	$K_{t_1} = 10$
1050	++	+	02	110	0	0	$K_{t_2} = 11$
1	++	+	02	120	0	0	$K_{t_3} = 12$
2	++	+	02	130	0	0	$K_{t_4} = 13$
3			0	0	0	0	0
4			0	0	0	0	0
5			0	0	0	0	0
6			0	0	0	0	0
7			0	0	0	0	0
1060	++	+	02	100	0	0	$K_{\text{rep}} = 10$
1	++	+	02	100	0	0	$K_0 = 10$
				1062 A			
1062			02	160	0	0	$T_{t_1} = 16$
3			02	160	0	0	$T_{t_2} = 16$
4			02	160	0	0	$T_{t_3} = 16$
5			02	380	0	0	$T_{t_4} = 38$
6			0	0	0	0	0
7			0	0	0	0	0
1070			0	0	0	0	0
1			0	0	0	0	0
2			0	0	0	0	0
3			0	0	0	0	0
4			02	160	0	0	$T_0 = 16$
				1075 A			
1075	++	+	02	401	0	0	$\varphi_0 = 40.1$
6	++	+	02	701	0	0	$\lambda_0 = 70.1$
7	++	+	0	430	0	0	$\gamma = 0.43$
1100	++	+	0	100	0	0	$a_\varphi = 0.1$
1	++	+	0	100	0	0	$a_\lambda = 0.1$

Address	Commands and numbers						Remarks
	Sign of		Order	A₁	A₂	A₃	
	No.	Order					
2	++	+	01	300	0	0	$N_\sigma = 3$
3	++	+	02	150	0	0	$K_L = 15$
4	+−	+	01	116	0	0	$\log_L = 1.16$
5	++	+	0	210	0	0	$B = 0.21$
6	++	+	02	180	0	0	$K_{1_{max}} = 18$
7	++	+	02	150	0	0	$K_{2_{max}} = 15$
				1110 A			
1110	++	+	04	100	0	0	$\Delta_{max}=1000$
1	++	+	04	100	0	0	$S_0 = 1000$
2	++	+	01	700	0	0	$m = 7$
3	++	+	01	400	0	0	$P = 4$
4	++	+	02	300	0	0	$K_1 = 30$
5	++	+	02	500	0	0	$K_2 = 50$
6	++	+	0	100	0	0	$A_K = 0.1$

TABLE 19. CONTROL INFORMATION FOR SP-6

Address	Commands and numbers				Remarks
	Command	A₁	A₂	A₃	
			1123 A		
1123	0	0	0	3240	$(0, 0, A_{mn})-(0, 0, 3240)$
4	0	0022	0	0	$[3(m-1), 0, 0] = (22, 0, 0)$
5	0	0005	0	0	$(m-2, 0, 0) = (5, 0, 0)$
6	0	0011	0	0	$(q-1, 0, 0) = (11, 0, 0)$
7	0	0011	0	0	$(r-1, 0, 0) = (11, 0, 0)$
1130	0	0	0003	0	$(0, n, 0) = (0, 3, 0)$
1	0	0006	0	0	$(m-1, 0, 0) = (6, 0, 0)$

Cells 1110–1117 contain: Δ_{max}—maximum epicentral distance; S_0—normalized multiplier for the computation of A_{10}; m—number of lines of the matrix A_{mn} of the set M_1; p—number of classes K_{f_j}; K_1—number of cycles to compute A_{10} from $K_{1_{max}}$ to $K_{2_{max}}$; K_2—similar but from $K_{2_{max}}$ to K_{min}; a_K—computation interval of A_{10} about K.

The control data are in cells 1123–1131 (Table 19) and mainly holds the same information as in Tables 3, 6, 9 and 13. Table 17 presents the results of the computations of 18 map points (2 columns) using the initial data of Tables 1, 17 and 18.

SP-7 PROGRAM TO COMPUTE THE K_{max} MAP ACCORDING TO THE SEISMIC ACTIVITY MAP

While describing the SP-6 program which uses formula (13), it was mentioned that the increase in the energy class of a strong earthquake leads to a considerable increase in the zone for the computation of seismic activity $\bar{A}$ (14).

It seems that, in the manual as well as the machine analysis of K_{max}, the values $\bar{A}$ in the peaks of the point under study should be computed on large areas, especially for classes $K_{max} \geqslant 17$. This means that to compute the value K_{max} in the outermost points on the map of the territory under investigation, there must be information about the epicenters of its peaks in the 150–300 km radius. Thus for Uzbekistan, one should have epicenter maps for Tajikistan and Kirgizia, otherwise the value K_{max} will be distorted in the periphery. Larger distortions are excluded by introducing corrections on the seismic background of the surrounding area (Zakharova, Seiduzova, 1969a). However, due to the inaccuracy of determining their value, this is not a better solution to the problem. It is preferable to use long-term observations for the epicenter maps. However, it is difficult to obtain such observations in Central Asia at the present time. There are few epicenter maps from which it is easy to get earthquake coordinates necessary for further computations. Lists of epicenters with all necessary informations have been published for only the last six years. Therefore, it is necessary to find other ways to get initial information while maintaining the accurate K_{max} computations. This may be achieved, it seems, by using seismic activity maps from the long-term observations of the seismic station network. The very first K_{max} map (Riznichenko, 1965) was actually compiled from an activity map. The seismic activity maps, constructed by various methods for the major seismo-active regions of the Soviet Union, may be found in special issues dedicated to the investigation of seismic regions (A.V. Kozlov, ed., 1969; V.N. Gaiskii, ed., 1970) and in the yearly periodical "Earthquakes in the USSR" between 1962 and 1966. From them, independent of the measurements, one can easily find the activity values of any grid, i.e., with any previously given interval, conditioned by the computation intervals of the activity map and the future map K_{max}. The SP-7 program is also based on initial information from the seismic activity map. Fig. 1 explains the method of entering the initial data set in the computer. Here, ABCD is the area of the future K_{max} map, A′B′C′D′—the area of the seismic activity map. The initial data consist of two matrices—A_{mn} which reflects the area A′B′EF (Fig. 1) and A_{kl} (area FEC′D′). The entire map of activity A is covered by a graduated grid with a_{φ} latitudinal and a_{λ} longitudinal interval. At the grid nodes, the activity values are drawn and punched along the columns beginning from the left lower corner, i.e., from point A′ (Fig. 1). The length of row n of the

PROGRAM SP-7

Address	Command	A_1	A_2	A_3
		0500 A		
0500	055	0522	1021	0522
1	013	0522	1123	0522
2	055	0545	1022	0545
3	013	0545	1125	0545
4	055	0552	1022	0552
5	013	0552	1124	0552
6	055	0764	1022	0764
7	013	0764	1126	0764
0510	055	0777	1022	0777
1	013	0777	1125	0777
2	055	0767	1022	0767
		0513 A		
0513	013	0767	1134	0767
4	055	1012	1022	1012
5	013	1012	1127	1012
6	055	0771	1030	0771
7	013	0771	1135	0771
0520	056	0000	1014	0000
1	016	0523	7741	0007
2	000	0000	0000	0000
3	016	0525	7741	0007
4	000	1034	1034	1107
5	075	0000	1046	1177
		0526 A		
0526	075	0000	0000	1206
7	004	1035	1036	1143
0530	016	0531	0554	0615
1	052	0000	0000	0000
2	075	0000	1045	1175
3	075	0000	1177	1176
4	452	0000	0000	0547
5	452	0000	0000	0543
6	004	1175	1143	1172
7	004	1176	1143	1173
0540	075	0000	1172	0140
		0541 A		
0541	0000	0000	0000	0000
2	056	0000	0616	0000
3	077	0000	0000	0000
4	001	1175	1072	1175
5	112	0000	0535	0001
6	075	0000	0000	0701
7	077	0000	0000	0000

(*Contd.*)

Address	Command	A_1	A_2	A_3
0550	075	0000	1045	1175
1	001	1176	1073	1176
2	112	0000	0534	0001
3	056	0000	0645	0000
		0554 A		
0554	075	0000	1040	0140
5	016	0556	7714	0007
6	075	0000	0160	1201
7	075	0000	0101	1151
0560	075	0000	1077	1152
1	005	1201	1152	0140
2	016	0563	7711	0007
3	002	1151	0160	1151
4	002	1060	1061	1153
5	005	1153	0140	0140
6	016	0567	7711	0007
		0567 A		
0567	075	0000	0160	1153
0570	005	1037	1074	1152
1	004	1151	1153	1151
2	004	1151	1152	1151
3	005	1151	1071	1202
4	052	0000	0000	0000
5	075	0000	1075	1145
6	075	0000	1076	1146
7	452	0000	0000	1007
0600	452	0000	0000	0762
1	004	1145	1143	1155
		0602 A		
0602	004	1146	1143	1156
3	056	0604	0605	0641
4	005	1041	1151	1240
5	075	0000	1155	0140
6	016	0607	7712	0007
7	075	0000	0161	1147
0610	075	0000	0160	1150
1	075	0000	1156	0140
2	016	0613	7712	0007
3	075	0000	0161	1157
4	075	0000	0160	1160
		0615 A		
0615	000	0000	0000	0000
6	016	0617	7712	0007
7	075	0000	0161	1161
0620	075	0000	0160	1162
1	075	0000	1173	0140

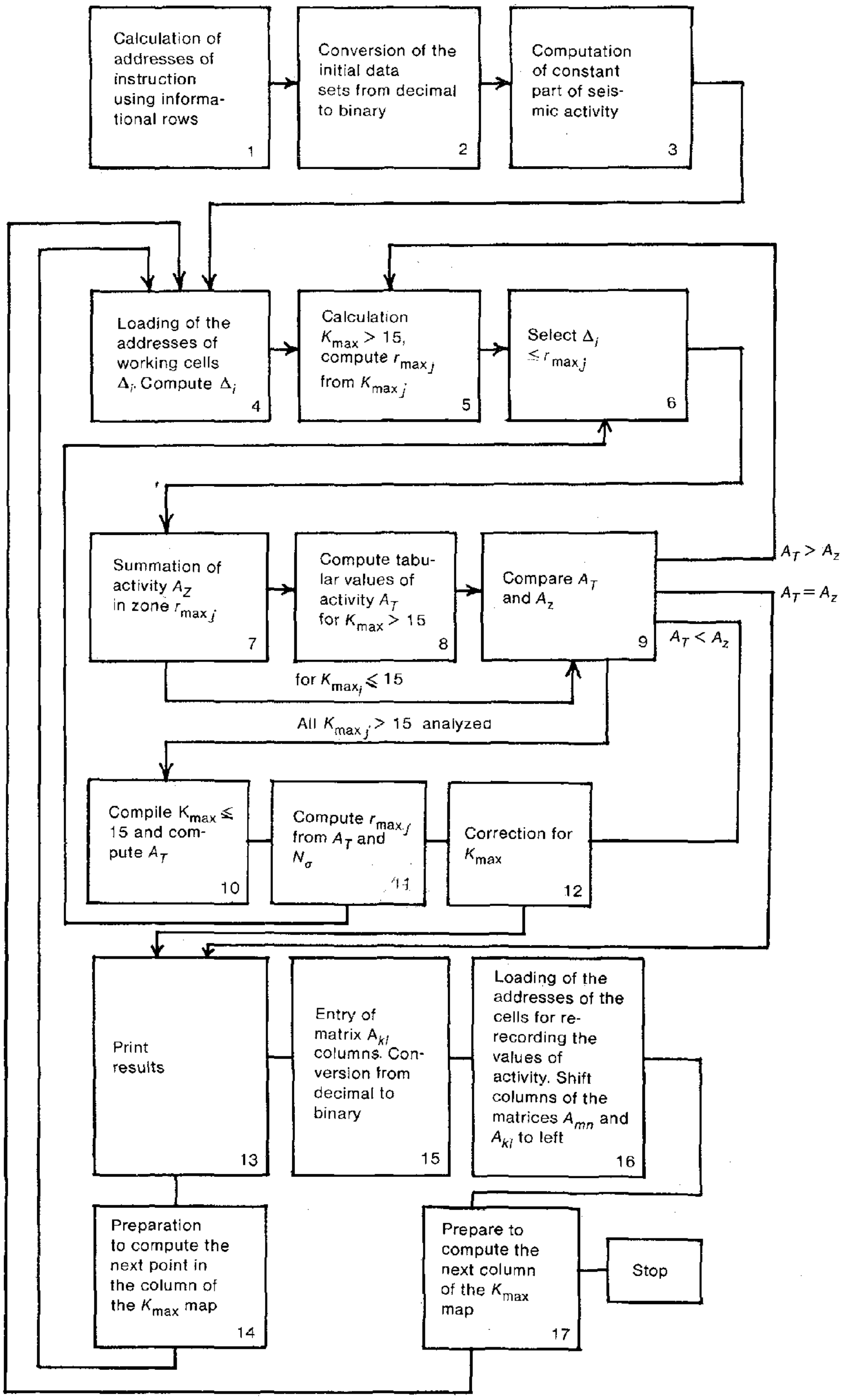
Address	Command	A_1	A_2	A_3
2	016	0623	7712	0007
3	075	0000	0161	1163
4	075	0000	0161	1164
5	005	1147	1161	1151
6	005	1150	1160	1152
7	005	1152	1162	1152
		0630 A		
0630	005	1152	1164	1152
1	001	1151	1152	1151
2	005	1150	1157	1152
3	005	1152	1162	1152
4	005	1152	1163	1152
5	001	1151	1151	1151
6	075	0000	1151	0140
7	016	0640	7716	0007
0640	005	0160	1143	1151
1	077	0000	0000	0000
2	013	0641	1026	0641
		0643 A		
0643	056	0000	0543	0000
4	056	0000	1210	0000
5	075	0000	0000	0710
6	002	1063	1034	1154
7	075	0000	1106	1140
0650	005	1201	1140	0140
1	016	0652	7710	0007
2	005	0160	1043	0140
3	016	0654	7714	0007
4	004	0160	1042	0140
5	016	0656	7710	0007
		0656 A		
0656	075	0000	0160	1203
7	075	0000	1203	1165
60	002	1062	1034	1166
1	075	0000	0000	1171
2	075	0000	0000	1167
3	056	0664	0665	0671
4	002	1165	1240	0000
5	056	0666	0670	0674
6	001	1167	0000	1167
7	013	0671	1025	0671
0670	013	0674	1025	0674
		0671 A		
0671	077	1165	2731	0000
2	076	0000	0674	0000

(Contd.)

Address	Command	A_1	A_2	A_3
3	056	0000	0676	0000
4	077	0000	0000	0000
5	001	1171	0101	1171
6	002	1166	0101	1166
7	076	0000	0667	0000
0700	004	1167	1171	1204
1	000	0000	0000	0000
2	002	1140	1103	1152
3	005	1152	1105	1152
		0704 A		
0704	001	1104	1152	1152
5	005	1152	1044	0140
6	016	0707	7710	0007
7	075	0000	0160	1205
0710	000	0000	0000	0000
1	000	0000	0000	0000
2	000	0000	0000	0000
3	002	1205	1204	0000
4	076	0000	0716	0000
5	056	0000	0754	0000
6	002	1204	1205	0000
		0717 A		
0717	076	0000	0756	0000
0720	056	0000	0736	0000
1	000	0000	0000	0000
2	075	0000	0000	0710
3	002	1064	1034	1174
4	075	0000	1107	1140
5	016	0726	0702	0710
6	005	1202	1102	1151
7	004	1151	1205	1151
0730	044	1151	0000	1165
0731	056	0000	1234	0000
		0732 A		
0732	075	0000	0000	0710
3	016	0742	0660	0710
4	000	0000	0000	0000
5	000	0000	0000	0000
6	002	1140	1070	1140
7	002	1152	0101	1154
0740	076	0000	0650	0000
1	056	0000	0722	0000
2	002	1205	1204	0000
3	076	0000	0745	0000
4	056	0000	0754	0000
		0745 A		
0745	002	1204	1205	0000

Address	Command	A_1	A_2	A_3
6	076	0000	0756	0000
7	002	1140	1070	1140
0750	002	1174	0101	1174
1	076	0000	0725	0000
2	056	0000	0756	0000
3	000	0000	0000	0000
4	005	1039	1070	1142
5	001	1140	1142	1140
6	001	1206	0101	1206
7	075	0000	1140	1207
		0760 A		
0760	016	0762	7751	0007
1	000	1207	4000	1207
2	077	0000	0000	0000
3	001	1145	1100	1145
4	112	0000	0600	0001
5	000	0000	0000	0000
6	000	0000	0000	0000
7	030	0000	0770	0000
0770	016	0772	7741	0007
1	000	0000	0000	0000
2	002	1065	1034	1170
		0773 A		
0773	056	0774	0775	0776
4	375	0000	0000	0000
5	052	0000	0000	0000
6	077	0000	0000	0000
7	112	0000	0776	0001
1000	013	0776	1032	0776
1	002	1170	0101	1170
2	076	0000	0775	0000
3	0000	0000	0000	0000
4	000	0000	0000	0000
5	000	0000	0000	0000
		1006 A		
1006	001	1177	1073	1177
7	077	0000	0000	0000
1010	075	0000	1075	1145
1	001	1146	1101	1146
2	112	0000	0577	0001
3	077	0000	0000	0000
4	055	0774	1031	0774
5	013	0774	1121	0774
6	055	0666	1122	0666
7	013	0666	1122	0666
1020	056	0000	0521	0000

BLOCK DIAGRAM OF PROGRAM SP-7



main matrix A_{mn} (A′B′, Fig. 1) should not be less than twice the radius r of the activity averaging zone for the largest class $K_{\max}$. The length of the column m should exceed the value $2r$ on the length of the future map ($K_{\max}$—AB). Such dimensions of the matrix A_{mn} insure the computation of the value of $K_{\max}$ for column AB. The requirements for the length of the column of the additional matrix A_{kl} are the same as those for the length of the main matrix column, i.e., $k = m$ (Fig. 1). The length of row l should insure the computation of the activity of the largest class $K_{\max}$ at points of the entire resulting map excluding column AB, i.e., should be equal to (AD—a_λ), where a_λ is the computation interval of $K_{\max}$ longitudewise.

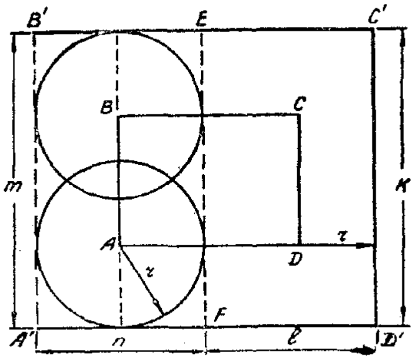


Fig. 1. Placement of initial data for the SP-7 program:
ABCD—Area of the map $K_{\max}$; A′B′C′D′—area of the map A; A′B′EF—main matrix of initial data; m—length of the column A′B′EF; n—length of the line (row) A′B′EF; FEC′D′—additional matrix of initial data; $k = m$—length of the column FEC′D′; l—length of the row FEC′D′; r—radius of the averaging zone A for the largest $K_{\max}$ of the area investigated.

The matrices A_{mn} and A_{kl} constitute the main M_1 and additional M_1' sets of initial data. If the main matrix is serially entered along with the SP-7 program and its members in the memory beginning from 4220, then the same addressing entry is required for each column of the additional matrix, that is, the net number after cell 4220 + kl. (Henceforth, mn and kl mean the number of members in the main and additional matrices of the initial data respectively.)

The punch cards of the additional matrix are entered only after the $K_{\max}$ values for its column AB are computed and printed. A shift of the entire matrix A_{mn} precedes the automatic introduction instruction, used in the program for this purpose. The shift is one column to the left for matrix A_{mn} representing area A′B′EF. The first column of the additional matrix A_{kl} is then entered in the empty place and $K_{\max}$ for the second column of the map ABCD is computed.

One more set of initial data M_2 is considered in the computation. This matrix is characteristic of the seismic regime of the region under investigation. In them are included the inclination of the earthquake repeatability curve; the energy class K_0 to which the seismic activity computation is related; class $K_{\min}$—the least of those in the region; period of appearance $T_{\min}$ of the class $K_{\min}$; coefficients of correlational dependence $K_{\max} = K_{\max}(\bar{A})$ log α, β and K_α; and value of the maximum proposed $K_{\max}$. In the same data set are included the initial point coordinates of matrix A_{mn} (point A' in Fig. 1)—φ_{A_0}, λ_{A_0} and distances between the grid points on the activity map, representing matrices A_{mn} and A_{kl}—a_φ and a_λ; coordinates of the initial point computation of the map $K_{\max}$—φ_0 and λ_0; the computation interval latitudinally a_φ and longitudinally a_λ and around K-a_K; N_σ—number of epicenters in the averaging zone of activity, $\bar{A}$, defining the given accuracy and others.

Besides data sets M_1, M_1', M_2 the initial data include a) control data with information about the number of elements in each line and column of the matrix A_{mn} and the total number of elements in it, b) similar information about the resulting matrix $K_{\max}$-K_{qr}; c) addresses of the initial cells, necessary for instructions to enter and transfer the initial data sets.

The computer memory is used in the following manner: the program itself is in cells 0500–1020; 1034–1107—set M_2; 1120–1133—control data. Set M_1 (matrix A_{mn}) is accommodated from cell 4220 and may engage all the remaining memory depending on the volume of mn excluding the number of cells m, which is necessary to record the first column of the matrix A_{kl}. Part of the memory is meant to record the intermediate data from the computation of $K_{\max}$, e.g., the distances Δ_i computed from each point of the computed $K_{\max}$ to the points of initial data set with activity values.

Block Diagram SP-7 (see p. 120)

The SP-7 program moves according to the block diagram. After the entry of the punch cards of the program and the initial data sets M_1 and M_2, control is given to block 1. Here the addresses for the instructions to translate the initial data are calculated, as well as the cycles to compute intermediate values and the exact value of $K_{\max}$ depending on the control data. In block 2, the initial data sets M_1 and M_2 are converted from decimal to the binary system. In block 3, the data from the multiple computations of the seismic activity values are prepared for the succeeding blocks. Here the constant part B of the value $\bar{A}$ has been computed. It depends only on the parameters of seismic regime of the region according to formula (37').

Blocks 1–3 prepare the main computation. In the succeeding blocks 4–12 the values of $K_{\max}$ are computed for the point under study. Thereafter a concrete $K_{\max}$ is chosen and dispatched for print. The entire row of values $K_{\max}$ is computed, the number of members of which depends directly on the step a_k. Meanwhile, in blocks 4–12 all further computations are continued for the initial computation point of the resulting map and are repeated with the following point, in accordance with the given computation step a'_φ and a'_λ (latitudinally and longitudinally). Block 4 computes the distance from the initial point of computation with coordinates φ_0, λ_0 to all grid nodes on the initial map of activity, representing matrix A_{mn} (A′B′EF) as in formula (40).

Block 5 computes the radius $r_{\max_j}$ of the averaging zone of seismic activity. Its value A_1 represents $K_{1_{\max}}$—largest of the proposed earthquake $K_{\max}$ in the region in accordance with the correlational dependence (13).

The value $r_{\max_j}$ is computed by formula (14). In block 6 all values Δ_i, computed in block 4, are compared with the values $r_{\max_j}$. For all $\Delta_i \leqslant r_{\max_j}$ the corresponding values of seismic activity A_i are chosen and totaled in block 7. The value of activity in the averaging zone of radius $r_{\max_j}$ is equal to

$$A_z = \frac{\sum_1^n A_i}{n}, \tag{49}$$

where n—number of points—initial map of activity nodes for which $\Delta_i \leqslant r_{\max_j}$.

Block 8 computes the tabular values of activity A_T for $K_{\max} = K_{\max_j}$ according to formula (13). Then control is shifted to block 9 where the values A_z and A_T are compared.

If $A_z > A_T$, the value $K_{\max}$ is larger than $K_{\max_j}$ in the ith point under study. On the other hand, the value $K_{\max}$ in the ith point is also less than $(K_{\max_j} + a_K)$, since at each point are analyzed all values of the maximum possible earthquakes from $K_{\max_1}$, $K_{\max_2} = (K_{\max_1} - a_K)$ and so on to $K_{\min}$. Therefore, control is shifted to print the values of $K_{\max}$, intermediate between $K_{\max_j}$ and $K_{\max_{j-1}}$, i.e., $(K_{\max_j} + 0.5\, a_K)$. The equality $A_z = A_T$ signifies total agreement of the investigated value $K_{\max}$ to the actual $K_{\max}$, and the computation is stopped. Control is shifted to print the point of value $K_{\max}$. With $A_z < A_T$ the investigated value of $K_{\max}$ is more than the actual one and it is necessary to analyze lower values of $K_{\max}$, viz., $K_{\max_2} = (K_{\max_1} - a_K)$, and control is shifted to block 5 to measure the value $r_{\max_2}$ of the averaging zone of activity, representing $K_{\max_2}$ in accordance with relation (14). Control is shifted from block 9 to block 5 only when $K_{\max_j} > K_{2_{\max}}$. Values $K_{\max_j}$ to $K_{2_{\max}}$ are analyzed in the same manner. When $K_{\min} < K_{\max_j} \leqslant K_{2_{\max}}$ the further analysis of the values $K_{\max}$ at the point is conducted differently. Control is shifted to block 10 to compute A_T, the value of the investigated $K_{\max}$. Further control is shifted to block 11, where the radius $r'_{\max_j}$ of the averaging zone of activity A_z is computed according to formula (37) with $\bar{A} = A_T$, obtained in block 10, and $N_\Sigma = N_\sigma$. The obtained values of r' are compared with all Δ_i for the investigated point, for which control is again shifted from block 11 to block 6. Thereafter the seismic activity A_z in the averaging zone of radius r' is computed in block 7 by superimposing separate activity values at points whose $\Delta_i \leqslant r'$. Further control is shifted from block 7 to block 9 to compare the values of activity A_T and A_z. The result is either printed (blocks 12 and 13), or lesser values of $K_{\max}$ at the computational points are investigated.

Various methods of investigating values of $K_{\max}$ in the intervals from $K_{1_{\max}}$ to $K_{2_{\max}}$ and from $K_{2_{\max}}$ to $K_{\min}$ are explained as in the SP-6 program.

Since the computation of A_z is conducted for the seismic activity map, actually for its discreet values A_i, forming the initial matrices A_{mn} and A_{kl}, it is important that their sum must include at least three values of A_i as in formula (49). The number n in formula (49) is determined by the relationship of values r (radius of the averaging zone of activity) and a (distance between the graduated grid points of the initial map of activity). With $r/a >$ 1 the number n would be more than 3. With this relationship, the value of activity in the averaging zone of radius r and its value of $K_{\max}$ are also determined.

If the values A_T and A_z do not equalize in the succeeding cycles to compute $K_{\max_j} > K_{\min}$, all the described operations are repeated up to $K_{\max} = K_{\min}$. This completes the program for the investigated point. Control is shifted to block 13 where the result is printed, and a serial number and the value of $K_{\max}$ is issued for each point of computation. Block 13 also analyzes the number of points N_T. With $N_T = q \cdot r$, where $q \cdot r$—number of points in the columns of the resulting matrix K, control is shifted to block 15. With $N_T < q \cdot r$ control is shifted to block 14 to compute the next point of the column. Here the coordinates of the next point are chosen and the addresses of the necessary instructions are loaded to compute $K_{\max}$. Next control is shifted to block 4 to compute distances Δ_i, etc.

The column of matrix A_{kl} is entered in block 15. This is necessary to compute $K_{\max}$ in the next column of the map. After shifting control to block 16 the addresses of the cells are restored to re-record the activity values and all the matrices A_{mn} and the columns of matrix A_{kl} introduced in block 15 are shifted one column to the left. Block 17 prepares the computation of $K_{\max}$ in the next column of the map and computes N_T. With $N_T = q \cdot r$, the number of members of the resulting matrix K_{qr}, the computation is stopped; if $N_T < qr$ control is shifted to block 4 to compute $K_{\max}$ in the first point of the next column K_{qr}.

The SP-7 program has a series of advantages concerning the sets of initial data over SP-6. First, the seismic activity maps of large territories are more accessible for investigations than the epicenter maps or similar lists. Second, the serialized initial material system formed in the matrix form, permits the computation of $K_{\max}$ for any desired large areas without using the additional memory of the computation. The information in the main memory is automatically shifted and the cells thus made free are used for additional data as already considered in the feeding instructions of the program. SP-6 uses maps of randomly placed epicenter. The computation of $K_{\max}$ for large territories must either use drums and magnetic tapes to increase memory, or prior group the epicenter coordinates so that it is possible to shift and automatically enter additional data. Either possibility can be achieved; however, it is much more convenient to avoid this complexity as in SP-7.

Illustrative Example

Unlike the other programs, the check-out version for SP-7 is somewhat complex. In explaining the programs SP-1, 2, 3, 4, and 6 where the main initial data set M_1 was codified straight from the epicenter catalog, it was sufficient to give the parameters (φ_i, λ_i, K_i) for some of them. Here we have from 7 to 20 to extend the volume of M_1 to 21 or 60 elements. Usually, the epicenter catalogs are formed in chronological order, therefore, the epicenters of set M_1 were more or less uniformly distributed along the region. This made it possible to work with the SP program. In SP-7 the data set M_1 is made of seismic activity values A from a corresponding map with a certain grid and fixed coordinates φ_{A_0}, λ_{A_0} of the initial point to be used for further computations.

In the computation of $K_{\max}$ for each point, SP-7 requires that the values of activity are totaled in an averaging zone with a changing radius up to 300 km and more. In this zone a different number of points are accommodated, depending on the given step A of the value of $K_{\max}$ to be analyzed Since SP-7 begins with the analysis of the largest $K_{\max}$, e.g., $K = 17$ or 18, then at the beginning of the computation at any map point, the activity in the zone is averaged for hundreds of values of A, which are selected successively from the nodes of the given grid. The coordinates of the node have been computed earlier using given interval A from the given point φ_{A_0}, λ_{A_0}. Therefore, it is not possible to limit the operation by a small number of values of A in one or two columns of initial matrix A_{mn}, since in all its cells, corresponding to remaining elements, a very large number (machine ∞) would be held and the program could not run. For the control SP-7, therefore, it is necessary to add several additional instructions, introducing zeros in the matrix cells A_{mn} which are not engaged with the values of A (Table 20). Now data set M_1 may hold the activity values A of one column of matrix A_{mn}, input 4422 A; and the column of matrix A_{kl}, input 6113 (Table 21).

The data set M_2 (Table 22) holds the constants and conditions of computation. The latter include the coordinates of the initial point of matrix A_{mn}–φ_{A_0} and λ_{A_0}, the given step of its elements—a_{φ_A} and a_{λ_A} latitudinally and longitudinally, the number of matrix elements—mn, number of its

TABLE 20. ADDITIONAL COMMANDS FOR CONTROL EXAMPLES OF SP-7

Address	Command	A_1	A_2	A_3
1025	052	0000	0000	0000
7	175	0000	0000	4422
6	112	1470	1026	0001
1030	056	0000	0500	0000

TABLE 21. DATA SET M_1 FOR SP-7

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				4422 A			
4422	++	—	02	250	000	000	$A_1 = 0.0025$
3	++	—	03	300	000	000	$A_2 = 0.0030$
4	++	—	02	350	000	000	$A_3 = 0.0035$
5	++	—	02	400	000	000	$A_4 = 0.0040$
6	++	—	02	550	000	000	$A_5 = 0.0055$
7	++	—	02	700	000	000	$A_6 = 0.0070$
4430	++	—	02	800	000	000	$A_7 = 0.0080$
1	++	—	01	100	000	000	$A_8 = 0.0100$
2	++	—	01	150	000	000	$A_9 = 0.0150$
3	++	—	01	200	000	000	$A_{10} = 0.0200$
4	++	—	01	400	000	000	$A_{11} = 0.0400$
5				4435 A			
4435	++	—	01	500	000	000	$A_{12} = 0.0500$
6	++	—	01	500	000	000	$A_{13} = 0.0500$
7	++	—	01	500	000	000	$A_{14} = 0.0500$
4400	++	—	01	500	000	000	$A_{15} = 0.0500$
1	++	—	01	400	000	000	$A_{16} = 0.0400$
2	++	—	01	300	000	000	$A_{17} = 0.0300$
3	++	—	01	250	000	000	$A_{18} = 0.0250$
4	++	—	01	220	000	000	$A_{19} = 0.0220$
5	++	—	01	210	000	000	$A_{20} = 0.0210$
6	++	—	01	200	000	000	$A_{21} = 0.0200$
7	++	—	01	180	000	000	$A_{22} = 0.0180$
				4450 A			
4450	++	—	01	160	000	000	$A_{23} = 0.0160$
1	++	—	01	140	000	000	$A_{24} = 0.0140$
2	++	—	01	120	000	000	$A_{25} = 0.0120$
3	++	—	01	100	000	000	$A_{26} = 0.0100$
4	++	—	02	000	000	000	$A_{27} = 0.0090$

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
5	++	−	02	800	000	000	$A_{28} = 0.0080$
6	++	−	02	700	000	000	$A_{29} = 0.0070$
7	++	−	02	600	000	000	$A_{30} = 0.0060$
4460	++	−	02	500	000	000	$A_{31} = 0.0050$
1	++	−	02	400	000	000	$A_{32} = 0.0040$
2	++	−	02	300	000	000	$A_{33} = 0.0030$
3				6113 A			
6113	++	−	00	400	000	000	$A_{34} = 0.3000$
4	++	−	00	500	000	000	$A_{35} = 0.5000$
5	++	−	00	500	000	000	$A_{36} = 0.5000$
6	++	−	00	500	000	000	$A_{37} = 0.5000$
7	++	−	00	400	000	000	$A_{38} = 0.4000$
6120	++	−	00	400	000	000	$A_{39} = 0.4000$
1	++	−	00	400	000	000	$A_{40} = 0.4000$
2	++	−	00	500	000	000	$A_{41} = 0.5000$
3	++	+	01	100	000	000	$A_{42} = 1.0000$
4	++	+	01	100	000	000	$A_{43} = 1.0000$
5	++	+	01	100	000	000	$A_{44} = 1.0000$
				6126 A			
6126	++	−	00	500	000	000	$A_{45} = 0.5000$
7	++	−	00	450	000	000	$A_{46} = 0.4500$
6130	++	−	00	430	000	000	$A_{47} = 0.4300$
1	++	−	00	410	000	000	$A_{48} = 0.4100$
2	++	−	00	400	000	000	$A_{49} = 0.4000$
6133	++	+	00	380	000	000	$A_{50} = 0.3800$
4	++	−	00	350	000	000	$A_{51} = 0.3500$
5	++	−	00	300	000	000	$A_{52} = 0.3000$
6	++	−	00	270	000	000	$A_{53} = 0.2700$
7	++	−	00	250	000	000	$A_{54} = 0.2500$
6140	++	−	01	700	000	000	$A_{55} = 0.0700$
				6141 A			
6141	++	−	01	370	000	000	$A_{56} = 0.0870$
2	++	−	01	250	000	000	$A_{57} = 0.0250$
6143	++	−	01	180	000	000	$A_{58} = 0.0180$
4	++	−	01	160	000	000	$A_{59} = 0.0160$
5	++	−	01	140	000	000	$A_{60} = 0.0140$
6	++	−	01	120	000	000	$A_{61} = 0.0120$
7	++	−	02	800	000	000	$A_{62} = 0.0080$
6150	++	−	02	600	000	000	$A_{63} = 0.0060$
1	++	−	02	500	000	000	$A_{64} = 0.0050$
2	++	−	02	300	000	000	$A_{65} = 0.0030$
6153	++	−	02	700	000	000	$A_{66} = 0.0010$

TABLE 22. DATA SET M_2 FOR SP-7

Address	Commands and numbers						Remarks
	Sign of		Order	A_1	A_2	A_3	
	No.	Order					
				1034 A			
1034	++	+	00	500	0	0	const = 0.5
5	++	+	03	360	0	0	$2\pi = 360°$
6	++	+	01	628	318	600	$2\pi = 6283186$
7	++	+	01	314	159	300	$\pi = 3.141593$
1040	++	+	02	100	0	0	const = 10
1	++	+	03	111	199	0	1° = 111190 km
2	++	+	01	300	0	0	const = 3
3	++	−	01	315	0	0	$1/C = 0315 \cdot 10^{-10}$
4	++	+	01	230	259	0	const = 2.30259
5	++	+	02	100	0	0	$K_{\text{rep}} = 10$
6	++	+	02	100	0	0	$K_0 = 10$
				1062 A			
1062	++	+	03	825	0	0	$mn = 825$
3	++	+	02	300	0	0	$K_1 = 30$
4	++	+	02	510	0	0	$K_2 = 51$
5	++	+	02	250	0	0	$n = 25$
6	++	+	2	372	500	000	$\varphi_{A_0} = 37.25$
7	++	+	2	640	000	000	$\lambda_{A_0} = 64.00$
1070	++	+	0	100	0	0	$a_K = 0.1$
1	++	+	04	100	0	0	$S_0 = 1000$
2	++	+	00	250	0	0	$a_{\varphi_K} = 0.25$
3	++	+	00	333	333	333	$a_{K_A} = 0.33$
4	++	+	02	110	00	0	$T_{\text{rep}} = 11$
				1075 A			
1075	++	+	02	402	500	0	$\varphi_0 = 40.25$
6	++	+	02	680	0	0	$\lambda_0 = 68.00$
7	++	+	00	460	0	0	$\gamma = 0.46$
1100	++	+	00	250	0	0	$a_\varphi = 0.25$
1	++	+	00	333	333	333	$a_\lambda = 0.33 \left(\frac{1°}{3}\right)$
2	++	+	01	800	0	0	$N_o = 8$
3	++	+	02	150	0	0	$K_\alpha = 15$
4	+−	+	01	116	0	0	$\log \alpha = -1.16$
5	++	+	00	210	0	0	$\beta = 0.21$
6	++	+	02	180	0	0	$K_{1_{\max}} = 18$
7	++	+	02	150	0	0	$K_{2_{\max}} = 15$

TABLE 23. CONTROL INFORMATION FOR SP-7

Address	Commands and numbers					Remarks
	Sign of		A_1	A_2	A_3	
	No.	Order				
				1120 A		
1120		0	0	6113	6052	$(O_1 A_{1,\,n+1}\ A_{1,\,n})$
1		0	0	4463	4422	$(O_1 A_{12} A_{11})$
2		0	0	4422	0	$(O_1 A_{11} O)$
1123		0	4422	4422	6112	(A_{11}, A_{11}, A_{mn})
4		0	0030	0	0	$(n-1, 0, 0)$
5		0	0040	0	0	$(m-1, 0, 0)$
6		0	0007	0	0	$(q-1, 0, 0)$
7		0	0001	0	0	$(r-1, 0, 0)$
1130		0	0027	0	0	$(n-2, 0, 0)$
1		0	1470	0	0	$(mn-1, 0, 0)$
2		0	6113	0	0	$(A_{1,\,n+1}\ 0, 0)$
3		0	6113	6113	6153	$(A_{1,\,n+1}, A_{1,\,n+1}, A_{m,\,n+1})$

columns—n; coordinates of the initial point of computation—φ_0, λ_0, A_0 and step of computation a_φ and a_λ latitudinally and longitudinally. The remaining cells of M_2 are named as in SP-6.

The control data for the illustrative example is shown in Table 23. Here A_{11} is the number of the initial cell of the first column of the matrix A_{mn}; A_{12}—number of initial cell at the second; A_1, n number of first cell of the last column; aA_{mn}—number of the last of its cells $A_{1,\,n+1}$—number of the initial cell of the first column of the matrix A_{kl}, $A_{m,\,n+1}$—last cell. The remaining names are the same as in the previous program.

The output of SP-7, based on initial data (Tables 20–23), for all columns of the map $K_{\max}$ (16 points) follows:

```
         N_T                      K_max
+++01 100000000        +++02 100000000.
```

In this only NN points change—N_T, whereas the values $K_{\max}$ remain the same as for point 1, therefore, the result for the last point would be as follows:

```
         N_T                      K_max
+++02 16000000        +++02 100000000.
```

Thus, for all 10 points $K_{\max} = 10$, i.e., does not exceed the energy class of the least of the representative earthquakes $K_{\min}$ in set M_2. This is explained by the small number of values of A in M_1.

Chapter V

Examples of the Computation of A and $K_{\max}$ Maps by SP Programs

The SP programs were used to investigate the seismicity of Uzbekistan. Thus maps of seismic activity were computed for the eastern part of the Ferghana Valley and its surrounding hilly terrain. The initial data of the SP-1, 2, 3 and 4 programs are mainly the same. Set M_1 was compiled using the catalog of Eastern Uzbekistan earthquakes from the Institute of Seismology, Academy of Sciences of the UzbSSR between 1968–1969. Here earthquakes with $K \leqslant 13$ were recorded according to energy when they occurred (Zakharova, Matasova, 1971). Earthquakes with $K = 13$ were chosen for the period 1929–1969; $K = 12$, $= 11$, $= 10$ from 1951 to 1969 and $K = 9$ from 1960 to 1969. Some presentations about the density of epicenter distribution in the investigated territory provide the map of earthquake epicenters (Fig. 2). Eastern Ferghana and its hilly terrain, for which the activity map was computed is shown here by a dash-dot line.

While calculating the map A, the values of K, φ, and λ were codified for each of the 500 earthquakes of set M_1. In set M_2, common to all the maps, were the values of energy classes K_{f_j} and corresponding to them, the periods of presentation T_{f_j}, viz:

$$\begin{array}{ll}
K_{f_1} = 9 & T_{f_2} = 8.5 \\
K_{f_2} = 10 & T_{f_2} = 18 \\
K_{f_3} = 11 & T_{f_3} = 18 \\
K_{f_4} = 12 & T_{f_5} = 18 \\
K_{f_5} = 13 & T_{f_5} = 40
\end{array}$$

$K_0 = 10$—class of seismic energy to which the value of activity is referred; $T_{\text{rcp}} = 8.5$—is the representative period of earthquakes with the lowest energy from those used in computation; $\gamma = 0.5$—inclination of earthquakes repeatability curve. All maps of A were calculated with an identical interval, longitudinally and latitudinally, equal to 0.1°. Values of A at each computation point were normalized around a 1,000 km^2 area and one year period. For detailed maps, computed by SP-1 and SP-4, the area of averaging zone is $S = 0.2° \times 0.2°$, i.e., about 350 km^2. While using SP-2 the area was changing and depended on the density of earthquake epicenters and the given minimum number of epicenters in the averaging zone—N_σ. The combined SP-3 program computed A for each point of the map using an averaging zone of $S = 350$ km^2; whereas with fewer than N_σ epicenters in it, it used a zone of varying area, as in SP-2.

Seismic activity maps A_{10} for the eastern Ferghana Valley and its hilly surroundings (areas) were computed by the SP programs (Figs. 3–7). Isolines A_{10} are shown everywhere with values $A_{10} = 0.01$; 0.02; 0.05; 0.1; 0.2; 0.5; 1.0. The maps A_{10}, computed by the summation method with constant detailing by SP-1 (Fig. 3) and the combination method by SP-3 (Fig. 6), generally present a similar picture of the distribution of seismic activity values. In the first case, for all points of the map and for their overwhelming majority in

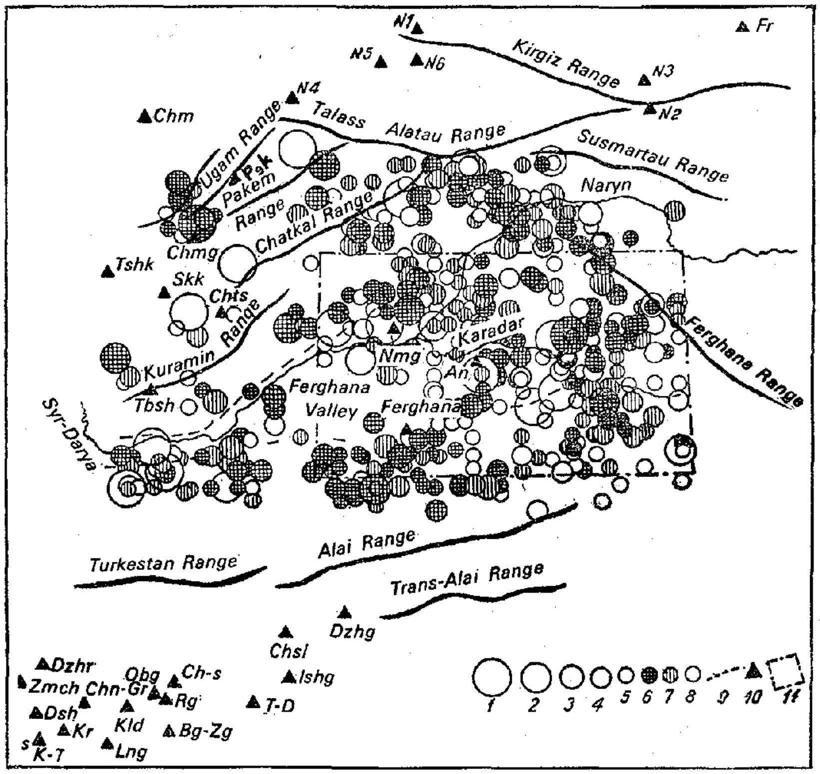


Fig. 2. Map of earthquake epicenters of Eastern Uzbekistan between 1951 and 1969:

Seismic energy: *1*—$K \geqslant 14$; *2*—$K = 13$; *3*—$K = 12$; *4*—$K = 11$; *5*—$K = 10$; Class of accuracy: *6*—*A*; *7*—*B*; *8*—*n/cl*; *9*—Boundary of Ferghana Valley; *10*—Seismic stations; *11*—Boundary of section for which the map A_{10} was compiled by computer.

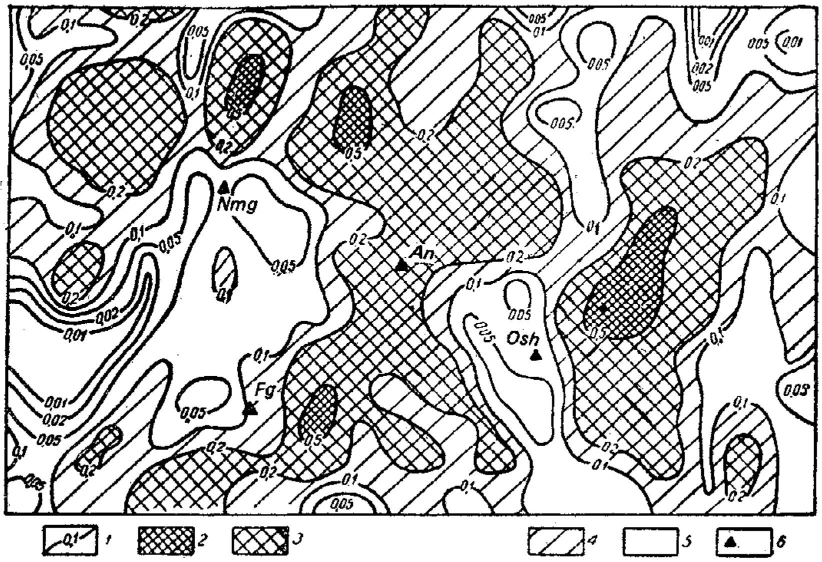


Fig. 3. Detailed seismic activity map A_{10} for Eastern Ferghana, computed by the summation method using SP-1:

1—Isoline A_{10} value of activity; *2*—$1.0 > A_{10} \geqslant 0.5$; *3*—$0.5 > A_{10} \geqslant 0.2$; *4*—$0.2 > A_{10} \geqslant 0.1$; *5*—$A_{10} < 0.1$; *6*—inhabited places.

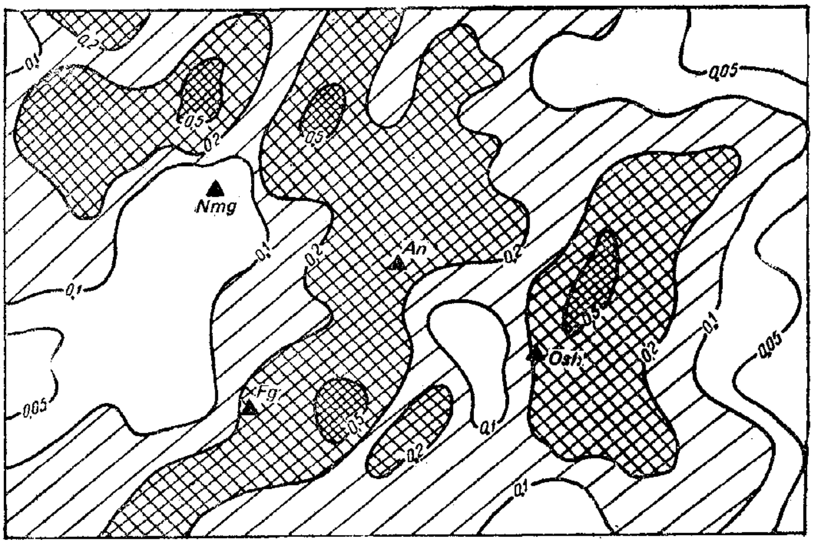


Fig. 4. Seismic activity map A_{10} with constant accuracy for Eastern Ferghana, computed by the summation method using SP-2 with $N_\sigma = 5$:

For legend see Fig. 3.

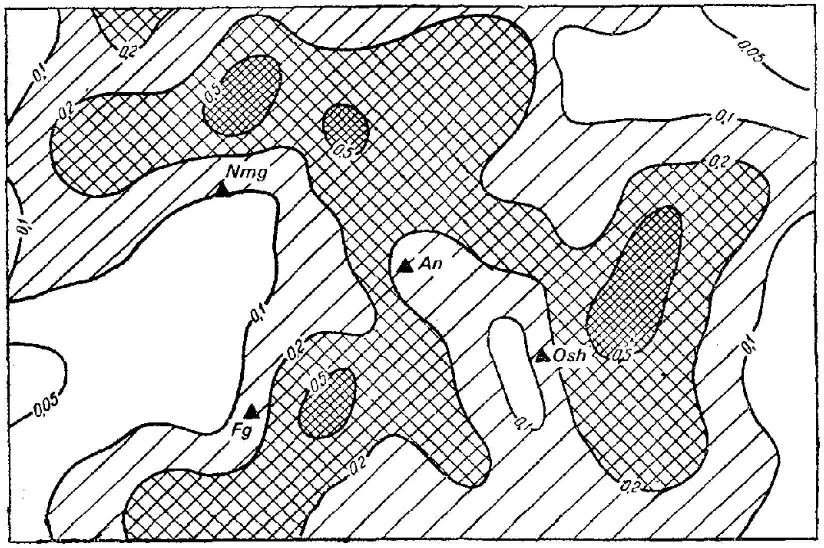


Fig. 5. Seismic activity map with constant accuracy for Eastern Ferghana, computed by the method of summation using SP-2 with $N_\sigma = 8$:

For legends see Fig. 3.

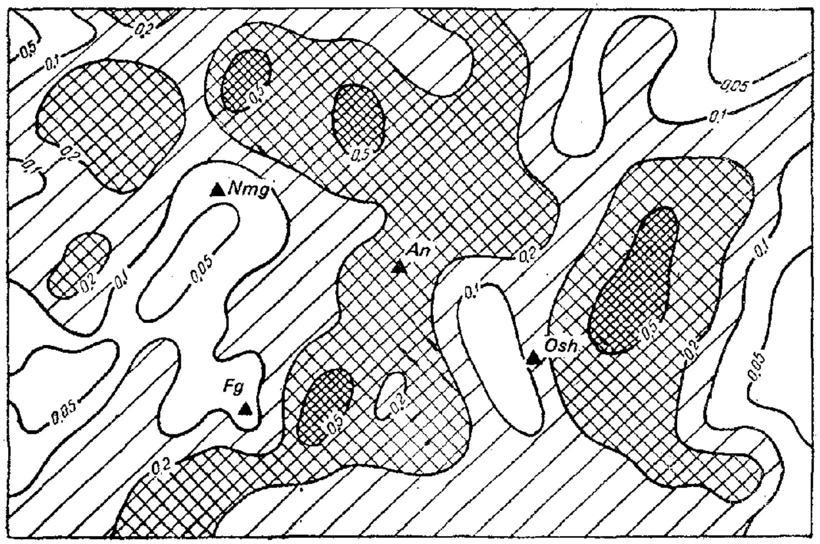


Fig. 6. Seismic activity map A_{10} for Eastern Ferghana. computed by the combination method using SP-3:

For legend see Fig. 3.

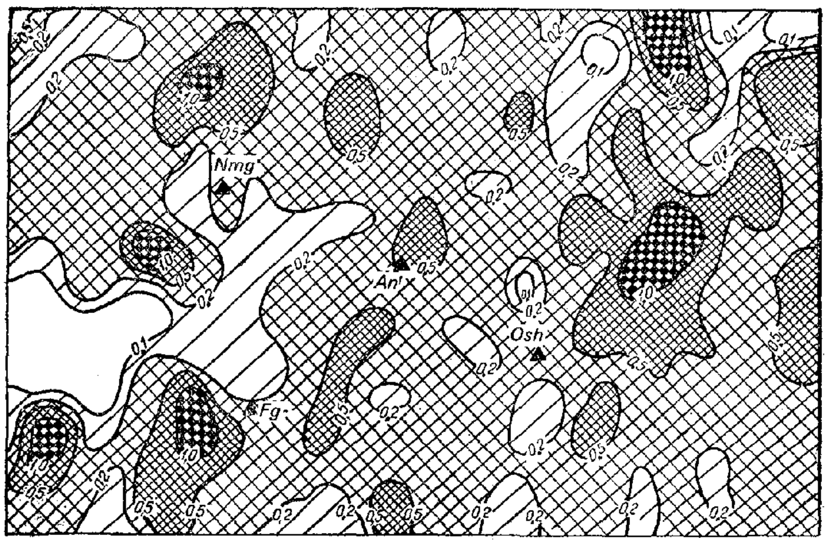


Fig. 7. Detailed seismic activity map A_{10} computed by the distribution method using SP-4:

1—Isolines of activity. Values of activity: 2—$A_{10} \geqslant 1.0$; 3—$1.0 > A_{10} \geqslant 0.5$; 4—$0.5 > A_{10} \geqslant 0.2$; 5—$0.2 > A_{10} \geqslant 0.1$; 6—$A_{10} < 0.1$; 7—inhabited places.

the second, the values of A_{10} were computed in the averaging zone of the same 0.2°×0.2° area of the geographical radius with not less than three epicenters N_σ.

Computations were stopped only for those points with averaging zones of activity of $N_\sigma < 3$ in SP-1 (Fig. 3) and a zero value of A_{10} was recorded for them. In SP-3 (Fig. 6) computations were continued with an increase in area until $N_\sigma = 3$. This explains the somewhat lesser differentiation of zone A_{10} (Fig. 6) compared to regions of lower activity values (Fig. 3) and also the difference of the minimum levels A_{10} on these maps. Their isolines A_{10} extend in two directions—northeast and northwest.

The background activity values, i.e., the values engaging a larger part of the computed territory consist of $0.2 < A_{10} < 0.5$ and cover the central northwestern and southeastern parts. The most extended region of lower activity values is in Ferghana valley itself (between the cities Hamangan, Andijan, and Ferghana); A_{10} does not exceed 0.2. In the hilly surroundings to the north and east, the value of A_{10} increases to 0.5 but nowhere reaches 1.0. All four of the regions of increased values of activity (where $A_{10} > 0.5$) are beyond the Ferghana Valley boundary.

Two are north-northeast of Namangan near the foot of Bozbutau and

Ortatokar, close to the North Ferghana flexure-fault zone. The third region is east of Osh and close to the Kurshabsk fold zone where the newest structures of the Alai and Ferghana ridges join. Finally, the fourth region of the increased value of A_{10} is between the cities of Osh and Ferghana on the northern slopes of the Alai ridge, close to the Southern Ferghana flexure-fault zone.

If the A_{10} maps are compared (Figs. 3, 6 and 4, 5), it is clear that the first is more detailed, since it was constructed mainly with constant detailing with $N_\sigma = 3$, i.e., with a small averaging zone of activity. The second was computed according to SP-2 with constant accuracy, in which, with $N_\sigma = 5$ (Fig. 4) and with $N_\sigma = 8$ (Fig. 5), there was a larger area of averaging zone. This also explains the increase in the zone of uniform activity on corresponding maps. This can be easily seen in Fig. 5 where are merged not only the small activity zones ($A_{10} = 0.1$–0.2) (Fig. 4), but also the background—$0.2 < A_{10} < 0.5$. The computer map of A_{10} according to SP-2 with $N_\sigma = 3$ has a similar configuration of activity isolines and also the same level as the maps on Figs. 3 and 6. Still further differentiated are the regions of uniform seismic activity on the map of A_{10} constructed with constant detailing. Their computations of activity values were conducted by the distribution method according to SP-4 (Fig. 7).

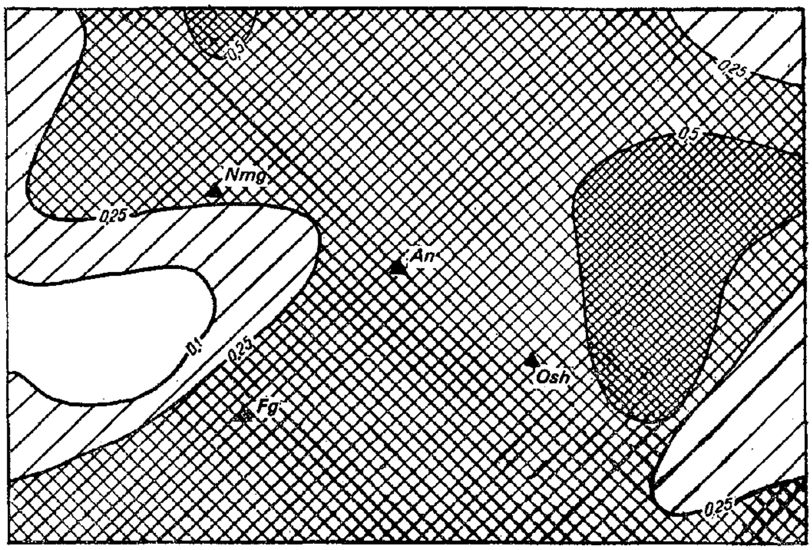


Fig. 8. Tracing from the seismic activity map with constant accuracy for Central Asia, manually computed by the summation method. Legend same as in Fig. 3 except values of activity *3*—$0.5 > A_{10} \geqslant 0.25$; *4*—$0.25 > A_{10} \geqslant 0.1$.

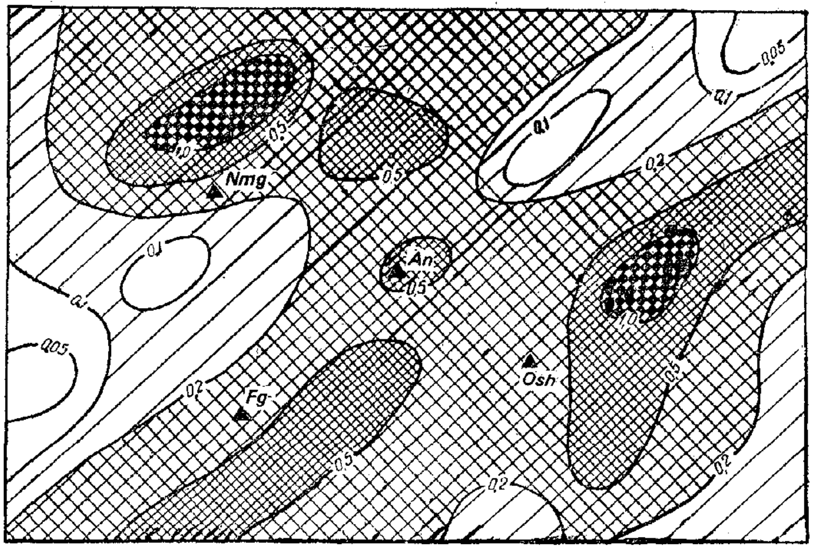


Fig. 9. Seismic activity map A_{10} with constant detailing for Eastern Ferghana, manually computed by the summation method: For legend see Fig. 7.

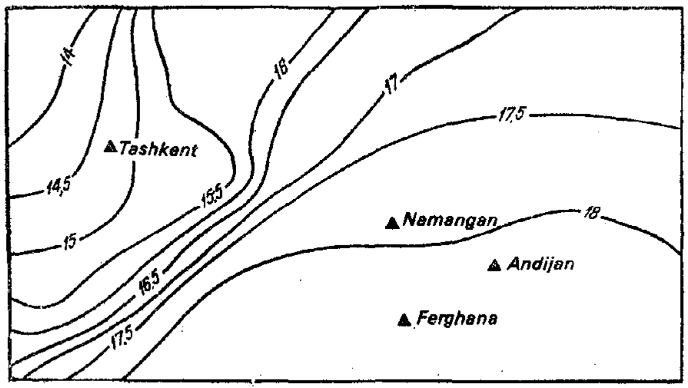


Fig. 10. Map of largest possible earthquakes $K_{\max}$ computed from the activity map using SP-7.

Here, with the same background activity the extent of the zone is considerably less with a larger increase of their values and level of the maxima of A_{10}. This depends on the method of computing the activity and the smaller value of the given number of epicenters in the averaging zone ($N_\sigma = 1$) in which the value of A_{10} is considered significant.

Let us consider the seismic activity maps computed (Figs. 3, 5), with the maps constructed manually (Figs. 8, 9). A strict comparison, it is regretted, was not possible since the maps computed by hand were not totally analogous to those of machine computations.

Figures 8 and 9 present maps in which most computation conditions are similar to the computer computations given in Figs. 3 and 5. Fig. 8 shows a tracing from the A_{10} map for Central Asia (Bune, Vvedenskaya, Gzovskii, Gorbunova, 1970). The map with uniform accuracy was compiled by computer. The activity values in the averaging zones of the changing area, depending on the epicenter density, were attributed to the centers of 1600 km^2 units. For initial data, a map of the representative earthquake epicenters with $K \geqslant 10$ between 1956 and 1966 was used. It was less detailed than illustrated on Fig. 5, where under strictly identical conditions the computation interval was 0.1°, i.e., the activity values were attributed to the centers of areas approximately four times less ($S = 350$ km^2). The activity levels of the Ferghana Valley and its hilly surroundings are identical (Figs. 8 and 5). In Fig. 9, a tracing from the seismic activity map of Uzbekistan is shown (B.B. Tal'-Virskii, A.I. Zakharova and I.B. Yakovleva, 1971). This map was constructed with constant detailing with a computation interval of 0.1°. The activity values in the averaging zone were computed by the summation method. The general isolines configuration of A_{10} is comparable here with those described in Fig. 3, but the level of A_{10} is almost twice higher. This is because during manual calculations, in the averaging zone, where earthquakes with $K = 9$ were absent, in formula (37) we used $K_{\min} = 10$. So the weight of each earthquake in the zone was almost tripled as compared with $K_{\min} = 9$.

Besides the above seismic activity maps, the map of maximum possible earthquakes were also computed with these programs. Fig. 10 shows a map of $K_{\max}$ for Eastern Uzbekistan computed by the SP-7 program. To compile the initial data set M_1, a seismic activity map of Central Asia was used, the main part of which was constructed according to the data from V.I. Bune and others (1970): The western part (between 64–68° E), according to B.B. Tal'-Virskii, A.I. Zakharova, and I.B. Yakovleva (1971) and the northern (between—43.5–45.5°N) were extrapolated from the values of $A_{10} = 0.02$–0.005 to 0.001, since observations about earthquakes are not conducted in this territory.

The values of A_{10} were drawn from this map with an interval 0.25° latitudinally and 0.33° longitudinally, i.e., in the centers of zones with nearly 3,600 km^2 areas to prevent overstating the initial data detailing (values A_{10} were calculated on the map to the centers of areas $S = 1{,}600$ km^2). In accordance with the plan to accommodate initial data for SP-7, the area of the activity map somewhat exceeded the area of the $K_{\max}$ map to insure the averaging of A_{10} in the zone responsible for the appearance of earthquakes with $K = 18$, and was limited by the following coordinates: 37–45.5°N latitude and 64–78°E longitude. The contours of the map $K_{\max}$ were denoted by the same letters ABCD (Fig. 1). The computation of the values of $K_{\max}$ was latitudinal and longitudinal with the same interval around K through 0.1 (a_K) from which the values of seismic activity A_{10} were drawn from the initial map, i.e., $a_{\varphi_K} = a_{\varphi_A} = 0.25°$ and $a_{\lambda_K} = a_{\lambda_A} = 0.33°$. The computations and characteristics of seismicity of the investigated territory in set M_2 are as follows:

1) The computation conditions of the initial map of seismic activity and codification of the values A_{10}:

$\gamma = 0.46$
$K_0 = 10$
$K_{\min} = 10$
$T_{\mathrm{pri}} = 11$

$N_\sigma = 8$
$S_0 = 1000$
$\varphi_{A_0} = 64^\circ00$
$\lambda_{A_0} = 37^\circ00$

$a_{\varphi_A} = 0.25$
$a_{\lambda_A} = 0.33$

2) The parameters of correlational dependence $A = A\,(K_{\max})$ and the computation conditions of the map $K_{\max}$:

$\log\alpha = -1.16$
$\beta = 0.21$
$K_\alpha = 15$
$K_{1\max} = 18$
$K_{2\max} = 15$

$a_\varphi = 0.25$
$a_\lambda = 0.33$
$a_K = 0.1$
$mn = 825$

$\varphi_0 = 40^\circ25$
$\lambda = 68^\circ00$
$1/c = 0.315\cdot10^{-10}$

On the computer $K_{\max}$ map (Fig. 10), the isolines are shown through 0.5 of the value of K analogous to the map (Fig. 11) constructed manually (Zakharova, Seiduzova, 1970). The relative distribution of the values of $K_{\max}$ on them are almost identical: increased values of $K_{\max}$ are noticed on the larger eastern part of the investigated territory (Ferghana Valley and its hilly surroundings in the north, east, and south). Here the corresponding isolines are considerably different and have the values $K_{\max} = 17$–18 (Fig. 10). The described region (Fig. 11) is contoured only by one isoline $K_{\max} = 17$. West of it, in the transitional region from the hill to the Pritashkent Valley, the values of $K_{\max}$ are reduced to 15.5–16 on both maps; their isolines are denser and extend more or less identically.

In the Pritashkent plains the smallest $K_{\max}$ are noticed for those computed for Eastern Uzbekistan—15.5–14 (Fig. 10) and 15.5–15 (Fig. 10). The maximum differences of 1.5 K in the absolute values of $K_{\max}$ were noticed on these maps on the small section between Ferghana Valley and Pritashkent. Here $K_{\max} = 17$–17.5 by computer as against 15.5–16 by hand calculation. The maximum possible earthquake values differ considerably (in unit of $K_{\max}$) in the Ferghana Valley where the computer gives $K_{\max} = 18$; it is 17 manually. On the northwest edges of Pritashkent with the same $K_{\max}$ difference of 1.0 K the machine computations are lower than those by hand

(K_{max} = 14 and 15 accordingly). This difference in the value of K_{max} is explained by nonuniform initial data. In the first case (Fig. 11) the map of earthquake epicenters was used as initial material. It was reliable only for the territory of the K_{max} map itself. Therefore, the seismic activity values, and also the values of K_{max}, are most accurately computed for those map points, whose averaging zones were wholly within the limits of the epicenter map. Seismic activity in the region surrounding this map was only approximate and should reflect on the results of the computation of K_{max}.

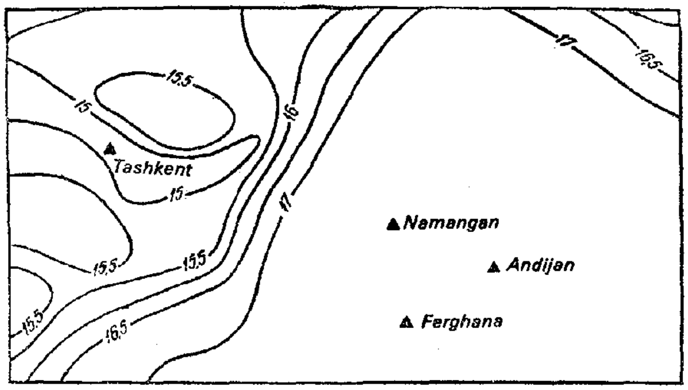


Fig. 11. Map of largest possible earthquakes K_{max}, computed from the epicenter map by hand.

The computer used initial data directly drawn from the seismic activity map. They somewhat exceeded the boundaries of the K_{max} map and made it possible to consider more accurately seismic activity in the averaging zones for each point. Therefore the values of K_{max} on Fig. 11 exceed those on Fig. 12* almost everywhere. A reverse relationship of the values of K_{max} in the Pritashkent Valley is because the earthquakes with $K = 8$ were considered for this territory (Fig. 12*). In the machine computation information about focal seismicity was taken as uniform for all of Eastern Uzbekistan, i.e., limited by the least class of energy $K = 10$.

Thus the programs SP-1, 2, 3, 4, and 5 may be successfully used not only to obtain long-term average values of the distribution of parameters of the seismic regime in space, but also to considerably simplify the investigation of the variation of the seismic process in time. SP-6 and SP-7, seemingly, may also be used to investigate the values of energy density in the foci of strong earthquakes.

*Correct as per the Russian original. This figure is not available in the Russian text—General Editor.

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