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WORKSHOP ON PATTERN RECOGNITION AND ANALYSIS OF SEISMICITY

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SEISMIC RISK FOR THE LARGEST CITIES OF THE WORLD

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SEISMIC RISK FOR THE LARGEST CITIES OF THE WORLD; INTENSITY VIII OR MORE.

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ABSTRACT

General methodolgy of probabilistic estimation of seismic risk, as a base for decision making, is described by an analysis of seismic risk for the cities with population ≥1 mln in active seismic regions of the world.

The estimations are based on seismotectonic regionalization of the world and on the three models: of earthquake occurence, strong motion (isoseists) and dynamics of population. The estimations are tested by comparison with actual earthquake history of the cities considered.

The test is successful, in spite of the fact, that all these models are grossly averaged due to the usual incompleteness of the data. This shows, that available data may be sufficient to estimate the seismic risk for a large set of objects, while not for each separate object.

During the 30 years, 1971-2000, 8 ± 3.5 cities and 40.1 ± 21.6 mlns of people in these cities will experience strong motions with macroseismic intensity ≥ VIII MMS. Counted are only the events, when such shaking covers ≥ 100 km^2, so that each event does spell disaster. The second estimation is large due to the explosion of urban population. More conservative data on the population growth reduce this estimation not more, than by 30%. It indicates, that global seismic risk is rapidly increasing, presenting new unexpected problems.

FOREWORD: OUTLINE OF METHODOLOGY

Estimations of seismic risk are the necessary base for decision - making, concerning prevention and mitigation of the damage from the earthquakes. Under the present state of art - including dominant psychology of the studies - the methodology of these estimationscan be best described on concrete examples. This paper and the subsequent one concern the opposite ends of the wide spectrum of the problems, presented by earthquake danger: One is the seismic risk for major cities, where only the economy losses inflicted by a single earthquake may reach $ 100 billions [1, 2], challenging the stability of the world's economy. Second problem is the fair earthquake insurance rate for rural areas, with smaller, though significant, potential damage. The results, obtained for the first problem seem to be of general interest indicating the steep ascend and changing nature of global seismic risk.

In both papers we use the conception, methods and assumptions, described in [3-5], together with corresponding computers software. Similar to some extent methodology was developed by R.Whithman, A.Cornell and their associates at Department of Civil Engeneering, Massachusetts Institute of Technology; it is described in the series of reports on Seismic Design Decision Analysis .

Further discussion refers to the methods, described in [3-5].

The formulation of the problem. The nature of decisions, regarding prevention and mitigation of seismic risk requires, that the data, relevant to seismic risk, are compressed into the probability of the damage from the earthquakes:

$$F_T(D \mid S)$$

Here F is the probability distribution function; it shows the probability, that the damage D from all the earthquakes during the time period T from T_1 to T_2 will exceed D. S symbolises the set of the executed safety measures.

Decision making regarding risk of any hazard is traditionally based on such distribution functions, especially in connection with the insurance. Seismic risk, due to certain unfortunate circumstances, presented an exception for a long time: it was characterized by a maximal possible strong motion, or, later, by frequency-of-occurence of strong motions with different intensity.

The objects. The nature of the problem requires, that seismic risk is estimated for specific objects. Following are the types of the objects, considered by the algorithm:

a) combination of points -- for example, buildings or small towns;

b) combination of lines -- for example, lifelines;

c) combination of two-dimensional areas--for example, economic regions, large cities, etc;

d) any combination of objects of types a, b, c.

The damage. Different measures of the damage have to be considered under different circumstances.

The following two measures are of main importance, since they directly characterize the losses inflicted by earthquakes:

1. Number of casualties: (a) total number;(b) the reduction achieved by safety measures.

2. Economic losses from earthquakes: (a) total losses; (b) losses prevented by safety measures. Let us clarify the meaning of this effect. In the course of a period of time studied, earthquakes occur. During each earthquake there is a possibility of loss. The sum of these losses is effect 2a. Part of the loss will be prevented; the sum of the prevented loss is effect 2b. The following measures indirectly characterize the losses:

3. Total number of people present in the zones of a given intensity of strong motion.

4. Total value of property present in such zones.

5. Total count of the objects, present in such zones. For point objects this is the number of points experiencing strong motion ; for lines or two-dimensional objects -- respectively the sum of the segments or areas experiencing strong motions.

The probability of total loss 1a, 2a is the direct measure of seismic risk. It is necessary to know also the probability of prevented loss 1b, 2b in order to optimize safety measures. Characteristics 3-5 give only an indirect idea of seismic risk (for example, the total value of property affected by strong motions only indirectly characterizes the possible losses). However, these indirect characteristics can be useful for preliminary analysis, especially since their calculation requires fewer data.

Models. In order to estimate seismic risk, it is necessary first to estabilish the following models: of the earthquakes sequence; of the strong motion from a single earthquake; of the "local" damage , i.e. the damage caused by a shaking of given intensity at a given point. The necessity of these models is the trait of the problem itself, and not of the particular method we use.

The data on strong earthquakes are rather limited, so that only crude models can be estabilished at present. However, crude estimates of seimic risk are sufficient for making many practical decisions. And, in any case, the suggested method allows to estimate the accuracy of the models, and thus to avoid unfounded decisions.

These models were so far represented as follows:

A model of earthquakes sequence is represented by distribution functions of random values $N(G_k, M_\ell, T)$. N is the number of earthquakes that can take place in T years in M_ℓ range of magnitude in regions G_k, $k,\ell = 1,2,\ldots$
These regions are defined by condition, that the distribution function of N has common parameters within each region. Accordingly, seismotectonic regionalization is a necessary preliminary stage.

An additional assumption is that the earthquakes in non-intersecting volumes (space - time - energy) are statistically independent; therefore the total number of earthquakes has the Poissonian distribution (after elimination of aftershocks).

Model of strong motions, generated by one earthquake. This model establishes the random values $J(\tilde{g} \mid g, M)$. Here J is the intensity of strong motion at point $\tilde{g}$ during an earthquake with hypocenter at point g and with magnitude M.

The suggested method applies to any measures of intensity. However, in practice we have yet only been successful in collecting enough material for strong motions in macroseismic scale. Hence the model comes down to a model of isoseists. Its parameters are random values, whose distribution depends on g, $\tilde{g}$, M.

An additional assumption is that with homogeneous soil conditions isoseismals are concentric elipses. Their parameters (area, elongation, azimuth of long axis) are random values, the distribution of which depends on the magnitude and coordinate of the epicenter. The average azimuth of the long axis coincides with the strike of the major faulting.

Model of local damage is based on three assumptions: the damage inflicted on a given object in a given point during a single earthquake depends on the intensity of strong motion only in this point and on the time of the earthquake; the total damage from a single earthquake is the sum of the values of the damage in each point; the values of damage from different earthquakes are statistically independent.

Accordingly, we have for the total damage

$$D = \sum_{T_1 \leq t_i \leq T_2} d_i \quad , \quad d_i = \sum_{p} d_{ip} \exp\left\{k(t_i - t_0)\right\}$$

where d_i is the damage, caused by the i-th earthquake; t_i - time of this earthquake; d_{ip} is the "local" damage in the p-th element of the object : exponential factor reduces the damage to

a common time and/or allows for time - dependance of damage. We usually represented the local damage as deterministic function of strong motion. The probabilistic function - damage probability matrix - was introduced in pioneering work by R.Witman and A.Cornell in the above mentioned reports. It is more adequate, but requires much more data. Obviously, the damage depends on the safety measures.

The algorithm consists of three following parts.

I: In the memory of a computer the image of the studied territory is constructed. It defines: for each point of the region - parameters of the first two models (earthquakes sequence and strong motion); for each point of the object - parameters of the model of the local damage.

Actually, the image includes the contours of the regions and parameters for each region.

II: Distribution function $F(x)$ of the damage from a single earthquake is estimated.

Let us clarify the idea of this function. An earthquake with fixed characteristics (hypocenter, magnitude and isoseists) produces certain damage. It is determined as a sum of the values of damage at each point of each objects. The above characteristics of earthquakes are random. Thus the total damage from a single earthquake is also a random value. The distribution of this value is evaluated in this part of the calculations. The general scheme of calculation follows.

In a discrete grid, all the points in an epicentral zone are considered; each point is regarded as a possible epicenter.

For each combination (epicenter, magnitude) all the parameters of isoseists--area, azimuth and elongation--are considered in succession. For each combination (epicenter, magnitude, parameters of isoseists) the strong motion at each point of each object is determined. Corrections are introduced for ground conditions if they are known. The damage in each point is determined, and then the total damage from this earthquake.

As a result, for each possible combination (epicenter; magnitude; area, azimuth and elongation of isoseists) we get a pair of numbers: x - the total damage, p - its probability. The value p is the product of the probabilities of each parameter in the given combination. The set of pairs (x, p) defines the distribution $F(x)$. Actual computational procedure is equivalent to this, but more economical: e.g. the variation of magnitude and area of isoseists can be considered jointly [4]. $F(x)$ refers to one arbitrary earthquake. We have also the distribution of the total number of earthquakes in the whole epicentral zone. From these two distributions the final result is obtained:

III. An estimation of seismic risk $F_T(D \mid S)$

-- distribution functions of the total damage D from earthquakes.

The basic characteristic of this function are: average $m_D(T)$, dispersion $\sigma_D(T)$ and a set of quantiles $D_p(T)$ -- the solution of the equation $F_T(x \mid S) = p$ for p close to 1. Roughly speaking, the total damage D exceeds the level $D_p(T)$ in $(1-p) \times 100$ cases out of 100; on the average it is equal to $m_D(T)$.

The possible applications of such estimation of seismic risk are discussed in [3] and illustrated in [5, 6]. The models are specified, depending on how the estimation is to be used: some problems require an extremal model, others– an average.

INTRODUCTION

1. A strong earthquake in a large city may amount to a disaster of a national scale, while a chain reaction of consequences may spread over the economy of the whole world [1]. The corresponding disaster-and-relief preparedness requires certain international endeavors. A comprehensive set of such endeavors, outlined under auspices of UNESCO and UNDRO, includes for example reinsurance, the planning of relief missions, the studies in earthquake prediction etc [2]. The design of these endeavors requires the advance estimation of global seismic risk.

2. In this paper we estimate the seismic risk for the cities with population one million or more, situated in the active seismic belts of the world. Two measures of risk are considered. One measure, denoted N, shows how many such cities may be affected by the strong motion of macroseismic intensity $J \geqslant$ VIII degrees MMS during 30 years. The second measure, denoted D, is the total number of people in these cities.

We include into the consideration only the earthquakes, which generate such strong motions on the area $\geqslant$ 100 km^2, so that most probably the consequences are grave. Both N and D are considered as random values and their probabalistic distribution functions are estimated.

To test how reliable our estimations are, we compare them with the actual occurence of past earthquakes.

3. The estimation is made within the framowork described in [3,4,5] ; we follow the conception, methods and assumptions outlined there and use the corresponding computers software. The experience of regional studies of seimic risk [5, 6] is used to a large extent.

The only methodological amendment concerns the time dependence of the effect of a single earthquake. This time dependence is allowed for by the factor exp $\{k(t-t_0)\}$, where t is the time of an earthquake and k - a real constant (rate of change); in the case considered here k is the rate of the population growth. It was assumed previously that k is the same for all objects. In the present study we remove this assumption, allowing for the fact that the rate of the population growth may be different for different cities. However, k is assumed the same within a group of cities spaced so closely to each other that a single earthquake may cause VIII-degree shaking in two or more of them.

4. Our estimations are based on the global summaries of three sets of data: on seismicity, strong motions and the dynamics of population of the cities. The data on seismicity are compressed into the estimation of the parameters of frequency-of-occurence law and maximal magnitude for each region of the world. This estimation and the corresponding seismotectonic regionalization of the world are described in details elsewhere [7]. On the strong motions we used so far the macroseismic data - the isoseists of intensity J = VII, VIII and IX degrees, MMS. These data were compressed into the model which represents the isoseists as [illegible] - area, orientation and elongation. [illegible] of the model are estimated separately for different types of seismotectonic regions.

The data on demography are represented by population and the rate of population growth for each city.

All the data are collected from avaliable publications and data files (except the global regionalization which is made in [7] especially for this study). Since the complete list of references would be forbiddingly large, we quote some sources only by the authors and publication year; only the major summaries are indicated for macroseismic data. The authors apologize for these forced omissions.

The authors are aware that the avaliable data are far from being perfectly complete; the macroseismic data are especially fragmentary and the demographic data are especially speculative. However, the imperfection of data is partly compensated by the statistical approach, i.e. by consideration of the whole set of cities, and we hope that actual values of N and D lie within the estimated limits for the cities together. This is confirmed by satisfactory agreement between our estimations of N and actual earthquake history. However, our estimations are hardly applicable for each separate city. The total estimations of D are especially influenced by two kinds of cities: with an exceptionally large population (agglomerations) and/or rate of population growth. Demographical data on these cities are most important for future improvements of our estimations.

5. In the pilot study published previously [8] , we considered the analogous problem for $J \geqslant$ IX degrees MMS. The estimations for $J \geqslant$ VIII, presented here, have the advantage ~~of being:~~

more to the point, since intensity VIII on the area $\geqslant 100\text{km}^2$ in a large city does spell disaster;

more reliable, since the data base is wider - both for the estimation of seismic risk and, most important, for comparison of

more stable, since we may consider more cities (76 instead of 52 for $J \geq IX$).

INITIAL DATA AND MODELS

1. The model of earthquake sequence.

The estimations of seismic risk are based on Poisson model of the sequence of earthquakes in a volume (time interval x epicentral zone x magnitude range); the average number of earthquakes in the elementary volume (1 year x 1000 km^2 x magnitude interval 0.1) is

$$\lambda = 10^{\alpha-\beta(M-5)} \times 0.1, \quad M \leqslant M_{max}. \qquad (1)$$

Parameters α, β and M_{max} are assumed constant within "quazi-homogeneous regions", which are outlined on the basis of seismotectonics.

The seismotectonic regionalization of the world is shown on Fig.1 (after [7]); it takes into account the position of major lineaments, the character of neotectonic movements and epicentral maps for magnitude $M \geq 5$. The uncertainty of the boundaries of the regions is up to 50-100 km; it is due to the nature of avaliable neotectonic information and inaccuracy of the data on epicenters. The regions on Fig.1 have linear dimensions of several hundreds km; they are smaller than well-known Gutenberg's regions.

Parameters α and β are evaluated by the method described in [9] . The data on the earthquakes were taken from the global catalogs [21, 22] for $m_B \geq 5$ and from the catalog [23] for Europe and adjacent regions, for $M_{LH} \geq 4.7$. Regional data have been used in four cases: for Tashkent, Caucasus, Shilong plato and Nevada, USA.

According to the method used in [9] , it was assumed that the value of β is common within some groups of regions, while the values of α may be different in different regions of the group. The likelihood of this assumption was tested in the course of computations. The estimated values of α and β in each region are listed in Appendix 1.

The basic version of (α , β) was obtained after elimination of the aftershocks, which is more adequate to the Poisson model (1) and to the corresponding method [9] . Aftershocks were defined by the space-time window 100 km x 7 days. The auxiliary version of (α , β) was obtained from complete catalogs. Calculations show that replacement of the basic version of (α , β) by the auxiliary version does not increase the estimations of risk. Partly it could be expected from the comparison of histograms of parameters α and β for the regions which contribute to seismic risk for the cities considered (the number of such regions is 62). In fact, histograms of α practically coincide. Histograms of β differ by a shift of .1: in 50% of regions main version of β lies between .6 and .7, while an auxiliary version lies between .7 and .8

The assumed maximal magnitude M_{max} does not exceed 8.9 everywhere and is often by .5 higher than the observed one for the last 70 years. Specifically, the following rough estimation was assumed for each region:

$$M_{max} = \min \left\{ 8.9;\ \max (M_1;\ M_2 + .5;\ M_3) \right\} \qquad (2)$$

Here M_1 and M_2 are the observed maximal magnitudes: M_1 - after [24] for 1886 - 1953, and M_2 - after [21 - 23] and [25] for 1904 - 1977 allowing for corrections by Kanamori [26, 27].

M_3 is the lower estimation of M_{max} obtained by the pattern recognition [10, 11]. The correction .5 is not added to M_1 since in [24] the magnitudes for 1896 - 1903 apparently are anyhow exagerated. According to [7] among the same 62 regions 50% have $M_{max} \geqslant 8.2$ and 70% have $M \geqslant 7.7$.

MODELS OF ISOSEISTS

According to the method, which we use here [3], the model of isoseists is parameterized as follows. The area where macroseismic intensity is $\geqslant J$ (J - degree isoseist) is an ellips. The ratio of principal axes $L(g, M) \leqslant 1$ depends on position of the epicenter g and on the magnitude of the earthquake M. The azimuth of larger axis (its angle with the meridian) is

$$A(g, M) = Az(g, M) + \Delta A$$

where A is the mean value and ΔA - the random deviation; the density distribution of ΔA is symmetrical, triangular and concentrated on the interval $\pm \Delta(g, M)$. For the area of the ellips $Q_J(M)$ it is assumed

$$lg\, Q_J(M) = a_J + b_J M + \xi \sigma_Q \qquad (3)$$

Here ξ is the random value with the truncated normal distribution within $|\xi| \leqslant 2.5$. The parameters of this model were determined by the analysis of observations; the method of the analysis is described in [12]. Only the VIII degree isoseists are directly relevant to our problem. However, to get more stable estimations of parameters we analysed simultaneously the data on VII-, VIII- and IX-degree isoseists.

The observations used in the analysis were taken from publications. We collected publications which include the parameters or the maps of VIII-degree isoseists. Our major sources are [13 - 16]. Preference was given to recently revised data. We discarded the isoseists which are: drawn not closed; or published in too compressed scale; or are of complicated shape; or have the area below 100 km^2. The exception was made for not closed isoseists in North India: they were included into the analysis under the assumption that they are symmetrical relatively to the major axis (oriented along the Himalayas). Finally, the isoseists for 231 earthquakes were selected for the further analysis. They are distributed between the regions as follows:

Balcans	87	Soviet Middle Asia	38
Italy	30	India and Himalaya	13
Caucasus	12	Kuril and Kamchatka	3
Western Turkey, Iran and Zagros	19	New Zeland	3
Japan	4	Western USA	3
		Central Europe	3

In other regions only single earthquakes were used.

Different macroseismic scales were reduced to MM scale by the widely accepted relations:

$$\begin{cases} VIII(MM) = VIII(MK\text{-}64) = VIII(MS) = VIII\tfrac{1}{2}(RF); \\ V(JMA) = VII - VIII(MM) \end{cases} \qquad (4)$$

(see for example, Trifunac M., Brady A., 1975; Smith W., 1976; Karnik V., Prochazoova D., 1978). For the further analysis the relation between Japanese scale JMA and the MM scale is most

important. Therefore, let us mention the most different opinion (Shebalin N.V., 1975) according to which V(JMA) =VIII-IX(MM)=VII-VIII (MK-64).

Parameters α, β and dispersion σ_Q are evalu-ated by the method of the orthogonal regression of $lg\, a_J$ on M with an a priori standard error in the magnitude $\sigma_M = .25$. According to the experience of studies [5,6] the scatter of observations was considered acceptable, if the data did not contradict the estimation $\sigma_Q \leqslant .25$ on the confidence level 95%. Otherwise the data were considered inhomogeneous by the focal depth or by the territory.

The observational data are too few to determine parameters of isoseists for each region on Fig.1 except may be the Balcans and Italy. On the other side, the data for the whole world ~~are~~ explicitly inhomogeneous in the above sense. That is why, the regions were merged into the following 5 groups, according to the dominant type of neotectonic movements.

S – strike-slip zones: Coastal Cordilleras of Venezuela; the South Island of New Zeland; San Andreas fault and Big Anatolian fault.

C – active continental margings.

H – Alpin-Himalaya belt and activated platforms.

A – Alpin belt of Europe; it was divided into two parts, with distinctly different area and orientation of isoseists:

AB – Italy and Adreatics,

AH – Greece, the Aegean basin, Dinarids and Alps.

This division of regions according to the type of neotectonic motions is in a partial agreement with the recent studies of source dimensions for the earthquakes with different mechanisms [17]. According to [17] the strike-slip sources are much longer. The differences between the size of normal, reverse, thrust and mixed faults is also reported in [17], basing on the data for continental margins (group C). However, statistically these differences are not significant; moreover, all the data [17] expect for the strike-slip faults are in good agreement, so that more detailed differentiation of regions of group C is not called for so far.

Table 1 and Fig.2 show the results of the orthogonal regression (3) for 5 groups of regions, for intensities J = VII-IX degrees MMS. The analysis reveals the inhomogeneity of data only in group H (Himalaya, India, Middle Asia, Iran etc). This is partly because of the variety of focal depth.

The comparison of parameters in different groups shows that one value of the slope is common for groups S, C and AB and another – for groups AH and H (see Fig.2, Summary). However, the groups with similar b_J have different levels a_J. The following values of a_{VIII}, b_{VIII} are assumed for computations:

Group:	AB	C	S	Interior Japan	AH	H
b_{VIII}	0.8	0.8	0.8	0.8	1.1	1.1
$-a_{VIII}$	1.66	1.84	2.23	2.44	4.31	4.69

The interior of Japan arc (A62, A67 on Fig.1) is singled out from group C because the estimated value of a_{VIII} is smaller here by .6, comparing to the rest of group C. Specifically, we have 4 isoseists of intensity V(JMA) for Japan and as it is seen

from Fig.2, C three of them, in the inside part of Japan arc, are of anomalously small size. This is in agreement with other data on the same area: small size of earthquake sources (V.Tsubokawa, 1973) and of the zones of early aftershocks (T.Utsu, 1969); it is encouraging, that the latter are exactly $10^{0.6}$ times less than in the external part of Japan arch. The uncertainty in recalculating JMA scale into MMS is not so acute here: competing version V(JMA) = VII(MM) can be rejected, since it would give even larger discrepancy between interior and exterior sides of Japan arc.

It is difficult to say whether similar discrepancy takes place in other island arcs. This could affect our estimations only for the city of Taibei (Taiwan).

It would be desirable to get a separate model for rift zones, for the estimation of risk for Beirut, Addis-Ababa, Tel-Aviv and Damascus. The data for this are rather scarce: average estimations for the Baikal (Shebalin N.V., 1982), one earthquake for the Dead Sea and one - for South West of US. All these data are shown on Fig. 2, AB; they imply anomalously high area of isoseists. This has a plausible explanation: stress-drop in rifts should be relatively low and therefore, under other conditions being equal, the earthquake of the given magnitude in a rift will have a greater size of the source and consequently a greater area of isoseists. By these reasons the model of group AB is accepted for the European rift and for the Dead Sea.

To analyse other parameters of isoseists (elongation L and azimuth Az) additional data have been used: isoseists for the pre-instrumental period; isoseists of other intensities; maps of aftershocks zones and the data on the orientation of the

rupture in the source. Following the experience of regional studies [6,12] we assumed different L and Az for three different ranges of magnitude: up to 5.8; 5.8-6.5; above 6.5. Subgroups Sa and Ca with longer elongation are singled out from the groups S and C; Sa includes the regions of large strike-slip faults; Ca includes linear continental margins and flat island arcs.

Azimuth of isoseists has been defined relatively to the strike of major lineament. We assumed that the mean azimuth coincides with this strike, which is indicated in Table 1 for cities considered. The random component of the azimuth has been discretized with the step 15°. The assumed range of scatter Δ (see page 6) decreases with the increase of magnitude. In the regions with complicated pattern of major lineaments the uniform distribution of Az was assumed. All the assumed values of L and Δ are summarized in table 2.

The elongation and azimuth of isoseists can influence our estimation in two cases: when 2 or more cities can be covered by a VIII-degree isoseist during the same earthquake (the vicinity of Djakarta, Los Angeles, San Francisco, Tokyo and Fukuoka); when a city can be covered by VIII degree isoseist from different regions with significantly different parameters of isoseists (Lima, Taibay, Instanbul, Calcutta and others).

DATA ON CITIES

We have selected the cities of the world with population above .8 mln at 1970 according to [18, 19]; it has been assumed that up to 1980 the population of each will reach at least a million. In the USSR we could select directly the cities with population a million or more according to 1979 census. Due to the lack of data the cities of the People's Re-public of China

have been excluded from the consideration, though at least 20 of them have the population of million and above.

The cities in the regions of low seismicity are also excluded. 37 of them have the population of million and above: 31 – in the Eastern US and Canada; 4 – in Southern Africa and 2 – in Egypt. The frequency of occurrence of VIII degree shakings in these regions is by about 2 orders lower than in regions considered here, so that the exclusion of these 37 cities has practically no influence on our estimations. In total 76 cities are selected, their total population is 148 mln (App. 2); 52% of this population is concentrated in 16 cities with the population $\geqslant$ 2,5 mln each. A quarter of this population lives in 4 exceedingly large cities: Los Angeles, Calcutta, agglomoration of Tokyo-Yokohama-Kawasaki and the rapidly growing agglomeration of Mexico.

The rate of the population growth in each city has been evaluated according to the actual variation of its population for consecutive 5-or 10 year periods of the last 20 years. The demografic data in our disposal [18] show the population growth either in a city itself or in a large demographic province (the last is the case for Africa, Latin America and South Asia). The assumed retrospective estimations of k are given in App.2 together with the territory for which the parameter is estimated.

To test our estimation of k we used it to compute the population of each city in the year of 2000. The results are summarized in the histogram on fig. 3b. It shows that some estimations of k are probably exaggerated. The largest values of k in App.2, starting from k about 5% mean the increase of population by a factor of 5-7 in 30 years. Accordingly, quite a number of cities would exceed the agglomeration of Large Tokyo: Instanbul, Karachi, Calcutta, Teheran, Lima, Manila, Mexico. It is especially difficult to imagine the city with the population of 46 million which Mexico will reach according to the retrospective estimation of k. A possible alternative for the values of k may be the projection of the rate of urban population growth up to the year 2000, according to the UNESCO data [18]

Europe (without the USSR)	1.3%	Latin America	3.6%
USA and Canada	1.4%	Eastern Asia	3.2%
the USSR	1.9%	South Asia	4.3%
Australia and Oceania	2.1%	Africa	4.6%

These estimations lead to not more than 4-fold increase of the population in 30 years.

We assumed the common values of k for the closely situated cities; it facilitates the computations and is justified by the averaged nature of most of demographic data. Each city was represented by a point on the map. To allow for its actual boundaries (i.e. for the area, occupied by each city) was not necessary due to the low accuracy of the boundaries of regions and averaged nature of the models. For example, the estimations of N and D for Tbilicy, represented as a point and as a circle of 50km radius, practically coincide [5]. Only for the largest cities it may be of consequence to allow for their actual contours; however, more detailed data are necessary for this.

ESTIMATION OF SEISMIC RISK

We estimate the number of cities N and the number of people in these cities D, which may experience the shakings of intensity $J \geqslant$ VIII MMS during 30 years, 1971 – 2000. The starting point of this interval is essential for the estimation of D only. The main attention is given to the basic characteristics of N and D: average values m_N, m_D; standard deviations σ_N, σ_D and upper estimations N_p, D_p.

Here X is the value which will be exceeded during 30 years only with small probability p:

$$P_z\{D > D_p\} < p.$$

We indicate N_p, D_p for p = 5% and 1%.

For the interpretation of the estimations of risk it will be necessary to keep in mind that the risk in some closely situated cities is not independent. As the measure of dependence we can use the conditional probability q of the following event: "the shakings of intensity $J \geqslant$ VIII on the area $\geqslant 100$ km^2 affect at least two cities under condition that they affect one city". The assumed estimations of the maximal magnitude and the model of isoseists lead to the division of our 76 cities into 40 mutually independent groups; 27 groups consist of only one city. For the composition of groups see Appendix 2. The estimations of q are also given there; we see that the dependence is essential within the following groups:

the Tokyo group (7 cities)	$q = 0.45$
Fukuoka and Kitakusu	$q = 0.34$
California group (6 cities)	$q = 0.13$
the Jakarta group (3 cities)	$q = 0.06$

For other groups $q \leqslant .015$. The Tokyo and California groups can be in turn divided into less interdependent subgroups. These considerations may be useful for more accurate calculations of risk and for estimation of the contribution of separate cities in global risk.

Let us describe now the results of computations. Their summary is given in Tables 3 and 4. The division of cities by three different degrees of risk corresponds to the estimations of seismicity and seismic risk for each city or group of interdependent cities. These estimations constitute the preliminary stage of analysis and are summarized in Appendix 2 (let us remind, that they are not to be used independently from global estimations – see p.4 of Introduction).

Appendix 2 contains the following estimations for each city or a group of cities:

λ – average annual number ("frequency – of – occurence") of shakings with $J \geqslant$ VIII MMS. For the group λ includes the cases, when one or more cities of the group is affected.

$\bar{D}^{\circ}_{loc}$ – average number of people which experience such shakings at the first year of the period considered (1971). Obviously for a separate city $D^{\circ}_{loc} = \lambda d$ where d is the population in 1971.

$\bar{D}_{loc}$ – average number of people which experience such shakings during a year (averaged over the whole period considered here, 1971 – 2000). Obviously,

$$\bar{D}_{loc} = \lambda d \, \frac{e^{kT}-1}{kT}$$

We assumed T = 30 years.

Values of λ, $\bar{D}^{\circ}_{loc}$, $\bar{D}_{loc}$ are the characteristics of seismic risk for each city or group of cities;

The value of D^o_{loc} is indicated, because being relevant to [illegible], it is free from quite a problematic demographic parameter k; note, that if all k are equal, D_{loc} are proportional to D^o_{loc}.

The possibility of k=0, when $D_{loc}=D^o_{loc}$ should not be ignored. It is close to projections for the urban population of technologically advanced Western countries for nearest 30 years. $k = 0$ also applies to the cores of many cities where the population is stabilized.

Fig.4 shows the histograms of the local parameters of risk for separate cities; not all the groups, but only five groups with largest q once - Tokyo, Kitakusu, California, Mexico and Jakarta groups are presented as single points (for composition of groups see Appendix 2). Histograms show that the cities may be divided into three categories by the degree of seismic risk: exceedingly high, very high and high risk.

The measures of risk for each of these categories are compared in tables 3,4.

We see that in the "high risk" cities about a half of the population is concentrated. However, they contribute only 7% of the total number of people affected i.e. 3 mln out of 40 mlns in 30 years. About 70% of cities belong to this category, but only 20% of all the occurences of $J \geqslant$ VIII falls on these cities. So, the risk for this category is really not so high, as for the other two.

For the first two categories the risk - in terms of the number of people affected - is about the same. This may seem strange, since the number of the earthquakes, generating $J \geqslant$ VIII, is also about the same for these categories (see last column of Table 3). With equal Λ the average value of N (m_N in Table 4) is higher for the Tokyo group since this group is closely spaced and the probability of one earthquake affecting several cities (parameter q) is larger here. Accordingly, it may be expected, that the difference in D will be even more higher, since the average population of a city in the Tokyo group is also larger. However, the second category has a higher rate of population grow-th, so that the value of k for this category catches up with the Tokyo group. Specifically, 70% of average value of D for the second group is contributed by four cities with high seismicity and very high value of k (6-7%): Taibei, Lima and Mexico with Guadalahara. Our major concern is - how stable are our estimations of risk to quite possible errors in the assumed rates of population growth (k in Appendix 2). To level (partly) the uncertainty in k, we assumed the average value of k for the whole second category. Then about three quarters of average m_D in the second category are contributed by the same four cities plus the cities of California, with their high seismicity and population, but low population growth (1.2-1.4%).

Summing up, the major contribution to seismic risk is made by:

(i) 6 cities with very large population, but relatively slow population growth (k below 2%) - Tokyo, Jokohama, Kawasaki, Osaka, Los Angeles and San Francisco.

(ii) 4 cities with present population not so large but with the very fast population growth (k = 6-7%): Manila, Lima and Mexico with Guadalahara.

These are cities for which the more accurate estimation of all three models - population growth, strong motion and

seismicity - is first of all necessary to check or to refine our global estimations.

The stability of our estimations of D can also be illustrated by the following alternate computations (for 17 cities of "very high risk" category).

Version	$m_D \pm \sigma_D$ mlns	D (5%) mlns	D (1%) mlns
major (from Table 3)	17 ± 15	46	65
without elimination of aftershocks	19.3 ± 15.7	49	67
k by UNESCO data [18]	11.6 ± 9.3	30	40

As it has been expected the inclusion of aftershocks is of little consequence. However, the difference in the parameter k is essential: with the values suggested by UNESCO, average D is smaller by about 30% or by 5 mln people; 5% quantile D (5%) is smaller by 15 mln people. This decrease is due to the fact, that for Manila, Taibei, Lima, Mexico and Guadalahara the UNESCO estimations of k are about two times smaller than the estimations assumed here.

The absolute decrease of D for all three categories of cities will be about the same, since the population of the Tokyo group seems practically stable (k = 1.2%), and the contribution of the third category is anyhow small (see Table 3).

COMPARISON WITH THE ACTUAL MACROSEISMIC HISTORY

The estimations of N can be checked by comparison with the available data on previous earthquakes. This will show the reliability of the models of earthquake sequence and isoseists; the conclusions are relevant to the estimations of D too, subject to the inhomogeneity in demographic data.

Let us remind that our estimations are made for:

- average ground conditions only;
- the cases when the area of VIII degree isoseists is ≥ 100 km;
- main shocks.

Accordingly, in summarizing the historical data the anomalies of ground conditions have to be roughly eliminated; the aftershocks and the very localized events have to be eliminated too.

The published data are summarized in the catalog (Appendix 3) and (for Tokyo) in table 5b.

The analysis of the data leads to the conclusion, that they are acceptably complete starting from the following centuries: for Tokyo - starting from XVIIth; for 15, 37 and 8 cities - starting from XVIIIth, XIXth and XXth centuries respectively. For other 15 cities we could not estimate, for which period the data are complete; these cities were excluded from the analysis (among them are all cities of Japan, except the Tokyo group, Taibei, San Juan and Addis-Ababa). These cities are excluded not due to the absence of events with $J \geq$ VIII there (about 40% of all cities has no such events reported, which may also be important for our test).

There are 82 events selected. Reported for most of them are the range of intensity and/or some data on the damage: number of casualties, economic loss, general characteristics of the event as destructive or catastrofic. Due to the large diversity of data the events in the catalog are divided into 4 classes:

"Reliable" (!) – 24%; positive identification by different authors as destructive or catastrofic, with $J \geqslant$ VIII.

"Probable" (+) – 13%; similar identification, but less positive or with corrections for the ground conditions.

"Uncertain" (?) – 19.5%; contradictory or uncertain identification of intensity; local earthquakes, when strong motion of J = VIII should be generated, but is not reported;

"Doubtful" (x) – 43.5%; very contradictory or uncertain data; data only from newspapers; J = VIII is just marginally or indirectly established. These cases are eliminated outright from the consideration.

Let us now describe the test: comparison of estimated N with actual data. The idea of this test is obvious: the period for which the data are complete is divided into consecutive intervals of duration T. In each interval the number of events n_i is estimated, i being the sequence number of the interval. The distribution of the values of n_i is compared with estimations of N for the same set of cities. Obviously, in calculation of n_i different weights should be assigned to the events of different classes. This procedure was applied to the data on three sets of cities:

Period	Number of cities	T'	ΔT
1701–1980	15	280	40
1801–1980	52 (including previous 15)	180	30
1601–1970	Tokyo only	370	74

Tokyo is considered separately due to the uncertainty in recalculation of JMA scale into MMS. The choice of ΔT is dictated by two contradictory conditions: the number of intervals $f = T : \Delta T$ and the average value of n_i (denoted $\bar{n}$): both should be not too small. With the above choice of ΔT f = 5–7 and $\bar{n}$ = 2–3. We determined from the catalog of events the values of n the corresponding average $\hat{m}_N(T)$ and standard deviation $\hat{\sigma}_N(\Delta T)$ Then from the data in Appendix 2 we calculated the corresponding theoretical values for the randon value $N(\Delta T)$: its average $m_N(\Delta T)$ and standard deviation $\sigma_N(\Delta T)$. Then we calculated the χ^2 criteria of the agreement between actual data n_i and theoretical estimations m_N, σ_N:

$$\chi^2_{obs} = \sum_{i=1}^{f} \frac{(n_i - m_N(\Delta T))^2}{\sigma^2_N(\Delta T)} \tag{5}$$

The level of significance of criteria (5) defined as

$$\varepsilon_{obs} = P_r\{\chi^2 > \chi^2_{obs}\} \tag{6}$$

where P_r means "the probability", can be found from any of two approximate distributions, namely:

(i) χ^2 – distribution with f degrees of freedom which is an approximate distribution of χ^2_{obs};

(ii) – approximately standard distribution of normalized valu of (5)

$$\chi^2_{norm} = (\chi^2_{obs} - f)/\sigma(\chi^2_{obs})$$

Here

$$\sigma^2(\chi^2_{obs}) = 2f + \frac{f}{\Lambda \cdot \Delta T} \cdot \frac{m_4}{m_2^2} \qquad (7)$$

is the dispersion of (5); Λ is the number of events for the whole set of cities, m_n is the n-th moment of the following random value: the number of cities covered by a VIII- degree isoseist during a single earthquake.

For the cities, considered here, m_4/m_2^2 is close to 1. Small values of ε_{obs} ($<$ .05) and/or large values of χ^2_{norm} (>2) mean the poor agreement of theory with observations. We shall use the ratio

$$\varkappa = \sigma(\chi^2_{obs})/\sqrt{2f} \qquad (8)$$

to check the value ε_{obs}, which is computed from tables of χ^2. $\varkappa = 1$, if the distribution of χ^2_{obs} and χ^2_f coincide. Therefore small values of $(\varkappa - 1)$ indicate, that ε_{obs} is a correct characteristics of the significance; positive $(\varkappa - 1)$ indicate underestimation of the significance.

Statistics of events and all the characteristics of the criteria (5)-(8) for years 1701-1980 and 1801-1980 are given in Tables 5a,b.

We assumed the weights 1, ½ and 0 for reliable (!), probable (+) and uncertain (?) data respectively (the classification of data is discussed above, page 20). Agreement between actual data and calculations is exceedingly - and unexpectedly - high. Specifically, table 5b(ε_{obs} in the first line) shows that the level of significance is above 30%. In other words, our theoretical estimations, based on earthquake statistics for 70 years of this century and on rather speculative model of isoseists led to correct projection of statistics of strong shakings for much larger periods, 280 and 180 years. This may seem unexpected, since our model does not allow for a diversity of regional features of seismicity and strong motion. The fact that our estimations proved to be correct is probably due to the statistical nature of our analysis: we considered the comparatively large set of cities, the almost homogeneous measures of the risk and large space-time domain. Under such circumstances the regional traits are leveled, including the inevitable errors due to the non-stationarity of the regional earthquake sequences and incompleteness of the catalog. In other words,

Our analysis summarized (over the space) the weakely interdependent random flows of the earthquakes; after this summation, by virtue of asymptotic theorems, the total flow of earthquakes becomes a Poissonian flow and the total effects (N and D) become random values with composite Poissonian distribution.

Much more difficult would be the estimation of risk for few individual cities: in such a case the demands to the data and to the models increase and may well become a stumbling block.

Let us illustrate this difficulty by the example of Tokyo. The data and the computations for Tokyo are summarized in table 5c. According to [20] during 370 years, 1601-1970, Tokyo experienced 31 earthquakes with J $\geqslant$ V, JMA scale; three more earthquakes had macroseismic intensity slightly below V ("V -"). Equalizing V JMA to VIII - IX MMS (page 8) we came to the disagreement, since according to our estimations during 370 years Tokyo should have

much less - between 11 and 18 (14.5 ± 3.8) - earthquakes with J ≥ VIII MMS. This disagreement can be due to: (i) the overestimation of MMS equivalent of intensity V JMA scale, or (ii) the underestimation of seismicity around Tokyo (parameter λ). Let us show, that both explanations are plausible.

(i) Let us assume that intensity J = V JMA is equivalent to J = VII-VIII MMS. Then events with J = VII MMS should be eliminated from statistics of real occurences. For a single point

$$n(VII)/n(J \geq VIII) \approx \frac{Q_{VII} - Q_{VIII}}{Q_{VIII}}$$

Here n(J) is the number of occurrences of intensity J and Q_J is the area of isoseist for the intensity J. This relation is strictly true for the uniform seismicity.

According to the model of isoseists (Fig.2c) this ratio is close to 1. Then out of 34 occurences only about a half can be assigned J = VIII MMS, which brings the actual data in disagreement with theoretical estimations.

(ii) Let us keep the original relation: J = V JMA is equivalent to J = VIII-IX MMS, but compare the data on seismicity around Tokyo, according to global catalog [21,22] and regional JMA catalog [28]. The number of the earthquakes with M ≥ 6 over 40 years (1941-1980) is about the same in both catalogs. The number of earthquakes with M between 5 and 5.9 can be compared only for 3 years, over which both catalogs seem sufficiently complete for M ≥ 5. The number of such earthquakes in JMA catalog is larger, than in [22], by a factor of 2 or 3 depending on how we recalculate m_B into M_S. In that case we underestimated seismicity for Tokyo, at least by a factor 2. The corresponding correction will again remove the disagreement between our estimation of N and actual data for Tokyo.

Other explanation of this disagreement is also possible. For example, the JMA catalog indicates a systematic decline of seismic activity around Tokyo during the past 70 years. Due to this decline the actual statistics before this century should be larger, than our estimations.

All these explanations are given *not* to explain away the discrepancy for Tokyo, - a posteriori explanations can not serve this purpose - but to illustrate that the estimation of risk is much more difficult for a single city, than for many cities together. In case of Tokyo a local estimation of risk remains open, until at least three questions are solved: relation between JMA scale and MMS; completeness of the catalog; trend of seismicity. This would be important also for global estimations, since Tokyo group contributes about a half of global risk.

The choice of the weights of different classes of data (page 20) is by no means unique. To test the stability of results we repeated the comparison of theoretical and observed data for three other sets of weights, indicated in three last lines of Table 5,ab. The stability is acceptable; not unexpectedly the first version gives the best results and the acceptance of doubtful data (third version) gives exaggerated estimations.

CONCLUSIONS

1. Main results of this study are summarized in Tables 3 and 4. They characterize seismic risk for 76 cities of the world with the population ⩾ 1 mln., situated in active seismic regions (except the territory of PRC). The major characteristics of risk are the following: 40 ± 22 mln of people in these cities and 8 ± 3.5 of these cities will experience the strong motion of macroseismic intensity ⩾ VIII MMS during 1971-2000. The total population of those cities is 148 mln in 1970.

2. The estimations for N are well confirmed by comparison with the available historical data: on 15 cities - for the past 280 years and on 52 cities - for the past 180 years. However, we do not claim the validity of separate estimations for each city: these estimations may have significant errors, which are levelled at the later stage, when we consider all cities together.

3. About 70% of people affected are the inhabitants of 11 cities: 6 cities with especially large population (Tokyo, Yokohama, Kawasaki, Osaka, Los Angeles and San Francisco) and 5 cities with especially fast population growth (Manila, Taibei, Lima, Mexico and Guadalahara). For these cities the further check of data and the tests of the models - of seismicity, strong motion and population growth - deserve special attention.

4. Dynamics of the population influences seismic risk to not lesser extent, that seismicity and the pattern of strong motion. The population growth in large cities and their agglomerations leads to a strong increase of seismic risk with the number of people affected averaging more than ten million per coming decades. This changes the nature of the problem of seismic risk: its relative priority and the nature of safety measures necessary in the nearest future. It would be important to understand, for example, what really is the situation described by the words: "VIII - degree shakings in the area of several hundreds square km in a city with population 30 mln".

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Table 7

ORTHOGONAL REGRESSION $lg Q_J = a_J + b_J M$;

J	Regions	n	$-a_J$	b_J	$\varepsilon \cdot 100$	$-a_J^{\Sigma}$	Regions	n	$-a_J$	b_J	$\varepsilon \cdot 100$	$-a_J^{\Sigma}$
VII	S	21	0.62	0.68	54	1.25	H	42	3.50	1.0	99	3.11
VIII		23	2.86	0.89	70	2.23		53	4.72	1.1	97	4.69
IX		10	7.17	1.40	45	6.62		22	6.75	1.3	22	5.79
VII	AB	44	1.03	0.73	60	0.94	AH	61	2.96	1.0	97	2.74
VIII		44	1.64	0.79	70	1.66		61	4.20	1.1	80	4.31
IX		18	5.19	1.25	95	5.69		21	4.76	1.1	54	5.42
VII	C	9	1.61	0.81	88	1.26						
VIII		17	2.31	0.86	91	1.84						
IX		3	-	-	-	6.47						
VII	Σ = S+AB+C	74	*	0.8	82	-	Σ = H+AH	103	*	1.0	83	-
VIII		84	*	0.8	72	-		114	*	1.1	95	-
IX		31	*	1.3	70	-		43	*	1.2	91	-

Notations:

n - volume of the sample.

ε - level of significance for the mean square residuals from orthogonal regression for $\sigma_Q = .25$ (or $\sigma_Q = .35$ for group H).

* - a_J are different in subregions of Σ shown in the last column.

Table 2

ELONGATION L (ABOVE) AND MAXIMAL DEVIATION OF AZIMUTH (BELOW) FOR THE MODEL OF ISOSEISTS

Regions	Sa	Sb	AB	AH	Ca	Cb	H
M < 5.8	0,5 30°	0,9 90°	0,6 45	0,8 90°	0,5 90°	0,6 90°	0,7 90
5.8 ≤ M ≤ 6.5	0,4 30°	0,5 90°	0,6 45°	0,6 90°	0,5 30°	0,5 30°	0,5 30°
M > 6.5	0,25 0°	0,5 90°	0,5 0°	0,6 90°	0,25 0°	0,5 0°	0,4 30°

ESTIMATED NUMBER D OF INHABITANTS OF LARGE CITIES AFFECTED BY STRONG EARTHQUAKES (≥ VIII DEGREES ON ≥100 KM^2) DURING 1971 - 2000

Category	Total population, mlns	D, mlns			Probability of no events	Λ per 100 years
		$m_D \pm \sigma_D$	D_p			
			5%	1%		
1. Exceptional risk (Tokyo group, 7 cities)	24	20 ± 15.5	48	65	8%	8
2. Very high risk (17) (17 cities)	47	17 ± 15	46	65	8%	8.6
3. High risk ~~(52)~~ (52 cities)	76	2.9 ± 3.3	9	15	28%	4.3
All cities (76)	147	40.1 ± 21.6	79.8	101.7	0.2%	21

~~note:~~ Λ is the average number of the earthquakes, which generate J ≥ VIII - MMS at least in one of the cities

Table 4

ESTIMATED NUMBER N OF LARGE CITIES AFFECTED BY STRONG EARTHQUAKES (≥ VIII DEGREES ON ≥100 KM^2) IN 30 YEARS

Category	Number of cities	N		
		$m_N \pm \sigma_N$	N_p	
			5%	1%
1. Exceptional risk (Tokyo group)	7	4.1 ± 2.8	10	13
2. Very high risk	17	2.6 ± 1.7	6	8
3. High risk	52	1.3 ± 1.2	4	6
All cities	76	8.0 ± 3.5	15	18

m_N - average; σ_N - dispersion; $N_N(p)$ will not be exceeded with probability (1-p).

p% ~~or 1%~~

Table 5

COMPARISON OF THEORETICAL AND OBSERVED STATISTICS
OF STRONG ($J \geqslant$ VIII) EARTHQUAKES IN LARGE CITIES OF THE WORLD.

a. 15 cities in 1701–1980 (according to the catalog in Appendix 3)

Weights for categories			ΔT							$m_N \pm \sigma_N(\Delta T)$	χ^2_{norm}	ε_{obs}
!	+	?	1701–1740	1741–1780	1781–1820	1821–1860	1861–1900	1901–1940	1941–1980			
1	1	1	5	5	2	6	6	4	4	4.6±1.7	5.7	< 0.0001
1	1	0	3	5	2	5	4	2	3	3.9±1.2	2.3	0.01
1	½	0	2	3.5	1.5	4	3	2	3	2.7±0.8	-0.1	0.48
1	0	0	1	2	1	3	2	2	3	2 ± 0.8	-1.0	0.92
Theoretical estimation:										$m_N \pm \sigma_N(\Delta T) = 1{,}8 \pm 1{,}3$	$\varkappa = 1.13$	

b. 52 cities in 1801–1980 (according to the catalog in Appendix 3)

Weights for categories			ΔT						$m_N \pm \sigma_N(\Delta T)$	χ^2_{norm}	ε_{obs}
!	+	?	1801–1830	1831–1860	1861–1890	1891–1920	1921–1950	1951–1980			
1	1	1	3	11	9	7	3	4	6.2±4.8	13	<0.0001
1	1	0	3	5	5	6	0	3	3.7±2.0	2.1	0.11
1	½	0	2.5	4	4.5	5.5	0	3	3.2±1.8	0.3	0.30
1	0	0	2	3	4	5	0	3	2.8±1.6	-0.2	0.51
Theoretical estimation:									$m_N(\Delta T) \pm \sigma_N(\Delta T) = 2.7 \pm 1.7$	$\varkappa = 1.11$	

c. Tokyo in 1601–1980 (after [20])

Intensity	ΔT					$m_N(\Delta T) \pm \sigma(\Delta T)$
	1601–1674	1675–1748	1749–1822	1823–1896	1897–1970	
J(JMA) ≥ V-	9	6	3	10	6	6,9 ± 2.5
J(JMA) ≥ V	8	4	3	10	5	6 ± 2.9
Theoretical estimation:						$m_N(\Delta T) \pm \sigma_N(\Delta T) = 2.9 \pm 1.7$

FIGURE CAPTIONS

Fig. 1. Seismotectonic regionalization of the the world'and position of the cities with population ≥ 1 mln in active regions (after [7])

1. cities
2. boundaries of the regions and their numbers in Appendix 1
3. Groups of regions for estimation of common parameter β
   4, 5, 6 – groups D21, D33, D34 respectively

Fig. 2. Area of isoseists $Q_J(M)$ for different types of regions. Data and ortogonal regression.

1 – regression
2 – regression for Japan.

Fig. 3. Histograms of demografic parameters in different cities:

a. population d in 1970
b. rate of population growth, k %.
c. projected population d^* in 2000

Fig. 4. Histograms of the characteristics of seismic risk for separate cities and closely spaced groups of cities. All characteristics refer to the shakings with intensity J ≥ VIII MMS at the area ≥ 100km^2.

a. Average frequency-of-occurence of shakings for a city or for a group of cities, λ .
b. The average number of people affected by shakings in the average year for a city or for a group, $\bar{D}_{loc}$.
c. The same in the starting year, for a city or for a group of cities, $\bar{D}^{\circ}_{loc}$.

MODELS OF SEISMICITY AND ISOSEISTS

Region (Fig.1)	Group of regions for the estimation of β	Seismicity					Isoseists		Cities, where the earthquakes of the region can generate J ≥ VIII
		without aftershocks			with aftershocks		Azymuth, Az°	Model from table 3	
		$-\alpha$	β	M_{max}	$-\alpha$	β			
1	2	3	4	5	6		7	8	9
A5	D13	1.91	0.69	8.5	1.91	0.69	135	Sa	Vancouver
A7	A9	2.79	0.86	7.8	2.79	0.86	•••	H	Vancouver, Portland Seattle
8	A9	3.04	0.86	7.5	3.04	0.86	•••	H	Vancouver, Portland, Seattle
9	A9	2.11	0.86	7.8	1.75	0.86	•••	H	Sacramento
10	D13	2.31	0.54	8.5	2.06	0.69	135	Sa	San Francisco, San Jose, Sacramento, Los Angeles, San Diego, San Bernardino
A11	A11	2.10	0.69	7.3	1.79	0.81	150	AB	Los Angeles, San Diego, San Bernardino
12	A12	1.85	0.66	8.6	1.75	0.68	105	Cb	Guadalajara
13	A13	2.10	0.56	8.9	1.83	0.66	105	Cb	Guadalajara, Guatemala, Mexico
14	D34	2.94	0.71	7.9	2.94	0.71	75	Sa	Guatemala
15	A16	1.94	0.68	8.6	1.94	0.68	90	Cb	San Juan
16	A16	2.09	0.68	7.5	1.80	0.68	115	Cb	San Juan
17	D33	2.61	0.72	8.4	2.61	0.72	90	Sb	Caracas
18E	D33	2.69	0.72	7.3	2.69	0.72	90	Sb	Caracas
18S	D33	2.69	0.72	7.3	2.69	0.72	30	Sb	Bogota, Cali, Medellin
19	A19	2.19	0.59	8.9	1.86	0.73	30	Sb	Bogota, Cali, Medellin
19S	A19	2.19	0.59	8.9	1.86	0.73	15	Sb	Guayaquil
21N	D15	2.49	0.61	8.4	2.28	0.68	15	H	Cali, Guayaquil
21S	D15	2.49	0.61	8.9	2.28	0.68	135	H	Lima

[illegible]		[illegible]	[illegible]	7.[illegible]	[illegible]	[illegible]	***	H	Lima
[illegible]		[illegible]	0.[illegible]	[illegible]	[illegible]	[illegible]	I5	H	Santiago, Cordoba
[illegible] N	[illegible]	[illegible]	0.67	[illegible]	I.77	0.76	I5	C b	Guayaquil
A2[illegible]	[illegible]	2.08	0.57	8.9	I.67	0.76	I35	C b	Lima
A2[illegible]	[illegible]	I.70	0.[illegible]	[illegible]	I.47	0.69	I5	C a	Santiago
A27	[illegible]	I.[illegible]	0.59	8.9	I.9[illegible]	0.69	I5	C a	Santiago
A57	[illegible]7	2.I2	0.78	8.8	2.08	0.82	I50	C b	Manila
A5[illegible]	[illegible]	I.5[illegible]	0.78	8.7	I.I7	0.82	I50	C b	Manila
A59	[illegible]7	I.60	0.78	8.0	I.47	0.82	I50	C b	Manila
A60	[illegible]	I.I2	0.64	8.8	I.2[illegible]	0.67	I5	C b	Taipei
A6I S	[illegible]	I.67	0.64	8.4	I.8[illegible]	0.67	90	C b	Taipei
A6I N	[illegible]	I.67	0.64	8.4	I.86	0.67	30	C b	Fukuoka, Kitakyushu, Kobe, Kyoto, Osaka, Nagoya
A62	[illegible]	I.92	0.67	[illegible]	I.92	0.67	60	Jap	Kyoto, Kobe, Osaka, Nagoya
A65	[illegible]5	I.90	0.85	8,5	I.67	0.92	I50	C b	Tokyo, Yokohama, Kawasaki, Nagoya
A66	[illegible]	I.4I	0.6I	8.9	I.45	0.63	***	C b	Tokyo, Yokohama, Kawasaki, Kyoto, Kobe, Osaka, Nagoya
A67N	[illegible]4	2.I0	0.63	8.2	2.I0	0.63	I5	Jap	Sapporo
A67S	[illegible]4	2.I0	0.63	8.2	2.I0	0.63	45	Jap	Tokyo, Kawasaki, Yokohama, Nagoya
A68	[illegible]	I.I2	0.68	8.9	0.85	0.69	***	C b	Tokyo, Yokohama, Kawasaki, Sapporo
A75	A75	I.72	I.08	8.I	I.63	I.I4	I05	C a	Surabaja, Djakarta, Bandung, Palembang
A76	A7[illegible]	I.56	0.76	8.[illegible]	I.49	0.79	I35	C a	Djakarta, Bandung, Palembang, Medan
A77S	A77	I.8I	0.92	8.9	I.8I	0.92	I30	C a	Medan
A77N	A77	I.8I	0.92	8.9	I.8I	0.92	I5	C a	Rangoon, Dacca
A7[illegible]	[illegible]I7	2.30	0.64	8.5	2.30	0.64	I05	H	Rangoon, Dacca
A8[illegible]	[illegible]I7	2.I5	0.64	[illegible]	2.I5	0.6[illegible]	***	H	Rangoon, Dacca, Calcutta

1	2	3	4	5	6	7	8	9	10
A84	[illegible]	[illegible]	0.[illegible]	8.I	2.00	0.64	***	H	Dacca, Calcutta
[illegible]	[illegible]	I.[illegible]	0.7[illegible]	8.9	I.67	0.8I	I20	H	Dacca, Calcutta, Lucknow, Kanpur, Delhi, Lahore, Lyallpur
A8[illegible]	[illegible]	2.37	0.74	8.5	2.28	0.8I	I20	H	Dacca, Calcutta, Delhi, Lachnow, Kanpur, Lahore, Lyallpur
A87	[illegible]	[illegible]	0.8I	7.4	2.3[illegible]	0.8I	I20	H	The same
A9[illegible]	[illegible]	2.0[illegible]	0.74	8.0	I.82	0.8I	I5	H	Lahore, Lyallpur, Carachi
A9I	[illegible]	2.25	0.78	8.8	2.25	0.78	90	H	Carachi
A94	[illegible]	2.I5	0.78	7.8	2.I5	0.78	75	H	Tehran
A95	**	2.20	0.92	7.5	2.20	0.92	I05	**	Tbilisi, Yerevan, Baku
A96	A96	I.84	0.97	7.8	I.78	0.97	I35	H	Baghdad
A98	[illegible]20	2.00	0.62	8.5	I.76	0.72	75	S a	Ankara; Instanbul, Aëtós
A99	[illegible]20	2.I2	0.62	8.2	2.03	0.72	90	S a	Ankara
AI00	[illegible]20	2.[illegible]	0.62	7.I	2.24	0.72	90	S a	Ankara
AI06	[illegible]	2.II	0.72	7.5	2.II	0.72	30	AB	Addis-Ababa
AI08	[illegible]	2.29	0.72	6.8	[illegible]	0.72	I5	AB	Tel-Aviv, Beirut, Damascus
AIII	[illegible]22	I.92	0.80	8.0	I.8I	0.83	***	AH	Aëtós
AII2	[illegible]22	I.55	0.80	7.5	I.37	0.80	***	AH	Aëtós
AII4	[illegible]2I	2.0I	0.96	8.3	I.95	0.99	***	AH	Belgrad, Budapest, Zagreb, Sofia
AII5	A2I	I.80	0.96	7.3	I.80	0.96	I20	AB	Zagreb
AII6	[illegible]23	2.36	0.95	6.5	2.36	0.95	***	AB	Vienn, Milano
AII7	[illegible]23	2.4I	0.95	6.8	2.4I	0.95	***	AB	Genoa, Marseilles, Milano, Turin
AII8	**	2.27	I.06	7.5	I.77	I.I3	I20	AB	Genoa, Milano, Neapolis Rome, Turin
AII9	**	2.37	0.85	8.0	2.33	0.90	I20	AB	Neapolis
AI20	AI20	2.44	I.05	7.I	2.32	I.II	75	AH	Alger, Tunis
AI22	AI22	2.59	0.88	7.0	2.59	0.88	I05	H	Barselona
AI24	AI2[illegible]	2.I7	0.92	7.5	I.94	I.I7	I5	H	Lisbon, Porto

1	2	3	4	5	6	7	8	9	10
AI25	[illegible]	2.24	0.71	7.5	2.24	0.71	90	S a	Lisbon
AI41	**	2.17	0.69	7.6	2.17	0.69	***	N	Tashkent

*) Additional letters N, S, E or W in the name of the region indicate respectively the Northern, Southern, Eastern or Western part of the region.

**) Published data, [5,6].

***) All values of A have the same probability. The model of isoseists (col. 8) determines only the distribution of L.

Appendix 2

DATA ON CITIES

Cities (groups)	Demography			λ Number of occurences of J≥ VIII per 1000 years	Number of people affected by J ≥ VIII, thousands per year	
	Population mlns	Rate of growth			first year $\bar{D}^{\circ}_{loc}$	average $\bar{D}_{loc}$
		k%	region **			
1	2	3	4	5	6	7
The group of Tokyo (q=45.2%)	24.1	0.12		83.1	654	666
Large Tokyo	15.7*		c	79.2	643	654
Kyoto	1.4*		c	1.09	1.53	1.56
Kobe	1.3*		c	1.08	1.40	1.42
Osaka	3.3*		c	1.08	3.56	3.6
Nagoya	2.4*		c	2.34	5.6	5.7
California group (q=12.6%)	14.5	1.2		15.2	44.6	53.6
Los Angeles	7.0*		c	3.14	22.0	26.5
San Bernardino	1.1		–	3.15	3.46	4.2
San Diego	1.4		–	3.54	4.96	6.0
San Francisco	3.1*		c	3.26	10.1	12.2
Sacramento	0.8		–	1.04	0.83	1.0
San Jose	1.1		–	3.28	3.61	4.3
Manila	4.1*	6.5	c	9.06	37.2	115
Taipei	1.8*	6.8	c	17.9	32.2	106
Lima	3.3*	6.2	c	10.4	34.3	99.8

1	2	3	4	5	6	7
Mexico group (q=1%)	10.0	5.6		4.3	31.2	80.7
Mexico	8.6*		c	3.49	30.0	78.0
Guadalajara	1.4		c	0.86	1.2	3.1
Santiago	3.1*	3.9	c	5.38	16.7	31.3
Djakarta group(q=5.9%)	6.6	3.9		5.35	15.4	28.9
Djakarta	4.6		c	2.51	11.5	21.8
Bandung	1.2		c	3.16	3.8	7.2
Pelembang	0.8		-	0.007	0.006	0.01
Instanbul	2.7*	5.9	c	5.07	13.2	36.7
Guatemala	0.8	4.4	Lat.America	12.8	10.2	21.8
Addis-Ababa	0.9	4.9	Africa	4.61	4.15	9.51
Alger	1.0	6.0	Alger	0.106	0.106	0.29
Ankara	1.2*	6.7	c	1.07	1.28	4.31
Aëtós	2.1	1.3	c	1.99	4.18	9.11
Baghdad	1.2*	4.3	c	0.0002	0.0002	0.0005
Baku	1.5*	[illegible]	c	0.002	0.003	0.004
Barcelona	1.7*	1.1	c	0.046	0.08	[illegible]

1	2	3	4	5	6	7
Bogota group (q=0.01%)	5.7	5.1		2.83	2.95	6.95
Bogota	2.9		Columbia	0.276	0.80	1.85
Kalli	0.9		Columbia	0.38	0.34	0.80
Medellin	1.1		Columbia	0.29	0.32	0.76
Guayaquil	0.8		Ecuador	1.89	1.51	3.57
Budapest group (q=0.8%)	7.0	3.1		3.51	4.25	6.95
Zagreb	1.2		Yugoslavia	1.02	1.22	2.01
Belgrad	1.2		Yugoslavia	0.89	1.07	1.76
Budapest	2.1		c	0.062	0.13	0.21
Viena	1.6		c	0.62	0.99	1.63
Sofia	0.9		Bolgaria	0.88	0.79	1.30
Beirut group (q=0.9%)	1.6	4.1		0.4	0.32	0.64
Beirut	0.8		Lebanon	0.23	0.18	0.35
Damascus	0.8		Syria	0.18	0.14	0.28
Calcutta group (q=1.5%)	16.7	2.9		2.30	2.97	4.74
Calcutta	7.0*		c	0.0013	0.009	0.014
Dacca	0.8*		-	0.33	0.26	0.41
Delhi	5.6*		c	0.04	0.14	0.22
Kanpur	1.3*		c	0.0053	0.007	0.01
Lucknow	0.8		-	0.046	0.037	0.06
Lahore	2.3		c	0.20	0.46	0.73
Lyallpur	0.9		-	0.02	0.018	0.029
Rangoon	1.2	2.9	c	1.69	2.03	3.04

1	2	3	4	5	6	7
Caracas	2.2*	5.3	c	0.52	1.13	2.78
Karachi	3.1	5.4	c	1.03	3.19	8.03
Kitakyushu group (q= 33.6%)	1.9	2.5		2.01	2.70	3.99
Kitakyushu	1.0		Japan	1.90	1.90	2.83
Fukuoka	0.9		Japan	0.79	0.71	1.06
Cordoba	0.8	1.5	Argentina	0.0003	0.0002	0.0003
Lisbon	1.6*	2.0	c	0.19	0.31	0.42
Marseilles	1.1	2.7	France	0.097	0.11	0.16
Medan	0.8	3.7	Indonesia	0.55	0.44	0.87
Milano group (q=0.3%)	3.8	1.5		3.71	4.74	5.98
Milano	1.7		c	1.16	1.97	2.49
Turin	1.2		c	1.43	1.72	2.17
Genoa	0.9		–	1.13	1.02	1.29
Porto	1.3	5.7	c	0.19	0.25	0.65
Rome group (q=0.08%)	4.0	2.2		1.48	3.68	5.18
Rome	2.8		c	1.18	3.30	4.67
Neapolis	1.2		c	0.30	0.36	0.51
San Juan	0.8	4.4	Lat. America	7.20	5.76	12.2

1	2	3	4	5	6	7
Sapporo	1.2*	2.5	Japan	2.8	3.36	5.1
Seattle group (q=0.5%)	3.4	1.8		0.25	0.29	0.37
Seattle	1.4*		USA	0.083	0.12	0.16
Vancouver	1.0		Canada	0.083	0.08	0.11
Portland	1.0		USA	0.083	0.08	0.11
Surabaja	1.6	3.2	c	0.0046	0.0007	0.005
Tashkent	1.4	2.8	c	0.59	0.83	1.27
Tbilisi group (q=0.1%)	1.7	2.6		4.17	3.45	5.17
Tbilisi	0.9		c	2.05	1.84	2.79
Yerevan	0.8		c	2.13	1.70	2.58
Tehran	3.2	6.0	c	0.59	1.89	5.20
Tel-Aviv	0.9	4.8	Israel	0.18	0.16	0.36
Tunis	0.7	3.2	c	0.11	0.08	0.13

*) Data on the city within the agglomeration.

**) "c" - city limits; " * " - no data.

Notations: q - dependence in a group (described in the text)

CATALOG OF DESTRUCTIVE EARTHQUAKES IN THE LARGEST CITIES OF THE WORLD, SINCE 1700.

City	Period of observations	Date of shaking	Degree MM	Effect of earthquake and auxiliary data	Rating		Reference
					reliability	century	
1	2	3	4	5	6	7	8
Alger	1801–1955	–	–	–		19	[23]
Ankara	1801–1955	1844.05.12?	–	J_0=7–9 between Ankara and Osmancik (according to newspapers)	x	19	[23]
Aëtós	1801–1955	1846.06.10	VIII?	Destructions on alluvium; .03 th casualties	?	19	[23]
		1867.02.04	–	–	x		23
Baghdad	800–1955	1769	–	–	+	18	<1>
		1864	–	Destructive <1>, absent in [23]	?		<1>
		1867	–	the same	?		<1>
Baku	1801–1975	–	–	–		19	[29]
Bandung	1900–1960	–	–	–		20	[30]
Barselona	1152–1900	–	–	–		18	<2>
Beirut	A.D.	1759	VIII-IX	–	+	18	<3>
		1837.01.01		destructions not strong, absent in <3>	?		[23]
Belgrade	1801–1900	–	–	–		19	[23]
Bogota	1634–1976	1743.10.18	⩾ VII	Churches destroyed	x	18	[31]
		1826.06.18	⩾ VII	Significant damage	x		[31]
		1917.08.29	VI-VIII	–	x		[31]
Budapest	1801–1955	–	–	–		19	[23]
Vancouver	1800–1970	–	–	–		19	[32]
Vienn	1801–1955	–	–	–		19	[23]
Guadalajara	?	1711.08.16	–	Many casualties, absent in [31]	x	20	[33]
Guatemala	1500–1980	1773.07.29	–	The city is destroyed, 0.1 thousands of casualties	+	18	<4>, [33]
		1917.12.25	VIII-IX	40% of building are damagod, catastrophe	!		<4>, [31]
		1918.01.03	–	The city is destroyed by aftershock	x		<4>, [33]
		1976.02.04	VI-IX	Catastrophe, 22.8 thousand of casualtiesl $ 1100 mln losses. M = 7.5			<4>, [34]
Genoa	1801–1955	–	–	–		19	[23]
Guayaquil	?	1868.08.16	–	Catastrophe, 40 casualties, losses$300 mln.	!	19	[34, 35]
Damascus	Xth century-1955	–	–	–		19	[23, 33]
Delhi	1670–1980	1720.07.15	VII-IX	–	+	18	[36]
Dacca	?	1897.06.12	VIII-IX M=8,7	J=7–8 [24], M=8.7	+	18	[34]

1	2	3	4	5	6	7	8
Djakarta	1900-1960	-	-	-		20	[30]
Yerevan	Xth century-1975	1883.11.03	-	Damage from a landslide	x	19	[29]
		1840.06.20	-	J_o= 8-9, the city is damaged	+		[29]
Zagreb	1801-1955	1880.11.09	IX	5oo buildings damaged, 3000 casualties	!	19	[23]
		1883.12.20	≥ VII?	A strong local shaking in Zagreb	x		[23]
Calcutta	?	1737.10.11	X	Catastrophe, 300,000 casualties	!	18	[34,37] <5>
		1842.11.11	IX	-	!		<5>
		1897.06.12	VII-VIII	J=7, allowing for the ground	x		[24]
Karachi	1843-1980	-	-			19	[36]
Caracas	XVI century - 1976	1812.03.26	X-XI	Catastrophe,10-18 thousans casualties is most strongest known damage	!	18	[31,33 34]
		1900.10.29	IX-X	Possibly J =VIII-IX			[31]
		1967.07.29	VIII+	Catastrophe; .25 thousand casualties, $ 100 mln losses, M=6.5			[30,33, 34]
Kanpur Lachnow	?	1833.10.04	IX	Possibly affected, the estimation are absent	?	19	[24]
Lahore	1670-1980	1827.09.24	VIII-IX	-	!	18	[36]
		1875.12.12	VII-VIII		x		[36]
Lima (The city is situated on loose soil with a high level of ground waters)	1555-1976	1746.10.28	X-XI	Catastrophe, 1.5 thousands casualties, city destroed	!	18	[31, 3
		1828.03.30	-	30 casualties buildings are damaged	x		[31]
		1940.05.24	VII-VIII	180 casualities, large damage, M = 8.4	?		[31]
		1966.10.17.	VI-VIII	100 casualties J = VII [33]	x		[36]
		1974.10.03.	V-VIII	80 casualties	?		<6>
Lisbon	XVI century - 1955	1755.11.01	-	Catastrophe 60-70 thousand casualties, tsunami	!	18	[34,3
		1858.10.11	VIII	-	!		[23]
		1890.02.21	-	J_o=V-IX strong local shaking, 2 churches destroyed	x		[23]
Los Angeles	1800-1970	1855.07.10	-	J = 8 RF	x	19	[38]
		1893.07.04	-	J_o= 8-9 RF, part of a city might have been damaged	x		[39]
Manila	XVI century - 1970	1796.11.05	-	-	+	18	[33]
		1824.10.26	-	-	+		[33]
		1863.06.03	-	300 casualties, catastrophe	!		[34]
Marseilles	1801-1955	-	-	-		19	[23]

1	2	3	4	5	6	7	8
Medan	1900–1960	–	–	–		20	30
Medellin	?	–	–	–		20	31
Mexico **(The major part of the city is situated on the loose alluvium, the intensity there is 1–3 degree higher than around**	1460–1976	1711.08.16	VIII	Heavy casualties	?	18	31
		1801.10.05	VIII	–	x		31
		1806.03.25	VIII	–	x		30
		1845.04.07	IX	Destructive	+		31
		1882.07.19	VIII	Destructive in some cities, 10 casualties	+		31
		1911.06.07	VIII	Significant damages 90 casualties	?		31
Milano	XV century–1955	–	–	–		19	23,33
Nagoya	?	1854.12.23	–	Catastrophe, 31 thousand of casualties	!	19	34
Neapolia	XV century – 1980	1930.07.23	–	J = 7 according to 7 1.9 thousan of casualties	x	20	23,34,
Pelembang	1900–1960	–	–	–		20	30
Portland	1800–1970	–	–	–		19	32,39
Porto	1801–1955	–	–	–		19	23
Rome	XV century–1955	–	–	–		19	23
Sacramento	1800?–1980	1872.03.26	–	Possibly damaged, scare data	?	19	35
San Bernandino	1800–1970	–	–	–		19	38,39

1	2	3	4	5	6	7	8
San Diego	1800–1970	1862.05.27	–	J = 8RF, "gravo shaking"	x	19	[38
San Francisco	1800–1970	1863.06.10	–	J_o= 9–10RF according to [38], J = 8RF	x	19	[35,3 39]
		1838.06.?	X	J = 8RF, according [36]	?		the same
		1852.11.22	–	J = 8RF	x		the same
		1865.10.08	–	J_o= 9RF, damages in a city	x		[35]
		1906.04.18	VIII–IX	J_o = 11RF, 750 casualties $524 mln losses, catastrophe	!		[35,34
		1957.03.22	VIII	2 districts of city are damaged	x		[35]
San Jose	1800–1970	1838.06.?	–	J=8 RF, city damaged	x	19	[38, 3
		1858.11.26	VIII	J = 8RF [39]	?		[35,38
		1906.04.18	VIII	J = 9RF, catastrophe	!		the same
Santiago	1575–1976	1730.07.08	?	Comparable with 1647, when the city was completely destroyed	+	18	[31]
		1906.08.17	VIII	20 thousands casualties, $ 256 mln losses, M = 8.6	!		[31,34
		1965.03.28	VIII	400 casualties within the city, $ 200 mln losses, catastrophe	!		the same

1	2	3	4	5	6	7	8
Seattle	1800–1970	1894.12.13	≥ VII	–	x	19	[32]
		1895.06.28	≥ VII	–	x		[32]
		1946.06.23	VII-VIII	Absent in [35]	?		[39]
		1949.04.13	VII-VIII	J = 8SP, damages on the alluvium, $ 25 mln losses	x		[33], < 8 >
		1965.04.29	VII-VIII	$ 12 mln losses	x		[35,3
Sofia	1801–1955	1858.09.30	–	40 buildings and 20 minarets destroyed (according to newspapers)	?	19	[23]
Instanbul	V? century - 1800	1754.09.02	VIII-IX	Possibly damaged scarce data		19	[15]
	1801–1955	–	–	–			[15,23
Surabaja	1900–1960	–	–	–		20	[30]
Tashkent	?	1868.03.03	VIII±1	Damage and casualities	?	19	[29]
		1886.11.29	VIII?	Weaker than in 1868	x		[29]
		1966.04.26	VIII	Area (J ≥ VIII) $< 10km^2$	x		[40]
Tbilisi	?	1819.01.29	–	Buildings are overturned, $J_o = 5-7$	x	19	[29], < 9 >
		1825. ?	–	Absent in [29, 40]	x		< 9 >
Tel-Aviv	1202–1978	1838 ?	–	J < 6 in 1837.01.01, < 10 >	x	19	[illegible]

1	2	3	4	5	6	7	8
Tehran	850–1872	–	–	Destructive earthquakes		19	<11>
	1873–1961	–	–	–			<11>
Tunis	?	1703.12.31	–	5.2 thousands of casualties, catastrophe, M = 8.2	!	19	[33]
	1801–1955	1887.01.06	VII-IX	Catastrophe	!		[23]
		1923.09.01	–	99 thousand of casualities, absent in [23]	?		[33]
Turin	1801–1955	–	–	–		19	[23]

*) Left column indicates reliability, according to classification on p.20. Right column indicates the first centure, for which the data are acceptably complete.

**) [ ] - reference list; < > - reference on authors:
1 - Alisnawi S., Ghalib H., 1975; 2 - Rosa A., Udias A., 1976; 3 - Ben-Marahem A., Nur A., Vered M., 1976; 4 - Cano J., 1977; 5 - Chandra V., 1977; 6 - Espinosa A., Husid R., ~~Algermissen S.,~~ 1977; 7 - Shenkareva G.A., 1973; 8 - Malone D., Bor S., 1979; 9 - Byus E.I., 1948; 10 - Vered M., Stream H., 1977; 11 - Ambraseys N, 1965.

Note. There are no data for the following cities: Kyoto, Kobe, Osaka, Kitakyushu, Fukuoka, Sapporo (Japan); Addis-Ababa, Kallia, Cordoba, Lyallpur, Rangoon, San Juan, Taipei. Data for Tokyo are given in the text.

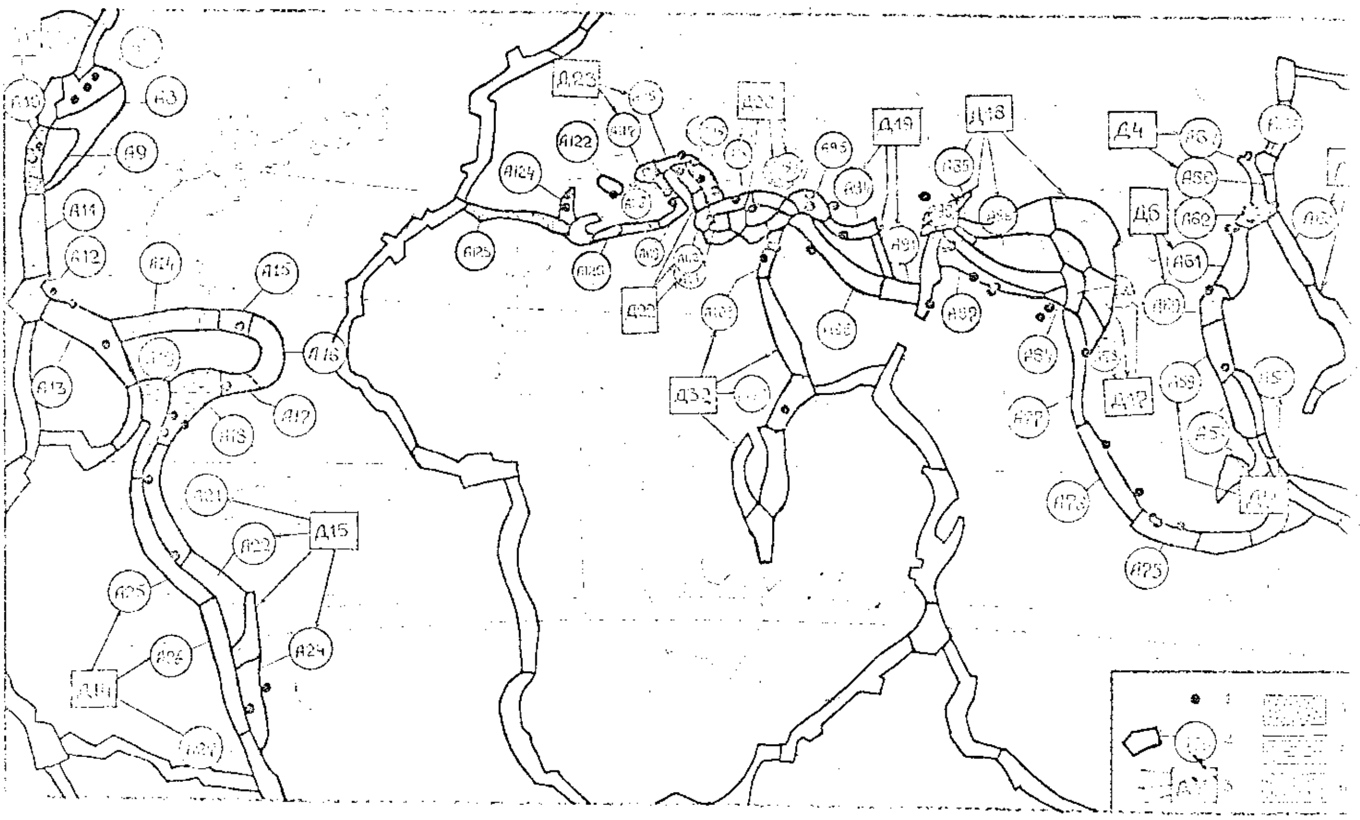
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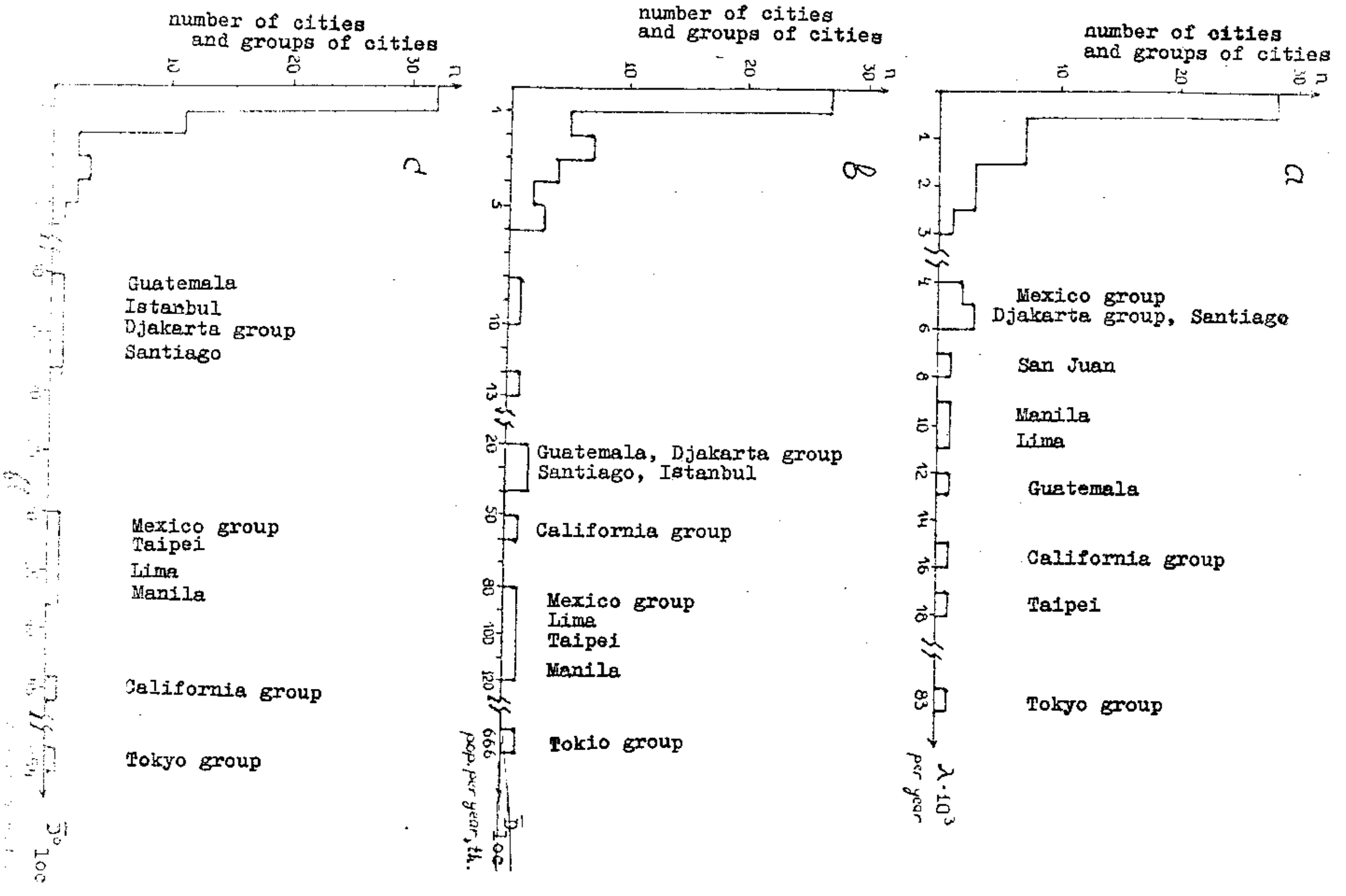
Fig. 1


a
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Djakarta group, Santiago
San Juan
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Lima
Guatemala
California group
Taipei
Tokyo group
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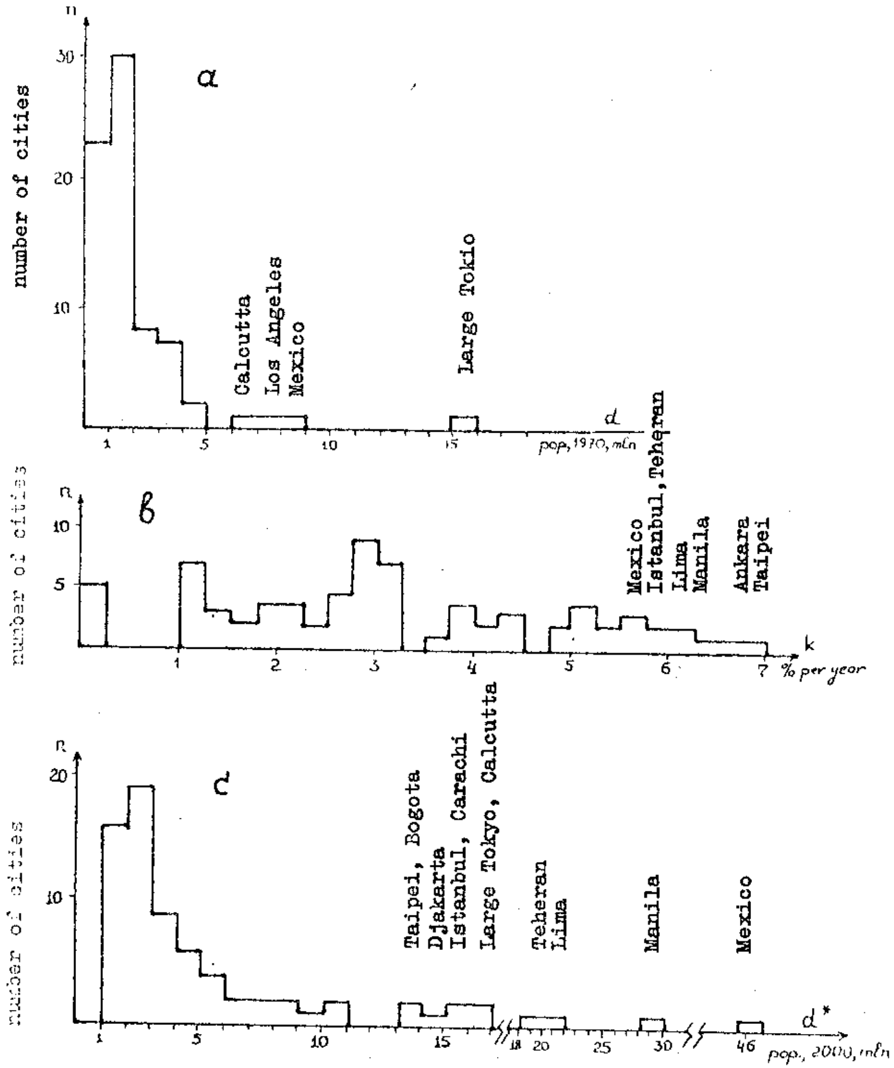
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Los Angeles
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Large Tokio
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number of cities
Mexico
Istanbul, Teheran
Lima
Manila
Ankara
Taipei
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number of cities
Taipei, Bogota
Djakarta
Istanbul, Carachi
Large Tokyo, Calcutta
Teheran
Lima
Manila
Mexico
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25
30
46
pop., 2000, mln

Fig.3