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Seismic Risk and Seismic Hazard: Introduction to Concept and Methodology

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SEISMIC RISK AND SEISMIC HAZARD: INTRODUCTION TO CONCEPT AND METHODOLOGY.

V.Keilis-Borok, G.Molchan.

Abstract.

Seismic risk is a measure of possible damage from earthquakes. Seismic hazard is an indirect characteristics of seismic risk showing reoccurrence of strong seismic motion.

Estimations of seismic risk have to facilitate the choice of a wide variety of seismic safety measures, ranging from building codes and insurance to establishment of rescue-and-relief resources.

Different representations of seismic risk are required for the choice of different safety measures.

Most of the practical problems require to estimate seismic risk for a territory as a whole, and within this territory - separately for the objects of each type: areas, lifelines, sites of the vulnerable constructions etc. The choice of the territory and of the objects is determined by jurisdiction and responsibility of the decision-maker who is using the estimations.

Conventional maps, showing seismic hazard in each separate point are also useful for preliminary qualitative orientation, though insufficient for most practical purposes.

Different representations of seismic risk or hazard cannot be recalculated from each other. For example, seismic hazard for a territory cannot be estimated by "integration over a map" showing the hazard in each point; seismic risk cannot be obtained by "multiplication of hazard by damage" etc. Each concrete representation has to be derived directly from the *primary models:* of earthquake occurrence; strong motion; territorial distribution of population and vulnerable objects; and in case of seismic risk - of the damage as well.

So, the major difference in existing approaches to seismic risk studies lies not in the methods of data analysis, but in selection of measures of seismic risk and of the primary models.

Average parameters of seismic risk and of the primary models are often misleading, even when the dispersion is estimated too. Most practical applications require confidence limits or the percentiles, so that the whole distribution function has to be estimated. That does not require more data. Test of results and efficient representation of some models are discussed.

I. GENERAL BACKGROUND

It seems convenient to remind here in a *simplified form* some basic aspects of seismic risk estimation, though they are commonly known.

Seismic hazard and seismic risk. Earthquakes cause strong motion of the ground; strong motion from an earthquake may inflict the damage: casualties among population and economic losses, immediate and long-term. Counting the episodes of strong motions, we estimate the seismic hazard. Summing up the damage, we estimate seismic risk. Both estimations are intrinsically probabilistic.

Primary models. To evaluate seismic hazard we have to determine first the three sets of probabilistic models: of earthquake occurrence; of the strong motion, caused by a single earthquake; of territorial distribution of population and property, along with their dynamics (this model is considered not in all studies). To evaluate seismic risk we have to add also a model of damage, caused by an episode of strong motion.

These models are necessary irrespective of what methodology is used and which measure of seismic hazard/risk is evaluated.

Crucial issue is the choice of measures ("parameterization") of seismic risk. The studies display a rich variety of the measures (representations) of seismic risk. Their choice ("parameterization") is crucial: it determines how useful, reliable and meaningful are the estimations, and how completely the data available are used.

The same is true for the primary models.

The choice of parameterization is dictated by two factors: how the results may be used to increase seismic safety, and what data are actually available to determine the primary models. These factors may have the opposite impact, e.g. demands of seismic safety may usually require more detailed estimations than the existing data allow for.

On the other hand, not all the details are really necessary for practical purposes, and it is always useful to remember the words of Prof. A.Krylov: "the first symptom of mathematical illiteracy is the unnecessary precision of computations".

II. REPRESENTATIONS OF SEISMIC RISK AND SEISMIC HAZARD.

Let us list the different representations suggested so far. Denote r(*a*) the time-interval between consecutive episodes of a strong seismic motion of a given intensity *a*. Intensity may be measured in ground acceleration, ground velocity, macroseismic scale, etc.

Two following representations of seismic hazard are most conventional.

(i) The maps of the average value of r(*a*) in each single point for selected values of *a*, r(*a*);

(ii) The maps of "maximal possible" value of *a* in each single point within a selected time-interval T, a_{max}(T).

Due to the high irregularity in the reoccurrence of a strong motion in a given point, **the average measures of seismic hazard may be misleading,** even when dispersion is supplemented. Moreover, **for different practical purposes different measures of seismic hazard are necessary:** either average or certain percentile etc. That is why the following more complete representation of seismic hazard was introduced [4,12].

(iii) Probabilistic distribution functions P(r/a) and P(a/T) in a single point.

Even when such complete distribution function is estimated seismic hazard in a single point has a limited meaning. First, the episode of a strong motion in a specific point is such a rare event that it can only be ignored, at the best - given low

priority ("put on the back-burner") by a decision-maker, responsible for this point only.

Consider, for example, an earthquake region like California or Italy. A destructive strong motion may occur once in 100-10.000 years in a specific town, but it occurs once in a few years in the whole region. Obviously, the danger of an earthquake commands higher attention on the regional level; there major responsibility belongs, and the most important decisions have to be made.

That is why most of the decisions concerning seismic risk refer, implicitly or explicitly, **not to separate points, but to a territory as a whole, where the safety measures have to be undertaken.**

Accordingly the following representation of seismic hazard has been developed:

(iv) Probabilistic distribution functions P(x/a, T) of seismic hazard for the objects on a certain territory as a whole: for the areas (e.g. populated ones); for a system of lines (e.g.life-lines); for a set of points (e.g. small towns).

Here, **x** is the measure of a hazard; **a** is part of the object, which may experience the strong motion of intensity ≥ **a** during a given time interval **T**. The examples of such estimations are shown in figs.1-3 and in Table 1.

The actual risk (possible damage) is very different for the objects of different type (e.g. megacity, village, sea bottom, gas pipeline) with the same reoccurrence of strong motion. These objects require different decisions. That is why parallel estimations of seismic hazard for objects of different types are often necessary.

The above representations concern seismic hazard. They do not allow for an essential factor: how many people and constructions may lie in the zones of the strong motion. For example, fig.1 shows that with probability 99% the areas of total size ≥ 15.000 km^2 will be affected by macroseismic intensity ≥ VIII during 30 years. Such estimation has a different practical meaning, when these areas are located in a desert or in a densely populated urban area.

That is why further approximation to the practical demands of public safety is provided by estimation of seismic risk. In other words seismic hazard is only indirect measure of seismic risk. It may be useful for some important practical purposes, providing that it is represented by confidence limits or distribution functions. However, many important purposes require at least rough evaluation of seismic risk, i.e. of the accumulated damage. It is easier to estimate its following measure, intermediate between risk and hazard.

(v) **Probabilistic distribution function for the total number of people which may be present in zones of strong motion of different levels; and for the total value of property in such zones, in terms of its cost or production capacity etc. Both for population and property the time dependence is allowed for. The examples are shown in figs.4,5.**

The ultimate factor in practical decision-making is the damage to population and economy.

(vi) **Probabilistic distribution functions for casualties and material losses. Casualties are represented by a death toll and wounds of different degrees. Immediate and long-term damage may be different: the consequences of an earthquake may spread in territory and in time, for example due to release of toxic material or due to chain reactions in economy.**

Seismic risk is highly concentrated in few objects (e.g. nuclear power plants, toxic waste disposals, some life-lines etc.) on which, the study of seismic risk should be focused. Specifically, it means that two representations of opposite nature are most important: maximal strong motion in the sites of extreme risk objects; and estimations of type (iv) or (v) for a sufficiently large territory (up to worldwide), where statistical approach makes sense. Identification of such objects is not simple; it is developed by Probabilistic Risk Analysis [14].

Each of the representations (i)-(vi), has to be determined directly from the primary models. They cannot be recalculated from each other.

For example, tempting as it is, seismic hazard for a territory (iv) cannot be estimated by integrating over the maps, showing territorial distribution of the hazard for each point. This is impossible, as seismic hazard in different points is interdependent: the points, close to each other, may be affected by the same seismic source. This interdependence is of paramount practical importance, causing the increase of dispersion of seismic hazard.

Integration over the map may provide only the average values which are as a rule misleading.

For similar reasons the population and property affected (measure (v)) cannot be obtained from the size of the objects affected (measure (iv)), multiplying it by density of population, cost of construction etc. That would give wrong results for two reasons: first, because of inter-dependence of the hazard in neighboring points; second, because we have to allow for the time-dependence of density of population, cost of construction etc.

So, to evaluate each measure of seismic hazard we have to step back to the primary models.

Similarly, one cannot evaluate seismic risk by "multiplying seismic hazard by damage".

III. PRIMARY MODELS

Their making or breaking is also an adequate parameterization, along with estimation of the whole distribution functions, instead of averages and dispersion.

We shall list here certain specific possibilities, which are easy-to-implement, well tested and could be used much more widely than they have been so far [1,3,9,10,13].

Model of earthquake occurrence N(M/T). It defines the number N of earthquakes with magnitude ≥M during the time-period T in a certain area.

Frequently Poisson distribution in time is assumed for N, with its average value $\bar{N}$ as the parameter. $N(\bar{M}/T)$ is almost always represented by the Guttenberg-Richter law,

$$\lg\bar{N} = A - BM, \quad M \le M_{max},$$

sometimes with the downward bend for the large magnitudes.

The model of earthquake occurrence includes also the following four models:

- Neotectonic zonation, necessary to outline the areas, for which the model (e.g. parameters A, B) is estimated, and three other models.
- The map of active faults, or lineaments which is necessary to define "maximal possible" magnitudes.
- Territorial distribution of maximal possible magnitudes.
- Sometimes - territorial distribution of predominant source mechanisms.

The following possibilities deserve particular attention:

- Maximal likelihood estimation of parameters A, B. The estimations of A and B are not independent. Accordingly, their joint confidence area has to be determined. Some examples are shown in fig. 6.

The methods developed open the following possibilities:

- To analyse jointly the earthquake catalogs for different time-periods, allowing for the difference in their accuracy and incompleteness of the catalogs.

In this way even the historical and instrumental data can be used together to reduce (A,B) confidence area without the loss of reliability (fig.6b) in spite of huge uncertainty in recalculation of intensity into a magnitude interval.

- To test the hypothesis that different seismotectonic zones have the same A and B or the same B though different A. This allows to determine which zones can be merged together, in order to reduce the confidence areas.
- To test the existence of downward bend of the Guttenberg-Richter law and estimate the position of this bend.
- To choose within the confidence area such combination of A and B which corresponds to intended application of seismic hazard estimation. So, for the Transbaikal railroad the decision to relax safety measure was considered. Accordingly, estimation from below ("exaggerated") was required for seismic hazard, and combination of (A, B) which maximizes the hazard was chosen. This combination is indicated by circle in fig. 6c.

Model of the strong motion caused by a single earthquake.

It consists of the following models:

- Strong motion for the "standard" homogeneous ground and for symmetrical radiation from the source.
- Ground corrections.
- Corrections for source mechanism.
- Corrections for anysotropy of the media, e.g. for different attenuation along and across the dominant structures.

"Ultimate" model of strong motion is its synthetic seismogram.

The following possibilities deserve particular attention:

- Parameterization of the standard strong motion.

It is most frequently represented by the "attenuation law",

$$a = a(d,h)f(M),$$

where d is focal depth and h is epicentral distance.

More reliable and statistically stable is parameterization by the area Q within which strong motion is $\ge a$, for example,

$$\lg Q(a) = C(a) + D(a)M + \xi_a$$

ξ_a being a random variable.

To introduce the corrections mentioned above it is convenient to represent Q by an ellipse, with elongation depending on orientation of faults and on earthquake magnitude.

- Computation of synthetic seismograms of strong motion.

They are often necessary in addition to basic parameters, which may be too simplistic for evaluation of possible damage. This is particularly important for the sites of high-risk constructions.

The methodology is developed to compute synthetic seismograms, allowing for all essential factors except may be critical non-linearity: 3D-structure; heterogeneity and unelasticity of the media; probable source mechanisms, properties of the ground.

The problem which remains open is to find low-dimensional representation of strong motion: few parameters, actually controlling the damage to constructions.

IV.DEMANDS OF PUBLIC SAFETY: HOW THE SEISMIC RISK ESTIMATIONS MAY SERVE PUBLIC SAFETY

1.Representation of the risk for a territory as a whole. The estimations of seismic risk are supposed to facilitate the decision-making, concerning its reduction. The decisions have to be made on a wide range of earthquake preparedness measures: building codes; insurance; establishment of rescue-and-relief resources and many others.

Different decisions have to be made on international, national, regional ("provincial") etc. levels, for the corresponding territories as a whole. As explained above, hardly any decisions may be made for a single localized object ("a point"). Important exception is the decision whether to ban the operation of a very high risk object. It may be banned on the basis of a_{max} in a point (construction site).

Accordingly, integrated representations such as (iv)-(vi) of seismic hazard for the territories, are required for practical purposes. Representations for a point (i)-(iii) provide useful qualitative review of a territory but they are, as a rule, inadequate for practical purposes. Fortunately, it is easier to estimate representations for real objects (iv)-(vi) than representations (i)-(iii) for a point, since:

- statistical concepts, used in estimations of seismic hazard, are hardly applicable to a point;
- the data, related to a single point, are always too scarce.

2.Evaluation of confidence limits (since average parameters are misleading). Not only seismic risk itself but also most of the

models, involved in its estimation, are intrinsically probabilistic, with large uncertainty. In addition, uncertainty is increased by incompleteness and low accuracy of the data base.

Accordingly, *not the average, but confidence limits are meaningful* in most cases. Confidence limits can't be substituted by dispersion, since the type of distribution functions involved is often not clear.

To illustrate the need for confidence limits or percentiles let us compare them with averages and dispersion, for the estimations shown in figs. 1-6 (after [2]).

Object	T,years	average	dispersion	95% percentile	
area (fig.1)	10	1.57	1.91	5.1	
[$10^3 km^2$]	30	4.71	3.31	10.7	
I ≥ VIII					
towns (table 1)					
I ≥ VII	30	6.1	2.8	11	
I ≥ VIII	30	0.52	0.75	2.0	
population(fig.4)	30	1.84	4.24	8.4	
[10^5 people]					
I ≥ IX					
production(fig.5)	10	28.1	51.8	114	
[mlrd.lire]	30	87.4	88.7	186	
I ≥ VIII					
roads, [km]:					
Rome-Naples (fig.2)					
I ≥ VIII	30	43.1	42.8	112	
I ≥ IX	30	7.5	15.1	34.7	
Transbaikal,(fig.3)					
I ≥ VIII	10	295	275.	678*	1100**
I ≥ IX	10	88.5	147.5	315*	580**

* - p=90%, ** - p=99%, I is macroseismic intensity MMS

It has to be noted that to estimate confidence limits or the whole distribution function does not necessarily require more complete data, than for the averages. On the contrary, when estimating distribution functions instead of average values, we make better use of existing data.

Test of reliability of the results on independent data is obviously a must, since estimations are based on many optional hypotheses, and the data are always of limited accuracy. The examples of such test are given in fig. 7.

Seismic hazard was represented by the number of cities, which may be affected by strong motion of macroseismic intensity ≥ I during T years. The data for this century were used to estimate probabilistic distribution of this number. Sufficiently complete macroseismic data existed for these cities for certain time periods in the previous centuries. This period was divided into T-years intervals. For each interval the number of episodes of strong motion was counted. As is seen in fig. 7, these points lie within the estimated interval (average ± dispersion). So, the estimations are confirmed. This is not always the case (and dispersion is not always sufficient).

The direct measures of seismic risk, in terms of damage itself (vi), so far are considered less frequently, since the damage probability matrix is difficult to evaluate, especially for casualties. Two examples of such estimations are given in fig.8 (after [12]) and Table 3 (after [10]). They suggest specific decisions (discussed in the next lecture). Theoretical framework for estimation of seismic risk is given in [12], for estimation of primary models - in [1,6,12,13].

Conclusions.

1. Most of the practical goals require estimations of seismic risk for the territories as a whole (such as (iv)-(vi) above). The choice of a territory depends on the charter of decision-maker

(international, national, regional etc.). For each territory the objects of similar vulnerability have to be considered separately.

Methods of estimations are developed in Russia, US, Italy, PRC and other countries. Examples are given in figs. 1-5 and Table 1.

2. Reduction of losses demands that attention is focused on very high-risk objects.

3. The representations of seismic risk and its indirect characteristics - seismic hazard - cannot be computed from each other, e.g. "integrating" over the maps of point estimations.

4. The average estimations of risk and of models are in most cases misleading and the dispersion does not help much (see page 9). Confidence limits or the whole distribution function have to be estimated; this does not require more data.

5. Reliability of results may be tested on independent data (such as in fig. 7).

6. The major difference in existing approaches to seismic studies lies not in the methods of data analysis, but in the choice of the measures of risk and of the primary models.

7. Different representations of seismic hazard are necessary in different circumstances.

Table 1

SEICMIC HAZARD
FOR 17 CAPITALS OF PROVINCES OF ARGENTINA

P_n % is the probability, that n cities will fall into the zone of intensity ≥ I during 30 years

I ≥ VII Average ± dispersion 6.1 ± 2.8						I ≥ VIII Average ± dispersion 0.52 ± 0.75	
n	P_n %	n	P_n %	n	P_n %	n	P_n %
0	0.14	7	13.3	14	0.8	0	32.1
1	1.25	8	11.1	15	0.4	1	45.2
2	3.7	9	8.4	16	0.3	2	17.9
3	7.5	10	5.8	17	0.11	3	4.4
4	11.3	11	3.7	18	0.05	4	0.3
5	13.8	12	2.3	19	0.03	5	0.1
6	14.6	13	1.4	≥20	0.02		

after [11]

Table 2 (after [9])

: Estimated number D of inhabitants of large cities affected by strong earthquakes (≥ VIII degrees on ≥ 100 km²) during 1971-2000

Category (n	Total population, mlns	D, mlns			Probability of no events	A per 100 years
		$m_D \pm \delta_D$	$x_D(p)$			
			$p = 5\%$	$p = 1\%$		
1. Exceptional risk (Tokyo group, 7 cities)	24	20 ± 15.5	48	65	8 %	8
2. Very high risk (17)	47	17 ± 15	46	65	8 %	8.6
3. High risk (52)	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. A is the average number of the earthquakes, which generate $J \geq$ VIII MMS at least in one of the cities, while the area of VIII-degree isoseist is ≥ 100 km².

: Estimated number N of large cities affected by strong earthquakes (≥ VIII degrees on ≥ 100 km²) in 30 years

Category	Number of cities	N		
		$m_N \pm \delta_N$	$x_N(p)$	
			$p = 5\%$	$p = 1\%$
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 : δ_N — dispersion ; $x_N(p)$ will not be exceeded with probability $(1-p)$.

Table 3 (after [10])

Insurance premium for rural dwellings in Georgia

Cost of all dwellings $S = 7\ 908.6$ mln roub.
Average annual number of destructive earthquakes $\lambda = 1.9$
Annual growth of the number of dwellings - 1 %
Basic interest rate - 8 %
Cost of insurance - U_T

	Risk, $P(X_T > U_T)$	T = 5 y.	T = 30 y.	T = 50 y.
Total damage, X_T, % of S		0.98±0.89	2.91±1.24	3.32±1.25
Profit margin:			Rates:	
break even, $U_T = \lambda \cdot m$	> 50 %		0.23 %	
$U_T = m + 2\sigma$	6 %	0.65 %	0.43 %	0.41 %
$U_T = m + 3\sigma$	2 %	0.86 %	0.53 %	0.50 %

m - average damage per event, σ - its dispersion

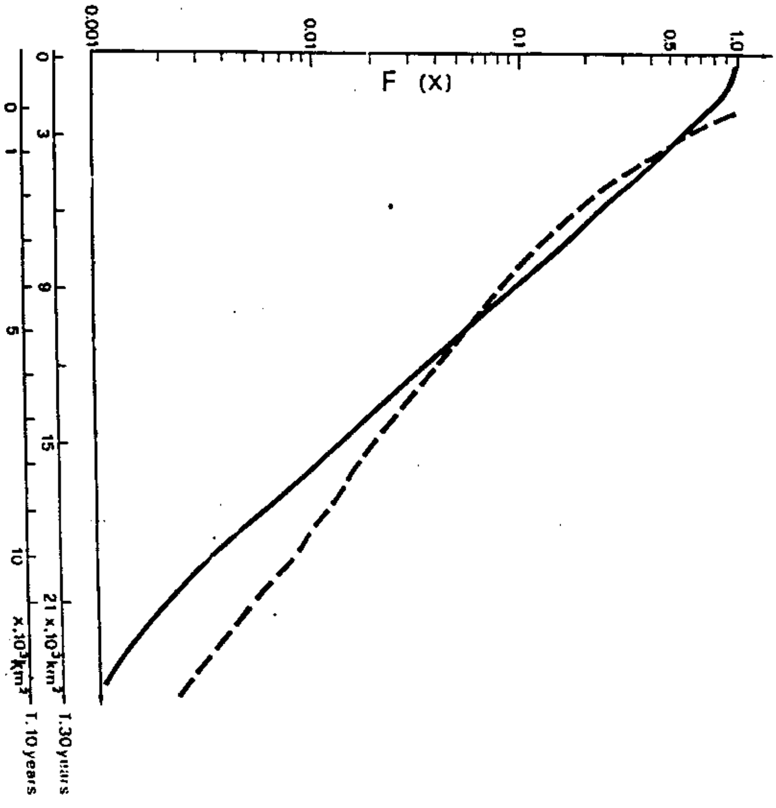


Fig. 1

SEISMIC HAZARD
FOR EIGHT PROVINCES OF CENTRAL ITALY

F(x) is the probability that x or more km^2 of the territory will fall into the zone of the strong motion of intensity I ≥ VIII during T years.

Solid line: T=30 years; dashed line: T=10 years.

after [2]

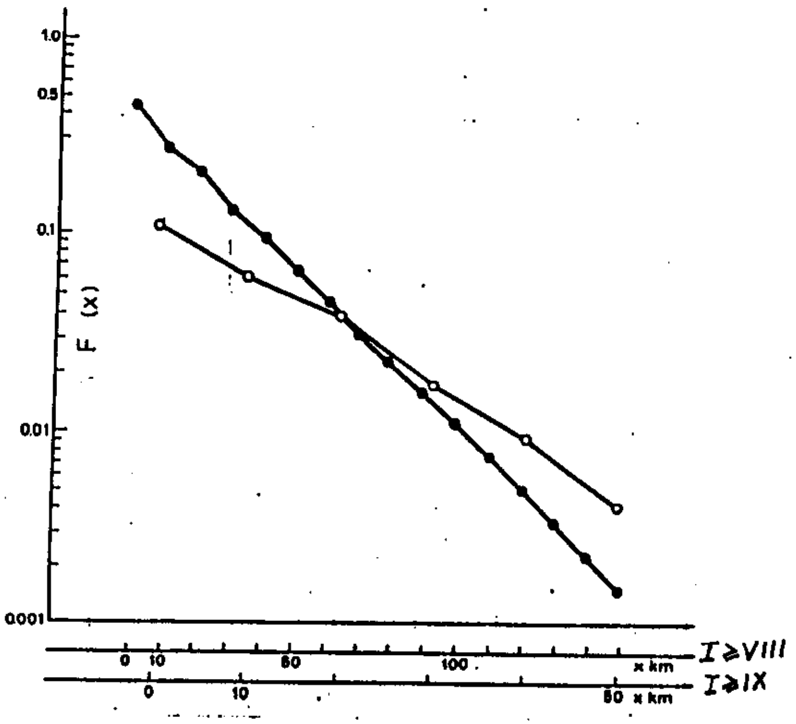


Fig. 2

SEISMIC HAZARD
FOR THE HIGHWAY ROME-NAPLES

F(x) is the probability that x or more km of the highway will fall in the zone of strong motion of intensity I ! VIII (dotted line) and I ! IX (open circle line) during a period 30 years

after [2]

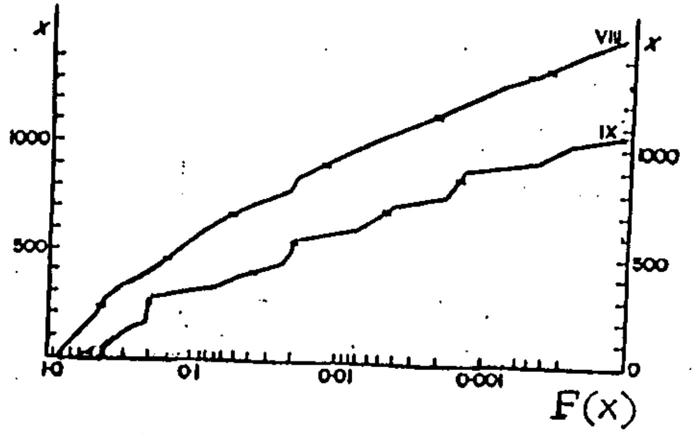


Fig. 3

SEISMIC HAZARD FOR THE TRANSBAIKAL RAILROAD

x - total length of its segments, which may fall into the zone of intensity ! VIII or !IX during 10 years

F(x) - distribution function of x. It shows the probability that the above length will not exceed x.

Only track is considered; bridges and other constructions are considered separately.

after [12]

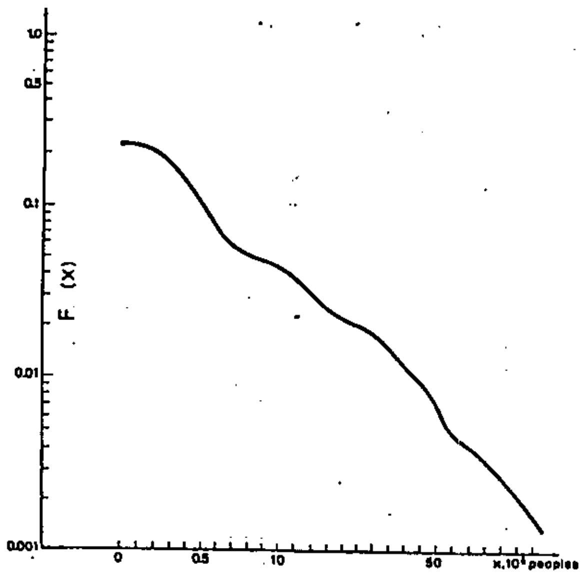


Fig. 4

SEISMIC HAZARD
FOR POPULATION OF THE CAPITALS
OF THE EIGTH PROVINCES OF CENTRAL ITALY

F(x) is the probability that x or more people will fall into the zone of strong motion of intensity I! IX during a period 30 of years
The annual increase of population is taken for 1% (after [2])

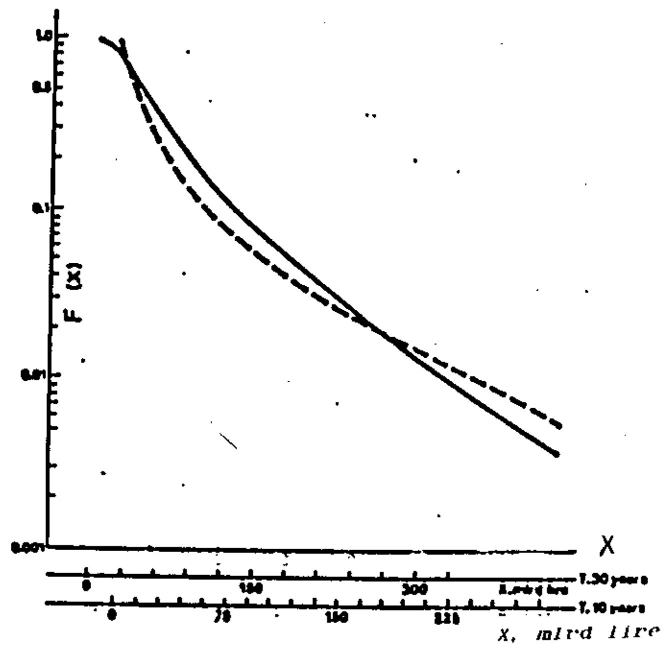


Fig. 5

SEISMIC HAZARD FOR THE ECONOMY
OF EIGHT PROVINCES OF CENTRAL ITALY

F(x) is the probability of the yearly industrial output [mlrd. lire] of the territories, which will fall into the zone of intensity I ! VIII during a period of 30 years (solid line) and 10 years (dotted line) (after [2])

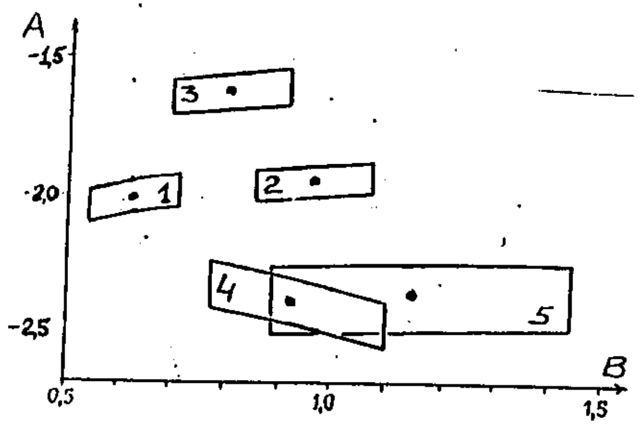


Fig. 6a

95% CONFIDENCE AREAS FOR PARAMETERS (A, B)
OF THE GUTENBERG-RICHTER LAW
$LgN(M) = A + (M - 5) B$

Regions of Southern Europe:

1 - Anatolia;
2 - Dinarides and Meditarranean arcs;
3 - Aegean basin;
4 - Alps;
5 - Ibero-Magrib.

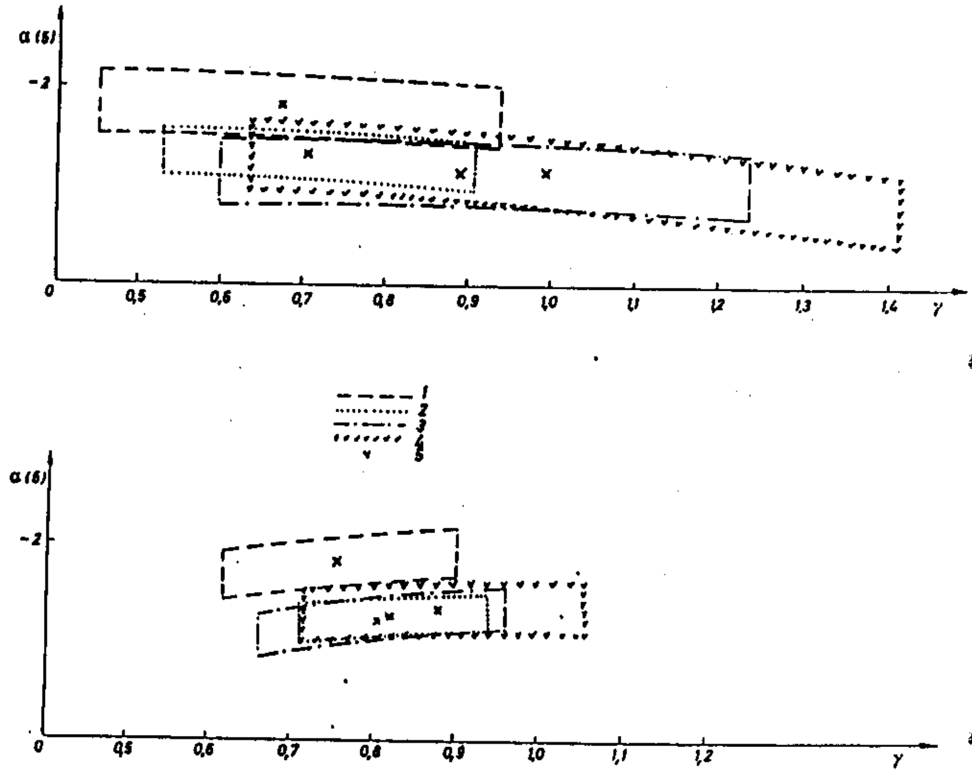


Fig. 6b

95% CONFIDENCE AREAS FOR PARAMETERS (A, B)
OF THE GUTENBERG-RICHTER LAW
$LgN(M) = A + (M - 5) B$
FOR ITALY, after [2]

Upper figure corresponds to instrumental data only,
lower - to historical and instrumental data together.

1 - Zone of intersection of major faults in central Italy;
2 - Zone of linear major faults in central Italy;
3 - South area, Basilicata, Calabria and Sicilia;
4 - Po-Valley and its mountain frame;
5 - Maximum likelihood estimations for

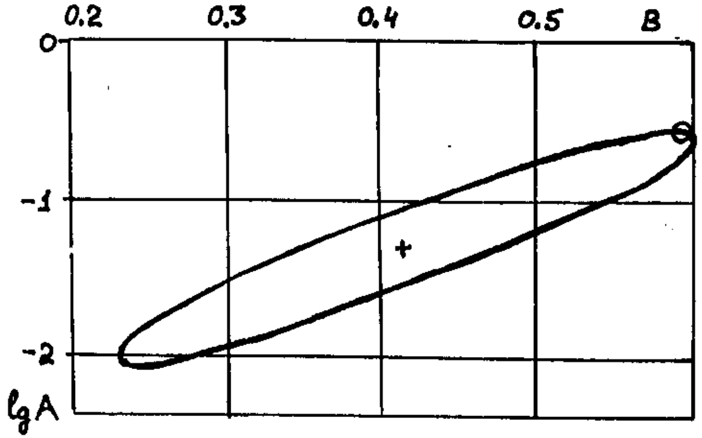


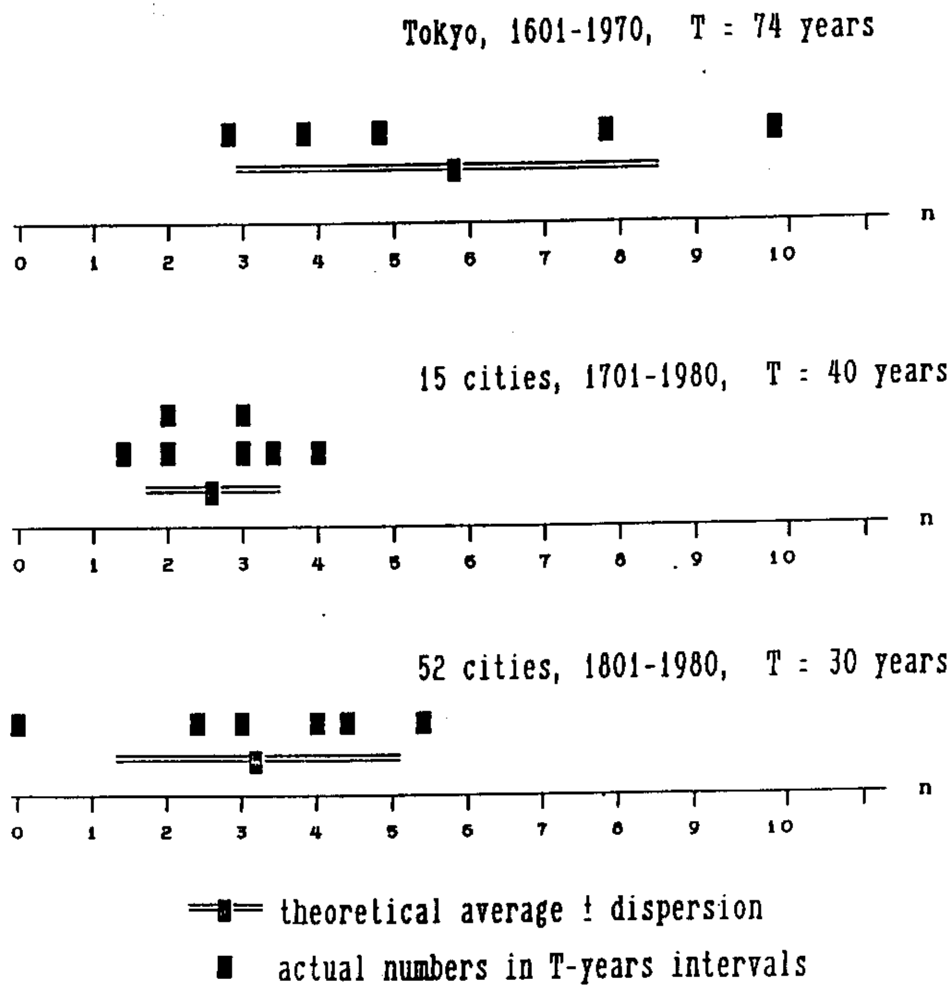
Fig. 6c

99.5% CONFIDENCE AREAS FOR PARAMETERS (A, B)
OF THE GUTENBERG-RICHTER LAW
LgN(K) = A + (K - 10) B
for the zone of Transbaikal railroad

Circle indicates combination of (A, B), which maximized seismic hazard.

Fig. 7a

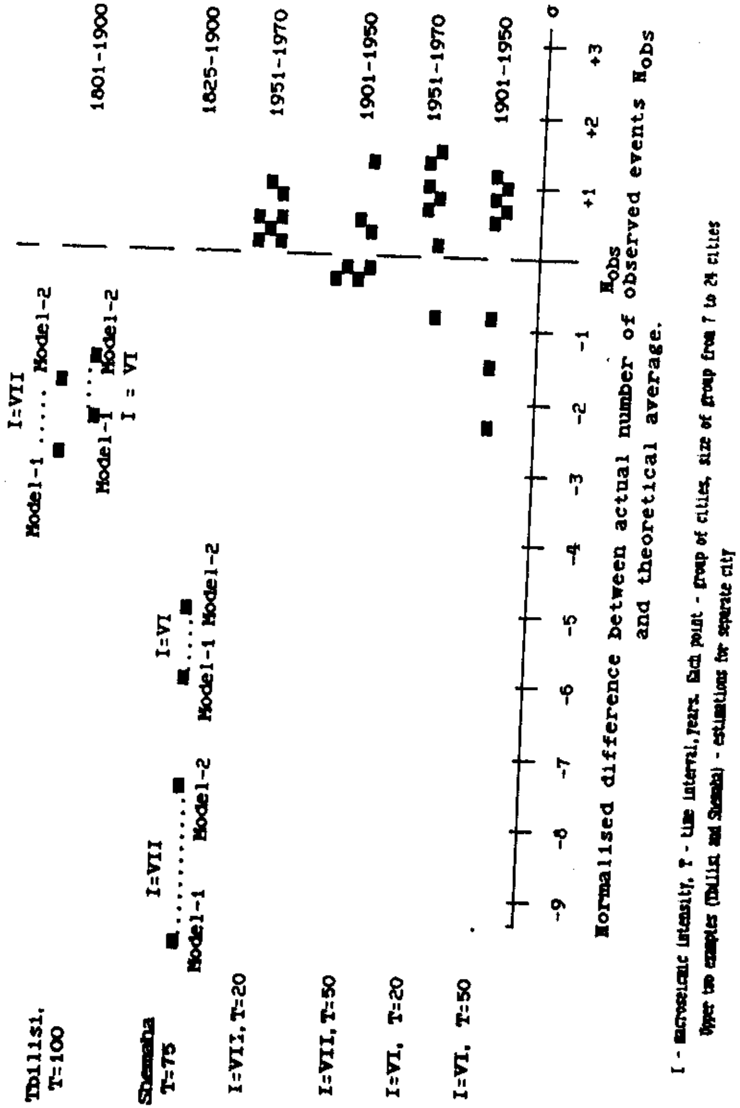
Theoretical estimations and actual seicmic history of megacites

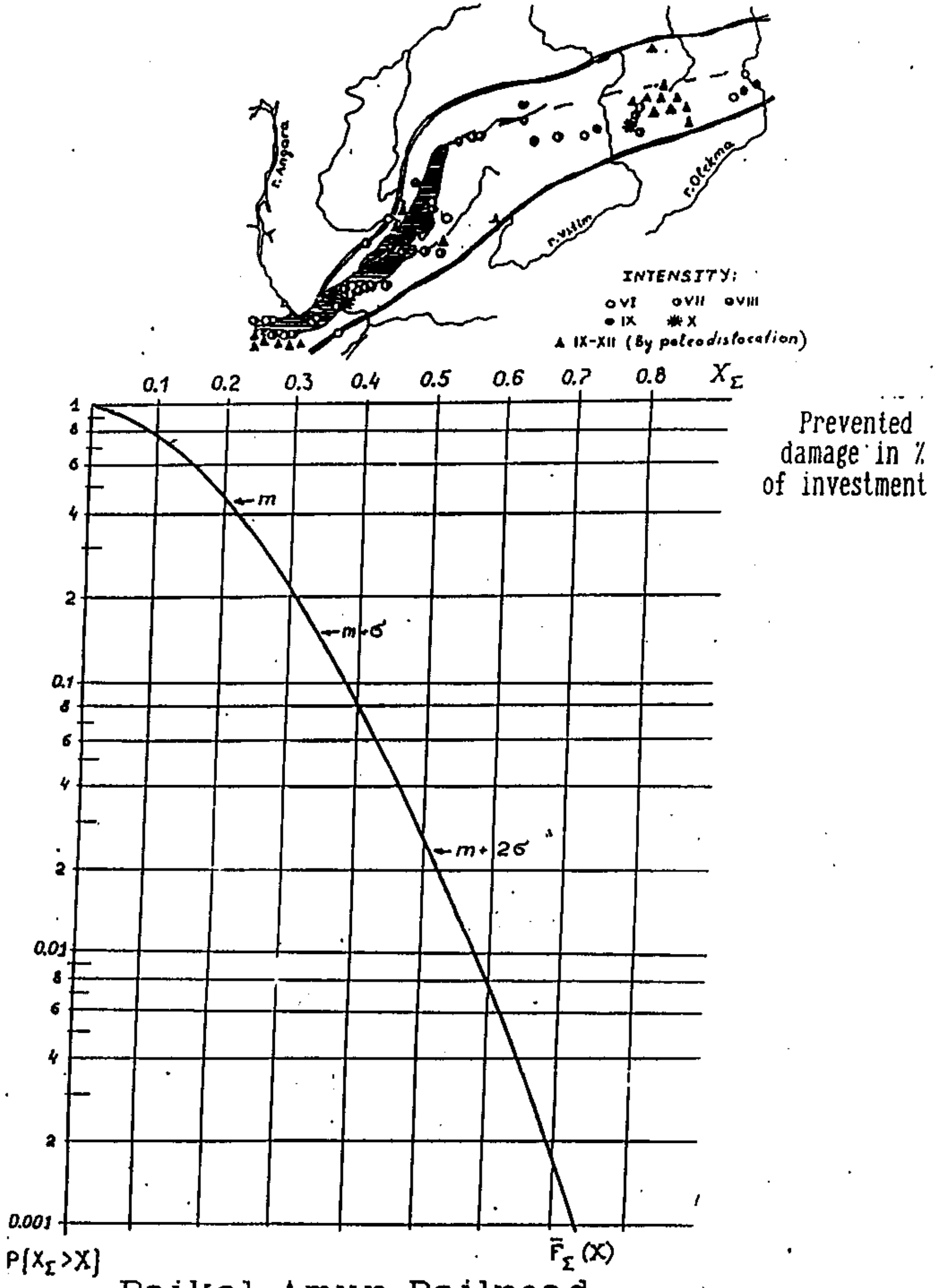


after [9]

Fig. 7b

Theoretical estimations and actual seicmic history of cities in Georgia (after [10])





Baikal-Amur Railroad

L.Kantorovich, G.Molchan, V.K-B, T.Kronrod, 1962-1986

PROBABILISTIC ESTIMATION OF SEISMIC RISK:

PLACES AFFECTED, DAMAGE INFLICTED,
STRONG MOTIONS REOCCURRENCE ...

EQUIVALENT OF THE FOLLOWING RANDOM SEQUENCE IS COMPUTED

$(\text{HYPOCENTER,TIME})_i \Leftarrow M_i \Leftarrow$ STRONG MOTION (AREA) $\Leftarrow$ GROUND CORRECTIONS $\Leftarrow$ OBJECTS AFFECTED $\Leftarrow$ DAMAGE INFLICTED

DISTRIBUTION FUNCTION OF THE FOLLOWING RANDOM VALUE IS ESTIMATED:

$$D = \sum_{i} d_i(hyp_i, M_i/t_i, sm_i) \qquad T_1 \le t_i \le T_2$$

MEASURES OF D

DIRECT:	INDIRECT:	PHYSICAL:
CASUALTIES ECONOMIC LOSSES	POPULATION, PROPERTY, SPECIAL OBJECTS AFFECTED	AREAS, LINES, POINTS AFFECTED

The problem:

random sequence is given, $(t,h,m,d)_i$

to find distribution function for

$$D = \sum_{i} d_i \exp(-bt_i)$$

H1: effects of different ea-s are independent.
Then the sequence is divided
into $N(dt \cdot dh \cdot dm)$ **and** $d(t,h,m)$

Solution is more compact in characteristic functionals (Laplas transforms) of all distributions:

Φ **- ea-ke sequence**

φ **- effect of a single ea-ke**

τ **- effect of all ea-s**

$$\tau(\theta) = \int_0^\infty \exp(\theta D)\,dF(D) =$$

$$= \Phi\left\{\ln\phi\left[\theta\exp(-\beta\tau)\,|\,t,h,m\right]\right\}$$

where

$$\phi(\theta|t,h,m) = \int_0^\infty \exp(\theta y)\,dF(y|t,h,m)$$

$\Phi(\varphi)$ - mean value of $\exp\left\{\iiint_{THM} \varphi(t,h,m)\ N(dtdhdm)\right\}$

H2: N - Poissonian

$$\Phi(\varphi) = \exp\iiint_{THM}\left[\exp\varphi(t,h,m) - 1\right]p(h|m)p(m)\,dtdhdm$$

$$\Phi(\theta|t) = \int_0^\infty \exp(\theta x)\,dF(x|t)$$

$$F(x|t) = \iint_{HM} F(x|t,h,m)p(h|m)p(m)\,dhdm$$

$$\tau = \exp\left\{\Lambda\int_T \phi\left[\theta\exp(-\beta t)/t - 1\right]dt\right\}$$

EARTHQUAKE PREDICTION AND EARTHQUAKE PREPAREDNESS

"Of course, things are complicated...
But, in the end every situation can
be reduced to a single question: do
we act, or not? If yes, in what way?"
E.Burdick

POSSIBILITIES

How to use earthquake prediction,
so far imprecise,
to protect population and economy?

To establish a wide range of safety measures,
combined in flexible scenaria
of responce to prediction
and escalated or deescalated
according to prediction.

How to choose a scenario?
Decision may be obvious, if guided
by estimation of current seismic risk
and scenaria of earthquakes.

How to improve prediction?

Start with averaging over large areas (10^2 km)
and time-intervals (years)
and converge step-by-step.

Use the experience in chaotic systems.

Place different observed fields
into a common model.

Beware of costly bulldozer approach
and precursors hunting.

DIVERSITY OF DAMAGE.

- triggering of ecological disasters by release of dangerous materials;
- destruction of constructions;
- fires;
- triggering of floods, avalanches, landslides, tsunamies, liquefaction of the ground etc.

Socio-economic impacts:

- disruption of vital services - supply, medical, financial, law enforcement etc.;
- epidemics;
- disruptive anxiety of population, profiteering and crime;
- interruption of normal functioning of economy, e.g. a drop in industrial production and employment, destabilization of prices, credit, commerce, stockmarket etc.

These calamities are developing in different time-scales Some of them may be inflicted by undue release of an earthquake prediction.

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SAFETY MEASURES

Permanent:

- Restriction of land use
- Building code
- Tightened safety regulations
- Enforced public safety services
- Insurance and taxation
- Monitoring earthquake precursors
- Preparation of the response to time prediction, and of post-disaster activities:
  planning; establishment of legal background;
  accumulation of the stand-by resources;
  simulation alarms;
  training of population etc.

Temporary:

- Enhancement of permanent measures.
- Emergency legislation (up to martial one)
- Mandatory regulation of economy
- Neutralization of the sources of high risk
- Evacuation of population
- Mobilization of post-disaster emergency services
- Preparation of measures for long-term post-disaster relief
- Monitoring of socio-economic changes, and prevention of prediction induced hazards

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