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Seismic hazard assessment in Northern Eurasia

Valentin I. Ulomov([1]), **Vladimir Strakhov**([1]) **and Domenico Giardini**([2])
([1]) *Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia*
([2]) *Istituto Nazionale di Geofisica, Roma, Italia*

Abstract
We review the programs in seismic hazard assessment conducted by the former USSR since 1930 and present the elements of the new five-year effort to produce a set of five seismic hazard maps for Northern Eurasia. We also review the plans for regional implementation of GSHAP and cooperation within Asia.

1. Introduction: hazard programs in the USSR until 1990

The work on seismic zoning of the USSR territory started in the 30's. The first normative map of seismic zoning (CP), prepared by the Seismological Institute of the Academy of Sciences of the USSR in 1937, was included in the «Regulations of earthquake engineering» and recommended for use by engineering organizations. In the coming years, the standard CP maps were reconsidered as new seismological and geological geophysical data were accumulated and the methods of engineering calculations improved.

In the 70's new methods of assessing earthquake constructions designs appeared, based not only on intensity data but taking into account quantitative characteristics of oscillations (accelerations) dependent on the intensity of shakings, magnitudes and epicentral distances. The concept that zones of most probable occurrence of earthquakes (the BO3 zones) should be marked on the maps (fig. 1) originated the new CP-78 map. A group of 40 scientific institutions (under the leadership of the Institute of Physics of the Earth, USSR Academy of Sciences) worked over this map in accordance with the coordination plan of the State Committee on Science and Engineering at the USSR Council of Ministers, with different technical assignments. The zones with shaking intensity V-IX were shown on the CP-78 map at the scale 1:5 000 000, a supplement to the State Engineering Codes. The recurrence of quakes with intensity VII-IX in 100, 1000 and 10 000 years is marked by the 1,2,3 indexes. The BO3 zones, with events with magnitudes $\geq$ 7.1, are shown in the regions with intensity IX, where residual deformations, destructive effects such as collapses, lanslides and mud flows may occur on the Earth surface in addition to seismic oscillations with intensity over IX.

The data that have been accumulated since 1978 allow to improve the CP-78 map, and provide a basis for new seismic risk assessment.

2. The new seismic hazard assessment program for Northern Eurasia

The purpose of the present investigations is the development of a new generation of scientifically sound seismic hazard assessment and seismic zoning of the territory of the countries of Northern Eurasia – Russian Federation and contiguous states (fig. 2).

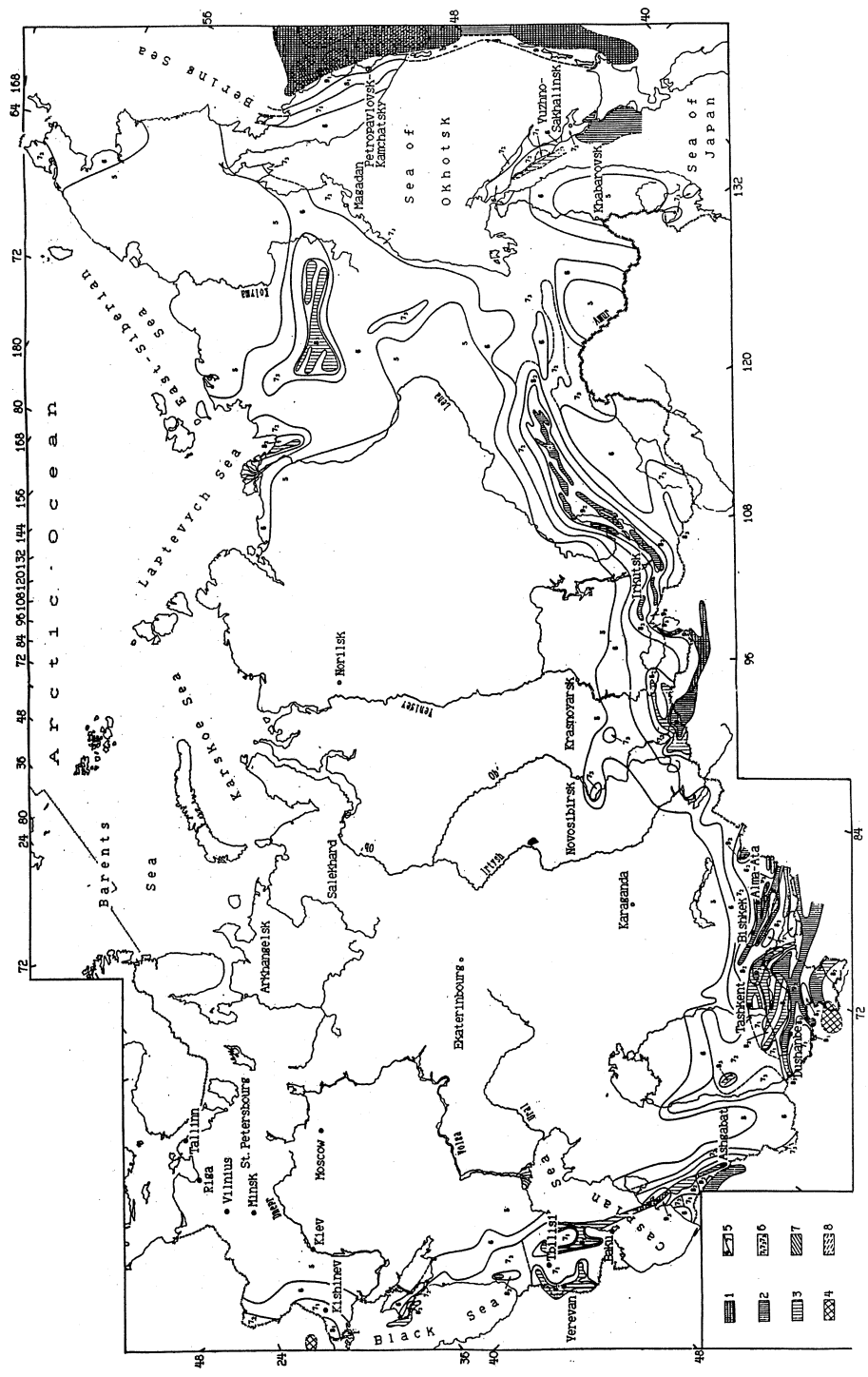

Fig. 1. Seismic zoning map of the USSR territory (CP-78). 1-4) Zone of possible earthquake occurrence – BO3: 1-M > 8.1, h=20-40 km; 2-M from 7.1 to 8.0, h=15-30; 3-M from 6.1 to 7.0, h=10-20; 4-M over 7.1 h=100-150 (Vrancea); h=150-200 km (Hindukush, the Pamirs). 5) Boundary between zones of normative intensity. 6) Index 7_1 indicates that in the next 50 years earthquakes with intensity 7 will occur with probability 0.5; index 7_2 the same with probability 0.95; index 7_3 the same with probability 0.995; the indexes with intensity values 1=8 and 9 are similar. 7) Zones with probability P=0.8 of earthquake occurrence with M > 8.1 in the next 70 years. 8) Zones with the probability P=0.2 of earthquake occurrence with M > 8.1 in the next 70 years.

Seismic zoning and seismic hazard assessment is the result of fundamental and applied seismological investigations. The seismozoning maps are part of a list of normative documentation, regulating planning and constructions in active regions. Every 10-15 years, while additional information on earthquakes is being accumulated and seismological knowledge improved, the maps are being renewed. However, these maps are also partially changed more often, practically after every large earthquake that occurs in a region shown on the map as less active from the seismic point of view. This happened to the CP-78 map that has been in operation since 1978: only in the last three years four earthquakes with intensity $\geq$ VII MM I occurred in the territory of Armenia (1988), Kazakhstan (1990), Georgia (1991) and in the North of Kamchatka (1991).

Seismic zoning is one of the most complicated and crucial problems of worldwide seismology. The complexity of the problem lies in its relation to the category of prediction based on incomplete information, poor and not always successful experience and insufficiently firm methodological positions. Therefore, each seismozoning map compiled in the past years appears to be inadequate to simulate real natural conditions, that along with low quality of construction continue to result in vast material damage and tens of thousands of human losses.

A number of specific reasons lowering the level of seismologic investigations and quality of seismic zoning maps is known at present. The critical points are:

– absence of scientific-methodological basis and geodynamic models, that adequately reflect the nature of seismic phenomena;

– irregular and inadequate knowledge of seismically active tectonics and contemporary geodynamics of different regions of the country and, genetically associated with them, of contiguous seismoactive zones of bordering countries and of vast platform territories with low activity;

– lack of reliable methods of estimation of value and recurrence of maximum possible earthquakes;

– lack of valuable comparative analysis of efficiency of the methods and techniques of seismic zoning applied in different regions;

– ignorance of historical and paleoseismological information on strong and hazardous earthquakes of the past;

– insufficient level of scientific coordination, leading to narrow administrative, departmental, but not regional and interregional approach to the study of genetically united seismoactive territories;

– irregularity and lack of control over the quality of state and individual construction, coupled to the lack of a proper system of insurance and of means to compensate material and social damage caused by earthquakes;

– non-optimal and irrational deployment of networks of seismological stations and observatories, often of insufficient technical standards;

– complete ignorance of developments and applications of methods of long-term prediction of seismic activity, to reveal specific focal zones of increased probability of strong earthquakes in the next years and to implement preventing measures.

The latest achievements in the fields of fundamental seismology and global geodynamics, in the dynamics of discrete hierarchycal and fractal geostructures, in the evolution of the seismic process and the corresponding conceptual and methodological developments allow today to improve and further develop new methods of seismic zoning.

To solve specific tasks, a comparative analysis of the existing methods and of their merits and drawbacks will be needed. A systematic approach to unify seismological, engineering-seismological, tectonic and other geological-geophysical data is required, for the detailed study of seismicity structures in each region on the contiguous foreign seismoactive territory, to estimate magnitudes of possible maximum earthquakes and their recurrence, to reveal potential focal zones also by instrumental, historical and paleoseismological data. It is necessary to develop stochastic models of focal seismicity adequately reflecting probabilistic character of seismic phenomena along with the deterministic ones.

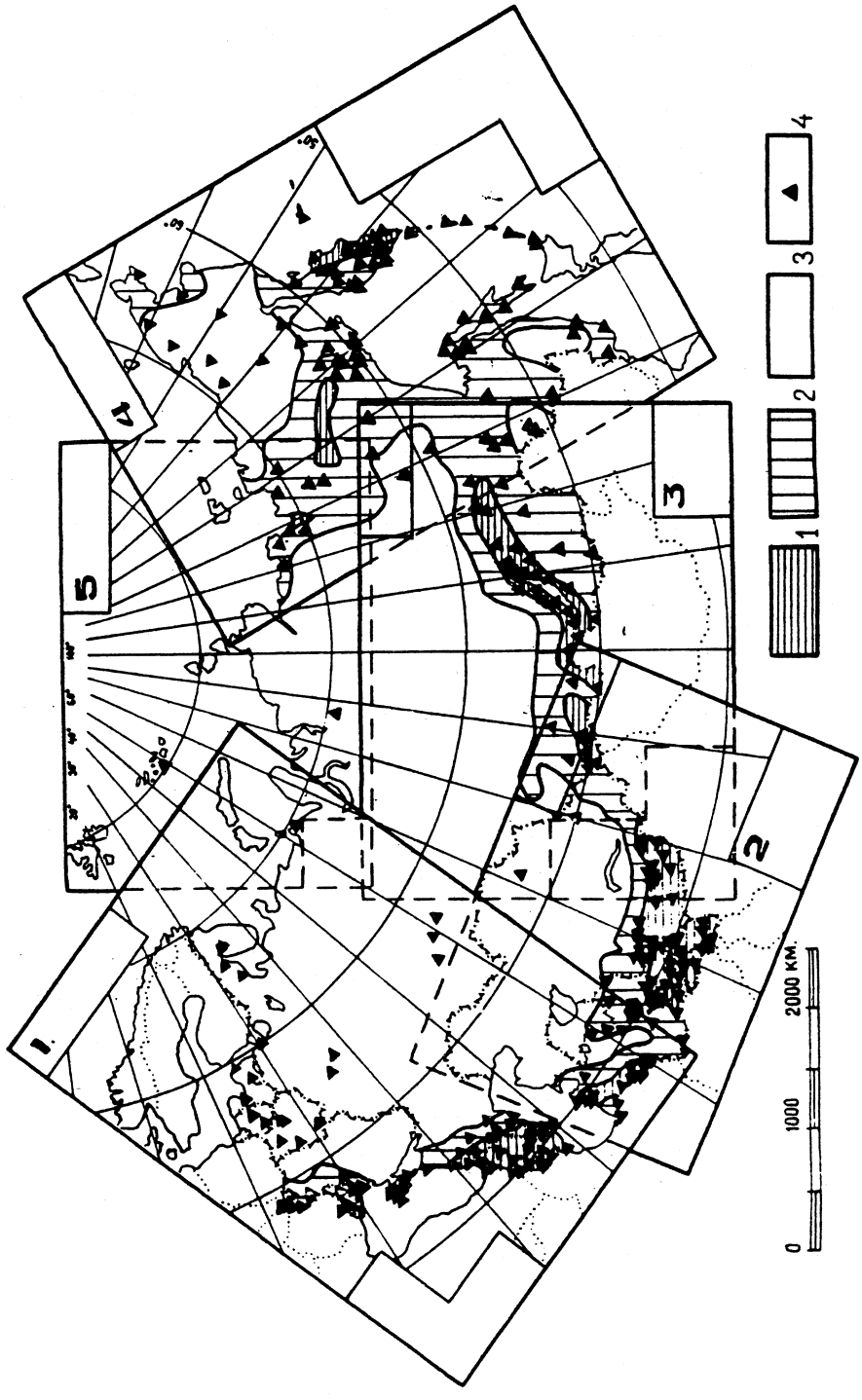

Fig. 2. Coverage of regional map sheets (conical equal space projection): the East-European platform and its mountain fringe (sheet 1); Central Asia and Kazakhstan (2); Siberia and Altai-Sayan-Baikal region (3); the North-East of Eurasia and shelf of marginal seas (4); the North of Siberia and the northern seas (5): 1) zones with intensity 8 and more; 2) intensity 6 and more; 3) intensity less than 6 from the seismozoning map SZ-78 (known 6 and 6-7 points on the East-European platform are not shown); 4) seismological observatories and stations.

The program of scientific research for 1992-1996 titled «Seismicity and seismic zoning of Northern Eurasia» was formulated firstly in 1990-1991 («Development of scientific basis of seismic hazard estimation and creation of new maps of seismic zoning of the USSR territory»). It is being implemented within the State scientific-technical program «Global changes in environment and climate», but now as an independent scientific direction «Seismicity and processes associated with it in environment». The program, as before, consists of seven principal stages of investigations.

2.1. *Development of methodological and scientific bases of qualitative estimation of seismic hazard (1991-1995)*

These investigations are aimed at revealing potential focal zones and estimating their seismogenic potential, the seismic effects and the associated seismic hazard. Already in the first stage (1991-1992) it is necessary to establish the parameters of the seismic zoning map, which, in particular, must reflect the nature of the seismological and geotectonical information. The regularities in the seismic and tectonic structures, the seismic regime, the qualitative correlations (fractal regularity) of geometrical and dynamic characteristics of hierarchical lithospheric structures and the hierarchy of spatial-temporal and energetic distribution of earthquakes are studied. Alternative models of lithosphere dynamics and seismic processes are constructed. New methods are developed, and the existing ones improved, to reveal potential focal zones, estimate the value Mmax and the recurrence in the time of possible maximum earthquakes. The following subjects are studied:

1) study of detailed structure, state of stress, strain distribution and dynamics of the lithosphere, creation of geodynamic models of seismogenic zones with the purpose of ranking their seismic potential (1991-1994);

2) study of seismicity distribution and regime and development of seismogenic models to identify seismic zones and estimate their seismic potential (Mmax) (1991-1995);

3) development of methods of assessment of seismic hazard with the purpose of improving the seismic zoning map (1991-1993).

2.2. *Creation of specialized data base and software system (1991-1993)*

The work consists in the acquisition, analysis and unification of seismological (including historical), geological-geophysical (including paleoseismological), tectonic, geodynamic and other data in digital data bases with a set of service programs and explanatory notes on the principles and methods of their compilation. The acquisition of unified catalogues of earthquakes will be incremented with information about location, technical equipment and development of network of seismic stations and engineering seismometric sites across the whole territory. The compilation of the data bases, naturally, will continue after the term stated above. Special attention will be paid to the acquisition of information on seismic phenomena in low active territories (the Eastern-European platform, the Urals, Siberia etc.).

Regional earthquake catalogue from a representative energetic (magnitude) level will be compiled for each of the five regions (fig. 3).

The following tasks will be completed in this section:

1) the creation of a unified general catalogue of strong earthquakes with $M \geq 6.0$ on the territory of Northern Eurasia (instrumental and macroseismic data) (1991-1994) in basic parameter format (1991-1992) and in extended format (1993-1994);

2) the creation of regional earthquake catalogues with M = Mmin (K = Kmin) with estimation of representativeness of data (1991-1992);

3) the compilation of geological-geophysical data bases for seismic zoning (1992-1993);

4) the creation of a data base of active tectonics and large fault systems (1991-1992);

5) the creation of data bases on the stress-strain state of the Earth crust and focal parameters of earthquakes (1991-1992).

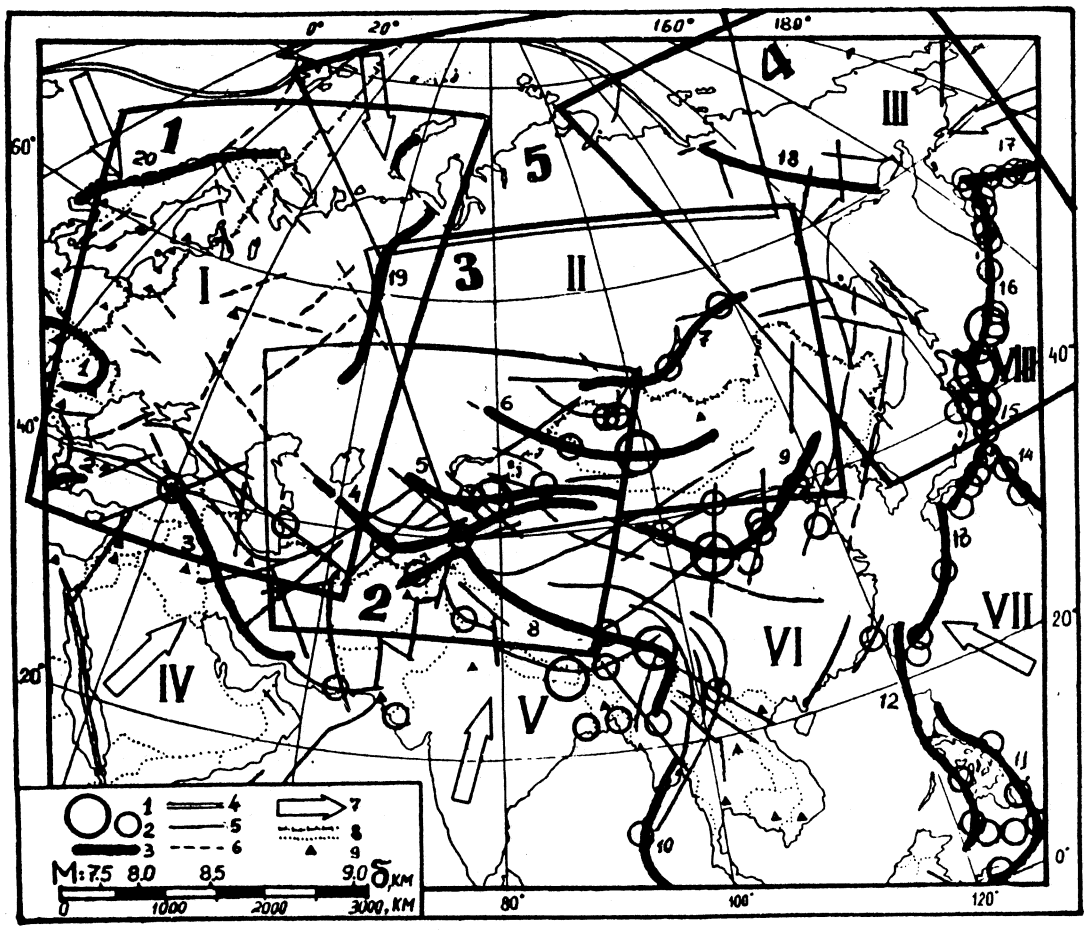

Fig. 3. Coverage of seismoactive regions of Northern Eurasia by regional map sheets NN 1-5 (azimuthal projection): 1,2) earthquakes respectfully with M ≥ 8.5 and M ≥ 8.0, occurred in the last century; 3) axes of the main active convergent regions (zones of contemporary subduction and their relicts on the continents); 4) axes of the main active divergent (rifts) zones; 5) seismolineaments of earthquake with M = 7.5; 6) proposed seismolineaments of earthquake with M = 5.0 of the East European platform; 7) direction of displacement of the main lithospheric plates (I - European, II - Asian, III - North-American, IV - Arabian, V - Hindustan, VI - Chinese, VII - Phillippines, VIII - Pacific); 8) state borderlines; 9) capitals of states.

2.3. *Analysis and mapping of basic parameters characterizing depth structure, active tectonics, present geodynamics and seismicity at the scale 1 : 2 500 000 (1991-1992)*

Mapping of seismicity and other geophysical fields, active faults, block division of the Earth crust and upper mantle, neotectonic and contemporary tectonic movements will be realized at regional and continental scales. The study of the stress-strain state of lithosphere and development of regional geodynamic models will be carried out. The methods to distinguish hidden active tectonic structures will be improved and the map of seismic re-

gionalization of the territory of Northern Eurasia will be derived. The analysis of sensitivity of operating and planned networks of seismic stations and observatories will allow to develop recommendations on their optimization and future development. Five regional map models of present geodynamics and seismicity of the territory of Northern Eurasia will be compiled according to the legend and will be prepared for publication at the scale 1:2 500 000.

The following tasks are carried out:

1) compilation of the map of instrumental seismological data for different time intervals on the scale: 1:5 000 000 (1991-1992);

2) compilation of regional maps of epicenters of earthquakes at the scale 1:2 500 000 (1991-1992) and of the territory of Northern Eurasia at the scale: 1:5 000 000 (1992-1993) with the corresponding explanatory notes and catalogues of earthquakes:

a) strong and felt earthquakes from ancient times up to 1990;

b) earthquakes with $M \geq Mmin$ for the period 1960-1990;

3) diagrams and maps of basic parameters characterizing seismicity and the seismic regime of separate epicentral zones, seismolineaments and seismoactive regions at the scale 1:2 500 000 (1991-1993) and for the whole territory of Northern Eurasia at the scale 1:5 000 000 (1993-1994);

4) compilation of unified regional sheets of isoseismal curves of strong and felt earthquakes at the scale 1:2 500 000 (1991-1992) and of the whole territory of Northern Eurasia at the scale 1:5 000 000 (1992-1993);

5) compilation of a catalogue and unified map of paleo and contemporary seismodislocations (1991-1992);

6) compilation of the map of present tectonic movements of the Earth surface at the scale 1:2 500 000, derived from geodetic data (1991-1992);

7) compilation of a map of neogene-quarternary movements at the scale 1:2 500 000 (1991-1992).

8) compilation of a map of active faults at the scale 1:2 500 000 (1991-1992);

9) compilation of a map of the stress-strain state of the Earth crust and focal parameters of earthquakes at the scale 1:2 500 000 (1991-1992);

10) a diagram of geophysical field elements, characterizing the depth structure and present geodynamics at the scale 1:2 500 000 (1991-1992);

11) compilation of regional models of contemporary geodynamics and seismicity at the scale 1:2 500 000 (1991-1992) and a map of seismogeodynamics of the whole territory of Northern Eurasia at the scale 1:5 000 000 (1992-1993).

2.4. *Study of parameters of crustal earthquake sources and structural-dynamic characteristics of the containing medium (1991-1994)*

The study of focal features of the most important earthquakes on the territory of Northern Eurasia includes the analysis of geometrical and dynamic characteristics of their structure and the correlation with geological-geophysical parameters of the medium, seismodislocations, morphological structure and macroseismic effect. We will also develop qualitative criteria to reveal potential earthquake sources (PES). An atlas of the most important earthquakes will be compiled; as a result, seismotectonic and geodynamic focal models will be created.

Two specific tasks will be:

1) studies (including field ones) of the features of strong earthquakes on the territory of Northern Eurasia (1991-1995);

2) creating an atlas model of focal zones of the most prominent earthquakes on the territory of Russia and contiguous regions (1991-1994).

2.5. *Development of methodological basis to identify zones of earthquake source occurrence (ESO) and compilation of a new map of ESO zones (1991-1994)*

This section includes development and comparison of different methods of mapping

potential focal zones with Mmax as well as the initial geological-geophysical seismological information on a regional basis; compilation and analysis of alternative models of the ESO zones, methods of their construction and research on the spatial-temporal development of seismogenic processes. Map models of the ESO zones for each of the five main regions at the scale 1:2 500 000 will be created as a result, and also a summary map of the ESO zones and potential large earthquakes with elements of long-term prediction of seismic activation across the whole territory under investigation at the scale 1:5 000 000:

1) compilation of summary regional diagram maps of the ESO at the scale 1:2 500 000, based on the acquisition and analysis of regional map models, made in 1986-1990 according to the program 0.74.03 (1991-1992);

2) compilation of ESO regional maps at the scale 1:2 500 000, based on the analysis of geological-geophysical seismological data (1991-1993);

3) compilation of summary regional maps of the ESO zones and potential large earthquakes at the scale 1:2 500 000 and for whole Northern Eurasia at the scale 1:5 000 000, based on the joint analysis of alternative models and compilation methods (1993-1994).

2.6. *Investigations of dynamic processes in the system «focus – medium – seismic effects», development of new theoretical and experimental methods of parametrization of seismic effects and their mapping for high and weak seismic territories (1991-1994)*

Engineering-seismometric and macroseismic data bases will be built and new methods will be developed to parametrize seismic effects taking into account focal radiation, propagation and local effects. The qualitative parameters, representing the expected seismic effects including regions with weak seismicity and shelf zones, will be estimated and mapped at the scale 1:2 500 000, based on the map of the ESO zones:

1) acquisition of engineering-seismological data (macroseismic and instrumental ones) on typical ground conditions and compilation of digital data base for the basic seismic regions (1991-1993);

2) development of methods to estimate and map intensity and qualitative characteristics of seismic effects, improvement of seismic intensity scale taking into account the new data and formulation of regional theoretical models of seismic effects (1991-1993);

3) mapping of seismic effects at the scale 1:2 500 000, based on the ESO zones, taking into account values and occurrence of maximum possible earthquakes.

2.7. *Compilation of regional sheets of seismic zoning at the scale 1:2 500 000 (1993-1995) and summary seismozoning map of the Northern Eurasia at the scale 1:5 000 000 (1995-1996)*

At this concluding stage (1993-1996) the new maps of seismic zoning of the territory of Russia and contiguous regions, including platforms, the continental shelf and the marginal seas will be compiled. In addition, further products of the program will be: a monograph on methodology and new methods of seismic zoning; original data bases in digital form; a map of contemporary geodynamics and seismicity of the territory of Northern Eurasia; improved new catalogue of strong earthquakes for all this territory from the ancient time until the present; regional earthquakes catalogue for the period of 1955-1995 for each of the regions and for all the studied territory as a whole; maps featuring depth structure and geodynamics of Northern Eurasia (gravity anomaly, neotectonic motion, active faults, recent motions of the Earth crust etc.); recommendations to improve seismological observations in Russia and on the territory of contiguous seismoactive regions.

3. Working plan

To successfully realize this program several elements are needed: the cooperation of

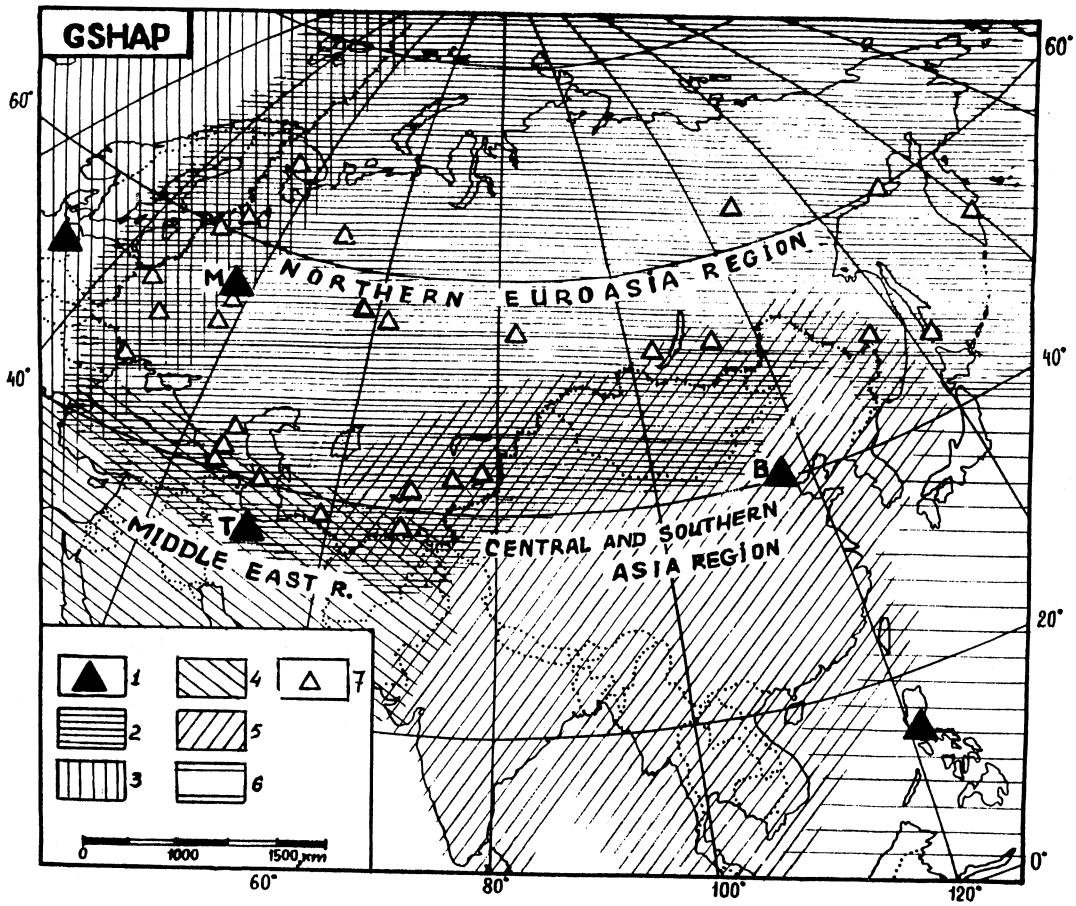

Fig. 4. 1) GSHAP Regional Centres: M-Moscow, T-Teheran, B-Beijing; 2-6) GSHAP Regions: 2-Northern Eurasia, 3-Continental Europe, 4-Middle East, 5-Central and Southern Asia, 6-East Asia-Oceania; 7) Northern Eurasia Regional Research Institutions.

specialists from the regions involved and neighbouring states to study the seismicity and the seismotectonics of territories genetically united; the joint work of seismologists, engineering seismologists, geophysicists, geologists and specialists in earthquake engineering; the optimization and further development of the system of instrumental (including digital ones) observations to monitor the seismic process even for small events; the creation of a dense network of accelerometers to record strong and destroying earthquakes, in order to accumulate the required information for quantitative estimation of macroseismic and seismic effects.

Over thirty institutes of the Academy of Sciences of the Russian Federation and the academies of science of the neighbouring republics and states, and a number of offices of other ministeries, as well engaged in this field, take part in the program. The head executor is the Institute of Physics of the Earth of RAS.

As it was already pointed out, each of the five regional sheets represents by itself an independent basis for compilation of the corresponding map at same scale of 1:2 500 000,

following a single legend and the same methodology.

Every regional map is accompanied by an explanatory note and by a single unified regional earthquake catalogue from the minimum energetic level, covering the whole corresponding regional map sheet.

The regional sheets overlap, allowing to coordinate the results of contiguous territories and, in addition to a set of regional maps, to compile a summary map of present geodynamics, seismicity and seismic zoning at smaller scale.

The term of implementation of the program is 1991-1996.

The support is provided by the Ministry of Science, Higher School and technical policy of the Russian Federation and the corresponding ministeries and departments in other states participating in the joint program.

4. International cooperation in the GSHAP framework

The program for the generation of new zoning maps for the territory of the Russian Federation has embraced the main elements of the Global Seismic Hazard Assessment Program:

a) the compilation of homogeneous data bases;

b) the cooperative approach and interaction with the bordering regions: Europe and the Mediterranean, the Middle East, Southern and Eastern Asia (fig. 4), a concept even more important in the Northern Eurasia as the seismic hazard concentrates on border areas (fig. 1);

c) the need to establish joint test-areas with the established GSHAP Regional Centres in Moscow, Teheran, Beijing and Potsdam (fig. 4);

d) the multidisciplinary approach toward the definition of the seismo-tectonic model.

In particular, cooperative efforts have already initiated toward the seismic hazard assessment in joint test-areas with the Middle East and Central Asia, and an agreement has been signed with the State Seismological Bureau of Beijing for the compilation of a joint seismic catalogue for the whole Northern Asia.