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The Global Seismic Hazard Assessment Program (GSHAP)

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Abstract
The UN International Decade of Natural Disaster Reduction (IDNDR) has endorsed, as an international demonstration project, the International Lithosphere Program's proposal for a Global Seismic Hazard Assessment Program (GSHAP). GSHAP embodies many of the strategies and priorities of the IDNDR; the principal targets are the developing countries located in active earthquake belts; the ultimate benefits will be national assessments of seismic hazards, available before the end of the decade in a standardized form, that can be brought to the attention of national decision makers for the implementation of risk mitigation strategies. The five-year program, initiated in 1992, is coordinated on a global and regional level, with a regionalized scheme based on the establishment of nine Centres in all continents responsible for coordinating hazard activities in their region and in selected test areas of prime seismotectonic relevance.

1. Introduction

The United Nations, recognizing natural disasters as a major threat to human life and development, designed the 1990-2000 period as the International Decade for Natural Disaster Reduction (UN/IDNDR; UN Res. 42/169/1987); the Decade goals are to increase worldwide awareness, foster the prevention and reduce the risks of natural disasters, through the widespread application of modern science and technology. As the first, necessary measure toward the implementation of risk reduction strategies, the Scientific and Technical Committee (STC) of the UN/IDNDR has endorsed international demonstration projects designed to improve the assessment of natural hazards (earthquakes, volcanoes, tropical hurricanes, floods, ...).

Earthquakes adversely affect large parts of the Earth, and vulnerability to disaster is increasing as urbanisation and developments occupy more areas that are prone to the effects of significant earthquakes. In order to minimize the loss of life, property damage and social and economic disruption caused by earthquakes, it is essential that reliable estimates of seismic hazard be available to national decision makers and engineers for land use planning and improved building design and construction. Among the spearhead programs endorsed in the UN/IDNDR context is the proposal of the International Lithosphere Program (ILP) for a Global Seismic Hazard Assessment Program (GSHAP), with the sponsorship of the International Council of Scientific Unions (ICSU).

The GSHAP proposal embodies many of the strategies and priorities of the IDNDR, filling a critical gap cited by many countries in attempting to assess properly the seismic hazard of their territory for the implementation of risk mitigation strategies. The program promotes a regionally coordinated, homogeneous approach to seismic hazard evaluation; the ultimate benefits will be national assessments of seismic hazards, available before the end of the Decade. The implementation of sound seismic hazard estimations into policies for seismic risk reduction will allow a focus on

the prevention of earthquake effects rather than intervention following the disasters.

2. Global seismic hazard

Earthquakes are the expression of the continuing evolution of the Earth planet and its surface. Earthquakes are the most deadly of the natural disasters affecting the human environment; indeed catastrophic earthquakes have marked the whole human history, accounting for 60% of worldwide casualties associated with natural disasters; a relatively small country like Italy averaged more than 100 000 casualties for each of the last three centuries.

Earthquakes occur worldwide; while gigantic events ($M>8.5$) happen only rarely and in restricted areas of the globe, large and moderate earthquakes ($6.5<M<8.5$) may take place in all continental areas, if with very different frequency; smaller seismic events ($5<M<6.5$) occur virtually everywhere. The average global seismicity records every year 1 very large event ($M>8$), 10 large events ($M>7$), 100 moderate events ($M>6$) and more than 1000 smaller earthquakes ($M>5$).

The economic damage inflicted by natural disasters and by earthquakes is increasing with time. The long-term effects of a catastrophic earthquake (the disruption of the economic chain, the human resettlement, the reconstruction to modern standards) may last decades and absorb a considerable part of a national budget; the reconstruction of the Irpinia region (Central Italy) after the 1980 event has exceeded 50 000 M$ to date, and the predicted damage which would be inflicted today by the repetition of the great 1923 Tokyo earthquake (M=8.3; 100 000 casualties) would total up to 25% of GNP of Japan.

Global seismic hazard and vulnerability to earthquakes are increasing steadily as urbanisation and development occupy more areas that are prone to the effects of significant earthquakes; the uncontrolled growth of megacities in highly seismic areas around the world is often associated with the construction of seismically unsafe buildings and infrastructures, and undertaken with an insufficient knowledge of the existing seismic hazard. Moderate and even small earthquakes may turn catastrophic in earthquake prone areas with poor building construction practice, as shown by the 1960 event in Morocco (M=5.8; 12 000 casualties) and the 1972 event in Nicaragua (M=6.2; 5000 casualties; damages for 40% of GNP).

While short- and mid-term earthquake prediction may one day be able to reduce significantly the death toll of earthquakes, the environmental effects (collapse of buildings and infrastructures, disruption of the productive chain, human resettlement) can be reduced only through a long-term prevention policy in earthquake-prone areas based on:

- the assessment of seismic hazard and risk;
- the implementation of safe building construction codes;
- the increased public awareness on natural disasters;
- a strategy of land-use planning taking into account the seismic hazard and the occurrence of other natural disasters.

The assessment of seismic hazard is the first link in the prevention chain and the first step in the evaluation of the seismic risk, obtained by integrating the hazard – the measure of the ground shaking associated to the recurrence of earthquakes – with local amplification factors tied to soil condition and with the intrinsic value and vulnerability of the existing buildings and infrastructure. Seismic hazard is assessed by most nations as the preliminary step toward the adoption of building construction codes.

The GSHAP and the UN/IDNDR provide an important chance to improve the global seismic hazard assessment by:

- coordinating national efforts in multi-national, regional projects;
- reaching a consensus on the scientific methodologies for the seismic hazard evaluation;
- ensuring that the most advanced methodologies be available through technology transfer and educational programs.

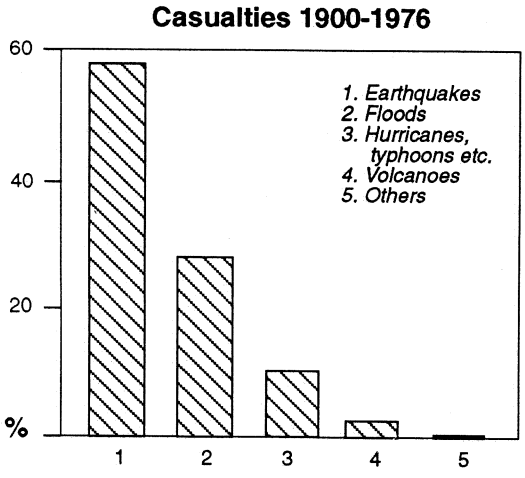

Fig. 1. Casualties from different types of natural disasters in the 1900-1976 period (percentage data from the IDNDR Office).

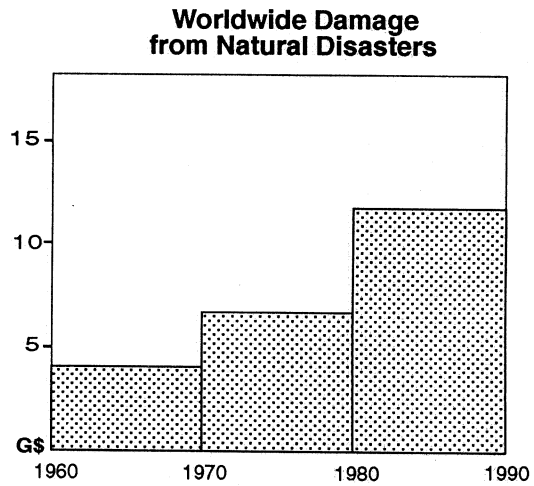

Fig. 2. Yearly average of worldwide damage from natural disasters in the last three decades (data from Münich Re.).

3. GSHAP overview

The GSHAP proposal by ILP has been endorsed as a demonstration project by the UN/IDNDR (III UN/IDNDR/STC; Geneva, March 1992) with the support of international scientific agencies (ICSU, IUGG, IUGS, IASPEI) and of UNESCO. The primary goal of GSHAP is to ensure that national agencies be able to assess seismic hazard in a regionally coordinated fashion and with the most advanced methods. The ultimate benefits will be national assessments of seismic hazards for use in risk mitigation strategies.

The program is coordinated at global level and implemented at regional and local scale, with a regionalized approach based on the establishment of Regional Centres to:

- assist national efforts;
- compile homogeneous regional data bases;
- ensure the needed coordination in across-boundaries hazard assessment;
- provide a framework for data exchange and the implementation of unified assessment procedures.

While the Regional Centres represent the backbone of the program, much of the initial work will be done at the national level to ensure that all of the appropriate data bases on historical and instrumental seismicity, strong motion and macroseismic data and knowledge of earthquake characteristics are assembled. A large portion of the budget will be devoted to ensuring the participation of relevant scientists from the developing countries in the regional workshops and in the joint hazard assessment at the Regional Centres.

The principal targets for GSHAP are the developing countries located in active earthquake belts. By mid Decade a computer-based model of earthquake potential and ground shaking potential will be available at each Regional Centre, to produce seismic hazard maps at appropriate regional and national scales. A training and educational program will be conducted at the Regional Centres, focusing on:

- the compilation of geophysical data bases;
- the assessment of seismic hazard;
- the use of hazard evaluation in the reduction of seismic risk;
- the technology transfer of the data bases, hazard model and computational programs to participating national agencies.

The role of the global GSHAP coordination is to promote the establishment of homogeneous criteria to deal at each Regional Centre with the four main components of seismic hazard assessment: earthquake catalogues, seismotectonics and earthquake source zones, strong seismic ground motion and seismic hazard computation. To ensure continued assistance and support and to emphasize the North-South transfer of technology and knowledge in hazard assessment, a restricted group of hazard experts under the lead of the GSHAP Coordinator will assist in the establishment and operation of the Regional Centres.

The GSHAP is coordinated with other seismic hazard programs undertaken by international organizations (*e.g.* IASPEI, ICSU, IUGG, PAIGH, ESC, HABITAT, UNESCO) and with the initiatives of the international earthquake engineering community (IAEE; WFEO/UATI). It will incorporate the results of three ILP projects: the World Stress Map, the World Map of Active Faults, and Paleoseismicity of the Late Holocene, initiated to improve understanding of the earthquake process and to integrate other geophysical and geological information to provide a firmer basis for the assessment of seismic hazards.

The first year of GSHAP implementation has been launched with a Technical Planning Meeting, held in Rome in June 1992, and with concentrated efforts in:

– establishing a regional subdivision of the world and selecting Regional Centres in all continents;
– devising homogeneous procedures for assembling data bases and assessing seismic hazard;
– initiating activities in test areas with high seismic hazard;
– obtaining support and resources for the program;
– nominating the Steering Committee and determining the management structure of the program.

Following this preparatory phase (1992-1993), GSHAP will consist of two phases; the first two-year phase (1993-1994) will target specific areas where the multi-national approach will be applied and comparative tests will be conducted to evaluate the performance of selected methodologies in different seismotectonic environments; the second two-year phase will expand the regional coverage of GSHAP and transfer the technology of the hazard computational capability from the Regional Centres to participating countries.

4. Products

The most important seismic hazard product that will become available in each of the Regional Centres by mid Decade will be a computer-based model of earthquake potential and ground shaking potential that can be utilized to produce seismic hazard maps at any required regional and national scale. To this purpose GSHAP will strive to establish homogeneous regional guidelines for:

– the creation of unified seismic catalogues;
– the definition of seismotectonic models, earthquake source zones and earthquake recurrence rates;
– the treatment of strong-motion data bases.

While this constitutes only the preliminary step needed for hazard assessment, it is potentially one of GSHAP's major achievements.

The computation of seismic hazard at Regional Centres will provide a forum for the comparative evaluation of existing methods and approaches in the assessment of hazard error and uncertainty. The global GSHAP coordination is aimed at selecting a suite of approaches to be implemented at all Regional Centres to:

– deal in homogeneous fashion with different seismotectonic environments;
– produce hazard estimates at appropriate national scales;
– depict various ground motion parameters meeting different engineering or national requirements.

As the present lack of a regional framework is cited as a severe worldwide limitation to seismic hazard assessment, the establishment of the Regional Centres will be a crucial achievement of GSHAP; these Centres are expected to remain in place as a resource to build upon and improve in future years, updating the hazard model as new geoscience information becomes available. Through its training and educational program, conducted at the Regional Centres, GSHAP seeks to foster the widespread application of advanced knowledge and methodologies in hazard assessment and its use in seismic risk reduction. An important product expected by mid Decade is the transfer of the data bases, hazard model and computational programs to any participating national agency for further detailed studies within their own countries.

Finally, in addition to the national implementation, GSHAP will produce by 1996 a series of regional seismic hazard maps at continental scale, to provide a useful global hazard reference framework.

5. Targets

The principal targets for GSHAP will be the developing countries located in active earthquake belts, that do not have adequate national programs for seismic hazard evaluation.

Countries with moderate seismic hazards, which they may not normally estimate and take into account, will also benefit from GSHAP; this will be especially true for regions with rare, but potentially very damaging earthquakes, where the hazard estimation can be based on knowledge from similar regions worldwide.

Countries that have both high seismic hazards and advanced national assessment programs will also be important targets for the program; their active participation will be a key to ensuring regional coordination, high technical and scientific standards, and ultimately the success of the program.

International funding and relief agencies will be provided with a reference framework of global seismic hazards which, coupled with vulnerability studies, can guide their efforts in the latter part of the Decade.

6. Coordination

The GSHAP is proposed by ILP, a program established by ICSU with joint sponsorship by the International Union of Geophysics and Geodesy (IUGG) and the International Union of Geological Sciences (IUGS); the links with the geological and geophysical fields ensure that the ILP structure is suited to secure the integration of seismology with other geophysical and geological information required in the assessment of seismic hazards. GSHAP will maintain close coordination with the ILP structure and programs and with the international hazards projects conducted in various regions of the globe.

GSHAP will provide a framework for enhanced cooperation in multi-national seismic hazard assessment by building on existing capabilities and assessment efforts at national and regional scales. GSHAP will sponsor the compilation of national and regional data bases to common standards and will support the implementation of hazard and risk assessment at national scale. Special emphasis will therefore be placed on obtaining close working relationships with the appropriate national seismological agencies and institutes, as these are the bodies that have the local seismological expertise and are ultimately responsible for championing the hazard assessment with local and national planning agencies.

As GSHAP is a program developed for the UN/IDNDR, it will integrate with other programs established for the Decade by international scientific organizations (IUGG, IASPEI, ICSU). GSHAP has been endorsed by the International Association of Seismology and Physics of the Earth's Interior (IASPEI) as one of the main contributions of the seismological-geophysical community to the Decade, with resolutions of the IASPEI Committee for the IDNDR (Geneva, March 1992) and of the European Seismological Commission (ESC; Prague, September 1992) and with the

establishment of a ESC/GSHAP liason committee.

To ensure that the program's seismic hazard products are appropriate to the needs of low-cost, earthquake resistant design and construction, a particular necessity exists to coordinate GSHAP purpose and activities with the international earthquake engineering community (WFEO/UATI, IAEE). At the 10 World Conference of Earthquake Engineers (Madrid, July 1992) GSHAP has been identified by the International Association of Earthquake Engineers (IAEE) as an important reference for the World Seismic Safety Initiative, an initiative in preparation for the UN/IDNDR.

7. Regional structure

The key to the GSHAP implementation is the establishment of Regional Centres to act as focal points for activities in seismic hazard assessment, hosted by main geophysical institutions in all continents:

1) North and Central America (UNAM, Mexico City);
2) South America (CERESIS, Santiago);
3) Central and Northern Europe (GFZ, Potsdam);
4) Mediterranean (CNPCRST, Rabat);
5) Continental Africa (University of Nairobi);
6) Middle East (IIEES, Teheran);
7) Northern Eurasia (IPE, Moscow);
8) Central-Southern Asia (SSB, Beijing);
9) East Asia-Oceania (PHIVOLCS, Manila).

This regional structure stems from considerations of seismotectonic homogeneity and political geography and is intended to maximize the transfer of advanced technologies. Regional boundaries are not intended to be rigid; national agencies in bordering areas will contribute to more than one Regional Centre.

GSHAP test areas, characterized by different tectonic environments and varying levels of seismic hazard, have been designed in all continents for the initial implementation of the program's goals and methodologies: South America, the Guatemala-Panama portion of Central America, Spain-Maghreb, the Adriatic plate (Mediterranean), the Central Rift system in Eastern Africa, Eastern Turkey-Iran, North India-Tibet-Burma, Indonesia-Philippines. The list is not final and will be integrated by Regional Centres with any area of interest.

8. Management

The GSHAP is coordinated at a global level but implemented at regional and local scale; the overall operation and administration of the program is conducted at four levels: Steering Committee, Coordinating Centre, Regional Centres and National Agencies.

8.1. *Steering Committee*

A Steering Committee has been named by ILP and includes directors of national and international seismological associations and leading authorities in seismic hazard assessment: H. Gupta (India), Chairman, P. Basham (Canada), Secretary, N. Ambraseys (UK), D. Ben Sari (Morocco), M. Ghafory-Ashtiany (Iran), A. Giesecke (CERESIS), G. Grandori (Italy), D. Mayer-Rosa (Switzerland), R. McGuire (USA), G. Sobolev (Russia), G. Suarez (Mexico), P. Zhang (China), D. Giardini (Italy), GSHAP Coordinator, M. Berry (Canada), ex officio, ILP Secretary General, and a representative from Japan.

The Steering Committee will serve for the five-year duration of the program with the following duties:

a) provide overall guidance and scientific direction to the GSHAP;
b) assist in obtaining support and resources for the program implementation;
c) develop and approve all technical specifications and strategies of the program;
d) oversee the activities of the Coordinating Centre;
e) represent GSHAP in international organizations and meetings.

8.2. *Coordinating Centre*

A Coordinating Centre and a program Coordinator have been established by ILP at the

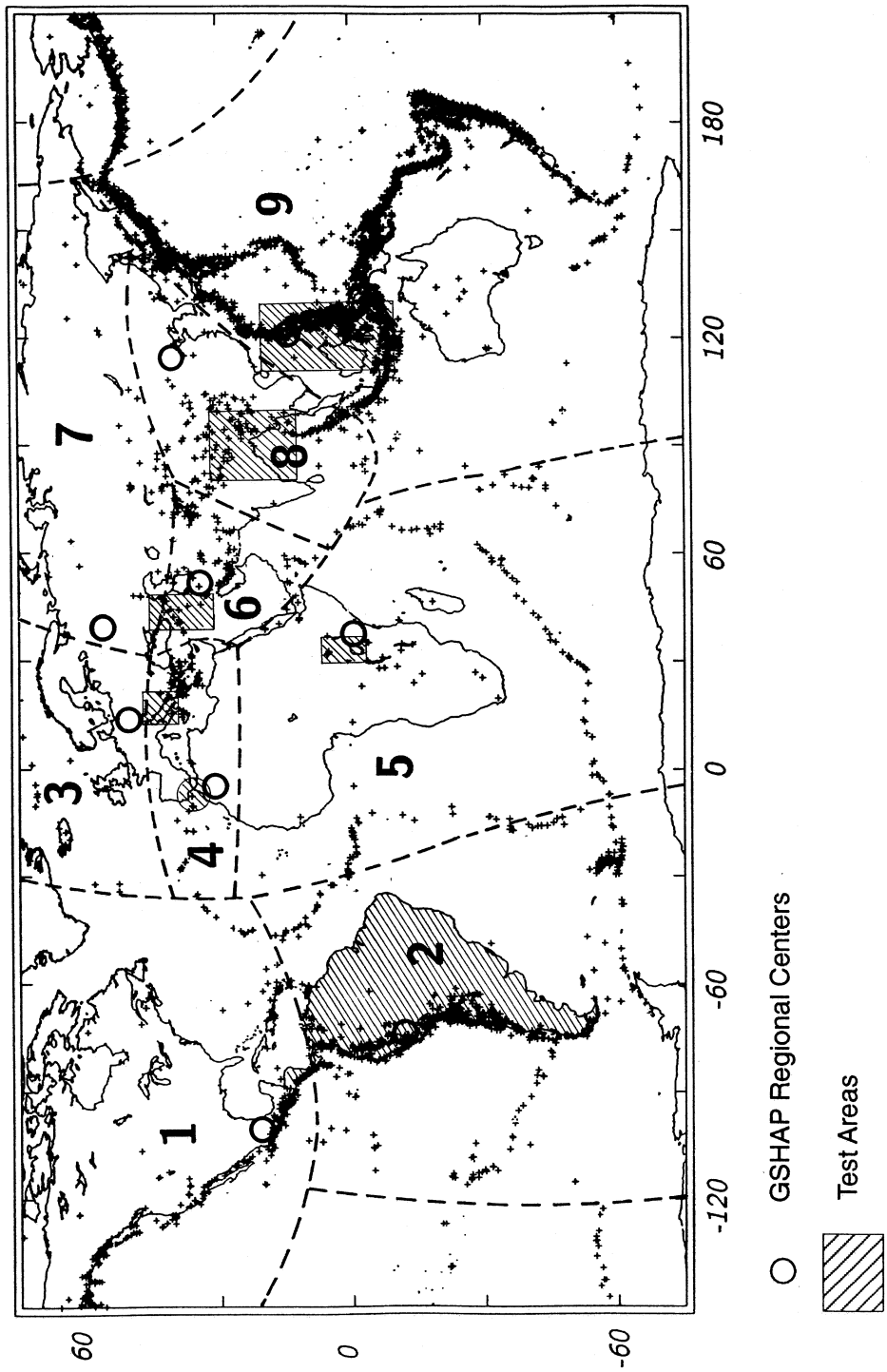

Fig. 3. Regional structure of the GSHAP.

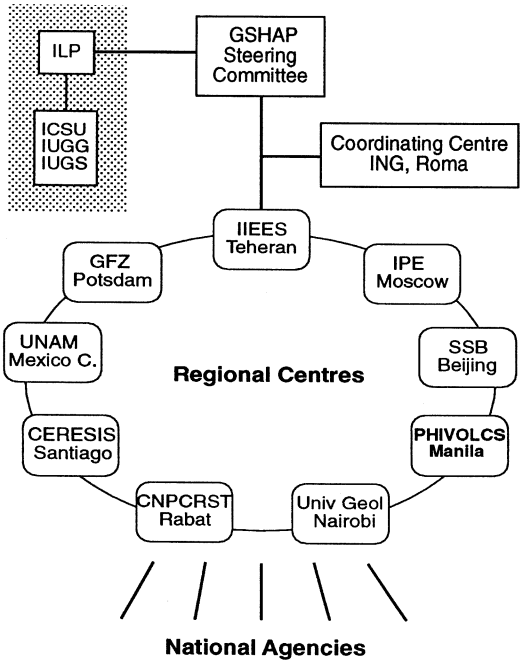

Fig. 4. Management structure of the GSHAP.

Istituto Nazionale di Geofisica of Roma, with the following tasks:

a) ensure global coordination in the GSHAP implementation;
b) assist in obtaining support and resources for the implementation of the program objectives and regional structure;
c) represent GSHAP in international organizations and meetings;
d) prepare progress reports for the Steering Committee;
e) organize the global publication and dissemination of GSHAP plans and results;
f) coordinate the development of the technical specifications and strategies for the program;
g) supervise the action of a restricted group of international experts in the establishment of the technical procedures and operation of the Regional Centres.

8.3. *Regional Centres*

The GSHAP activities are conducted mostly at regional and national level. Each Regional Centre is headed by a Regional Coordinator, a respected scientist with recognized leadership in regional seismotectonics and hazard assessment and assisted by a panel of experts drawn from the region. The following activities are conducted under the responsibility of the Regional Coordinator:

a) establish the Regional Centre: physical location, equipment, personel;
b) identify and activate an operative network of national correspondents in all nations in each region;
c) prepare a five-year plan detailing the structure and goals of each Regional Centre;
d) organize meetings of national representatives to review existing efforts and schedule regional activities;
e) prepare and submit funding requests to secure support and resources;
f) identify test areas for the implementation of the GSHAP multinational approach and assemble joint regional geophysical data sets;
g) coordinate the compilation and analysis of regional data bases and catalogues and the assessment of regional seismic hazard;
h) organize the training and educational program;
i) represent GSHAP in regional organizations and meetings;
j) maintain close coordination with the other Regional Centres and the program Coordinator;
k) prepare progress reports;
l) organize the regional publication and dissemination of GSHAP plans and results;
m) cooperate in devising technical specifications and strategies of the program.

8.4. *National Agencies*

As the ultimate benefits of the program will be improved national assessments of seismic hazards, the national seismic agencies are the bodies that have the local seismological expertise and will be responsible for championing the hazard assessment with local and national planning agencies and with the inter-

national groups. On them rests the responsibility and merit of transforming the GSHAP operating framework into a fruitful program.

9. Technical procedures

GSHAP aims at establishing the consensus of the scientific and engineering community on a wide set of criteria for seismic hazard assessment suitable for application in different seismotectonic regimes around the world. The preparatory phase of the GSHAP has, among its key objectives, the definition of a preliminary set of technical specifications to be implemented and tested at the Regional Centres in the first phase of the program, to deal in homogeneous fashion with the basic elements of modern seismic hazard assessment, grouped into four main categories: 1) earthquake catalogues, entailing an as comprehensive as possible description of past earthquakes; 2) earthquake sources, the geological features that can be assumed to produce future earthquakes; 3) earthquake effects, the ground shaking and other effects that earthquakes will produce; 4) hazard computation, the calculation of ground-shaking parameters of engineering use, usually with an associated probability of occurrence, at a specific site or throughout a region.

9.1. *Earthquake catalogues*

The most fundamental information for a hazard assessment is the record of past earthquakes in a region as captured by the earthquake catalogues. Among the important concerns are the completeness of the catalogues (whose details must degrade as one goes back in time) and whether sufficient studies have been conducted to estimate the earthquake sizes and locations in order to assess the implications of a modern recurrence. There are no established standards on the specific contents of the seismic catalogues and on the standardization of parameters such as those that specify earthquake size.

9.2. *Earthquake sources*

A description of future earthquakes is based on a combination of the knowledge of past earthquakes and of the geological features (faults) on which they occurred. As it is often difficult or impossible to associate earthquakes with specific faults, a seismogenic source may be described as a geographical area of assumed uniform earthquake occurrence. Among the characteristics of earthquakes sources that must be defined are the rates at which the earthquakes are occurring within each source as a function of size, and the largest earthquake that can occur within each source.

9.3. *Earthquake effects*

The assessment of seimic hazard is based also on the measure of the ground shaking produced by the passage of seismic waves. The shaking will vary with earthquake size, with distance from the earthquake source, with the characteristics of the rocks through which the waves pass, and with the local foundation conditions, *e.g.*, rock or soft soil. The ground shaking was characterized in the past by direct measure of the damage caused by the earthquake (the seismic intensity) and most recently by instrumental values of ground acceleration; the data used to characterize ground shaking are very variable in quality and quantity around the world. Conversely there are also a variety of ground shaking parameters that can be displayed on hazard maps, for example, to represent ground shaking effects important to design and construction of different types of structures; the choice for an individual country may be tailored on the basis of parameters traditionally used in national building codes. A goal of the GSHAP approach is to select reference parameters for regional hazard maps in order to provide comparisons of hazard over broad regions.

9.4. *Seismic hazard computation*

Seismic hazard computation methods fall into two general categories: historic and deductive methods.

«Historic methods» are based on the historical record of earthquake occurrences; they are

of simple conception, as they do not require geological interpretations of earthquake sources, and ideally applied to seismic catalogues spanning periods longer than the local seismic cycles. «Deductive methods» are based on the characterization of the seismogenic structures (faults and areal sources) and account for hypotheses such as migration of seismicity and seismic «gaps» (locations at which a large earthquake is overdue). The methodological choice may depend largely on the availability and completeness of the seismological, geophysical and geological data bases; often it reflects also the phylosophical inclination of the analyst. With either method it is important to clearly define the variability of the seismic hazard analysis, to quantify for the end user the degree of confidence in the estimate.

The development of the technical specifications for the hazard assessment in the GSHAP framework has been conducted by:

– requesting recommendations from recognized world authorities in the four hazard elements;
– eliciting technical reports from established international commissions and groups;
– holding a Technical Planning meeting in Rome on June 1992, with the participation of 70 hazard experts from 27 countries and in representation of main international seismological agencies.

The detailed technical guidelines adopted for GSHAP by the Steering Committee are contained in this volume.

10. Plan of activities

The first year of GSHAP activities initiated with the Technical Planning meeting and the installation of the Steering Committee (Rome, June 1992) and ended with the second meeting of the GSHAP Steering Committee (Mexico, April 1993), which evaluated the status and prospectives of the GSHAP and made final decisions on the program technical procedures.

This preparatory phase was devoted to:

– define the technical procedures, the regional structure, the plan of activities and the funding strategy of the program;
– establish the Regional Centres and initiate regional activities;
– obtain the endorsement of international scientific agencies and programs;
– establish connections with existing initiatives in seismic hazard assessment.

Following this preparatory phase, the program schedule has been planned to develop in two phases.

Phase I: 1993-1994. The first phase will target the test areas; among the planned activities are:

– organizational meetings held at the Regional Centres, to be attended by technical specialists and representatives of national seismological agencies of each area and by appropriate members of the Steering Committee and of the Coordinating Centre;
– multi-national, comparative tests conducted to evaluate the performance of selected methodologies in different seismo-tectonic environments;
– the compilation of national data bases, following GSHAP specifications, and their transfer to the Regional Centres;
– the assemblage of regional data bases and development of seismic hazard model;
– the training and educational program conducted at the Regional Centres;
– the continuing effort to establish homogeneous criteria for the compilation of regional data bases and the computation of seismic hazard;
– the program evaluation by the Steering Committee and the Regional Coordinators.

Phase II: 1994-1996. The second phase will complete the regional coverage of GSHAP through:

– a second round of meetings at the Regional Centres to review the seismic hazard estimates of the test areas and expand the action at the Regional Centres to the whole regions;
– the compilation of national data bases, following GSHAP specifications, and their transfer to the Regional Centres;

– the assemblage of data bases and development of seismic hazard model for the whole regions;

– the training and educational program conducted at the Regional Centres;

– the final review meeting, attended by the Steering Committe, the Regional Coordinators and participants to the Technical Planning meeting of 1992;

– the formulation of plans for the maintenance of the capabilities at the Regional Centres into the future.

11. Budget

A consistent program budget is required to secure the key elements of the program:

– the regional and global coordination;
– the operation of the Regional Centres;
– the training program;
– the participation of national scientists in the Regional Centres activities and meetings;
– the test area experiments;
– the publication of the hazard products;
– specific national efforts in the compilation of geophysical and geological data bases.

Assuming an average expense of 100 000$ per year for each Regional Centre, the overall budget for the whole GSHAP operation can be crudely estimated to be of the order of 5M$.

At present GSHAP seeks resources to support the operation of the test areas and Regional Centres; the funding scheme followed in GSHAP is based on four steps:

1) funding and development agencies are identified which can be interested in sponsoring activities in one area or Regional Centre;

2) contacts are established by the Coordinating Centre to introduce the GSHAP framework and explore possibilities;

3) a detailed proposal to sponsor activities in a region or in a test area is submitted by the Regional Centre, upon verification by the Coordinating Centre;

4) international agencies (ICSU, UNESCO, ILP, UN/IDNDR) provide support where appropriate.

Several initiatives in this framework are already under way and specific proposals have been submitted to funding agencies.