Office of the United Nations
Disaster Relief Co-ordinator
(UNDRO)

Natural Disasters and Vulnerability Analysis

Report of Expert Group Meeting
(9-12 July 1979)

FOREWORD

During the last two decades natural disasters have tended to be more destructive as they affect ever larger concentrations of population. While the response of the International Community has primarily focussed on relief action, it is now also realized that the actual and potential consequences of natural hazards are becoming so serious and so increasingly global in scale, that much greater emphasis will henceforth have to be given to pre-disaster planning and prevention.

The effects of natural phenomena must be viewed not only in humanitarian and broad social terms, but also in economic and development terms since natural disasters are indeed a formidable obstacle to economic and social development. When calculated as a percentage of gross national product, the losses caused by disasters in many disaster-prone developing countries more than off-set economic growth. Consequently, there has been a growing awareness by Governments of the need to pay more attention to disaster preparedness and prevention, and to recognize the fact that pre-disaster planning should be an integral part of national development policy.

In the developing countries, rapid urbanization and the increase of populations living or settling in hazardous areas are matters of growing concern, as they contribute to ever heavier losses of life and to mounting costs of disaster damage. In disaster-prone areas, orderly urban expansion becomes prohibitive unless investments in infrastructure, housing and other services are protected from such damage at all stages of their development.

The formulation and enforcement of land-use policies and plans, as well as appropriate building codes, are key factors for the orderly establishment and safe growth of human settlements. These should logically be based on knowledge of existing natural hazards present and on analysis of the disaster risks which may result. This method of risk identification and evaluation has been referred to in the past by UNDRO as "vulnerability analysis". *Through vulnerability analysis it becomes possible to make rational decisions on how best the effects of potentially disastrous natural events can be mitigated through proper planning, as well as through a system of permanent controls.*

The concept of "vulnerability analysis" *has over the years been developed by UNDRO, notably in the UNDRO Compendium of current knowledge on disaster prevention and mitigation (Volumes: 3 — Seismological Aspects, 4 — Meteorological Aspects, 5 — Land Use Aspects, 6 — Engineering Aspects (under preparation), 7 — Economic Aspects), and in two technical co-operation projects in pre-disaster planning: Composite Vulnerability Analysis, A methodology and case study of the Metro Manila Area, Report of an UNDRO Technical Advisory Mission, 1977; and Planning for the Prevention of Natural Disasters, Central American Regional Project, Report of a Technical Co-operation Mission 1978.*

In 1979, after six years of research and development, UNDRO convened an international Expert Group Meeting of scientists and planners specialized in the major natural hazards of meteorological, geological and geophysical origin, to review UNDRO's work in vulnerability analysis, provide further guidance on defining concepts and developing methodologies for applying the results of such analysis to practical physical planning and building techniques in disaster-prone developing countries, and lastly to advise UNDRO on its further activities in this field. The present publication is the report of that meeting.

Geneva
August 1980

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ANNEXES

I. INTRODUCTION

The United Nations Disaster Relief Co-ordinator, Mr. Faruk N. Berkol, convened an Expert Group Meeting on Vulnerability Analysis which was held at the United Nations Office at Geneva from 9 to 12 July 1979. The meeting was attended by specially invited experts, by representatives of U.N. Agencies and other organizations concerned with natural disasters, and by staff of the Office of the United Nations Disaster Relief Co-ordinator (UNDRO). The Agenda for the meeting is given in Annex I and a list of participants is given in Annex II.

Opening the meeting, the Co-ordinator welcomed the participants and stressed the fundamental importance of applying vulnerability analysis prior to the development of any locality, country or region in which natural hazards pose a threat to human life property. The subject should be of major concern not only to UNDRO but to everyone involved in planning and development in areas prone to natural disasters. The Co-ordinator described the functions of his Office in regard to disaster relief co-ordination, disaster preparedness and disaster prevention as conferred by the United Nations General Assembly. The Co-ordinator expressed the firm conviction that all activities related to pre-disaster planning should be based on a sound knowledge and understanding of the hazards and risks involved. He explained that as a result of the study of the problems caused by natural disasters, new methods and techniques for investigating vulnerability were constantly being developed, and that it was essential that these should be readily applicable in disaster-prone developing countries. For such countries the aim should be to establish reliable and straight-forward techniques to assess vulnerability at all scales, from the national level to the individual site. The Co-ordinator gave this as the theme of the meeting.

The Director of UNDRO's Relief Co-ordination Preparedness and Prevention Division summarized the main points to be considered by the meeting as follows:

- Definitions and concepts in risk management;
- Means of improving the understanding and co-operation among scientists, planners and administrators;
- The further development of techniques in vulnerability analysis and risk management.

II. ORGANIZATION OF THE MEETING AND PRELIMINARY DISCUSSIONS

Dr. S. T. Algermissen was elected Chairman of the meeting. It was agreed that discussions would take place alternately in plenary session and in two working groups, one to concentrate on geophysical phenomena (earthquakes, volcanoes, earth movements, etc.) and the other to deal with atmospheric phenomena (tropical cyclones, tornadoes, thunderstorms, etc.). Professor N. Ambraseys was elected Chairman of the working group on geophysical phenomena, and Professor J. Dooge was elected Chairman of the working group on atmospheric phenomena. Mr. P. J. Meade was appointed Rapporteur.

The Chairman initiated a general discussion on the questions the meeting needed to examine, and invited UNDRO representatives to give additional guidance or explanations on detailed aspects of vulnerability analysis.

The Chairman then called upon the representatives of other organizations (see Annex II) to make statements. All statements agreed on the importance of the questions to be considered by the meeting and examples were given of the necessity to carry out vulnerability analysis during the pre-investment stage of development projects in disaster-prone countries.

In view of its special relevance to the work of the meeting, the Chairman asked Mr. Fournier d'Albe (UNESCO) to describe the UNESCO programme on earthquakes which had been in operation for some 18 years. Mr. Fournier d'Albe said that the programme had evolved from a purely scientific programme in seismology to a widely multi-disciplinary attack on the problem of earthquake risk management. He outlined the steps by which it had been possible to arrive firstly, at an assessment of earthquake hazard in terms of describing ground motion which could be used directly by engineers in the design of earthquake resistant structures; secondly, at an assessment of the vulnerability of human lives, property, productive capacity, etc., to seismic ground movements; and, finally, at an assessment of risks, defined as a probability of loss, as well as the use of this risk assessment in pre-disaster planning, notably in the elaboration of long-term preventive measures. UNESCO's programme on natural hazards also included work on volcanic eruptions and landslides, in which a similar approach had been adopted. Mr. Fournier d'Albe felt that, despite differences in vocabulary, UNESCO and UNDRO had in fact evolved similar methodologies and that it should not be difficult at this meeting to reach agreement on common concepts and terminology for work on natural hazards.

The representatives of the World Meteorological Organization (WMO) explained that three of WMO's programmes, the World Weather Watch Programme, the Tropical Cyclone Programme and the Operational Hydrology Programme, would contribute directly to the scientific data and techniques required for vulnerability analysis. Within these programmes, WMO carried out a project financed by the United Nations Environment Programme (UNEP) in 1974/1975 on the quantitative evaluation of disaster risks from tropical cyclones. The report on this project had been published as WMO Special Environmental Report No. 8. A sequel to this report was a WMO/UNEP project, begun in 1976, to test techniques of flood risk evaluation in 6 countries in Central America, and to plan and implement measures to minimize loss of life and material damage caused by hurricanes. This project was completed in 1978 and had yielded valuable results. In 1979 WMO launched a Hydrological Operational Multipurpose Sub-programme (HOMS) which included a component in flood-risk mapping.

The representative of the United Nations Development Programme (UNDP) described the role of UNDP in the field of technical co-operation and the work of the UNDP Offices in developing countries. These Offices acted on behalf of UNDRO in the event of a natural disaster. He added that in the various developing countries, the Resident Representative of UNDP was responsible for 5-year country programmes and was therefore closely concerned with considerations of disaster prevention and preparedness. It should be noted that by virtue of a formal agreement between the Disaster Relief Co-ordinator and the Administrator of UNDP, the UNDP Resident Representative was also the UNDRO representative in the field.

The representative of the United Nations Centre for Human Settlements (HABITAT) said that the activities of his organization had mainly consisted of technical co-operation with governments to prepare plans for medium range and long range post-disaster reconstruction, particularly housing construction. Projects had included:

- physical planning for reconstruction and development after earthquakes;
- housing and building reconstruction after earthquakes;
- housing reconstruction after hurricanes and floods.

A small number of publications had also been produced in the area of earthquake-resistant housing design and construction techniques. Currently under consideration was the creation in HABITAT of a Task Force on Disasters to provide timely advice on planning and building in the immediate aftermath of disaster, and also on the formulation of project proposals for longer term planning and reconstruction.

In the general discussion it was explained that a common methodology in vulnerability and risk assessment was required for scientists, planners, engineers and developers alike. It was agreed that existing UNDRO publications (see Annex V) should serve as a background to the work of the meeting and should also, as necessary, be critically reviewed. One recommendation of the meeting might be that UNDRO should consider whether any of these publications should be revised and updated.

A discussion followed on composite vulnerability analysis*, questioning its relevance and applicability. There was a general feeling that information should be provided separately on the nature and degree of the risks from each phenomenon even if a composite map were constructed in addition.

The meeting, before proceeding to separate discussions in working groups and taking into account the points highlighted in the opening statements of the Co-ordinator and of the Director of the Relief Co-ordination, Preparedness and Prevention Division, agreed that the main questions for detailed consideration were as follows:

1. Clarification of concepts concerning risk and vulnerability,
2. Advice on what types of information were required to assess risk and vulnerability,
3. Advice on methods and techniques to use such information for pre-disaster physical planning and building,
4. Advice on (inter alia):
    a) composite risk analysis, and scales of analysis (for example seismic microzonation);
    b) risk mapping, extrapolating risk information into planning and building recommendations and/or constraints;
5. Advice on:
    a) UNDRO's role in the promotion and development of vulnerability analysis techniques, particularly among the U.N. Agencies;
    b) the training of teams in damage assessment, risk evaluation and mitigation in disaster-prone developing countries.

The meeting accepted that an important issue was the interface between science and planning. A major objective would therefore be the provision of straightforward, practicable techniques for evaluating risk and vulnerability for planning purposes.

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*Composite vulnerability analysis: simultaneous assessment of different natural hazards in a given location expressed as one total (or composite) risk.

III. CLASSIFICATION OF CONCEPTS AND TERMS

The series of UNDRO studies of current knowledge on Disaster Prevention and Mitigation use the terms *natural hazard risk* and *damage probability*, and define *vulnerability* (or *disaster risk*), the product of the values of these two terms. (See for example page 4 of Volume 5 on "Land-Use Aspects of Disaster Prevention and Mitigation"). Similar terms are used in a different sense in seismic studies. Thus Mr. Fournier d'Albe of UNESCO in his paper on "Earthquake Prediction and Risk Management*" uses the term risk to denote the possibility or probability of loss, and defines this as the product of *seismic hazard*, *vulnerability* and *value*, vulnerability in this case being a measure of the proportion of the value which may be expected to be lost as the result of a given earthquake. It is clearly desirable to avoid, if possible, such conflicts of nomenclature and to establish a set of terms for use in disaster studies which will be widely understood and accepted.

The meeting proposed therefore that the following terms and definitions be used:

- *NATURAL HAZARD* meaning the probability of occurrence, within a specific period of time in a given area, of a potentially damaging natural phenomenon.
- *VULNERABILITY* meaning the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total loss).
- *ELEMENTS AT RISK* meaning the population, buildings and civil engineering works, economic activities, public services, utilities and infrastructure, etc... at risk in a given area.
- *SPECIFIC RISK* meaning the expected degree of loss due to a particular natural phenomenon and as a function of both natural hazard and vulnerability.
- *RISK* meaning the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of specific risk and elements at risk.

The above definitions include all the terms used in the UNDRO studies and in UNESCO

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*Background paper presented to European Space Agency/Council of Europe Seminar on earthquake prediction, Strasbourg, France, 5 to 7 March 1979. Available from UNESCO's Earth Sciences Division on request.

publications but in several cases the terms used do not correspond. The relationship between the three sets of terms is shown in *Table I:*

Table I

UNDRO	UNESCO	PROPOSED
risk	*hazard*	*natural hazard*
damage	*vulnerability*	*vulnerability*
vulnerability	—	*specific risk*
—	*value*	*elements at risk*
—	*risk*	*risk*

The proposed definitions appear to be close enough to general usage to have a good chance of wide acceptance. Annex III provides supplementary theoretical discussion of the concept of vulnerability and proposals for the practical evaluation of the risk attached to natural hazards.

An additional concept which may prove of value in practical applications is that of *RESISTANCE* which controls the level of vulnerability. Resistance depends on numerous factors such as land-use patterns, population and development densities, the quality and implementation of design and the ability to arrest the action of destructive forces in their initial stages thereby avoiding the development of chains of destructive events.

The *ESTIMATED LEVEL OF RISK* should be calculated as a fundamental element of any physical development planning exercise in the following categories:

- post-disaster settlements reconstruction,
- settlement renewal and modernization,
- expansion of existing settlements,
- building of new settlements,
- development and/or restructuring of the national/regional settlements networks and systems.

The definition of an estimated *RISK* for alternative site selections and alternative development programmes, should be seen as a major tool in planning and decision-making procedures for preventing or mitigating the consequences of the natural phenomena on the one hand, and to limit development and operational costs on the other.

Policy formulation should encompass the concept of *LOCALLY ACCEPTABLE RISK.*

In order to define *LOCALLY ACCEPTABLE RISK*, alternative policy and planning options should be formulated and examined. Predictably, each alternative solution will present some internal conflicts between locally acceptable levels of risk and socio-economic goals. Nevertheless, the general notion and philosophy of *RISK* and of *ACCEPTABLE RISK* should be applied to all physical planning activities in order to ensure a safer and more appropriate process of urban and regional development. To that end, at the very least a simplified methodology and concept of *RISK* should be elaborated taking into account availability of local data, planning technology and trends in these fields. It is also imperative to define the reasonable minimum requirements for a meaningfull *RISK* definition exercise. This challenge could be seen as an important element of UNDRO's work programme.

IV. TYPES OF INFORMATION REQUIRED

In order to assess the disaster risk of an area, data on the following categories are required:

- *Natural hazard*
- *Vulnerability*
- *Elements at risk*

4.1 *Natural hazard*

Techniques for the assessment of natural hazards are reasonably adequate, but in some areas and in some scientific disciplines there may be deficiencies of basic data both in quantity and quality. For the natural phenomena of main interest — meteorological and hydrological phenomena, earthquakes and volcanoes — it is essential that data requirements for the assessment of natural hazard should be formulated and, where gaps are identified, urgent steps should be taken to close them. These steps are important since natural phenomena are complex, and for their complete description and future development a number of different parameters are required (thus a tropical cyclone is described in terms of its direction, speed of movement, maximum wind strength, the value of the surface pressure at its centre, etc..).

The preparation of hazard maps presents no particular problems, given adequate data of reasonable quality. In order to establish risk, a planner would expect to be provided with hazard maps for each phenomenon which is known to occur in the area under consideration. For example, hazard maps might be prepared for the extent of flooding for one or more average return periods, for flooding due to river flows exceeding the bankfull discharge, and for flooding due to storm surges in coastal and estuarine areas. There might, in addition, be other hazards of a geological nature which would have to be mapped (for example fault lines, loose unconsolidated soils, etc) and overlaid.

4.2 *Vulnerability*

Information on vulnerability is less plentiful, less reliable and less clearly defined than the information usually available on natural hazards themselves. Various categories of data are required, relating not only to the details of possible material damage, but also to the degree of social and economic disorganization that may take place.

There is a pressing need to assemble and publish as much information as possible on the damage that has occurred in past disasters. It might be met by the co-ordination and extension of damage surveys which have already been undertaken in a number of developed and developing countries.

Of particular interest in this connexion are the questionnaires on disaster damage forming part of the Anti-disaster Planning Programme of the State Government of Tamil Nadu, India — see Annex IV.

Clearly, UNDRO could play a key role in the stimulation and co-ordination of such work among disaster-prone developing countries.

4.3 *Elements at risk*

Information on elements at risk, such as population, property, public utilities, industry, infrastructure, etc.., is normally taken into account as standard planning and engineering practice, even when disaster prevention and mitigation are not specifically taken into account. The inclusion of a disaster prevention and mitigation perspective in land-use planning and in other areas of physical planning requires a somewhat different classification and definition of the elements at risk. The work involved in this reclassification would be fully justified by the resulting improvement in the efficiency of planning procedures.

V. METEOROLOGICAL AND HYDROLOGICAL PHENOMENA

Natural disasters of atmospheric origin are closely associated with hydrological features. The violent winds and prolonged and heavy rainfall of a tropical cyclone may cause a disaster on their own account, but other factors also come into existence: excessive rainfall may lead to river flooding and landslides, whilst strong winds may be the primary but not the sole cause of storm surge. It is worth noting that the greatest losses in human lives are caused by river floods and storm surges.

5.1 *Tropical cyclones*

The small, intense depressions of tropical latitudes are called tropical cyclones (or typhoons or hurricanes, depending on the region in which they occur). A tropical cyclone forms over the open sea and usually moves towards land on reaching which it either moves into the interior or travels along the coastline. A large area, perhaps several countries, may be affected by a tropical cyclone during its active existence of several weeks, and the toll in terms of loss of life, material damage and economic losses may be extremely heavy, even to the extent of cancelling economic growth over a period of years*. In the North West Pacific more than 30 tropical cyclones may be expected to develop each year. In other regions the frequency is usually lower.

The fundamental characteristics of tropical cyclones are:

(i) Frequency of occurrence, intensity, speed and direction of movement, etc.;

(ii) Wind and rainfall distribution;

(iii) Storm surges — frequency/height distribution, and relationship to meteorological parameters.

The hydrological component of tropical cyclones is concerned mainly with the following subjects:

(i) Hydrometeorological aspects of tropical cyclone rainfall — depth/duration/frequency relationships;

(ii) Use of hydrological models for estimating probabilities of flood river discharges associated with rainfall of given characteristics.

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*Techniques for the assessment of natural hazard are described in some detail in Special Environmental Report No. 8: The Quantitative Evaluation of the Risk of Disaster from Tropical Cyclones, 1976. Secretariat of the World Meteorological Organization, Geneva. Sales No. 455, English/French/Spanish, 143 pages, Price 50 SFr. ISBN 92 - 63 - 10455 - 7.

5.2 *Tornadoes*

A number of dangerous meteorological phenomena — tornadoes, thunderstorms, lightning and hail — are conveniently classified within the description "severe local storms". These storms have a relatively short life cycle and affect small areas rather than large regions. Although any of these phenomena can be a serious threat to life and property, the tornado is the most dangerous of all, and is capable of bringing total devastation to settlements and development lying in its path. Tornadoes are liable to form when the wind, temperature and humidity conditions through a deep layer of the atmosphere are such as to generate strong convection of air near the ground. Although such conditions are favourable for tornado genesis, it is by no means certain that a tornado will automatically form. The mechanism involved is not yet sufficiently understood. Nevertheless an analysis of the meteorological elements which determine the vertical structure of the atmosphere will give frequencies of occurrence of conditions which might result in the formation of a tornado in a given area. For the purposes of a realistic assessment of tornado hazard, these statistics should be used in conjunction with records of actual occasions when tornadoes were experienced in the area.

5.3 *River Floods*

Excessive rainfall is the basic cause of a river flood but there are simultaneously other contributory factors. These may include structural failures such as the collapse of the walls of a reservoir or the embankment of a river proving insufficiently robust to contain the strong flow of water. When rainfall is of very high intensity, the resulting flood may be of sudden onset, usually described as a flash-flood. This phenomenon is particularly dangerous because it leaves very little time for any adequate warning or evacuation. If a river flood takes place near the coast, the hazard may be enhanced if, at the same time, strong onshore winds cause a storm surge (see 5.4 below).

In order to describe river flood hazards, hydrologists undertake the preparation of two basic maps. One map delineates areas liable to flooding on average once every 10 years; the other map shows corresponding areas for 100 year flood cycles. A flood event which may be equalled or exceeded only in 100 years (i.e. a flood with a probability of occurrence of 1 per cent), would inundate large areas of the flood plains, whereas a 10 year flood (i.e. a flood with a probability of occurrence of 10 per cent) would cover a much smaller area, mainly in the neighbourhood of the river banks. The methods employed by hydrologists can readily be applied for the preparation of maps for return periods other than those mentioned. Such a requirement should be decided in accordance with local data and experience.

In hydrology, the usual practice is to characterize a flood by its peak discharge, or peak stage. In principle, it is necessary to estimate the peak stage at every point along the river channel. The raw material for such an investigation consists mainly of the available rainfall and streamflow data. These data are analysed and used with catchment, and other hydrological models, to estimate flood frequencies and extent of inundation.

5.4 *Storm surges*

Storm surge is caused by strong winds and low barometric pressures (usually generated by a cyclone) blowing over a large sea surface. Water is thereby lifted and driven towards the coast. Where the depth is shallow, the return flow is retarded by friction at the sea bed, and the excess water piles up on the shore line until it eventually invades the hinterland. The originating phenomenon will probably be accompanied by heavy rains. Thus, the sum total of destruction may prove to be exceptionally high because of the contribution of three major factors – storm surge, heavy rainfall and increased discharge, if not actual flooding, from rivers. Although the worst storm surges occur in association with tropical cyclones, the phenomenon is not confined to the tropics alone. Any low-lying coastal region may experience storm surge when a deep depression over the sea accompanied by strong winds, approaches the shore.

The most vulnerable parts of a coastline lying in the path of tropical cyclones are bays and shallow estuaries. To assess the hazard it is necessary to make a frequency analysis of storm surge heights along different sections of vulnerable coastlines, and to consider, in addition, the possible combined effects of the meteorological surge *and* the astronomical tide. Confidence in the assessment of the hazard will depend greatly on the quality of the data received.*

5.5 *Avalanches*

The estimation of avalanche hazards is based on studies of past records of avalanche events and also, on climatological data and terrain conditions. However, it should be stated that avalanche hazard assessment is extremely difficult because there is no accepted theory of avalanches, and little is known about the mechanism that triggers them. A great deal remains to be learned about the interaction of weather, terrain and snow conditions.

5.6 *Landslides*

The subject of landslides is discussed in greater detail in Section VI, in conjunction with earthquakes. However, consideration should also be given to the possibility of landslides where heavy rains and floods may occur.

Landslides hazard is difficult to estimate as an independent phenomenon. It seems appropriate, therefore, to associate landslides with other hazards such as tropical cyclones, severe local storms and river floods. This consideration is clearly observed in countries which, for the purpose of preventing or mitigating flood damage, also adopt measures to prevent hillside erosion and landslides.

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*For more detailed discussion of data requirements, reference should be made to Publication No. 500: Present Techniques of Tropical Storm Surge Prediction. Report on Marine Science Affairs, No. 13, 1978. Secretariat of the World Meteorological Organization. English, 87 pages, Price 20 SFr.

VI. EARTHQUAKES

6.1 *Seismic aspects*

Seismic hazard is defined as the probability *F(r)* that a certain ground motion parameter will be exceeded in a period of *(T)* years. It is essential that the users of primary seismological data, or of hazard figures, should be aware of the inaccuracies inherent in the data and of possible errors in the determination of individual parameters. Users should always ask seismologists and geologists for an assessment of the accuracy and confidence in the information and advice which they provide.

The procedures which provide probabilistic values of seismic hazard cannot always be followed in practice. Simple approaches may be used if the data required are not available, or if a rough estimate of hazard would be acceptable. In many countries, the largest macroseismic intensities that have been observed so far are regarded as defining the level of the hazard and, using this technique, maps can be constructed. However, such an approach may result in dangerous gaps since earthquakes may occur in places where no activity had previously been reported. Efforts are therefore being made, using geotectonic evidence, to improve the maps by extending the zones of largest macroseismic intensity, *(I max.)*.

6.1.1 *Calculation of seismic hazard*

Figure I shows in the form of diagrams the sequence of actions to be taken by government authorities on the one hand, and by earth scientists and earthquake engineers on the other hand, in order to draw up and implement plans for the mitigation of earthquake disasters. In this way, facilities, data and techniques may be made available for the calculation of seismic hazard. At all stages in the implementation of the plan there would, of course, be full decision between the government authorities and the scientists and engineers concerned.

The flow diagram on the right of *Figure I "Planning for the Mitigation of Earthquake Disasters"* shows the *steps* involved in meeting the practical objective of calculating seismic hazard. The *steps* are in boxes numbered *1* to *12* and comments on some of them are set out below:

Step 1: The basic data required for this step are of two types. The first consists of historical reports on earthquake damage (non instrumental, macro-seismic) from which the epicentre location and the size of the earthquake in terms of macroseismic intensity, *I*, are estimated. (Evidently, earthquakes off the coast or in unpopulated areas may escape the record partly or totally). The second type consists of data on earthquake parameters based on the analysis of seismograms. However, reliable locations on a world wide scale are not available before 1964, and earlier determinations of epicentre co-ordinates may be in error by 50 - 150 km, depending on the number and position of seismic stations. Historical records are urgently needed but they, as well as instrumental determinations prior to 1964, must be carefully checked before being processed. For the sake of reliability and consistency of statistical treatment, the principle of homogeneity in space, time and magnitude should be adhered to.

Step 2: In catalogues and in seismic maps the differential accuracy of earthquake parameters must be indicated.

Step 3: Active tectonics are indicative of increased seismic risk. The activity of a region may be denoted by recent and continuing vertical and horizontal movements, uplifting of coast lines and by large strains.

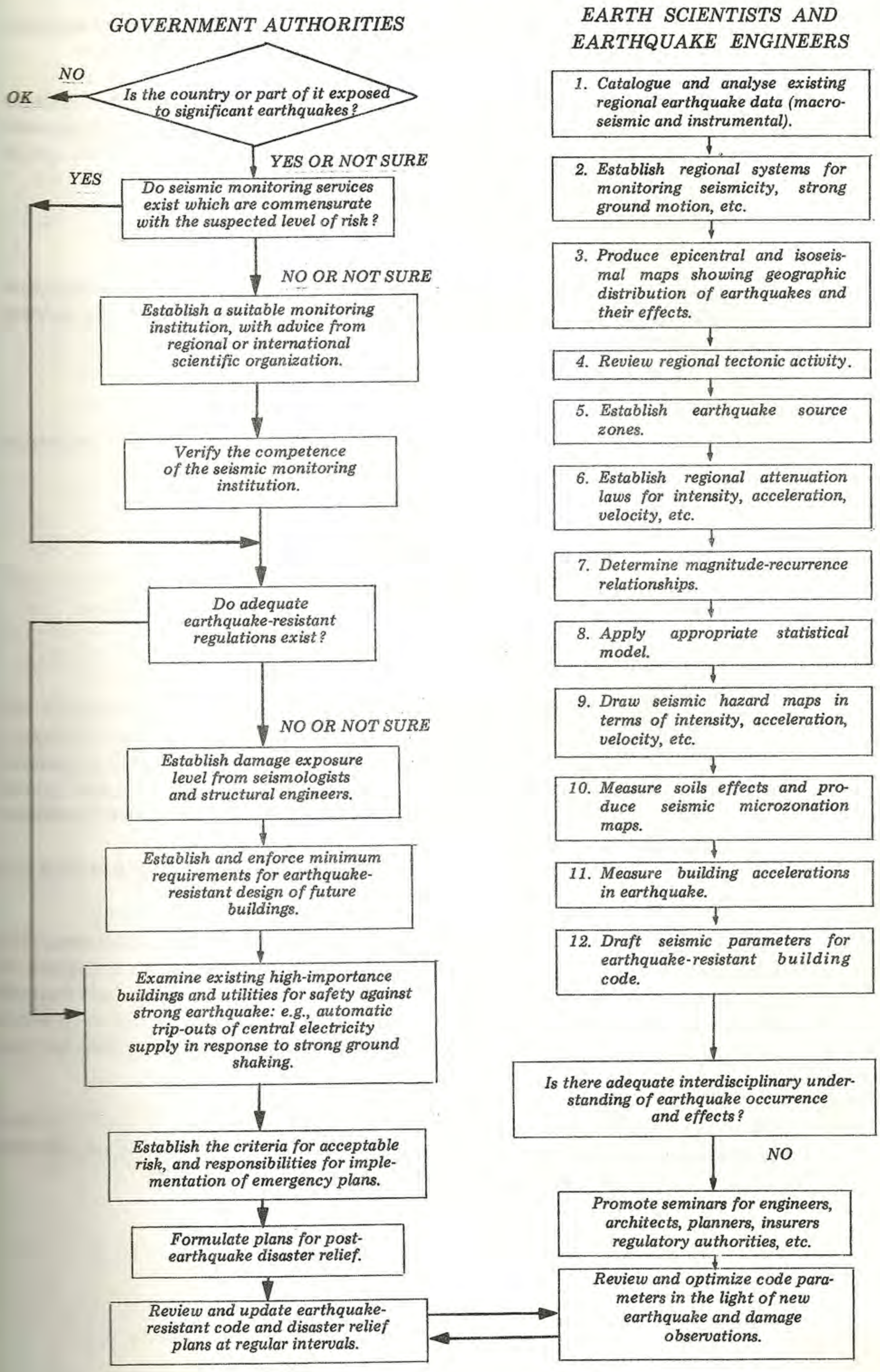
Step 4: Potential source areas are identified by means of the clustering of known epicentres and/or the location of faults active during the neotectonic era. The most difficult problem is the classification and period of movement along the faults.

Step 5: Suitable empirical curves are selected in order to represent the alternation of ground motion in relation to the variables — distance (D), magnitude (M), and focal depth (h). The main parameters may be the macroseismic intensity (I), or acceleration (a), or particle velocity (v), or displacement (d). A major problem is the lack of reliable attenuation curves for the most active regions. If curves from other regions are used, the resulting hazard figures should be used with caution. The attenuation curves usually refer to bedrock or to average ground conditions.

Step 6: The relationship between the average annual number (N) of earthquakes and their magnitude (M) defines the level of earthquake activity within the source area. The upper threshold magnitude limit (M_{max}) is estimated with the aid of several techniques of varying reliability, e.g. Gumbel's theory of extreme values, correlation of the lengths of active faults with (M_{max}), curvature of the recurrence plots, etc.

Step 7: Statistical models usually, as in the case of the Poisson model, assume independent events and a constant trend of earthquake activity, i.e. that the pattern of earthquake occurrence in the past will be repeated in the future. These assumptions are not strictly true and merely provide a first approximation, the reliability of which depends on the length of the sample. For mapping purposes the calculations are made for points of a grid and contours are then drawn.

FIGURE I: PLANNING FOR THE MITIGATION OF EARTHQUAKE DISASTERS



6.1.2 *Example of an empirical formula*

Many major earthquakes occur in close association with faults that have been recognized, or could have been recognized, in advance of the earthquake.

From studies of a number of cases of faulting, relationships may be established between the magnitude of the event *(M)*, the associated length of rupture *(L)* and maximum displacement *(R)* in centimetres. The following empirical formula, for example, is applicable in the Middle East:

$$Ms = 1.1 + 0.4 \log (L^{1.58} \quad R^{2}) \text{ for } 8 \geq M \geq 5$$

This equation or similar expressions for other areas may be used to estimate the maximum expected magnitude which might result from faults of known or inferred length and mobility in the area of interest.

6.1.3 *The activity of faults*

Using geological, seismological and historical data it is often possible to assess the relative activity of a geological fault and to classify it into one of the following categories:

(i) *Active*
(ii) *Potentially active*
(iii) *Uncertain activity*
(iv) *Inactive.*

These categories are described briefly below:

(i) *Active faults* — These are marked by historical or recent surface faulting associated with damaging earthquakes; by tectonic fault creep or geodetic indication of fault movement; by geologically young deposits being displaced or cut by faulting; by fresh geomorphic features characteristic of active fault zones present along the fault trace; by physical ground water barriers in geologically young deposits; by stratigraphic displacement of quaternary deposits by faulting; by offset streams.
Seismologically, earthquake epicentres are associated with individual faults with a high degree of confidence.

(ii) *Potentially active faults* — There is no reliable report of historic surface faulting; faults which may be found in older alluvial deposits but are not known to cut or displace the most recent alluvial deposits; geomorphic features characteristic of active fault zones are subdued, eroded and discontinuous; water barriers may be present in older materials. Seismologically, there is alignment of some earthquake foci along the fault trace but locations are assigned with a low degree of confidence.

(iii) *Faults of uncertain activity* — This category is used if the available information is insufficient to comply with criteria which would establish fault activity. If the fault is considered critical to the sites, additional studies are necessary to establish its category.

(iv) Inactive faults — A thorough study of local sources of historical information has not given evidence of any activity. Geologically, features characteristic of active fault zones are not present and no geological evidence has been found to indicate that the fault has moved in the recent past and has been recognized as a source of earthquakes.

6.1.4 *Fault recognition*

Criteria for recognizing an active fault may be summarized under geological, seismological and historical headings as follows:

(i) Geological criteria — An active fault is indicated by young geomorphic features such as:

- fault scarps
- triangular facets
- fault rift
- pressure ridges
- offset streams
- enclosed depressions
- fault valleys
- rejuvenated streams
- folding or warping of young deposits
- ground water barriers in recent alluvium
- echelon faults on recent surfaces.

Erosional features are sometimes associated with active faults but are not necessarily indicators of active faults.

(ii) Seismological criteria — Earthquakes and micro-earthquakes when fairly precisely located with the aid of instruments may indicate an active fault. However, a lack of known earthquakes should not be regarded as an indication that a fault is inactive.

(iii) Historical criteria — Historical sources such as manuscripts, personal information and local traditions may contain valuable data on past earthquakes. Fault movements or creep may be detected from displaced man-made lineaments.

6.2 *Hazards during earthquakes*

While an earthquake is in progress, major hazards may arise as a result of the particular geological materials present in the localities where seismic shocks are taking place. Some notes on this important aspect are given in the following sub-sections.

6.2.1 *Fractured bedrock on steep slopes*

Large masses of fractured rock forming the walls of valleys may be dislodged by a strong seismic shock. If the difference in elevation between the potentially unstable mass and the valley floor is sufficient for the mass to gain high momentum, the mode of movement will change from sliding and tumbling to an extremely rapid and destructive flow of rock fragments.

Once mobilized, such a flow has high kinetic energy and may travel a considerable distance up the opposite valley side or turn down the valley at speeds up to 200 km/h for a long distance, destroying everything in its path.

An example of a very destructive rock fall - debris avalanche - is that caused by the 31 May 1970 earthquake in Peru which caused a portion of the north-west face of Huascaran Peak to fail. The mass crashed down on the lower slopes, picked up water and flowed with high velocity down the valley. It surmounted a ridge and overwhelmed the city of Yungay, killing about 19,000 inhabitants. The effects of the subsequent flow of debris down the Rio Santa were felt far downstream and included damage to a major hydroelectric power plant which was put out of operation for many months.

The Yungay disaster was not an unprecedented occurrence. A similar, smaller failure killed several thousand people at Ranrahirca, an adjoining town, in the 1960's. Moreover, the presence of old debris avalanche deposits in the valley indicates that there have been several similar occurrences in the past. The present re-located site of Yungay is on such an old deposit and for this reason the hazard to present inhabitants still remains.

6.2.2 *Loose surface materials on steep slopes*

Steep slopes of coherent bedrock often have a surface covering of weathered material or soil a few metres thick. This material is often wet or saturated by rain or snow melt and the contact with underlying firm material forms a surface of low shear strength. Earthquakes can cause this layer to fail and descend rapidly, destroying farms on the slope and villages in the valley below. Such failures have resulted in heavy casualties in many areas of the world particularly in mountainous regions in tropical and temperate climates. The situation is aggravated where slash and burn agricultural practice has destroyed natural vegetation cover.

There may also be loose deposits on steep slopes not derived from the underlying rock but by deposition from the air, such as volcanic pumice or loose wind-blown silt. If such deposits are deep, a particularly dangerous hazard arises. Slope failures during the 1976 Guatemala earthquake were practically confined to areas covered by dense layers of pumice. In some regions more than 50 per cent of the slopes failed, sending soil and trees into the valleys below. Large and catastrophic failures of thick deposits of wind-blown silt (loess) have occurred repeatedly in Central Asia, such as the disaster in Kansu province China in a 1970 earthquake where some 100,000 people were killed by loess flows that came off the slopes and filled the valleys. Similar failures of loess have caused heavy damage in Tadzhikistan in the USSR.

6.2.3 *Liquefaction of loose flat-lying sedimentary deposits*

Some deposits in flat alluvial valleys have a very loose structure that is disturbed by seismic vibration. In consequence the component particles of a "sensitive" clay or fine sand, for example, assume a closer packing and smaller bulk volume. If the layer is initially saturated, the load from material above would not be carried by solid-to-solid grain contact but by the interstitial water. A soil in such a condition has effectively zero shear strength, and thus the sediments above are free to move under gravity forces towards any free face. The whole of the material above the liquefied layer may then spread laterally and break up into smaller units. Moreover, if buildings are founded upon a layer which is subject to liquefaction they may subside, break up, or tip over. Standard penetration tests and mechanical analysis of soils may be used as a first estimate for determining liquefaction potential.

6.2.4 *Cohesive natural embankments, levees and earth dams*

More or less homogeneous cohesive materials may fail by slumping along curved shear surfaces under strong seismic shock, particularly if the material is saturated. Failures in the open air are generally not common or so rapid that they present a serious hazard to life although property may be destroyed.

However, if the material forms a levee or dam and is saturated, at least in part, failure may be rapid and extensive and lead to release of impounded water with consequent hazard to life and property. An example is the failure of the lower San Fernando Dam at the time of the San Fernando earthquake (USA). The dam was not completely breached but only 3-4 feet of freeboard remained. The lives and property of about 50,000 people in the urban area below the dam were imperilled and immediate evacuation was necessary until the water behind the dam was lowered to a safe level.

6.3 *Landslides*

6.3.1 *Concepts and risk management*

The term "landslide" is here used in its broad sense to include downward and outward movement of slope-forming materials - either natural rock and soil or artificial fill - by falling, toppling, true sliding along a surface or surfaces of shear failure, or by distributed movements involving lateral spreading or flowing.

Although individual slope failures generally are not so spectacular or so costly as some other natural catastrophes, they are more widespread and the total financial loss due to slope failures probably is greater than that for any other single geologic hazard to mankind. Moreover, much of the loss of life and damage occurring in conjunction with earthquakes and heavy rainfall are due to landslides triggered by shaking or by water.

Risk management requires knowledge of the specific areas which are subject to the hazard and, if possible, the ability to predict the time of occurrence. In this context, landslides are a type of hazard that is susceptible to a considerable degree of rational management. The kinds of geological and topographic environments that lead to high incidence of slope failures and the triggering agents that precipitate failure are relatively well known. Mapping of areas subject to slope movements and delineation of the degree of hazard are now being successfully pursued in many parts of the world and the techniques used can be widely applied at various levels of detail and sophistication.

Figure 2, taken from a paper by Oyagi (1978), gives a schematic outline of the policy-making and investigational procedures which should be undertaken in planning to prevent or to mitigate landslide disasters.

6.3.2 *Information required to assess risk*

Devastating landslides rarely occur where there have been no previous failures in adjoining or nearby areas, unless, of course, the activities of man have produced a new and dangerous setting. Therefore, the requirements in delineating the hazard are:

(i) Knowledge of *where* past failures have occurred. Such knowledge is generally available from local records. For evaluation of the hazard in broad areas, the interpretation of aerial photographs by an expert in landslide recognition is effective, quick, and not very expensive. This technique should, however, be validated by examination on the ground.

(ii) In order to make an adequate assessment of the stability of areas that have not yet failed, it is necessary to determine *how* and *why* the existing failures occurred. A geologist trained in photo-interpretation can often make reasonable inferences regarding the mechanism of failure and, in favorable circumstances, tell something about the geological conditions that contributed to instability. However, actual ground examination is generally necessary as well.

(iii) For many purposes it is necessary also to determine, if possible, *when* failure occurred. This condition requires, for historic failure, correlation with all available information concerning possible triggering events, such as earthquakes, heavy rains, erosion, or man-made excavations.

The kinds of information required will range in detail from areal surveys to physical borings, sampling, testing of materials, and stability analyses, depending on the appropriate scale of the investigation and on the investment cost of the proposed development. In any event, experience has shown that the benefit/cost ratio of adequate information on engineering geology prior to development or design is very high, of the order of at least 10 to 1 and, in some cases, nearly 1,000 to 1.

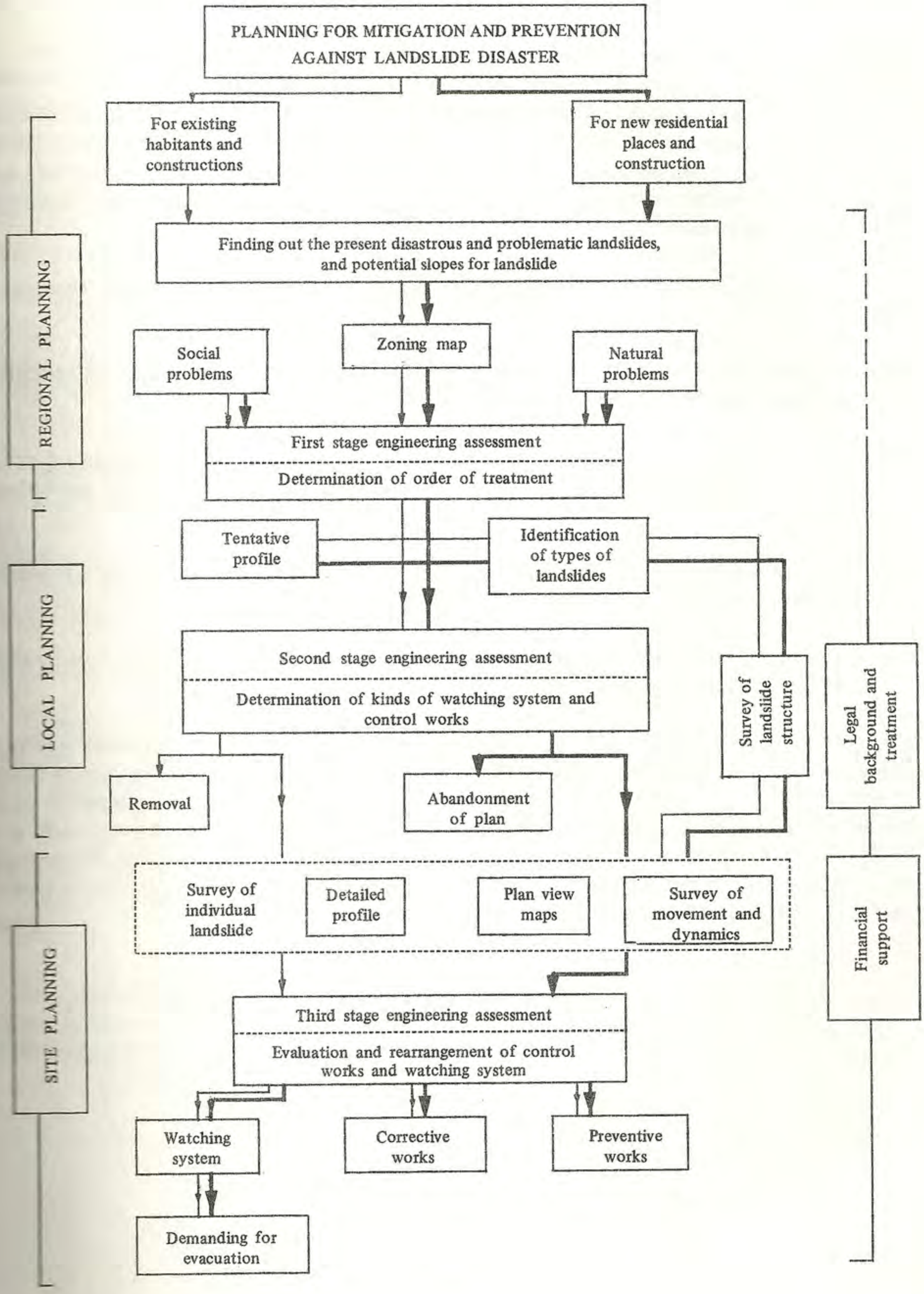
6.3.3 *Advice on using information*

The most effective application of information concerning slope stability is clearly to be made prior to development or construction. This precautionary action can be provided for by national, state, or local legislation, statute, ordinance, or building codes. Such legal instruments exist in many areas and can serve as models for appropriate design of land-use constraints elsewhere.

In the main, it is a matter of education and of promotional effort by engineering geologists among planners, legislators, and the public to show what can be done, at what cost, and with what benefits.

As in most hazards, avoidance or prevention is much more effective than cure. Once a landslide has started at a critical site, re-establishing stability is almost always a difficult, expensive and time-consuming task. Avoidance is often practicable and simple given adequate pre-investigation. Protection, if the area cannot be avoided, is often possible by means of appropriate modification of design. Cure can in itself be extremely expensive.

FIGURE 2: GENERAL SCHEME FOR PLANNING AGAINST LANDSLIDE DISASTERS (Oyagi 1978)



6.3.4 *Composite risk analysis and mapping*

Landslide incidence and susceptibility have been mapped at scales ranging from 1 : 7,500,000 (in the U.S.) to 1: 1,000 - 2,000, in many other parts of the world in all kinds of environments.

6.4 *Seismic microzonation*

Seismic hazard analysis provides probabilities of occurrence or exceedance of a certain ground motion parameter related to a reference ground for which the attention functions are compiled. However, for planning or construction on the scale of a town, the hazard estimates should be modified because of the strong influence of the ground on the frequency and amplitude of ground motion.

The procedure of determining the corrections is called seismic microzonation. The existing methods use:

(i) recordings of weak shocks or aftershocks at locations with different ground conditions and the process of extrapolation of the data to records of large shocks;

(ii) theoretical calculation of ground response using information on thickness of layers and on elastic parameters of underlying rocks, and assuming a given input at the soil-bedrock boundary;

(iii) simultaneous recordings of seismic noise (with periods of 0.1 second up to 1.0 second) at different points of an area and comparison of the amplitude;

(iv) measurement of seismic impedance using the propagation velocity of *P* and *S* waves along profiles crossing the area.

The above techniques are listed in the order of preference and the application of two or three such methods is desirable. The results may substantially change the average hazard figures. The above techniques provide information only within the elastic range of deformation of the foundation materials and should be used with caution in deposits of low shear strength or in materials which may lose their shear strength with increasing intensity of shaking. The scientific uncertainties which beset micro-zoning techniques demand that extreme caution be taken when trying to carry out micro-zoning of recent alluvial deposits.

VII. VOLCANOES

7.1 *Introduction*

Volcanic emergencies differ from other types of large-scale emergency such as earthquakes and hurricanes in that it is possible to delineate very specific and relatively small danger areas of generally less than 100 km^2 where devastation may be nearly total. In a situation where an eruption threatens to become violent, evacuation becomes a logical and necessary step. Precursors to a possible violent eruption of a known volcano may develop over a period as long as many months before the eruptive climax, and this poses the problem of deciding upon the point at which the evacuation of population becomes necessary and also the point at which the evacuation should be ended.

In other regions where volcanic activity occurs at locations over a wide area without clear correlation with previous craters, the interpretation of possible precursors is more difficult. Decisions involving mitigation of risk after the outbreak of an eruption should, however, be based on experience of the character and course of previous eruptions at the better-known volcanoes in the region.

There are numerous different types of volcanic activity which present substantially different hazards. For example, glowing avalanches may descend the flanks of a volcano at speeds in excess of 100 km/h, whilst lava flows generally advance at no more than a few tens of metres per hour. A detailed review of the different types of volcanic activity, their physical consequences and the appropriate protective measures to be applied is given in the UNDRO publication entitled "Disaster prevention and mitigation — Volume 7 : Volcanological Aspects".

7.2 *Hazard zoning*

Information on volcanic hazard needed by civil defence authorities in volcanic areas is best presented in the form of hazard zoning maps. Such maps must be based on the records of each volcano's history, using all historical data supplemented and extended back by stratigraphic studies. The products of each eruption should be identified, their areal distribution and volume measured, and the type of eruption established. It is also worthwhile monitoring the chemical composition of the materials emitted during the course of a prolonged eruption, because systematic change in composition can in some cases be correlated with the type and violence of volcanic activity.

Such zoning maps show the nature and frequency of specific volcanic hazards, and hence the risk to life and property. These maps are assential when planning action to minimize risk if and when an eruption happens.

7.3 *Risk assessment and mitigation*

Where the type of volcanic activity is capable of causing total devastation, the vulnerability is 100 per cent and the risk is directly proportional to the hazard. A numerical assessment of the hazard should be made by vulcanologists after they have carried out a systematic and comprehensive study of relevant historical precedents.

The nature and violence of most volcanic phenomena make it practically impossible to reduce the vulnerability of human life and property to below 100 per cent. The only way to mitigate risk is therefore to reduce the elements at risk either, on a long-term basis, by restricting human settlement and investment in hazardous zones or, on a short-term basis, by evacuating populations and movable goods from such zones during periods of increased hazard (i.e. periods of actual or predicted eruptive activity).

There nevertheless remain certain possibilities of reducing vulnerability to some volcanic phenomena such as ash falls, lapilli showers, etc. Sloping roofs are less liable than flat roofs to collapse under layers of ash; windows of houses may be boarded up to reduce the risk of fires started by incandescent lava bombs, etc; some agricultural crops are less vulnerable to ash falls than others.

7.4 *Methods of hazard assessment*

The essential problem of volcanic prediction is not the identification of the onset of an eruption, but the assessment of the level to which the activity will ultimately escalate and the rate of escalation. There are no specific precursors to eruptive climaxes such as the emission of glowing avalanches, and it is therefore necessary to assess the situation on a probabilistic basis, utilizing:

(i) Global statistics for the onset of glowing avalanche emission as a function of time elapsed after the beginning of the eruption.

(ii) Regional statistics on the ratio of eruptions, which have included glowing avalanche emission, to those which had no associated avalanches.

(iii) Historical data on, or geological reconstructions of, the particular eruptive characteristics of the volcano in question.

(iv) A weighting factor to take into account the trend of activity, i.e. whether increasing or decreasing, at the eruption in question.

From recent studies made on the first two of the above items, probability statistics can be given for example for the time interval between the onset of eruption and the emission of the first glowing avalanche. From these the probability can be given whether a glowing avalanche is yet to occur, as a function of time elapsed since the eruption onset. Similar probability assessments based on global or regional experience could be made for other types of volcanic activity, e.g. tephra falls, mudflows and lava flows. The problem of quantifying the hazard is one of the least well defined but one of the most critical issues in volcanic risk management.

VIII. RISK ANALYSIS — A METHODOLOGY

8.1 *Factors affecting impact*

Much work has been done in the earth sciences to define the physical characteristics of earthquakes, storms and floods. Less has been done to carry the analysis one step further, i.e. to increase the basic understanding of how these natural phenomena by their severity, including the occurrence of natural disasters, can affect lives and property.

For a number of purposes (such as disaster preparedness, regional and settlement planning and insurance activities), it is necessary to estimate the casualty and damage potential of geophysical events on existing or future populations and properties at risk, using whatever pertinent information is currently available. Operational decisions must be made on a day-to-day basis whether or not appropriate background knowledge is available.

One method that has been found to be useful particularly for insurance purposes is based upon the utilization of computer simulation techniques for approximating the overlapping and interaction of storm, flood and earthquake severity patterns with the spatial arrays of population and properties at risk.

The interaction of four factors determines the magnitude of natural hazard impact:

- The first factor is the geographical pattern of the severity of the phenomenon. For a tropical cyclone, it is the pattern of highest wind which occurred during the storm's passage and the geographical extent and depth of coastal inundation caused by the storm surge. For an earthquake, corresponding examples are the geographic pattern of strong motion, the potential for fire following and earthquake, and flooding caused by the possible occurrence of an accompanying tsunami.
- The second factor is the number, spatial distribution and density of population which is exposed to the effects of the various natural hazards.
- The third factor is the vulnerability of the elements at risk when they are subjected to a given wind speed, flood depth or strong ground motion intensity.
- The final factor is the effect of local conditions in modifying the severity of the event at a given location. In the case of wind, speed and direction can be markedly affected by natural topographical features, such as hills and valleys, and by the presence of towns or even isolated buildings. In regard to storm surge, the depth and extent of the inundation at a given coastal location is influenced by the shape of the coastline, the depth of offshore water and, of course, by any defences such as sea-walls. As regards earthquakes, local ground conditions can markedly affect the severity of ground motion. The spatial interactions of these factors determine the loss-producing potential of the storm or earthquake.

8.2 *Method of approximation*

In order to approximate the risk, a means was needed for obtaining a quantitative specification of the geographical arrays of various populations and properties at risk in the United States. A computerized grid system was constructed which was based upon a one-tenth of a degree latitude by one-tenth of a degree longitude unit grid. About eighty-five thousand units are needed to represent the three million square mile area of the forty-eight continguous states. Each grid area contains about 100 square kilimeters at the latitude of northern Florida. Information on population, their vulnerabilities to loss, and the effect of local influences on the severity of an event can be assigned to each grid.

For general impact assessment purposes, a detailed measure of the geographical distribution of the two hundred and twenty million persons and fifty million single-family dwellings in the United States has been obtained by allocation of numbers of persons and properties to the appropriate grid unit addressed in the computerized data bank. This national grid system is currently being used to assess the casualty and damage potentials of the various effects associated with the occurrence of different geophysical events. For earthquakes, the effects of strong ground motion on low-rise, medium and high-rise buildings and the possibilities of fire following earthquake are estimated. For tropical cyclones, the wind and storm surge hazard impacts are simulated. Effects of associated phenomena caused by severe thunderstorm activity (e.g. along a squall line, tornadoes and hail) are also approximated.

Specification of the geographical severity patterns (maximum wind speed, surge depth, ground motion) that can be expected as a result of the occurrence of a geophysical event can be attempted. To provide a means of approximating these patterns, mathematical generators have been developed. These computer-derived patterns are compared and verified with actual storm and earthquake patterns whenever possible. In general, they provide adequate approximations of observed conditions although each geophysical event has its own uniqueness. However, there are internal consistencies and physical constraints on pattern size, shape and severity gradient among events with comparable physical characteristics. It is these pattern consistencies on which the mathematical generators are based. For tropical cyclones, the geographical severity patterns (maximum wind speed and storm surge depth) are based upon particular combinations of physical characteristics (storm intensity as measured by central barometric pressure, storm size, rate of storm movement, stage of development and so storm path). For earthquakes, the geographical pattern of effects is expressed in terms of modified Mercalli intensity. In the case of California this pattern is expressed in terms of spectral velocity or spectral acceleration by wave length category for various types of buildings based upon physical characteristics of an earthquake (Richter magnitude, depth, epicentre location, type and orientation of fault zone). These mathematically generated severity patterns, which are based upon currently available information in meteorology and seismology, provide a very rough first approximation of the geophysical event that can be applied to the population-at-risk array for obtaining at least order-of-magnitude estimates of potential impact.

8.3 *Simulated impacts*

These generated patterns are mathematically superimposed upon the spatial arrays of population and property in the affected areas. Interaction of the casualty and damage vulnerabilities of the population and property array together with these severity patterns provide a measure of impact potential of the simulated storm or earthquake. Summarization of the computed effects can be made by individual grid unit, country, state, wind speed, surge depth or ground motion intensity category. Damage impact potential of a simulated storm or earthquake to a specific kind of property such as buildings of a given type, can be expressed in terms of the number of buildings that are exposed to wind, surge depth, or ground motion of a given intensity, the number of buildings that would be damaged, and the expected value of the damage to the affected buildings.

8.4 *Possible application to urban and regional planning*

In spite of many drawbacks, for example because of the lack of appropriate input data, computer simulation techniques provide one means of utilizing the meagre amounts of pertinent data and knowledge that are currently available, for making order-of-magnitude assessments of the potential impact of the various natural hazards. In many situations the results of simulation analyses, provide insights into the casualty and damage-producing capabilities of a natural phenomenon to a degree which cannot be obtained using other approaches.

The interpretation of results can highlight the relative importance of various pieces of input information in determining the magnitude of the potential impact. The need for a better knowledge of the vulnerability of population and properties when a geophysical event of a given severity occurs, has been emphasized in the simulated impacts that have been calculated.

A version of this approach could possibly be used in developing countries in order to identify gaps in the information and data required for making natural risk impact assessments. It is possible that many of the basic information needs of the regional and city planner can be satisfied with the use of current knowledge about the physical characteristics of storms and earthquakes in the area, without waiting for a number of years for more detailed and accurate information. A computerised simulation approach has been used to provide flood loss estimates for the fifty million single-family dwellings affected by this hazard in the United States. The results of these simulations provided a basis for the development of a joint federal government and insurance industry national flood insurance programme which is now operational.

IX. RISK ANALYSIS AND PHYSICAL PLANNING

Disasters have major direct and indirect socio-economic effects, in addition to the physical destruction that may occur. This is even more significant in developing countries where the lag between economic development and demographic growth is already considerable.

As has been said above, disasters have both immediate and long-term implications and plans formulated for disaster-prone areas should cover both these contingencies. It should also be remembered that a disastrous occurence may initiate a chain of severe hazards in addition to the direct impact damage.

Risk analysis and mapping should be carried out not only to meet the requirements of physical planning but also of sound economic and social development. Maps needed for such purposes should indicate risk implications of each type of natural phenomenon and attempt to identify and guide the formulation of appropriate action programmes, development controls, land-use zoning regulations and special building codes, etc. For the respective types of hazards these should ideally be at the micro-level. It is also necessary to provide a composite risk indicator for guiding policy decisions on development planning and macro-level land-use zoning. The approach to risk assessment and mapping should be aimed at meeting these criteria so as to provide useful guidance to generalists such as planners, administrators, entrepreneurs and the community at risk. The information to be provided for these objectives should include space defined information on magnitude, frequency, duration, areal extent and speed of onset.

The series of action programmes that would need such detailed risk assessment and description include:

1. *Physical planning*

   (a) *Long term*

   - *(i)* Regional plans, master plans (macro-level) including settlement development plans.
   - *(ii)* Re-development and re-settlement plans.
   - *(iii)* Area development plans (micro-level).
   - *(iv)* Land-use and zoning (micro-level).
   - *(v)* Development control.
   - *(vi)* Special building codes including guidance on construction techniques.
   - *(vii)* Master plans and detailed plans for infrastructural facilities.
   - *(viii)* Plans for evacuation routes and development of safety shelter network and communication links.

(b) Short term

- *(i)* Site selection for temporary emergency facilities (transit camps, relief centre network organization, supply routes, etc.).
- *(ii)* Development of alternative relief/rescue routes and communication links.

2. *Socio-economic planning*

- *(i)* Industrial and other capital intensive development projects.
- *(ii)* Scheduling of human activities in terms of restricting/reducing such activities in defined crisis periods, modifying cropping patterns for avoidance of crisis period and introducing appropriate alternate non-vulnerable species, etc., in areas of risk.

3. *Administration*

Organization of administrative machinery for pre- and post disaster operations at governmental, non-governmental and community levels.

X. RECOMMENDATIONS

1. UNDRO, as the focal point in the United Nations system for activities and studies concerned with disasters, should in the implementation of the following recommendations and in other appropriate ways, further develop and extend its co-operation with UN agencies and with other bodies having responsibilities in the field of disaster management.

2. In view of the very wide potential application context of risk and vulnerability analysis, UNDRO should make fuller use of specialist advice in the formulation of projects in this field.

3. The report of this meeting should be regarded as an interim study of the problems of vulnerability and risk. UNDRO should circulate the report, inviting comment from UN member countries, specialized agencies and other interested bodies. At the same time UNDRO should arrange for detailed studies of vulnerability analysis leading to a comprehensive publication on the subject. The proposed new publication would cover such activities as the testing of the terminology proposed in Chapter I for all types of natural disasters, the preparation of a more detailed specification of the types of information required for all the different natural disasters, the calculation of specific risk and total risk for a number of examples of important natural hazards, assembly of examples of the use of information on natural hazard and vulnerability in the planning process, and so on. (The meeting was pleased to learn that plans for the proposed publication are included in the UNEP/UNDRO series of monographs on Disaster Prevention and Mitigation).

4. It is recommended that existing UNDRO publications be reviewed, where appropriate. The case study on composite vulnerability analysis in the Metro Manila Area should be revised in the light of the concepts developed at the present meeting.
   In this way consistent series of publications would be produced comprising:
   - *a)* a basic report on concepts and methodology,
   - *b)* a series of volumes on current knowledge of various aspects of vulnerability analysis and related problems,
   - *c)* case studies providing valuable guidance to all concerned.

5. Taking into account the recommendations and proposals of this meeting, studies of vulnerability analysis, such as that concerned with the Metro Manila Area, should be continued, preferably in the form of pilot projects involving the participation of local organizations and their staffs and co-ordinated by UNDRO. In addition, UNDRO in conjunction with UNCHS (Habitat) should promote studies of the impact of national disasters on human settlements.

6. UNDRO should initiate and collaborate in programmes aimed at a considerable expansion of the amount of data available on natural hazard, vulnerability and risk relating to all types of natural disasters and should organize a project for the development of a methodology on damage assessment.

7. UNDRO and UNCHS (Habitat) should jointly organize an emergency task force for immediate and appropriate response to on the occurrence of a natural disaster affecting human settlements.
   The task force would evaluate the impact of a disaster on the settlement structure and would draw conclusions on physical planning and urban design patterns and the interrelated vulnerability. The task force would also advise local authorities on action to be taken urgently and would formulate proposals for technical assistance programmes.

8. UNDRO should organize training courses in developing countries on damage assessment, vulnerability analysis and risk assessment.

9. UNDRO should undertake periodical reviews of progress achieved in damage assessment, vulnerability and risk, and should try to ensure steady advance over the whole spectrum from hazard analysis to policy and planning decisions.
   Such reviews might usefully be carried out in conjunction with appropriate research institutions. In these reviews the main emphasis should gradually shift from hazard/vulnerability/risk definition and analysis to the development of planning techniques using knowledge and experience gained.

10. UNDRO, besides adopting the terms and definitions produced by the meeting, should endeavour to promote their general usage, at the same time inviting comments on the value of these terms and definitions in practical application.

11. UNDRO should support in all appropriate ways earthquake reconnaissance missions, such as those organized by UNESCO. Such missions would, *inter alia*, gather quantitative observational data, thereby helping to overcome the extreme paucity of such data relating particularly to the vulnerability of buildings and structures to earthquake ground movements.

AGENDA

1. Opening of meeting — Address by the UN Disaster Relief Co-ordinator.
2. Election of Chairman and Rapporteur.
3. Adoption of agenda.
4. Plenary review and discussion of work undertaken by UNDRO and others in vulnerability analysis: comments on UNDRO studies, definition of concepts and parameters.
5. Organization of meeting into working groups to consider specific aspects of the problem, and preparation of draft reports and recommendations on each of them.
6. Discussion in plenary of group reports and amalgamation of these into an integrated whole.
7. Adoption of report.
8. Closure of meeting.

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- Food and Agriculture Organization
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- United Nations Centre for Human Settlements (Habitat)
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- United Nations Development Programme
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NOTE ON THE DEFINITION OF THE CONCEPT OF VULNERABILITY AND ON THE EVALUATION OF THE RISK ATTACHED TO NATURAL PHENOMENA

1. *General*

The purpose of this note is to summarize the main lines of a method for evaluating in a way as simple as possible the probable loss associated with natural hazards for a given population of construction, facilities, etc., at a given site.

The concepts to be introduced or taken into account are:

- the randomness of natural hazards at the given site,
- the vulnerability of the structures located on the site,
- the importance of the elements (human population, capacities of production, dwellings, invested capitals, etc.) possibly affected, these elements are referred to as "elements at risk",
- the risk which is the probable loss to be expected within a fixed period of time (period of reference).

Each kind of phenomenon defined, with respect to its effects on the site, by its magnitude (x) which is a variable or a set of variables. The distribution of (x) is generally known through the function $\emptyset\ (x)$, which defines the probability of the magnitude x being exceeded within the period of reference. Alternatively, the functions $F(x) = 1 - \emptyset\ (x)$ which defines the probability of x not being exceeded, or $p(x) = \frac{dF}{dx}$, which is the probability density function, can be used.

The vulnerability may be expressed as the degree of damage inflicted on a structure or on a population of structures by a natural phenomenon of given magnitude. Let α be this degree of damage which is expressed as a random function of x. It is a function of x

$$\alpha = \alpha\ (x)$$

2. *Theoretical background*

A complete solution of the problem should involve the randomness of the mechanical properties of the structures (especially their strength) and of their vulnerability as defined above.

In this case, the evaluation of the risk should be performed in the following way:

The distribution of the hazard (H) is known through its probability density function $p_H(x)$ or the probability of exceedance $\emptyset_H(x)$.

The distribution of the strength *(S)* is known through its probability density function $p_S(h)$ or the probability of non-exceedance $F_S(x)$.

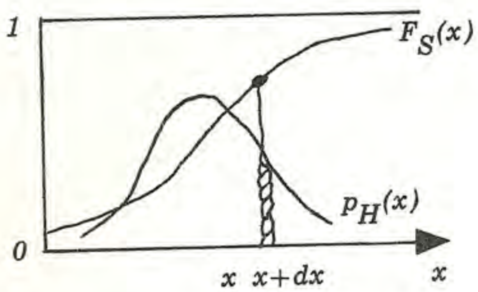

Figure 1

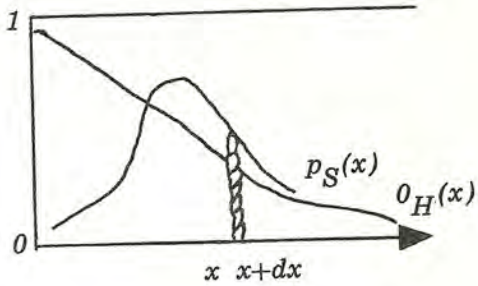

Figure 2

From Figure 1, it may be seen that the probability of failure associated with the probability of the hazard x being comprised between x and $x + dx$ is:

$$df = p_H \, F_S \, dx$$

From Figure 2, it may be seen that the probability of failure associated with the probability of the strength x lying between x and $x + dx$ is:

$$df = p_S \, \emptyset_H \, dx$$

so that the probability of failure for the whole distribution of x is:

$$f = \int_0^{\infty} p_H \, F_S \, dx = \int_0^{\infty} p_S \, \emptyset_H \, dx$$

The elementary specific risk associated with the probability of the magnitude of the event between x and x dx is:

$$\frac{dr}{(er)} = \alpha(x) \, p_H \, F_S \, dx = \alpha(x) \, p_S \, \emptyset_H \, dx$$

where *(er)* are the elements at risk and, the whole distribution, the specific risk is:

$$\frac{r}{er} = \int_0^{\infty} \alpha(x) \, F_S(x) \, p_H(x) \, dx = \int_0^{\infty} \alpha(x) \, p_S(x) \, \emptyset_H(x) \, dx$$

In both expressions, the first two terms under the sign of integration depend only upon the structures, and the third one only upon the natural phenomenon. The first two terms thus define the vulnerability when taking into account the randomness of the properties of structures. It may be seen that this definition changes depending upon whether the hazard is introduced through its probability of exceedance or through its density of probability.

Simplifications and practical applications

As the available data are not sufficient for treating the problem is the sophisticated way sketched above, and as such complexity is not desirable for practical purposes, simplifications appear to be necessary.

The first simplification is to consider that the randomness of the strength of structures and, as a consequence, of their vulnerability, is negligible with respect to the variability of the hazard.

In this case the function $\alpha(x)$ has a profile rather similar to the one represented in Figure 3.

Figure 3

From Figure 3 it may be seen that the elementary specific risk associated with the probability of the magnitude x lying between x and $x+dx$ is:

$$\frac{dr}{(er)} = \alpha(x)\; p_H\;(x)\; dx$$

and for the whole range of magnitudes, the specific risk is:

$$\frac{r}{er} = \int_0^{\infty} \alpha(x)\, p_H(x)\; dx$$

Taking into account the particular values of α for $x < x_0$ or $x > x_1$ yields:

$$\frac{r}{er} = \int_{x_0}^{x_n} \alpha\;(x)\; p_H\;(x)\, dx + \emptyset_H\;(x_1)$$

A further simplification, is to replace the curve (x) by a step function (Figure 4).

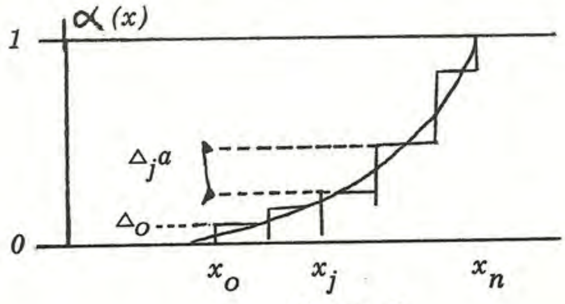

Figure 4

It may be seen that in this case the expression of the specific risk takes the form:

$$\frac{r}{(er)} = \sum_j \Delta_j \alpha \phi_j$$

The probability of exceedance ϕ_j is generally tabulated. The designer has only to compute the $\Delta \alpha$ from the table of the values of α and perform the summation above.

ANNEX IV

AN EXAMPLE OF A QUESTIONNAIRE ON DISASTER DAMAGE*

Questionnaire I

A SOCIO-ECONOMIC HOUSEHOLD SURVEY TO FIND OUT THE EXTENT OF DAMAGE CAUSED BY THE RECENT FLOODS AND LANDSLIDES IN THE NILGIRIS TOWN/DISTRICT

I. *GENERAL INFORMATION:*

1. Place ....
2. Taluk ....
3. District ....
4. Name of the Head of the Household ....

	Adults	Children
5. Household		
Male		
Female		

6. *a)* Household income from employment	Employment in Numbers	Monthly income in Rs.
i) Employment in private Offices		
ii) Employment in Government Offices		
iii) Employment in Plantations		
iv) Employment: Daily Wages		
v) Self Employed		

b) Household income from other sources	Monthly income in Rs.
i)	
ii)	
iii)	

c) Total monthly income of the Household in Rs.

7. Does the household posseses a dwelling Unit YES / NO

....

a) if "YES" please give details: Terraced/Tiled/Thatched/Mud Walls

b) if "NO" where are you put up:

8. Particulars regarding the property of the Household:

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*This questionnaire was used in the Anti-disaster Planning Programme of the State Government of Tamil Nadu, India.

Immovable		Movable	
List of items	Approximate value in Rs.	List of items	Approximate value in Rs.
a.		*a.*	
b.		*b.*	
c.		*c.*	
d.		*d.*	
e.		*e.*	
f.		*f.*	

II. *LOSS OF LIFE AND LIMB TO THE MEMBERS OF THE HOUSEHOLD:*

1. Has any member of the Household been affected physically by the floods or the landslides . . . . YES/NO
2. If "YES" state the nature of disablement: . . . . Sex: . . . . Age: . . . . Number: . . . . .
   - *i)* Loss of human life . . . .
   - *ii)* Physically hadicapped . . . .
3. Give details about the mishap: . . . .
4. Has the Household experienced any loss in domestic animals: . . . . YES/NO
5. If "YES" give particulars of the nature of loss: . . . .

Sl No.	Kind of animal	Number of animals lost	Value of animals lost in Rs. No.
	i) Cows		
	ii) Bullocks		
	iii) Sheep		
	iv)		
	v)		
	vi)		

III. *ECONOMIC LOSS TO THE HOUSEHOLD:*

1. Damage to Immovable property: Nature of damage Value of loss in Rs.
   - *a)* Dwelling house: . . . .
     - *i)* Washed away by the floods: . . . .
     - *ii)* Collapsed: . . . .
     - *iii)* Partially damaged: . . . .
2. Damage to Movable property:

Items	Nature of damage	Extent of damage	Nature of the damage in Rs.
a) Agricultural implements			
b) Bullock Carts			
c) Cycles			
d) Motor Cycles			
e) Tractors and Trucks			
f) Cars			
g) Pump Sets			
i) Oil engines			
ii) Electric installations			
h) Others			

3. Damage to crops:

a) Areas under cultivation:

Items	Extent in acres	Extent of afected area in acres	Value of loss in Rs.
a.			
b.			
c.			
d.			
e.			

b) Lands of the Household damaged due to floods and landslides:

Sl No.	Nature of damage	Extent in acres	Value of loss in Rs.
i)	Silt		
ii)	Uneven surface		
iii)	Loss of fertility		
iv)	Inundation		
v)	Others		

c) Source of Irrigation: Wells/Borewells/Piped water/Rain fed/Others

d) In there any damage to the irrigation supply: YES/NO

e) If "YES" please give details: . . . .

Sl No.	Irrigation system	Nature of damage	Extent of damage	Extent of loss in Rs.
i)	Wells			
ii)	Borewells			
iii)	Piped water			
iv)	Others			

4. Have you insured your crops? YES/NO
   - *a)* If "YES" what is the amount you have insured for?
   - *b)* Have you claimed compensation? YES/NO
   - *c)* If "YES" have you got it?
   - *d)* If "NO" what is your problem?

5. Other belongings of the household which haveeconomic value damaged may be listed out below:

Item	Nature of damage	Extent of damage	Value of loss in Rs.
i) Domestic utensils			
ii) Furniture			
iii) Textiles			
iv) Jewellery			
v) Foodgrains			
vi) Title deeds/bonds/share certificate/promissory notes/Mortgage deeds etc.			
vii) Others			

IV. *IMPACT ON THE SOCIAL CONDITIONS OF THE HOUSEHOLD BY THIS NATURAL DISASTER*

1. How does the Household feel the burden of this natural havoc?
2. Has the Household received the relief offered by the Government? YES/NO
3. If "YES" explain the nature of relief in detail:
4. If "NO" how did the members of the Household manage the situation?
5. Do you think whether the social tenor of your life has been affected in any way by the disaster? YES/NO
6. If "YES" how?
7. Remarks if any:

ANNEX IV

Questionnaire II

A SURVEY OF INDUSTRIAL ESTABLISHMENTS TO ASSESS THE DAMAGE CAUSED BY RECENT FLOODS AND LANDSLIDES IN THE NILGIRIS DISTRICT

MANUFACTURING/SERVICING

I. *IDENTIFICATION AND GENERAL DESCRIPTION*

1. Name of the establishment . . . .
2. Location
   - *i)* Municipality . . . .
   - *ii)* Ward/Area . . . .
   - *iii)* Street . . . .
3. Nature of ownership . . . . Proprietary/Partnership/Public or Private Ltd/Co-operative/Other
4. Date of the establishment of the firm . . . .
5. Number and type of Unit(s) . . . .
6. Name of
   - *i)* Principal products . . . .
   - *ii)* Services . . . .
7. *a)* Number of working days (last year) . . . .
   - *b)* Number of shifts . . . .
8. Capacity and production
   - *a)* What is the installed capacity of your establishment . . . .
   - *b)* What is the annual production
     - *i)* Quantity . . . .
     - *ii)* Value in Rs. . . . .
   - *c)* What is your production target for the year 1978
     - *i)* Quantity . . . .
     - *ii)* Value in Rs. . . . .
9. Raw material used:

	Items	Quantity	Value in Rs.
a.			
b.			
c.			
d.			

10. Employment

    Total working force employed
    - *i)* Men in numbers . . . .
    - *ii)* Women in numbers . . . .

11. Where are your products marketed
    - *i)* locally ....
    - *ii)* outside ....

12. Mode of transportation of finished goods: ROAD/RAIL

13. Whether this organization making profit or not: YES/NO

14. If "NO" what is the extent of loss ....

II. *DAMAGE CAUSED TO THE ESTABLISHMENTS BY THE RECENT FLOODS AND LANDSLIDES*

1. Has your establishment been affected by the recent natural disaster: YES/NO

2. If "YES" the extent of damage in terms of:
    - *a)* Number of man days/hours lost ....
    - *b)* Loss of total production
        - *i)* Quantity ....
        - *ii)* Value in Rs. ....
    - *c)* Damage to the building:

	Item	Nature of damage	How it occurred	Value of the damage in Rs.
i)	....	....	....	....
ii)	....	....	....	....
iii)	....	....	....	....

d) Damage to the machinery:

	Item	Nature of damage	How it occurred	Value of the damage in Rs.
i)	....	....	....	....
ii)	....	....	....	....
iii)	....	....	....	....

e) Loss of life and limb to the employees of the organization:
- *i)* Was there any loss in human life? YES/NO
- *ii)* If "YES" how many deaths?
    - Male ....
    - Female ....
- *iii)* How did it happen? ....
- *iv)* Was any one handicapped physically? YES/NO
- *v)* If "YES" how many?
    - Male ....
    - Female ....
- *vi)* How did it happen? ....
- *vii)* What is the nature of disablement? ....

f) Is there any damage caused to the stored items? YES/NO *g)* If "YES" what is the nature of the damage:

	Item	Nature of damage	How it occurred	Value of the damage in Rs.
i)	....			
ii)	....			
iii)	....			
iv)	....			

h) What is the approximate total loss caused by this disaster in Rs.

ANNEX IV

Questionnaire III

PROFORMA FOR COLLECTING THE PARTICULARS OF DAMAGE CAUSED BY THE RECENT FLOODS AND LANDSLIDES IN NILGIRIS FROM VARIOUS GOVERNMENTAL, SEMI-GOVERNMENT ORGANIZATIONS AND LOCAL BODIES

I. *DAMAGE TO GOVERNMENT ORGANIZATIONS*

1. Government of India undertaking:
   - Nature and extent of damage caused to the functionary departments of the Central Government organization in detail.

Name of the functionnary department	Nature of damage	Extent of damage	Damage in terms of Km/acres distance/area	Value loss in terms of Rs.
1. Central Public Works Department				
2. National Highways				
3. Post & Telegraphs				
4. Telephones				
5. State Farms Corporation				
6. Nationalized Corporation				
7. Central Warehousing Corporation				

2. State Government Undertakings
   a) Highways Department
      i) Damage caused to roads, bridges and culverts

Items	Nature of damage	Extent of damage	Damage in Km/in Nos.	Value loss in Rs.
By floods:				
1. Roads				
2. Culverts				
3. Bridges				
4. Others				

Items	Nature of damage	Extent of damage	Damage in Km/in Nos.	Value loss in Rs.
By land-slides:				
1. Roads				
2. Culverts				
3. Bridges				
4. Others				

b) Public Works Department:

  i) What is the damage caused to irrigation tanks? . . . .

  ii) Nature and extent of damage caused by the disaster? . . . .

  iii) What is the nature and extent of damage caused to the Traveller's Bungalow and buildings maintained by the P.W.D.?

    — Nature of damage . . . .
    — Number of buildings affected . . . .
    — Extent of damage . . . .
    — Value of loss in Rs. . . . .

c) Other Departments affected by the floods and landslides:

  i) Hospitals

    1. Nature of damage . . . .
    2. Extent of damage . . . .
    3. Damage to equipments and vehicles if any . . . .
    4. Damage to buildings . . . .
    5. Damage to medicines . . . .
    6. Damage to medical stores . . . .
    7. Value of loss in Rs. . . . .

  ii) Educational Institutions

    1. Number of institutions affected . . . .
    2. Nature of damage . . . .
    3. Damage to buildings . . . .
    4. Damage to equipments . . . .
    5. Extent of damage . . . .
    6. Value of loss in Rs. . . . .

  iii) Warehousing Corporations

    1. Number of godowns affected . . . .
    2. Nature of damage . . . .
    3. Extent of damage . . . .
    4. Damage to the stored articles . . . .
    5. Damage to buildings . . . .
    6. Value in loss in Rs. . . . .

  iv) Civil Supplies Corporation

    1. Nature of damage . . . .
    2. Extent of damage . . . .
    3. Value of loss in Rs. . . . .

  v) Government Transport System

    1. Is there any damage caused to the transport vehicles: YES/NO
    2. If "YES" what is the nature of the damage? . . . .
    3. Total number of vehicles damaged . . . .
    4. Is there any damage to the transport depots? YES/NO
    5. If "YES" what is the nature of the damage? . . . .
    6. The extent of damage . . . .
    7. Total value of loss in Rs. . . . .

II. *DAMAGE TO THE SEMI-GOVERNMENTAL ORGANIZATIONS*

1. Tamil Nadu Water and Drainage Board-Damage to: **Buildings/Installations**

  i) What is the nature of the damage? . . . .

  ii) What is the extent of the damage? . . . .

  iii) Value of loss in Rs. . . . .

2. Tamil Nadu Electricity Board

   a) What is the damage caused to:

      i) Transmission lines ....

      ii) Transformer stations ....

      iii) Buildings ....

      iv) Others ....

   b) What is the nature of damage ? ....

   c) What is the extent of damage ? ....

   d) Value of loss in Rs. ....

III. *DAMAGE TO LOCAL BODIES*

The nature and extent of damage caused under the following categories:

Major Heads	Nature of damage	Extent of damage	Damage in terms of distance/Nos. etc.	Value loss in Rs.
1. Roads				
2. Educational Institutions				
3. Buildings				
4. Hospital				
5. Water Supply				
6. Sewage				
7. Municipal Markets				

IV. *SPECIFIC SUGGESTIONS IF ANY*