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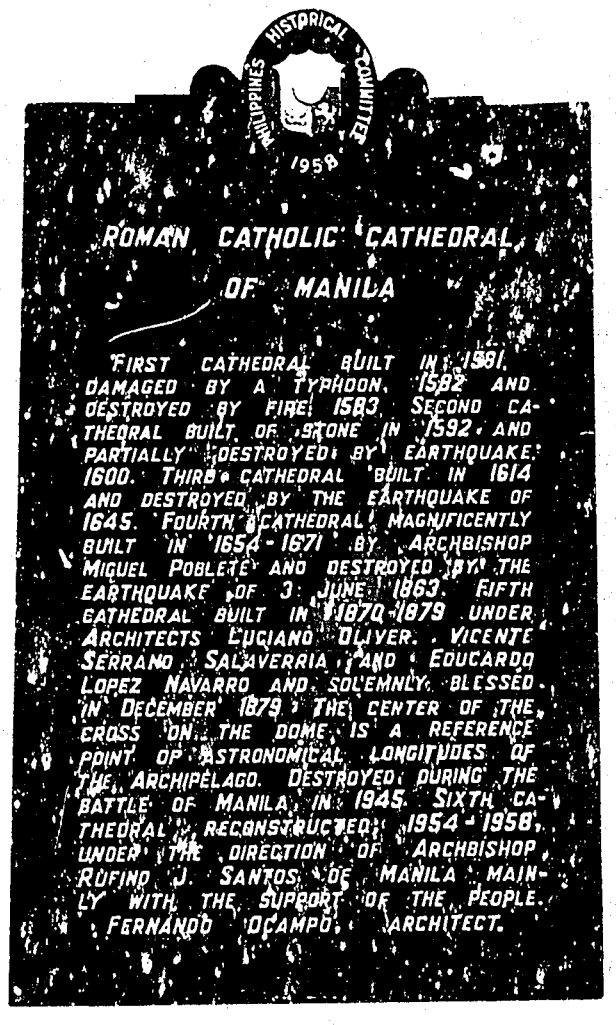
Series on Seismology

VOLUME I



SUMMARY

Front Cover

Plaque mounted on the west front of the latest Manila Cathedral illustrating the destructiveness of earthquakes in Southeast Asia.

SOUTHEAST ASIA ASSOCIATION OF SEISMOLOGY

AND EARTHQUAKE ENGINEERING

Mr. Ho Tong-Yuen, President
Dr. R. L. Kintanar, Vice-President

Series on Seismology

Volume I

Earthquake Hazard Mitigation Programme in Southeast Asia: Technical Evaluation, Executive Summary, and Final Report

PART A - EXECUTIVE SUMMARY

PART B - INTRODUCTION AND BACKGROUND

PART C - TECHNICAL REPORT AND EVALUATION OF RESULTS

PART D - CONCLUSIONS, RECOMMENDATIONS, AND ACKNOWLEDGEMENTS

by

E. P. Arnold

E. P. Arnold, Series Editor and Programme Co-ordinator

April 1986

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E.P. Arnold, Project Co-ordinator and Editor

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PART A EXECUTIVE SUMMARY

This document constitutes the final report for the project titled "An Earthquake Hazards Mitigation Program in Southeast Asia". It contains, in addition to this summary, a background of the project, a technical summary and evaluation of results, and a set of conclusions, recommendations, and acknowledgements.

The background includes a planning study which was performed by the U.S. Geological Survey and conducted in 1981. The goals were (1) through appropriate research to provide the governments of Southeast Asia (in this case, the governments of the Association of Southeast Asian Nations (ASEAN)) with the information necessary to formulate codes of earthquake resistant building design and to institute appropriate land-use codes; and (2) to establish an institutional framework for the continued study of earthquake hazards and to promote professional growth of scientific and technological capabilities in the ASEAN countries. Not all of the work proposed in the planning study could be finished but much has been accomplished.

The Southeast Asia Association of Seismology and Earthquake Engineering (SEASEE) was chosen as the institution on which to base earthquake hazard research as it was both ASEAN-wide in scope and a quasi-governmental organization. This project has increased not only the prestige of the organization itself, but also the professional expertise now available within the region. Administration, management, and professional leadership were provided by the U.S. Geological Survey.

The main body of this report concerns the primary scientific and technological accomplishments which have been made thus far. These are:

1. A complete set of the felt effects of earthquakes, which include damage and casualties, has been compiled. The first entry is for an earthquake in 624 B.C. in Thailand; the first entry in Indonesia is from 88 A.D.; the first in the Philippines is 1589; and the Malaysian catalogue, which also includes Singapore, begins in 1805. These catalogues of events were all translated into English and comprise about 5,000 pages. These compilations are to determine the recurrence frequencies of great earthquakes and to determine how fast earthquake effects diminish with increasing distance from the earthquake source (attenuation).

2. A catalogue of instrumentally located earthquakes was compiled dating from the year 1904 for the purposes of (1) more accurately locating the earthquakes, (2) associating them with known geological features and (3) more accurately measuring their size. There are over 3,000 events in this catalogue which was supplied on magnetic tape.

3. Nearly 2,000 focal mechanism solutions from instrumental data were collected or newly computed to aid in the interpretation of seismotectonic features.

4. From the data supplied in items 1 and 2 above, mathematical functions representing the attenuation of earthquake intensity with distance

from the earthquake were derived so that seismic hazard maps can be constructed in the future.

5. Seismotectonic interpretations were made relating earthquake occurrence to geological and tectonic features. These are presented as eight full- colour maps of the region in a common scale (1:3 000 000, mercator projection). These maps accompany this report.

6. Finally, using all the information above, the whole of Southeast Asia was divided into seismic source zones for the purpose of constructing seismic hazard maps. It is anticipated that earthquake hazard maps of the region will be developed in a later phase of research by SEASEE and the countries themselves.

This programme, thus far, is certainly a success. As it stands, all of the raw material necessary to construct seismic hazard maps and to embark on a programme of loss estimation is complete.

The basic data and analyses developed in this project represent the critical information required for earthquake hazard analysis. These data in themselves will be of great help to land use planners, building designers and, most particularly, disaster relief officials in the formulation of earthquake hazard reduction programs. As an example, figure 1 is a map of Indonesia which shows the areas of that country which have experienced destructive earthquakes in the 20th century (Ismail, 1985). The seismotectonic map of Indonesia appended to volume V of this work displays contours of maximum observed intensity which is a rudimentary type of hazard map in itself. Indeed, the documentation of the maximum observed earthquake shaking in the form of a maximum intensity map is an essential and critical step in any earthquake hazard reduction programme. Table 1 gives the population (United Nations, 1985) in each of 11 highest hazard areas indicated in figure 1, the average recurrence interval of destructive earthquakes in the first 79 years of the 20th century, and the maximum Modified Mercalli intensity experienced in that region since 1821 as taken from the seismotectonic map. It is stressed that these are very preliminary results and are not probablistic predictions of future events and may be the result of an accident of history. These results do, however, represent what might be expected in a very rough sort of way and should be used only for relating recurrence intervals from one area to another within Indonesia rather than for the absolute values of the intervals which are likely to be several times smaller. The reason why these areas have been selected is not only because of the existence of destructive earthquakes in them but because Indonesia, as well as most other Southeast Asian countries, has a predominantly rural population. Cities and towns represent only 22 percent of the population and those towns are mostly small. Since the population density for Indonesia (Sumatera, Java, Bali, and Lombok, in particular) is so great, one cannot put the question as to which urban area(s) is most at risk--the entirety of the most populous islands are. It is, however, natural that any government will want to assure as much protection as possible for its major cities, particularly the capital, since that is where a country's wealth is concentrated.

This can be reinforced by adding that the design of most Indonesian domestic buildings of masonry in both the cities and the countryside afford

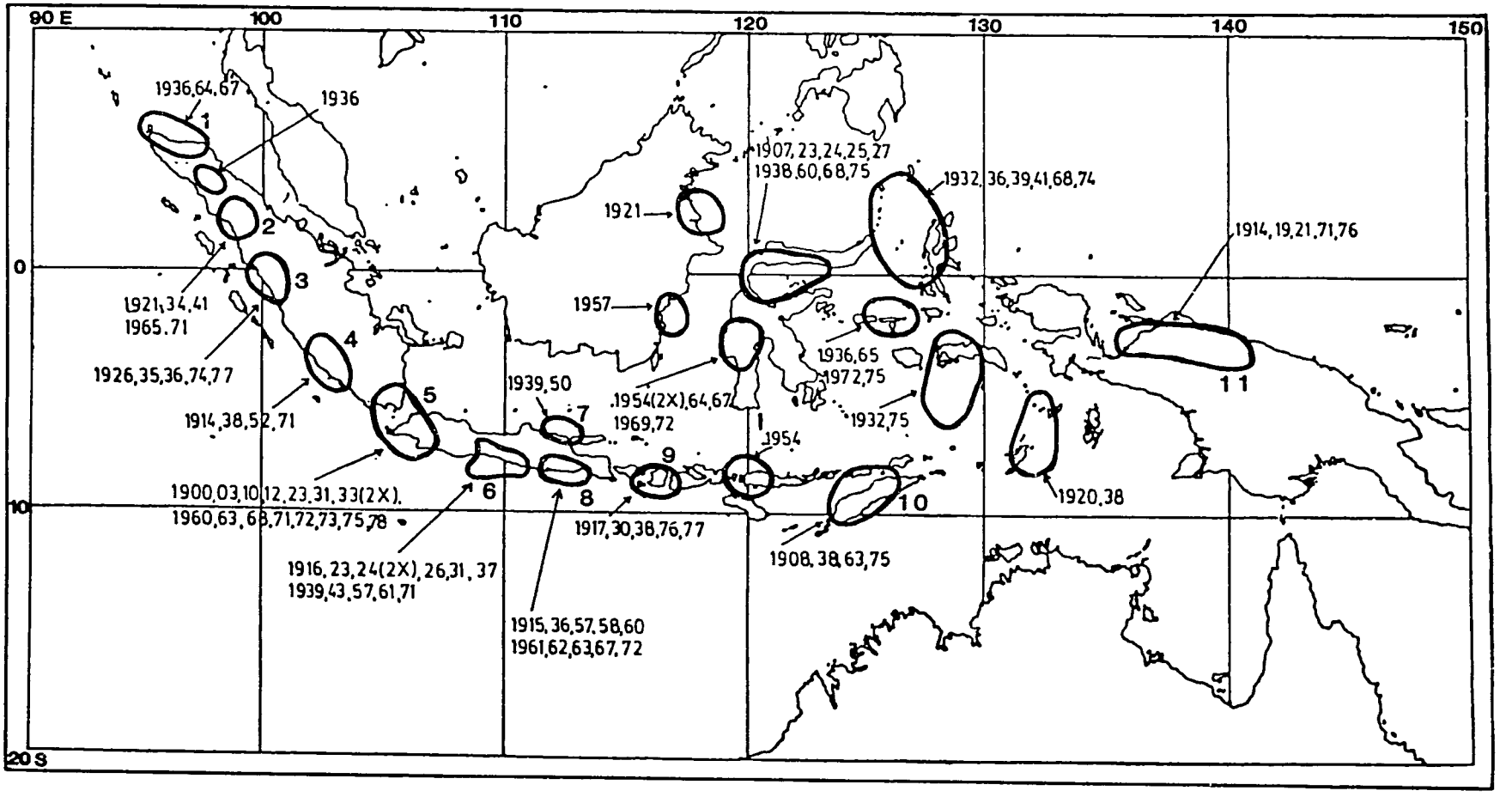

Fig. 1 Map of Indonesia showing clusters of damaging seismic activity from 1900 to 1979. The two digit numbers give the year of occurrence and the numbers correspond to the areas enumerated in table 1.

TABLE 1

SOME INDONESIAN AREAS AT RISK

Area* (principal cities)	1980 population (m)	Average recurrence interval** (years)	Maximum intensity (MM) 1821-1979
1. Northern Sumatera (Banda Aceh)	1.9	26	X
2. North-central Sumatera	2.7	16	X
3. Central Sumatera (Padang)	3.0	16	X
4. Southern Sumatera (Bengkulu)	3.4	20	X
5. Western Java (Sukabumi)	16.7	5	X
6. South Central Java (Yogyakarta, Surakarta)	9.4	7	X
7. Northeast Java (Surabaya)	5.3	40	VIII
8. Southeast Java (Malang)	7.4	8	X
9. Bali-Lombok	2.75	16	IX
10. Timor (Dili, Kupang)	1.5	20	IX
11. Irian Jaya (Jayapura)	1.1	16	IX

*Areas are identified on figure 1 by number.
**For the period 1900-1979.

little earthquake resistance. They are built of poorly fired brick which are usually deformed thus requiring very thick mortar which itself is made of partially rehydrated lime and unwashed sand with much organic matter; the mortar is usually exceedingly soft. The house is then stuccoed and a timber framed, pantile roof, usually very heavy and life threatening, is added. Figure 2 shows the sort of damage such structures undergo from even mild earthquake ground motion. They were about 100 km from the magnitude 6.2 earthquake of 1979 Dec 17^{d} 19h 48m off the coast of northeastern Bali.

Since these structures constitute a large proportion of the housing stock on the most populous islands, emergency planners should direct some of their efforts to educating the builders of these houses in the techniques for making the structures more earthquake resistant (see Boen, 1978 and the section under Other Activities). Such a programme could be made more tractable at first by limiting the areas to those shown in figure 1.

The hazard in the Philippines, the other highly seismic country in Southeast Asia, was analyzed in much the same way as Indonesia above but the regions selected were the official population regions used by the Philippine Commission on Population (1986). Table 2 lists the average return period for experiencing a site intensity of VII MM, population, area, and maximum observed intensity for each region; these are illustrated in figure 3.

Attention is called in both the Indonesian and Philippine cases, to the large disparity amongst regions of each country with respect to the frequency of seismic activity rather than the maximum intensity ever experienced. This fact should be of great interest to emergency planners.

One should bear in mind that the return periods or recurrence intervals shown in tables 1 and 2 are probably too large, that is to say, the actual earthquakes are probably more frequent than represented in the tables. This is because of poor chronicling and so is more evident in Indonesia than in the Philippines. One would have expected that the return periods along the Sunda Arc would be about the same as along the eastern Philippines.

Tables 1 and 2 indicate that the activity in some regions is far more frequent than in others. As an example, the Ilocos region of Luzon can expect to have some damage every year on the average whereas the Cagayan Valley will only experience damage every two years or so. Likewise the whole of the eastern part of the archipelago will, on the average, experience a damaging earthquake about every two years or so. Damage is defined here as MM intensity VII or greater and it should be noted that it is the collapse of buildings, either partial or complete that causes death and injury to inhabitants. It should also be noted that population is a fair indicator of the amount of property at risk.

In the case of Indonesia, the interpretation is not as clear. The areas chosen by Ismail (1985) are really contours enclosing the epicentres of clusters of twentieth century damaging earthquakes; the affected areas are probably much bigger, enclosing a larger population than listed in table 1 and the level of damage required to figure in the list is greater than for the Philippines. All that said, the activity in western Java is at least five times that of northern Sumatera and threatens eight times more people and

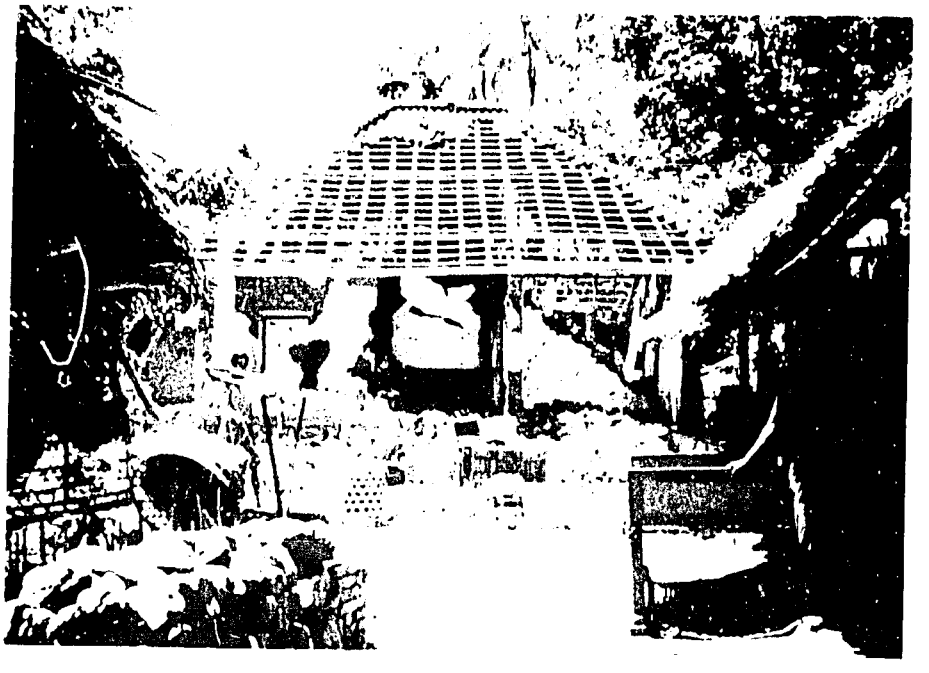

Fig. 2 Two photographs illustrating earthquake damage to domestic masonry structures in the most populous parts of Indonesia. The damage was from the earthquake of 1979 Dec. 17d 19h 48m 23s UTC, m_b=6.2 occurring near the village of Culik (Tsulik) in extreme northeastern Bali. The shock was over 100 km away but not a masonry building was left standing.

TABLE 2

PHILIPPINE POPULATIONS AT RISK

Region	Observation period	Average return period (years)	Population at risk ($x10^6$)	Area ($km^2 \times 10^3$)	Maximum MM intensity (1589-1983)
I (Ilocos)	1865-1983	1.2	3.903	21.6	X-XI
II (Cagayan Valley)	1850-1979	2.5	2.520	36.5	X
III (Central Luzon)	1850-1979	2.2	5.456	18.2	IX
IV (Southern Tagalog)	1850-1979	1.8	6.330*	11.9*	X
V (Bicol)	1850-1979	1.7	3.922	17.7	X
VI (Western Vizayas)	1860-1979	4.4	5.092	20.2	X
VII (Central Vizayas)	1880-1979	9.0	4.195	14.9	IX-X
VIII (Eastern Vizayas)	1860-1979	1.9	3.073	21.5	IX
IX (Western Mindanao)	1870-1979	3.0	2.863	18.7	X
X (Northern Mindanao)	1880-1979	1.4	3.179	28.4	X

TABLE 2--Continued

Region	Observation period	Average return period (years)	Population at risk ($x10^6$)	Area ($km^2 \times 10^3$)	Maximum MM intensity (1589-1983)
XI (Southern Mindanao)	1860-1979	1.7	3.836	31.7	X
XII (Central Mindanao)	1860-1979	3.0	2.598	23.2	X
Metropolitan Manila	1820-1976	4.6	6.942**	0.636	X

*For lack of data, Marinduque, and Palawan are not included. Palawan is nearly aseismic whilst Marinduque province is not shown because of poor chronicling.

**The weekday population is estimated to be over 9 million through an influx of commuters.

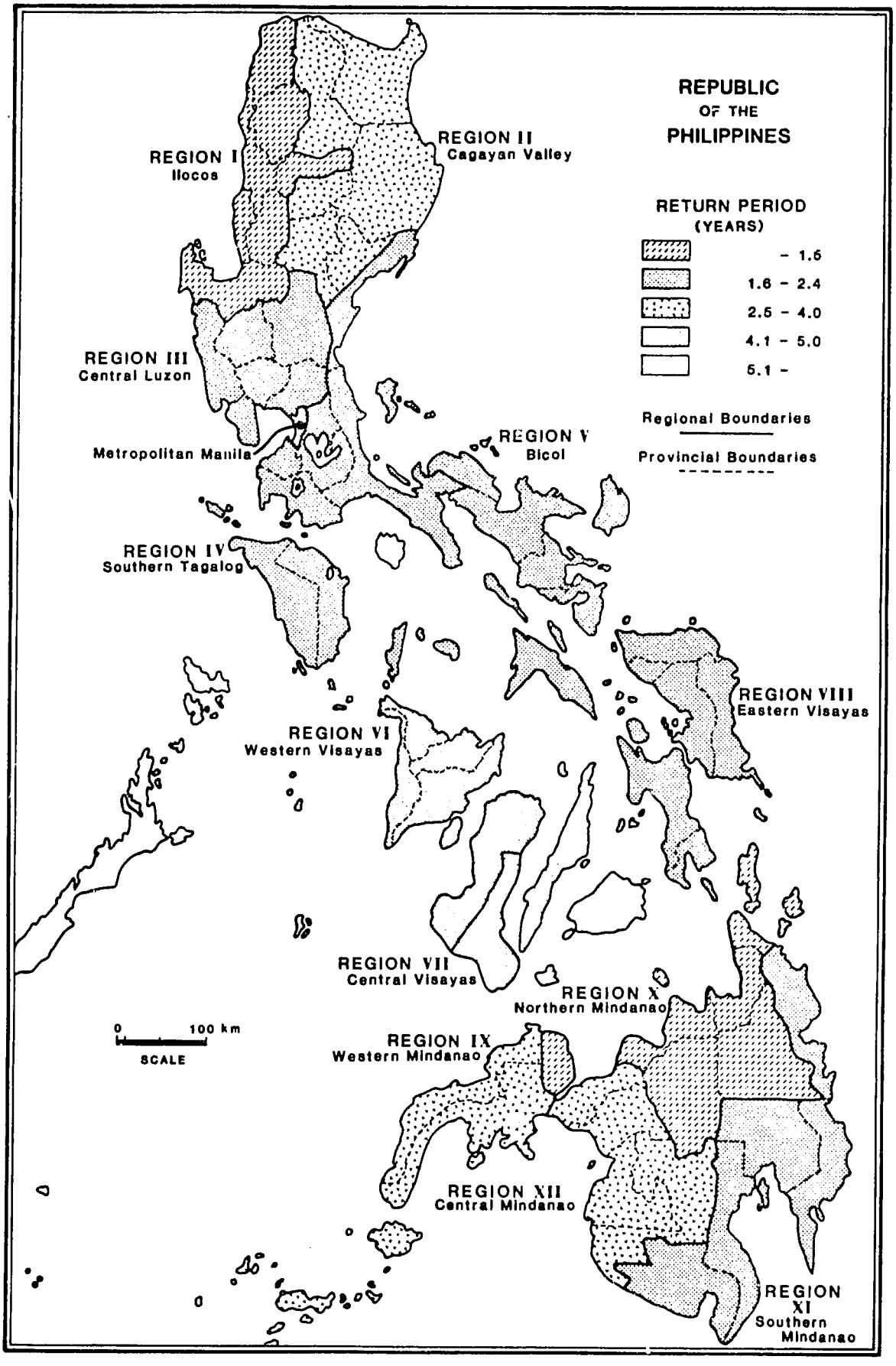

Fig. 3 Map of the Philippines showing the thirteen population regions and average return periods for an occurrence of a site intensity of VII MM. Areas left blank are without data or aseismic.

their property. It is obvious where decision makers should allocate their resources especially since it is western Java that is one of the most prosperous districts and therefore has most to lose.

These results are not unexpected if one examines either the contours of seismic flux as shown on the accompanying seismotectonic maps or in figure 4. Seismic flux is the amount of energy released by earthquakes as seismic waves for a unit area in a year. Contours of high seismic flux indicate either a few very large quakes, an extremely large number of small quakes, or usually a large number of moderate earthquakes over a time span. In general, the moderate earthquakes ($5.5<M<7.5$) are the ones that do the most damage and cause the most casualties over the years. Although the effect of a moderate earthquake is individually less than a magnitude 8 or greater event, in the aggregate, moderate quakes are far more devastating to a populace and its economy because of their more frequent occurrence.

A strategy for earthquake hazard mitigation in Southeast Asia can be formulated from the results presented here. As stated before, a hazard mitigation programme for the large cities should be instituted in all of Southeast Asia by the appropriate disaster management agencies in cooperation with each country's geophysical, geological, and engineering agencies. These programmes should consist of formulating seismic provisions for building codes if not already in place; strengthening them where feasible; and mounting a vigorous campaign to enforce them on new structures. These programmes should also include a campaign to persuade owners of existing structures that it is in their own best interest to "retrofit" their buildings to bring them up to building-code standards.

In Indonesia, if one defines a large city as one with a population in excess of 300,000, then the cities at most risk are, in addition to Jakarta,

City	Island	Population (1980) in thousands
Bandung	Java	1462.6
Malang	Java	511.8
Padang	Sumatera	480.9
Surabaya	Java	2027.9
Surakarta	Java	469.9
Makassar	Sulawesi	709.0
Yogyakarta	Java	398.7

Here, "at risk" means that the city lies in or close to one of the clusters of damaging seismic activity shown in figure 1. Since it is possible that this distribution is an accident of history and, even though it is less likely, a damaging earthquake can occur almost anywhere in the archipelago, the other cities of this size or larger are

City	Island	Population (1980) in thousands
Banjarmasin	Kalimantan	381.3
Medan	Sumatera	1379.0
Palembang	Sumatera	787.2
Pontianak	Kalimantan	304.8

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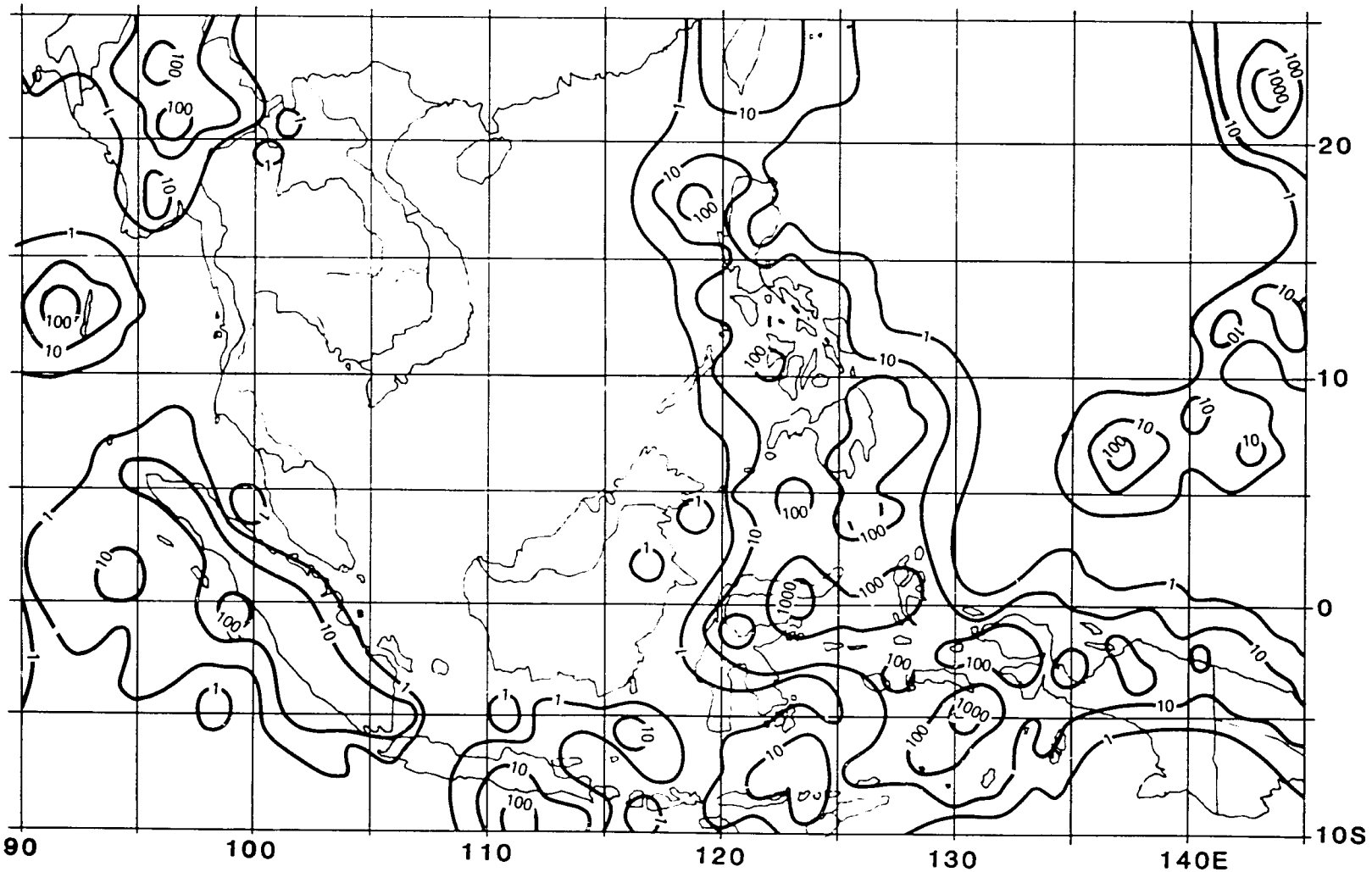

Fig. 4 Map of Southeast Asia showing contours of seismic flux in 10^{15} ergs/km^2/year. After Lomnitz (1974).

Following the same procedure as above, the cities most at risk in the Philippines in addition to Manila are

City	Island	Population (1980) in thousands
Bacolod	Negros	262.4
Cagayan de Oro	Mindanao	227.3
Davao	Mindanao	610.4
Iloilo	Panay	244.8
Zamboanga	Mindanao	343.7

In the Philippines a large city is defined here as having a population of 200,000 or more (roughly equivalent in economic importance to one of 300,000 in Indonesia) and "at risk" means being in a region that has an average return period for occurrences of intensity VII MM less than 4 years. There are also three sites--Baguio, Angeles City, and Olongapo all on Luzon--whose importance is far greater than their populations suggest that should be added to the above list.

The other large city having a diminished but finite possibility of experiencing a damaging earthquake based on this study and the principle stated above for Indonesia is Cebu having an official population of 490,300 in an urban agglomeration of 1-2 million, thus constituting the second largest city in the country.

In both the Philippines and Indonesia but most especially in Indonesia, some attention should be paid to selected portions of the countryside where the danger of moderate-magnitude damaging earthquakes is high and a significant portion of the nonengineered buildings are weak. Few moderate earthquakes are likely to be catastrophic, thus their effects are more manageable if plans are made in advance. Here the term countryside is taken to mean not only the rural areas but also the small cities, towns, and villages in a region. As discussed previously, moderate earthquakes, repeated several times per year, can, in the aggregate, cause very great economic loss and a considerable number of casualties.

Plans should be developed by the disaster management agencies to deal with the effects of moderate earthquakes, if this has not already been done, and implemented in regions of high seismic activity as a first step. This plan should not unduly stretch the resources of the disaster management agencies since the number of great cities for which planning is required is small. Such a plan would also have the advantage of being able to deal with the regions surrounding large cities in the event of a large earthquake.

From table 1 and figure 1, the areas most at risk in Indonesia are numbered 5, 6, and 8 all on the Island of Java. In the Philippines, from table 2 and figure 3, the areas to concentrate on are Region I, the Ilocano area of Luzon, and Region V, Northern Mindanao.

In addition, there must be an ongoing programme of research which will lead to a more accurate definition of the earthquake hazard to which each city and countryside area is subject. This will enable planners and managers to order their priorities. The most needed items in this category are probabilistic earthquake hazard maps which display contours of maximum ground motion

expected to occur in a given time frame. The production of these maps has been proposed, see Appendix B. Another study is also necessary to complete a programme of earthquake hazard mitigation for Indonesia and the Philippines. The study would be designed to help planners and disaster managers interpret hazard and zoning maps in terms of the action they should undertake to provide the greatest protection for the lives and property of their peoples at minimum cost.

The strategy for Thailand and Malaysia follows a different course; earthquake hazard mitigation should be concentrated in the largest cities and on large civil engineering projects outside them. This is where these countries are most vulnerable; that is to say, it is the tall buildings in large cities and the power stations, dams, etc., that are most at risk from long period waves from large earthquakes at some distance. Thailand is fortunate in this regard since there are only six localities with a population of over 100,000 inhabitants in a country of 44 million people that are likely to have buildings of over, say, 10 stories. Likewise, Malaysia has but 12 over 100,000. This makes the problem for the emergency planners tractable. The obvious choices for beginning mitigation programs in these two countries are Bangkok and Chieng Mai in Thailand and Kuala Lumpur and Penang in Malaysia.

Much more research needs to be done, however, on the response of buildings to earthquake waves in these two countries and on the effects of ground amplification due to the great thicknesses of unconsolidated sediments underlying the great cities surrounding the South China Sea.

The reader is reminded that the strategies outlined above can be sharpened and placed on a more quantitative basis through the development of probabilistic ground motion maps. The present data, however, provide considerable information for emergency planners and provide guidance for future work.

A discussion of the current state of earthquake disaster management and efforts to revise building codes and engineering practices are given in Part C of this report under the heading of "Other Activities".

For those readers wishing more information on the construction of probabilistic seismic hazard maps they are directed to Algermissen and others, 1982. This paper has a good bibliography of other works on the subject.

PART B INTRODUCTION AND BACKGROUND

Introduction

Southeast Asia is one of the most seismically active areas in the world. It lies at the intersection of the earth's two major earthquake systems. One of these completely encircles the Pacific, while the other stretches from the Mediterranean through the Near East, skirts the northern border of India, and passes through Samatera and Java to meet the circum- Pacific system in the New Guinea area. The interaction of these two systems results in large numbers of earthquakes with a complex distribution and great variety of focal depths.

Because of the high population density, more people are subjected to some degree of earthquake risk in Southeast Asia than anywhere else in the world. Over 200 million people live in an area in which there are at least one great earthquake every decade, a large earthquake every year, and perhaps a thousand small earthquakes, some of which cause damage, every year. The risk is not just to life and limb; investments of thousands of millions of dollars in commercial, industrial, and domestic developments are at risk as well.

Little was done to mitigate the effects of earthquakes in this region until the 1970's. In 1960 the United Nations Educational, Scientific, and Cultural Organization (UNESCO) sent a five-man mission to the region to evaluate the risk and study the level of seismological and engineering competence. In 1968 a follow-up mission by Mr. G. A. Eiby of New Zealand was carried out to update the 1960 mission's report. As a result, a meeting of seismologists from the involved countries was held in Bandung, Indonesia, in 1969. On the recommendation of the participants at this meeting, a regional project was proposed to the United Nations Development Programme (UNDP) and was accepted in principle. In late 1971 the author was commissioned by UNDP to carry out a feasibility study to make estimates of what could be accomplished in the region to raise the standards of seismological expertise. The result was the Regional Seismological Programme for southeast Asia sponsored by UNDP and executed by UNESCO as described more fully in the next section.

To give some notion as to the level of formal seismological work in the region in 1971, there were a mere seven stations in an area about the same size as the United States. All the stations were of the World Wide Standard Seismograph Network (WWSSN) type. Because of the island nature of the region, all stations except one had to operate at exceedingly low magnifications. In the Philippines there was one seismologist publishing papers of international quality, an active but small observational group at the Philippine Weather Bureau and at the Manila Observatory, and an association devoted to earthquake engineering. In Indonesia there was one earthquake engineer operating on an international basis and a small group at the then Institute of Meteorology and Geophysics. Other groups were active but went undetected by the author. In Malaysia no seismology of any kind had been undertaken; in Thailand a small center existed for seismology related to WWSSN stations. In all four countries a geological survey existed but with the exception of the one in Indonesia, it is not altogether clear that the study of earthquakes was part of their activities.

The UNDP Regional Seismological Programme for Southeast Asia

As an antecedent to the present USAID/OFDA programme, one could not fail to mention this programme with respect to earthquake hazard mitigation in Southeast Asia because of the interest in seismology and earthquake engineering that it generated within the region. This was due to a large extent to the existence of a permanent project manager within the region and a number of consultants who spent considerable time touring the region and conducting training sessions and related activities. Each consultant, in general, spent at least three months each year in the region.

The immediate objective of this project was to re-organize, strengthen, and expand the regional seismological observatory networks in the participating countries of Southeast Asia (Indonesia, Malaysia, the Philippines, and Thailand) and to promote the necessary facilities for regional cooperation. That is, the aim was to provide facilities that would detect and locate in three dimensions, all earthquakes in the region with Richter local magnitudes of four or greater. With this infrastructure, the governments of the cooperating countries could receive basic data concerning the earthquake hazard on a continuing basis and thus be able to elaborate appropriate measures for protection against earthquakes.

It has been shown that earthquakes (1) are a major and continuing risk in two of the countries involved in this project (Indonesia and the Philippines) and (2) present at least a nominal hazard in the other two countries as shown later. This is perhaps an underestimate especially in Thailand as shown in Part C of this report. Earthquakes are a factor that must be taken into account in all aspects of development in structural engineering, land-use assignment, economic forecasting, public safety, etc. The long-term effects of the project and the USAID one that was to follow may therefore be expected to pervade all aspects of national life.

As intimated in the introduction, it was necessary to instrument this region with seismographs of considerably different response characteristics than those of the somewhat older WWSSN type which were designed for operation in the interiors of continents. Because of the primarily island environment in Southeast Asia, it was necessary to choose instruments that had a maximum response at periods well below the 6 seconds which represent the peak of microseism noise due to wave action at sea and at the same time not such a short period as would make it overly sensitive to what is commonly called "cultural noise". Cultural noise is due to traffic, construction, machinery and the like. A maximum response at 0.33 seconds was chosen with the magnification falling at 12 db per octave with period in both directions. Recording was by pen and ink on low-acid, lint-free paper. The reason for this selection was because (1) it gave a visual record and (2) the seismograms could be stored in nonair-conditioned rooms without significant deterioration as would have been the case with either photographic or heated pen recorders.

All in all, these stations have worked exceedingly well, perhaps beyond reasonable expectations. The governments of each of the member states acquired the land, built seismometer enclosures and recording houses as well as some housing for observers at each of the new stations, and as provided the manpower for operations.

Table 3 is a list of the existing stations as of November 1985, which number about 60 and figure 5 is a map showing their positions. The UNDP programme provided 27 of these, the old U.S. Coast and Geodetic Survey provided the seven WWSSN stations, and the remainder were furnished by the respective Southeast Asian governments. This represented a very considerable counterpart effort on the part of these governments especially considering that at least one operator has to be provided for each station. In addition, a few technicians were provided for the purpose of making repairs. One of the difficulties of such a network is that the actual seismometer cannot be more than 25 metres from the recording station and since all of the seismograph stations are operated by national weather bureaux, many of the sites were selected not because of their seismological suitability but because meteorological observers were present and could double as station operators for the network. Several other logistical problems at first tended to force the selection of stations near larger centers or existing meteorological stations but these problems are discussed later in this report. At the time of installation, however, it was thought that the simplest possible system would yield the greatest and best results. The systems that were originally installed were kept as simple as possible. This provided the best results at a time when the systems were run by novice operators. More complicated features, after all, could be added later.

Early in the formulation of the UNDP project, it had been intended to establish a very strong regional center through which all the data would flow and where final computing of epicenters and storage of data from the whole region would be carried out. This idea was very quickly abandoned; such a center would have left no initiative whatever to the national centres and would not have provided the necessary training on a national basis. The station operators and contingents from each of the national centers were taught to read seismograms and to repair the equipment if something should go wrong which was, unfortunately, commonplace. Each national centre was provided with a computing program for both locating and archiving epicenters.

Since good locations in such an area require data from outside any of the countries' national frontiers, a communication system was devised which relayed all data between each of the national centres and to the two international centres (International Seismological Centre (ISC) and National Earthquake Information Service (NEIS)) which serve all of seismology. This communication system used the services and good will of the U.S. Department of State Diplomatic Telecommunications System. It is, of course, still in use.

On the very last day of the UNDP programme's existence, the four countries involved, with legal aid from UNESCO and UNDP, established the Southeast Asia Association of Seismology and Earthquake Engineering (SEASEE). It may very well have been a mistake to leave the establishment of SEASEE till such a late date in the programme for its statutes (see Appendix A) established it as a very loose-knit organization with no provision for income other than that from aid-giving agencies.

All in all, however, the UNDP program met its stated objectives very well indeed. It has provided for a number of years now the data for locations of Southeast Asian earthquakes to a far greater accuracy both in position and magnitude than was ever possible before 1975.

TABLE 3

SOUTHEAST ASIAN STATION CO-ORDINATES

Station Name	International Code	Latitude	Longitude
Indonesia:			
Ambon	AAI	03°41'13.20"S	128°11'40.20"E
Balikpapan (New)	BKB	01°15'37.80"S	116°53'46.80"E
Balikpapan (Old)	BKB	01°15'21.00"S	116°54'55.80"E
Banda Aceh	BSI	05°29'46.20"N	095°17'40.80"E
Denpasar	DNP	08°40'37.80"S	115°12'36.60"E
Djakarta	DJA	06°11'00.00"S	106°50'10.20"E
Gumong Sitoli	GSI	01°18'12.00"N	097°34'32.40"E
Jayapura	JAY	02°30'53.40"S	140°42'16.80"E
Kahang-Kahang	KHK	08°21'51.60"S	115°36'29.40"E
Kepahiang	KSI	03°38'01.80"S	102°35'32.40"E
Kotabumi	KLI	04°51'47.40"S	104°51'24.00"E
Kupang (Kinemetrics)	KUG	10°09'49.80"S	123°35'21.00"E
Kupang (Sprengnether)	KUPT	10°09'04.80"S	123°36'19.20"E
Lembang	LEM	06°49'34.80"S	107°37'03.00"E
Manado	MNI	01°26'34.80"N	124°50'22.20"E
Padangpanjang	PPI	00°27'24.60"S	100°23'49.20"E
Palu	PCI	00°54'17.40"S	119°50'12.00"E
Prapat	PSI	02°41'42.00"N	098°55'26.40"E
Saumlaki	SLI	07°58'54.00"S	131°17'54.00"E
Sawahan	SJI	07°44'03.00"S	111°45'57.60"E
Sorong	SWI	00°51'46.80"S	131°15'35.40"E
Tangerang	TNG	06°10'18.00"S	106°38'46.20"E
Tanjung Pandan	TPI	02°45'27.00"S	107°39'12.60"E
Tretes (New)	TRT	07°42'14.40"S	112°38'06.00"E
Tretes (Old)	TRT	07°41'55.80"S	112°38'21.60"E
Tual	TLE	05°38'15.00"S	132°44'58.80"E
Tuntungan/Medan	TSI	03°30'03.00"N	098°33'52.20"E
Ujung Pandang (Makassar)	MKS	05°13'04.20"S	119°28'11.40"E
Waingapu	WSI	09°40'07.80"S	120°17'52.20"E
Malaysia:			
Ipoh	IPM	04°34'46.20"N	101°01'31.80"E
Kluang	KGM	02°00'56.40"N	103°19'08.40"E
Kota Kinabalu	KKM	06°02'39.60"N	116°12'52.80"E
Kuala Lumpur	KLM	03°06'09.00"N	101°38'40.80"E
Philippines:			
Abra de Ilog	ABP	13°26'38.40"N	120°43'37.80"E
Baguio	BWP	16°24'16.80"N	120°36'07.80"E
Cagayan de Oro	CGP	08°27'17.40"N	124°41'39.00"E
Callao Caves	CVP	17°42'16.20"N	121°49'18.00"E

TABLE 3--Continued

SOUTHEAST ASIAN STATION CO-ORDINATES

Station Name	International Code	Latitude	Longitude
Philippines:--Continued			
Catarman, Samar	CNP	12°30'37.80"N	124°39'47.40"E
Davao	DWP	07°07'37.80"N	125°39'20.50"E
Lahug, Cebu (Old)	CCP	10°20'40.00"N	123°54'40.00"E
Legaspi	LGP	13°09'22.20"N	123°44'01.80"E
Mactan, Cebu	MAP	10°19'22.20"N	123°58'50.40"E
Manila	MAN	14°39'36.00"N	121°04'40.80"E
Mt. Pasian (New)	PPH	07°50'57.00"N	126°11'13.80"E
Palo, Leyte	PLP	11°09"54.00"N	124°58'43.80"E
Pandan (New)	PDP	11°42'51.60"N	122°05'46.20"E
Pandan (Old)	PAP	11°44'00.60"N	122°06'52.20"E
Pasuquin	PIP	18°19'32.40"N	120°37'07.80"E
Puerto Galera	PGP	13°30'07.20"N	120°57'10.20"E
Puerto Princesa	PPR	09°46'34.92"N	118°43'51.00"E
Santa	SZP	17°33'06.80"N	120°27'18.48"E
Tuguegarao	TGP	17°39'08.40"N	121°45'34.20"E
Zamboanga	ZMP	06°55'10.44"N	122°03'48.00"E
Thailand:			
Bhumipol Dam	BDT	17°14'39.60"N	099°00'10.80"E
Chieng Mai	CHG	18°48'49.80"N	098°56'37.80"E
Kanchanaburi	KDT	14°47'05.40"N	098°35'33.60"E
Loei	LOE	17°24'22.80"N	101°43'47.40"E
Nakhonswan	NST	15°40'21.60"N	100°07'58.80"E
Nong Plab	NPT	12°35'23.40"N	099°44'01.80"E
Pak Chong	PCT	14°40'51.00"N	101°14'39.60"E
Songkhla	SNG	07°10'37.20"N	100°36'59.40"E

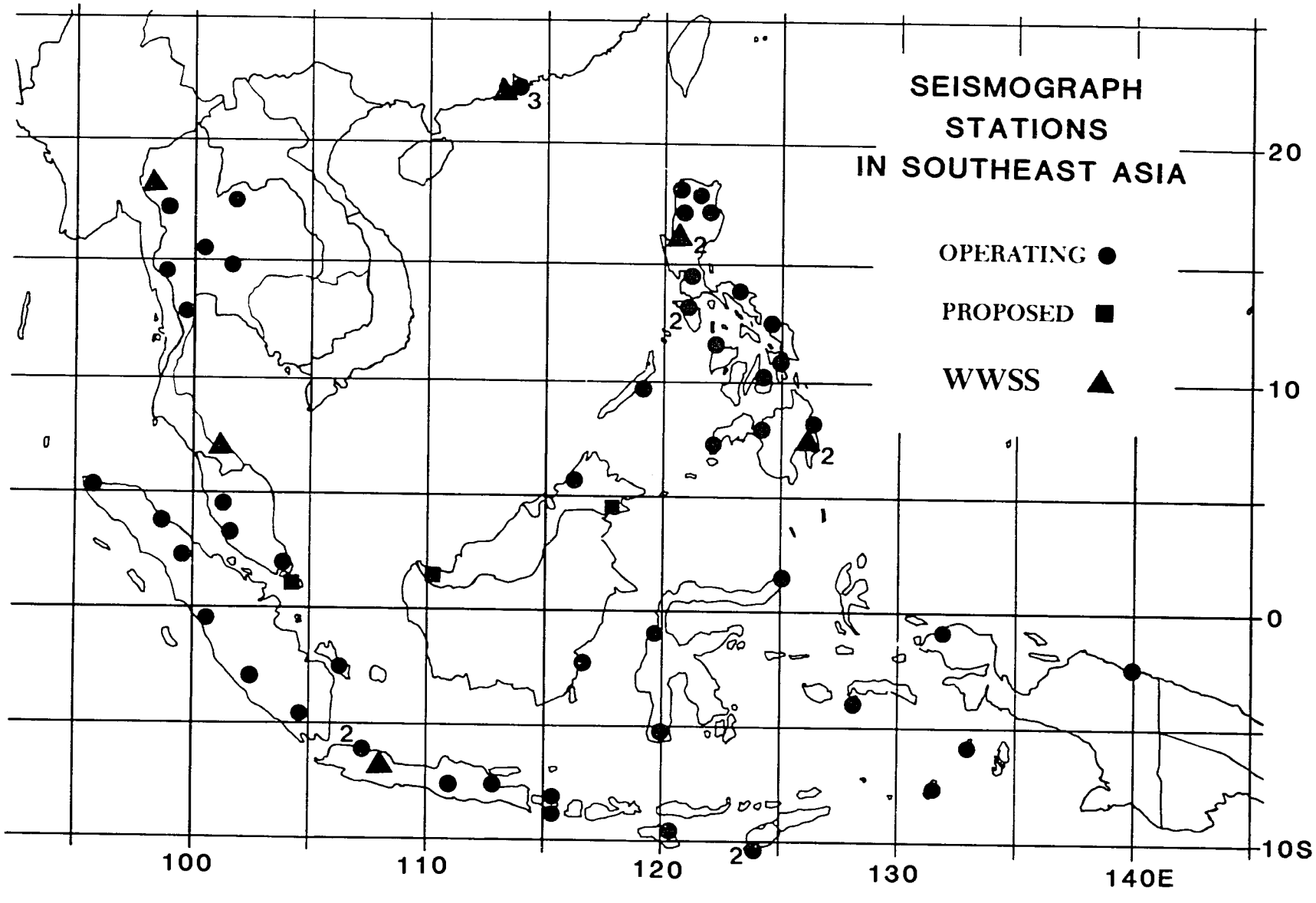

Fig. 5 Seismograph Stations in Southeast Asia. All stations are operated by SEASEE member agencies except the two World-Wide Standard Stations (WWSS) in the Philippines. Numbers indicate that there are more than one station at a site or nearby.

Origins of the USAID-Sponsored Earthquake Hazard Mitigation Program in Southeast Asia

On 2 February 1980, the President of the Southeast Asia Association for Seismology and Earthquake Engineering (SEASEE) delivered to the Director of the Office of Foreign Disaster Assistance, Agency for International Development (OFDA/AID) a request for assistance in carrying out an earthquake hazard mitigation program in the Southeast Asia region. Specifically, the region is to include the states that belong to the Association of Southeast Asian Nations (ASEAN). The request for assistance was accompanied by a preliminary project proposal. As a result of that request, OFDA sponsored a planning study by the U. S. Geological Survey which would form the basis of further involvement by OFDA in earthquake hazards studies in the region. The travel portion of that study was performed between 16 February and 18 April, 1981, the resulting report of this study was delivered to OFDA in October 1981.

The purpose of the study was to examine work already done that could contribute to an earthquake hazard mitigation programme in the Southeast Asian region and to determine and evaluate the level of contribution which could be provided by individual experts and organizations within each member state to such a programme. It was also necessary to determine the level of commitment on the part of the governments of each member state and the level of counterpart funding that they would be willing to provide. The Planning Study also included a section outlining the goals and objectives of an earthquake hazard mitigation program and provided a strategy for carrying out these objectives. That is, a plan of work was developed. A complete copy of that report is reproduced as Appendix A of this report. The following is a summary of the results of the Planning Study.

The governments of the ASEAN states, most especially Indonesia and the Philippines, expressed genuine concern about the threat to their countries that earthquakes posed. From historical experience, they understood the risk posed by large-to-great earthquakes and the consequences that would ensue. It was obvious that they were sincere in their desire to begin a hazard mitigation program and continue with it because they were willing to devote a considerable amount of their own funds to make it a success. Even though the governments of Malaysia and Thailand did not think there was a very great threat to their nations from earthquakes, they too were willing to commit funds.

Goals and Objectives

The ultimate aim of an earthquake hazard mitigation program is twofold: (1) it should provide the required basic information for governments to frame building and land-use codes and for engineers and others to appropriately design structures, and (2) such a program should develop an institutional framework within each country for continued earthquake hazard assessment and public information. One should keep in mind the above two objectives throughout the reading of this report as a great deal of emphasis was placed throughout the programme on the second objective of developing an institutional framework within ASEAN. SEASEE was selected as the base organization which, as it has turned out, was a good decision. A strong institutional framework is desirable, first, to relieve aid-giving agencies of the continued, long-term responsibility for such a programme. But, more importantly since hazard

assessment anywhere is an iterative task requiring new scientific and technological knowledge be added to the old to provide updated assessments, an institution must be created if it does not exist to do this job within the region itself by regional staff. If several organizations are available to work on various details of such a programme, they should be brought together in co-operative effort. It is one of SEASEE's goals to do just that by incorporating both governmental and non-governmental agencies in each country under one "umbrella" organization.

Work Plan

The following is an abbreviated version of a plan of work set out in the planning study in Appendix A of this report.

1. The first task will be to collect as complete as possible seismological data base. This is to include a catalogue of instrumental epicentres as well as a catalogue of intensity surveys for as many historical events as possible. This will also entail collecting as many relevant focal mechanism solutions as possible and, where none exist but the raw data for them does, compute new ones.

2. Prepare regional seismotectonic maps that will provide a framework for the proper interpretation of historical seismicity and seismic hazard. This will entail collecting as much new geological information as possible.

3. Prepare a delineation of the seismic hazard. This delineation would be primarily directed toward ground shaking on a regional or at least national basis with special attention to site conditions in important urban areas. An attempt is to be made to identify areas where geological effects and where tsunamis may be a significant threat.

4. Once hazard and, perhaps, zoning maps are available, it will be necessary to develop recommendations for additions to the building- codes and land-use provisions thereto. These must be developed in close cooperation with Southeast Asian engineers, scientists, and government officials so that the building codes and land-use provisions are both practicable and enforceable.

5. Provide for the development of an institutional framework supporting continued earthquake hazard assessment and education.

At the present time, items 3 and 4 of the work plan have not been met; the following section of this report (Part C) is devoted to a summary and critique of the work done thus far.

The following Participating Agency Service Agreements (PASA's) were concluded between the Office of Foreign Disaster Assistance and the U.S. Geological Survey:

Project Title	PASA or Amendment Number	Starting/Completion Dates
Planning Study for Earthquake Hazard Mitigation in Southeast Asia	BPD-0001-P-IC-1024-00 BPD-0001-P-IC-1024-01	5 Jan. 1981-31 Mar. 1981 Extended to 30 Sept. 1981
Upgrade of Seismic Network in Southeast Asia	BPD-0001-P-IC-1024-02 BPD-0001-P-IC-1024-03	5 Jan. 1981-31 Oct. 1982 Extended to 31 Oct. 1983
Orientation Programme in Engineering Seismology and Earthquake Engineering for Southeast Asian Nations	OFD-0999-P-IC-1107-00	15 Sept. 1981-31 Oct. 1982
Earthquake Hazard Mitigation Programme in Southeast Asia	OFD-0999-P-IC-1107-01 BOF-0999-P-IC-1107-02 BOF-0999-P-IC-1107-03 BOF-0999-P-IC-1107-04 BOF-0999-P-IC-1107-05	15 Sept. 1981-30 June 1983 Extended to 30 June 1984 Extended to 30 Sept. 1984 Extended to 31 Dec. 1984 Extended to 30 June 1985

Familiarization Training in Engineering Seismology and Earthquake Engineering for Southeast Asian Nations, 21 June-7 July 1982, Denver, Colorado

So that all of the Southeast Asian staff who would be working on this project would start at the same level of knowledge, it was thought best to hold a course of instruction for working-level personnel from the SEASEE- member states. The lecturers not only came from the U.S. Geological Survey but from other U.S. Government agencies and private concerns. A list of lecturers and the titles of their talks is given below along with a list of the participants and the countries from which they came. In connexion with the latter, a number of Panamanians attended because USAID was sponsoring a similar program there as well.

Date	Lecturer	Title
21 June	E. P. Arnold	Opening Remarks
	S. T. Algermissen	Earthquakes and the Mitigation of Their Effects
22 June	M. Hopper	Gathering and Interpretation of Intensity Data
23 June	E. V. Leyendecker	Earthquake-Resistant Design
24 June	W. Hamilton	Subduction and the Tectonics of Convergent Plate Margins

Date	Lecturer	Title
24 June	E. L. Krinitzsky	Specifying Earthquake Motions in Engineering Design
25 June	D. M. Perkins	Probability and the Time of the Next Large Earthquake
28 June	E. P. Arnold	The Study of Seismicity
29 June	D. M. Perkins	Probability and Strong Ground Motion
30 June	P. C. Thenhaus	Delineating Seismic Source Zones for Regional Probabilistic Ground Motion Hazard Mapping
01 July	R. E. Jackson	The Nuclear Regulatory Commission and Seismic Safety Decisions
02 July	D. G. Friedman	Computer Simulation of Earthquake Hazards
06 July	K. V. Steinbrugge	The Nature of Earthquake Damage
07 July	K. V. Steinbrugge	Continuation of above (morning)
	S. T. Algermissen	Summary
	E. P. Arnold	Closing Remarks

Participants: Mr. Hariman, Mr. Hartono, Mr. Kusdaryanto, Mr. Soetardjo, and Mr. Tular from Indonesia; Mr. A. David, Mr. W. Omar, and Mr. Ong Tiong-Chiong from Malaysia; Mr. F. Dejoras, Mr. F. Estuar, Ms. L. C. Garcia, Dr. A. Lazaro, Dr. E. Tabujara, and Mr. R. G. Valenzuela from the Philippines; Ms. Bupha Pongsawat, Mr. Sugit Yensuang, Dr. Tawatchai, and Mr. Visit from Thailand; Mr. C. Kiamco, Mr. J. Noriega, and Mr. J. Pascual from Panama.

PART C TECHNICAL REPORT AND EVALUATION OF RESULTS

Evaluation of Macro-Seismic Data Collection and Interpretation

Introduction

The purpose of this part of the programme report was to develop, as complete as possible, a catalogue of earthquakes from each of the participating countries. By complete, it is meant that the catalogue will go back in time for as long as possible and, within that time frame, as many earthquake reports as is possible will be recorded especially for those earthquakes that caused damage. The catalogues each contain original observations not just references to them. Each of the four catalogues include the reports of earthquakes in adjacent areas where the effects of earthquakes outside the country in question can reasonably be thought to extend within the country's boundaries. As an example of the latter, many Burmese earthquakes are included in the catalogue for Thailand because earthquakes and the effects of large earthquakes in the east of Burma are felt and cause damage in Thailand. To calculate recurrence rates and Gutenburg-Richter "b-values" (Richter, 1958) for the Burmese earthquakes, smaller Burmese earthquakes are also included.

To the ininitiate or, for that matter, some workers in the field of engineering seismology, it might be unscientific to include earthquakes from 600 B.C. or even earlier in the catalogues. The feeling that many people have is that observations from an unscientific age (by comparison to our own) are somehow unreliable. If one considers, however, only the factual evidence in these reports, it matters little what the observer thought about the causes of the earthquakes he is reporting. By factual evidence I mean the existence of the earthquake, the date and time of occurrence, the area affected, the approximate location of the earthquake or at least the area of maximum destruction, and a description of the damage to man-made structures and any concurrent geological effects. In the four countries of interest to this project, earthquake reporting, until the advent of the present century, was done by a priestly or mandarin class who were probably much more reliable in their reporting than the news paper and television reporters at work today. Certainly the mandarins were more disinterested as a group than the reporters who are today the primary source for damage reports for most earthquakes even in the United States although, happily, this condition is now changing.

The quality of an earthquake catalogue can be judged on the bases of (1) length of reporting time, (2) exhaustiveness of investigation, (3) number of damage reports, (4) unifying language, and (5) common intensity measure. Damaging earthquakes are generally rare events. Hence, to accurately estimate the recurrence rate of these earthquakes, it is desirable to have as many accounts of damaging shocks as possible. On the basis of a short catalogue, documenting only a few damaging shocks, one could easily misestimate the recurrence rate by one or two orders of magnitude. This is particularly important in the case of seismic source zones which have an intermediate return period for great earthquakes (those with a magnitude of 8 or more). For those source zones that have great earthquakes occurring every 50 years or less, it is not difficult, in general, to obtain a catalogue of sufficient length to get a good estimation of the return period for great earthquakes. Where the return period is 100 or more years but non-zero, a catalogue length of many centuries may be necessary. As an example, consider the subduction

zone to the west of Sumatera. There has certainly not been an earthquake of $M_s \geq 8$ in the last 100 years or more (McCann et al., 1979) even though there are several recorded in the more distant past as listed in the microfiche addendum to volume V of this work. On the other hand, the frequency of earthquakes in the range of $6 \leq M_s \leq 7.9$ is high in this region. Consider also the case of the subduction zone off the island of Java. McCann et al. (1979) identify the subduction zone to the south of Java as a seismic gap having very few great earthquakes indeed as is confirmed by the historical record presented here in volume V. On the other hand, the frequency of earthquakes in the range $6 \leq M_s \leq 7.9$ is very high on this island which is home to most of the Indonesian population. It is these moderate-sized earthquakes that cause most of the damage and casualties from earthquakes.

Characteristic of the historical record, that is highly desirable but not always possible to achieve, is its exhaustiveness; that is, the degree of completeness. In the days before instrumental recording, this was very difficult to achieve save for simple comparison of sources. In regions like Southeast Asia where communications were primitive before the present century, this has posed considerable problems. This is not to say that the news didn't travel in pre-instrumental days but rather that it was slow and the interest in natural disasters tends to cool very rapidly. Before the 19th century the fastest mode of travel was, of course, seaborne so that we can expect that our most complete catalogues will come from the Philippines and Indonesia. Land communications of course were very slow so that we can expect the completeness of the catalogue from Thailand and its adjacent areas to be much more incomplete. This is borne out by the fact that in Thailand *per se* the only reports of damage that have been preserved are those from the capital at the time or its immediate environs.

Another desirable feature of any historical catalogue of earthquakes is the collection of the largest possible number of damage reports from geographically located sites in the neighbourhood of the epicenter. The reason for the desirability of such a characteristic is so that estimates of attenuation of seismic waves can be made. There are many reasons for not achieving this characteristic. First, villages and towns disappear for one reason or another and all trace of them is lost. Secondly, names or their orthography change because of changed colonial administration. Third, language changes. Fourth, the resettlement of a town occurs at some distance from its original site but it retains the same name, hence disturbing its geographical position. As shown later on, in the Philippines and in Thailand few of these changes have occurred since the first earthquake entry into their respective catalogues. As a consequence, in the Philippines, a large set of isoseismal maps have been drawn. On the other hand, Indonesia has undergone at least three changes of colonial administration and language changes as well as a number of changes in orthography, which makes finding older settlements very difficult indeed.

Another characteristic of a good catalogue is that it is presented in a *lingua franca*, and in this case where four countries are involved, one understood by all. English is the *lingua franca* of Southeast Asia just as Spanish is for most of the Latin American population. It was therefore decided by SEASEE that *all* its publications would be in English so that its work could be available to all its own members as well as the world at large.

The reason for producing an historical record or a catalogue of past events in the context of this project is to help produce hazard estimates. The measure of hazard is expressed as a probability of the maximum ground motion intensity experienced at a particular geographical location within a specified time frame. The historical record can be generalized or smoothed such that the locations of earthquakes given become source zones; maximum intensities after conversion to magnitudes can be related to frequency of occurrence through the Gutenberg-Richter law.

Contributions from the Philippines

Summary of Results

The catalogue of felt earthquakes for the Philippines is presented in four separate parts which reflect changes in the organization of seismology in the country and extends from 1589 to 1983. It is prepared by the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), the Philippine member agency to SEASEE. The four parts present earthquakes whose dates of occurrence range from 1589-1864, 1865-1899, 1901-1942, and 1948-1983. In addition a fifth part was added which comprises the effects of only destructive earthquakes in the Philippines throughout the entire time period covered above, 1589-1983. It should be noted that a diligent effort was undertaken by the Philippine National Archives for any descriptions of damage from earthquakes that antedated the Spanish occupation of the Philippines which began 1521 although it is not in the Philippine text. One could reasonably have expected to find some reports since the Pilipinos possessed a written language for at least a millennium prior to Spanish times, yet none were found. One can only conclude from this that the Spanish destroyed these records for unknown reasons.

A great deal of the material in the first two parts was taken from the work of Fr. William Repetti of the Society of Jesus (Repetti, 1946a). The material came from church chronicles, reports of individual clerics, government documents, historical publications, personal diaries, and letters of private individuals. The PAGASA team has added to, edited, and checked the validity of this work. Most of the additions were made for the earthquakes during the 19th century; the editing was done throughout.

For the time period 1900-1942, a wholly different problem was encountered. No compilation of earthquake data previously existed on which a new compilation could be based. Publications containing such data that were known to have existed could not, at first, be found because of the dislocations of war and reorganization along with the ravages of the weather (paper deteriorates rapidly in the tropical climate if air conditioning is not provided) and the natural predisposition of workers to throw away items which have not been consulted for some time. A very diligent search was required to resurrect the collection by going as far afield as Japan and the United States.

As is the case with all of the country reports, no information was available for the years of the Second World War although it is known that some existed. What happened to it is simply not known in most cases (Repetti, 1946b). From 1948 onward the search for original material was considerably easier but not without some difficulty. A typhoon in 1971 destroyed many records including the entire collection of seismograms which dated back from

the late years of the 19th century. Despite all these difficulties, all of the records were either replaced or found and a complete record compiled, translated into English from Spanish times to and including 1983, the only gap being the war years and the two years following it.

In addition to the above complete catalogue, a section is included (vol. IV, Part E) which lists only those earthquakes which were "destructive". Here the word destructive is taken to mean either that buildings or other works of man were rendered unfit for use or there were geological effects; e.g. landslides, mud fountains, etc., that are normally concommitant to destruction of buildings. This list comprises 63 events throughout the recorded history of the Philippines. Of these 63 events, 35 were used to construct an intensity attenuation curve (site intensity as a function of epicentral distance) for each of five of the seven seismic source zones in the Philippines. These results are set out in vol. IV, Part F, of the report. Figure 6 below is a map of the epicenters of 35 of the 63 earthquakes reported in Part E of volume IV. The remaining 23 earthquakes were not plotted because they were offshore and lacked instrumental data for an accurate locations. Figure 7 shows the intensity attenuation functions for five of the seven seismogenic zones which will be discussed later. These are results from vol. IV, Part F; particular attention should be paid to the map of seismogenic zones reproduced as figure 16 in this volume.

Discussion of Results

This catalogue is a model for others to follow in that it has all of the desirable characteristics that a catalogue should have as discussed in the introduction to this section. Firstly, it is as complete as it can be under the circumstances. The only addition to its completeness would have been the records from precolonial times which almost certainly existed but which were destroyed by the conquerors. Secondly, it contains all of the original text so that future researchers are at liberty to make their own assessments. Thirdly, it contains many observations of individual and locatable sites. It might have been better if the Philippine researchers had published a list or gazetteer of locations mentioned in the catalogue along with their geographical coordinates. This was not thought to be necessary, however, because the names of places in the Philippines have not changed nor do locations vary much over the centuries. Fourthly, it has all been translated into a high quality lingua franca, in this case English which is the lingua franca of the region as well as for much of the world. Large portions of this catalogue were written in early-modern Spanish which is almost like another language to even Spanish speakers. It must also be said that English is the lingua franca of even just the Philippines; it is the only language Pilipinos have in common. Fifthly, any intensity assessments made from these observations are made using the same explicit rules and procedures from earthquake to earthquake, thus lending a measure of homogeneity.

The same characteristics which apply to the main catalogue apply to the catalogue of destructive earthquakes. In this particular catalogue all of the earthquakes have been given maximum intensity assessments which appear to be about right or slightly high considering the general weakness of the structures built before the present century. Previous assessments were made either on a special Manila Observatory scale or on the Rossi-Forel scale. All assessments in this catalogue use the Modified Mercalli (1956 version) scale.

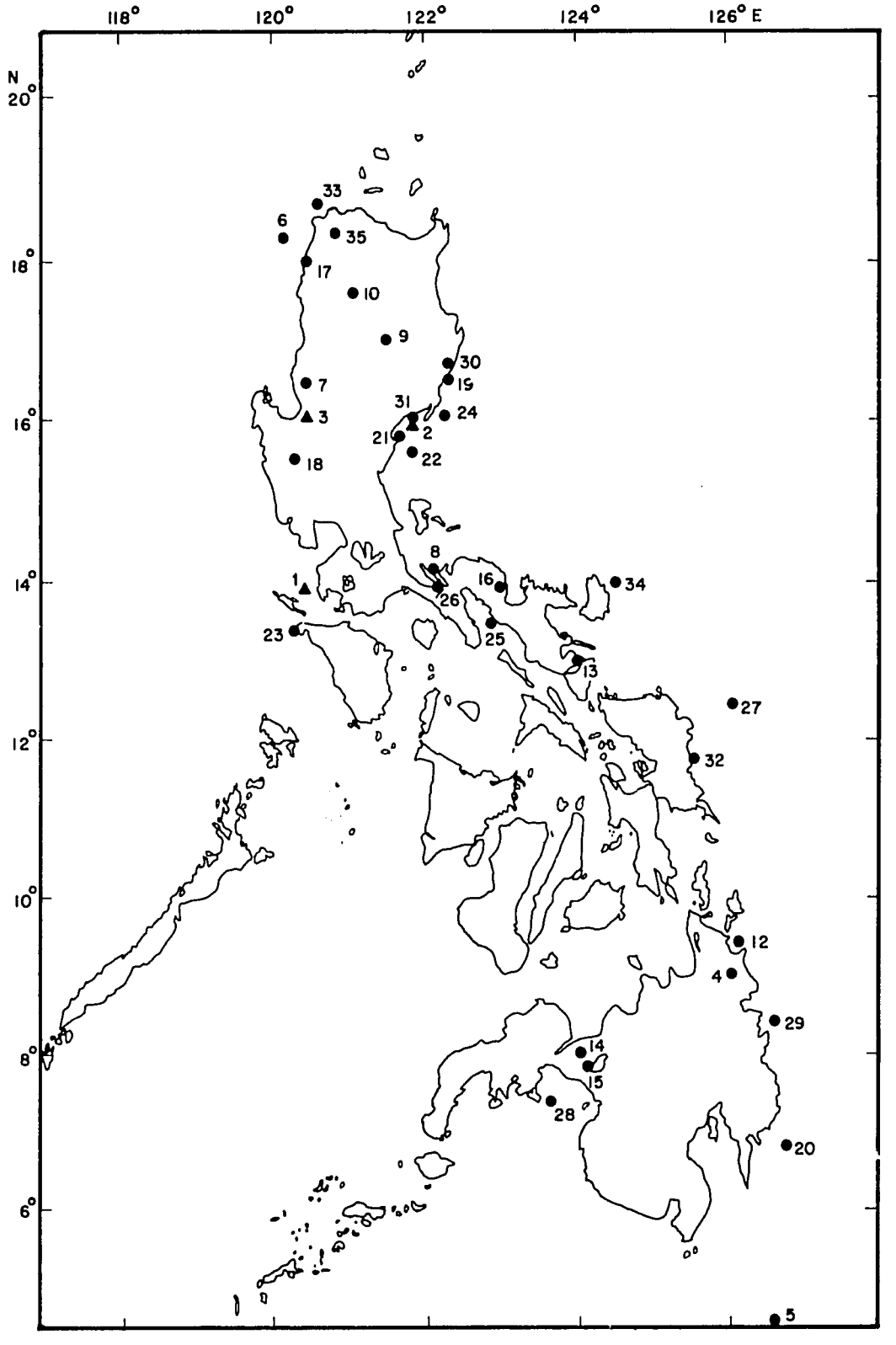

Fig. 6 Location of earthquakes in the Philippines used in calculating the attenuation of intensity as a function of epicentral distance. Solid circles are instrumentally determined epicenters and solid triangles are those which are estimated from isoseismal maps.

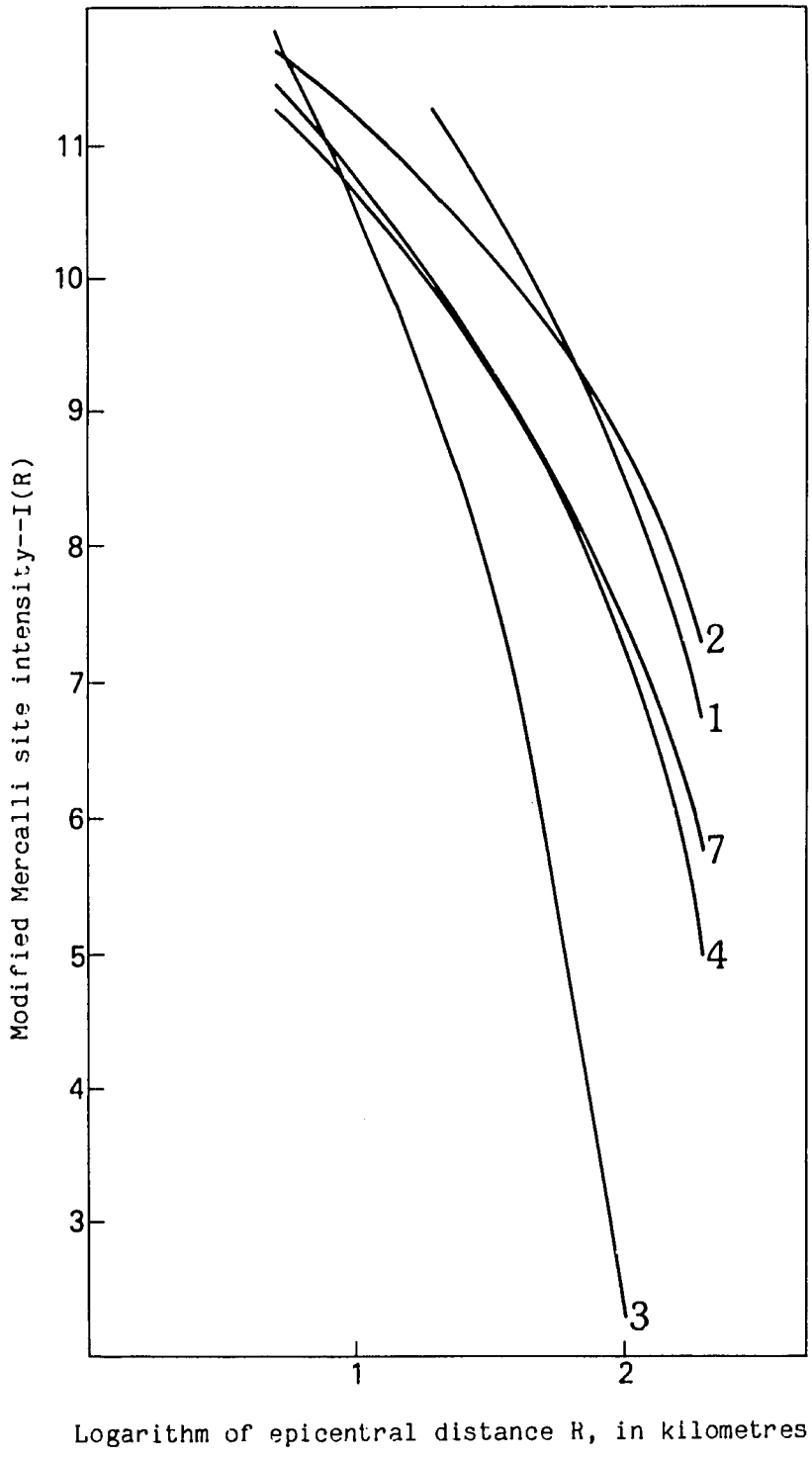

Fig. 7 Intensity-attenuation relations for five of the seismic source zones in the Philippines. The curve number refers to the zones listed in table 4 and illustrated in figure 18.

In the section dealing with the assessment of intensities and the estimation of attenuations, 35 earthquakes ranging in dates between 1852 and 1983 were used to derive the attenuation of intensity with epicentral distance. Only three earthquakes in the 19th century were used, the rest being in the 20th century where instrumental locations could be used. For calculating the attenuation of intensity in each of the seven seismogenic zones which are outlined in the penultimate section of this volume, the following relation by both Su (1980) and Howell and Schultz (1975) was used:

$$I(R) - I_0 = a - bR - c \log R \qquad (1)$$

where I(R) is MM site intensity as a function of epicentral distance, Io is the maximum intensity experienced, presumably at the epicenter, and R is the epicentral distance in kilometers. The zones are indicated in table 4 and mapped in figure 16. The 35 events are divided by zones as shown in table 5.

TABLE 4

SEISMIC SOURCE ZONES IN THE PHILIPPINES

Zone 1	-	East Luzon subduction zone
Zone 2	-	Philippine trench
Zone 3	-	Philippine fault
Zone 4	-	Double forearc associated with Manila trench
Zone 5	-	Manila trench
Zone 6	-	Negros and Sulu trenches
Zone 7	-	Cotabato trench and the northern extension of the Molucca Sea plate

TABLE 5

DISTRIBUTION OF EARTHQUAKES IN ZONES

Zone	1	2	3	4	5	6	7
No. of earthquakes per zone	8	8	1	12	0	0	6

TABLE 6

VALUES FOR a, b, AND c FOR THE VARIOUS SEISMOTECTONIC PROVINCES

Zone	A	B	C
1	6.391013	-0.008066	-3.045896
2	3.036227	-0.009080	-1.714270
3	3.448681	-0.054480	-3.332591
4	3.686528	-0.016540	-1.893100
7	4.958582	-0.085856	-2.590441

In equation 1 the coefficient c is associated with the geometrical spreading factor and b to the absorption of energy. It is the latter that we are most interested in. The results are given for each seismotectonic zone are given in table 6. One also notices that seismogenic zones 5 and 6 have no representation in the events listed even though there is a high degree of activity in both cases as located instrumentally. In the case of the Negros and Sulu trenches, zone 6, the activity is from fairly small earthquakes under magnitude M_b of 6.0 so that the effects are minimal. In the case of the Manila trench the earthquakes are, in fact, a good deal larger but much farther from land and hence their effects again are very small. The difficult situation is that of the Philippine fault activity for which there is only one earthquake out of the 35 that can be associated with it or for that matter within 25 km of it. Again, except for this one earthquake, most of the activity seems therefore to have few, if any, intensity observations associated with them. It should be re-emphasized here that, as in the case of practically all island countries, the population and therefore the structures to be damaged exist around the coasts; the interior consists mostly of mountainous jungle. The exception to this of course is the Great Central Plain of Luzon which is very heavily populated. In any case, the attenuation curve for the Philippine fault zone should be taken for what it is, numbers based on one datum.

Something should be said at this point concerning the drawing of isoseismal maps for the purpose of this study. In all but a few cases the ellipticity of the isoseismals seems questionable. Take for example the earthquake of 20 August 1937 (vol. IV, fig. 9, p. 758); all of the observations are very nearly in line with the major axis of the ellipse and none whatever are available to justify the size of the minor axis. This author would prefer to see circular rather than elliptic isoseismals in this particular case. They would do just as well as a method of smoothing. It is also true that this earthquake also may very well be associated with the Philippine fault zone as is the event of 12 July 1911 (vol. IV, fig. 5, p. 754). In the case of the latter event, there seems to be some evidence for the ellipticity given and, although the instrumental epicenter would place it in the Philippine trench

zone the macroseismic data would place it on the Philippine fault. Certainly in 1911 instrumental epicenters were extremely unreliable, this one being given only to the nearest degree; this author would prefer to believe the macroseismic evidence.

Contributions from Malaysia

Summary of Results

Malaysia has comparatively few earthquakes on its own territory, mostly in eastern Sabah. It most certainly feels the effects of a large number of earthquakes which occur in Sumatera. Unfortunately, Malaysia was the last of the great states of Southeast Asia to be populated and developed. Little of historical value was found in the records of the Portuguese and Dutch colony at Malacca before the British arrived at Penang in 1786 and the subsequent establishment of the Crown Colony of Singapore in 1819. The SEASEE team from the Malaysian Meteorological Service (MMS) scanned every possible source throughout the 19th and 20th centuries to find records of earthquake damage and felt reports. This included both government gazettes and newspapers and other sources from 1805 in Peninsular Malaysia, from 1870 in the province of Sarawak in North Borneo, and from 1884 in Sabah also in North Borneo. As is the case in the other SEASEE countries the record of felt effects and damage is being continually updated. As well as providing the raw data for intensities from the beginning of the 19th century onward for both peninsular Malaysia and North Borneo, the MMS team has included a study of earthquake intensities in Malaysia presenting several isoseismal maps (unfortunately without the positions of observations) for both areas. They present an isoseismal map, again without observations, of the event of 26 July 1976 which was studied in the field by them and present a plot of data points for that earthquake of intensity versus epicentral distance but do not calculate an attenuation characteristic. They also present two maps of maximum observed earthquake intensity for peninsular Malaysia and North Borneo.

Discussion of Results

Considering the paucity of earthquakes in Malaysia and the lack of an earthquake catalogue to use as a starting point, it took prodigious effort to compile the Malaysian contribution. Site intensities given in this catalogue appear to be too low by at least one intensity degree. As an example, one should refer to the report from Penang for the event of 1967 April 12 at 4 hours. The passage referring to the Old Central Market cites that a wall had collapsed and that the building was badly damaged. This is hardly intensity IV. It is undoubtedly more like intensity V or even VI in places. There are a number of such instances throughout this compilation but, at the same time since this an extensive compilation of various narratives, any future scientist can make his own assessment.

One of the reasons for going to all this trouble in a country that does not have many earthquakes on its own territory is to help the Indonesian scientists with the low-intensity region of Sumateran earthquakes. The author calls attention to the peninsular Malaysian reports for the earthquakes of 25 November 1833 and 16 February 1861. A second reason and by far the more important is that, when the 19th and early 20th century effects of earthquakes in peninsular Malaysia were noted, the buildings were never more than three

stories high in Kuala Lumpur and Singapore but now there are many buildings between 20 and 50 stories in both these cities. Great earthquakes in western Sumatera will certainly have an adverse effect on these taller structures which perhaps can be predicted from these earlier data.

Contributions from Thailand

Summary and Discussion of Results

An exhaustive catalogue of earthquakes experienced in a large region extending from eastern India to Tonkin, from southern China to the Malay Peninsula is given in two parts. It comprises earthquakes as early as 624 B.C. and continues to mid-1984. Naturally more is known about 20th century earthquakes than the earlier ones but it is nonetheless informative. The reason the catalogue contains earthquakes from such a vast area is that the effects of these distant shocks are felt in Thailand including damage therefrom. The reader as an example is directed to the earthquake of the year 460 in the 7th lunar month (see vol. II, Part A). These earthquakes almost undoubtedly occurred in eastern Burma the last of which must have been of great magnitude. Like all good catalogues, most of the old units which were originally used have been converted into modern metric ones save for dates.

Also presented are a number of isoseismal maps of interest (figs. 8, 9, and 10). The first gives the felt areas for a number of early 19th-century Indian earthquakes, one of which reinforces the point above that a shock near Dacca was felt in Bangkok as well as Chieng Mai in 1912. Figure 9 is an isoseismal map of the great Mandalay earthquake of 1912 which gives an intensity III at Bangkok and is probably a V or more at Chieng Mai. Evaluation of contemporary reports (vol. II, p. 176-178) place the intensity at V on even VI at both Bangkok and Chieng Mai. Figure 10 is an isoseismal map for two events, the solid lines representing the Pegu earthquake of 5 May 1930 and the Pyu earthquakes of 3 and 4 December of the same year. This series of earthquakes produced not only serious effects in Burma but both of these series of shocks caused damage ranging to intensity V or VI in Bangkok (see vol. II, p. 196-197 and p. 208-209). It is hard to say what effect these earthquakes would have had on modern tall buildings in the Thai capital.

One should also note from the three earthquakes in figures 9 and 10 that intensity decreases much more rapidly toward the northwest than to the southeast. This could be because of soil conditions, the northwest direction being primarily mountainous with little soil cover and the southeast being mostly great alluvial plains. This explanation is not entirely satisfactory since Mandalay is in an alluvial plain. Perhaps there are geological factors involved. This question should be resolved.

For lack of observations of intensity for the 12 seismic source zones to which this region has been divided (see later section), no attempt has been made to derive attenuation functions even though data for some of the zones exist and should be derived in the future.

A map of contours of maximum observed intensity for Thailand and adjacent areas is given as figure 11 and repeated on the Thai sheets of the seismotectonic map attached. The data from Parts A and B of volume II of this report were used to compile this map.

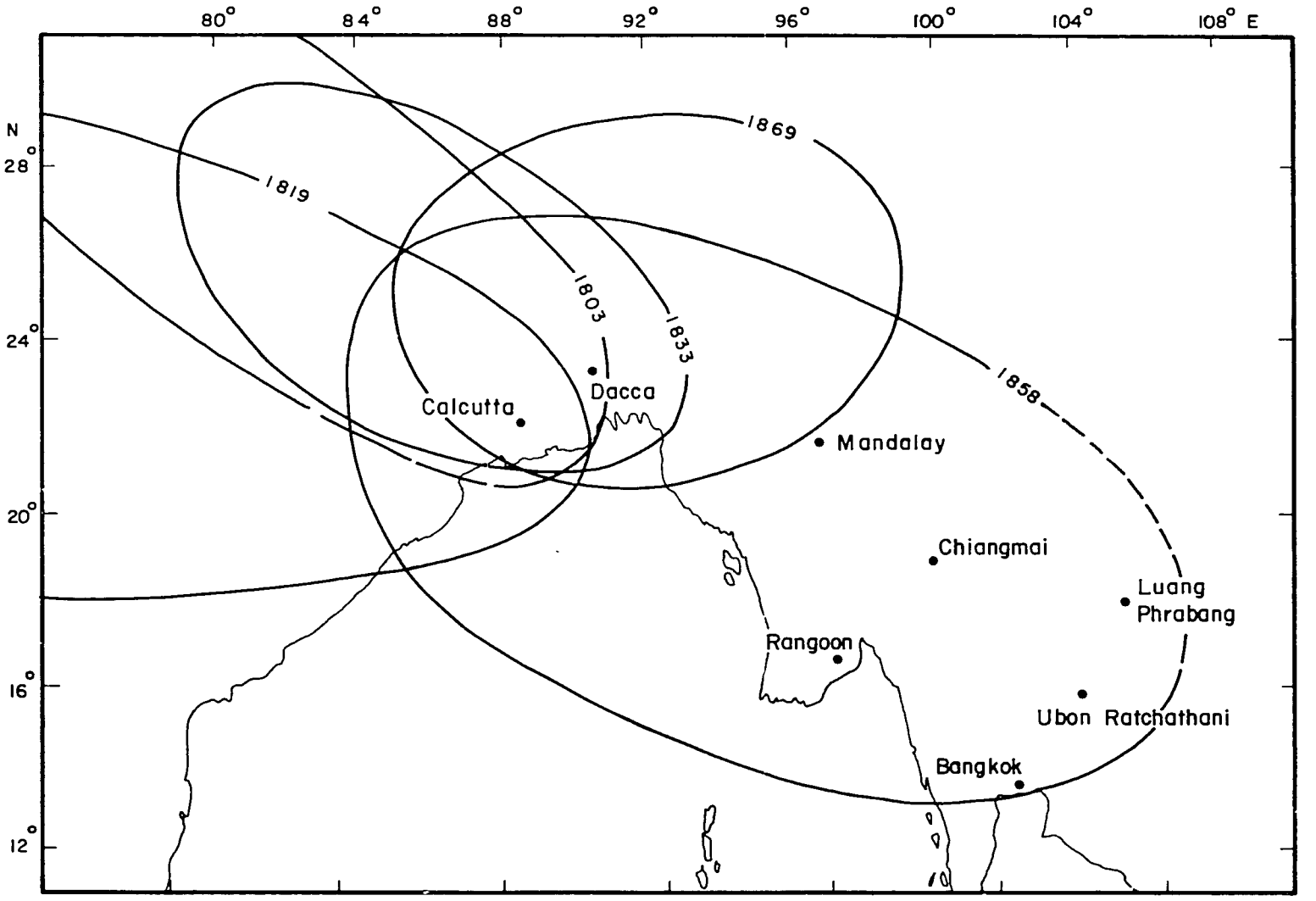

Fig. 8 Limits of felt areas for five 19th century Indian earthquakes (after Oldham, 1883). The earthquake of interest to this study is the one for 1858 which includes Bangkok in the felt area.

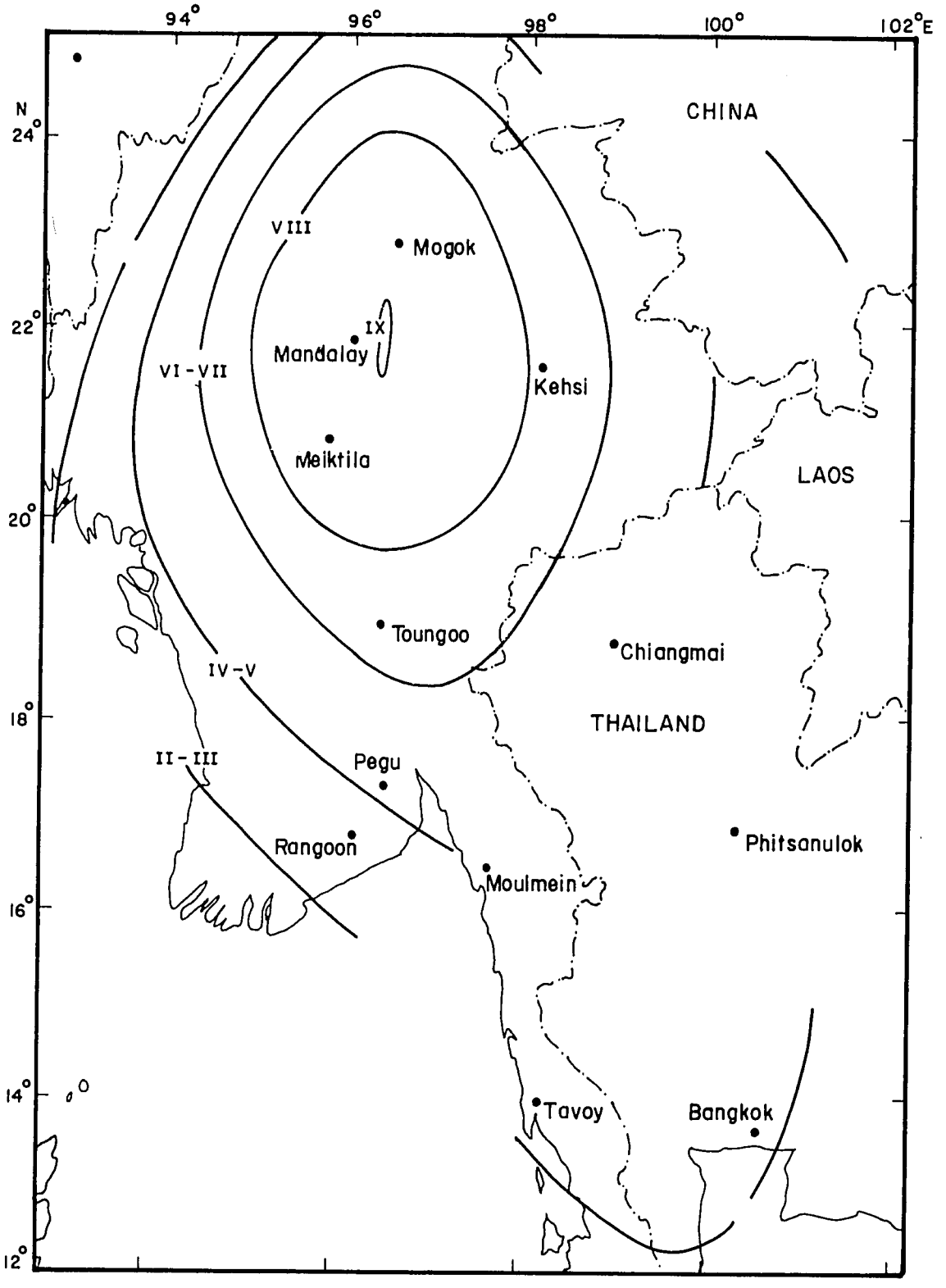

Fig. 9 Isoseismal map of the Mandalay earthquake of 23 May 1912 (after Brown, 1914).

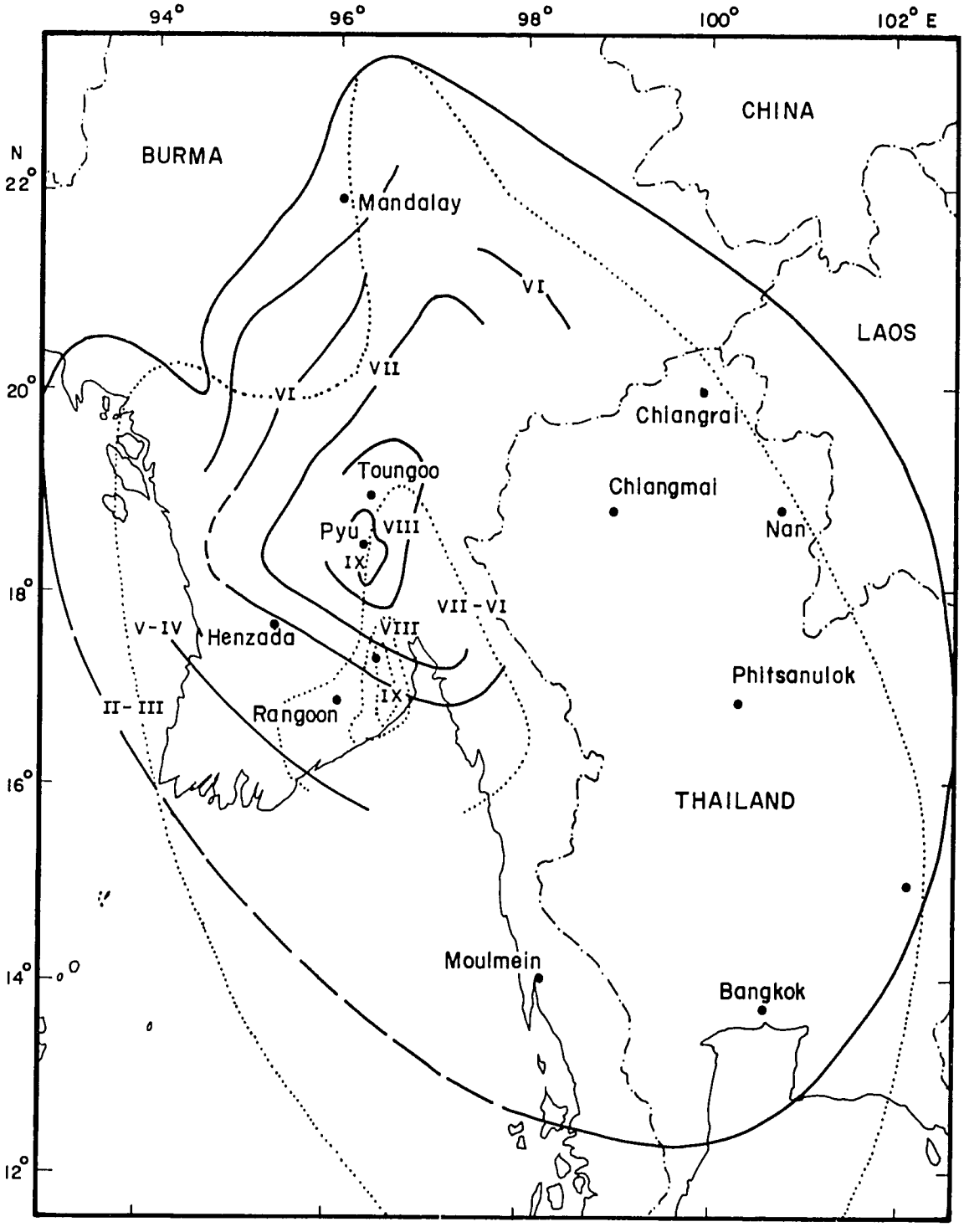

Fig. 10 Isoseismal map showing the Pegu earthquake of 5 May 1930 (dotted lines) and the Pyu earthquakes of 3 and 4 December 1930 (solid lines) (after Brown and Leicester, 1933).

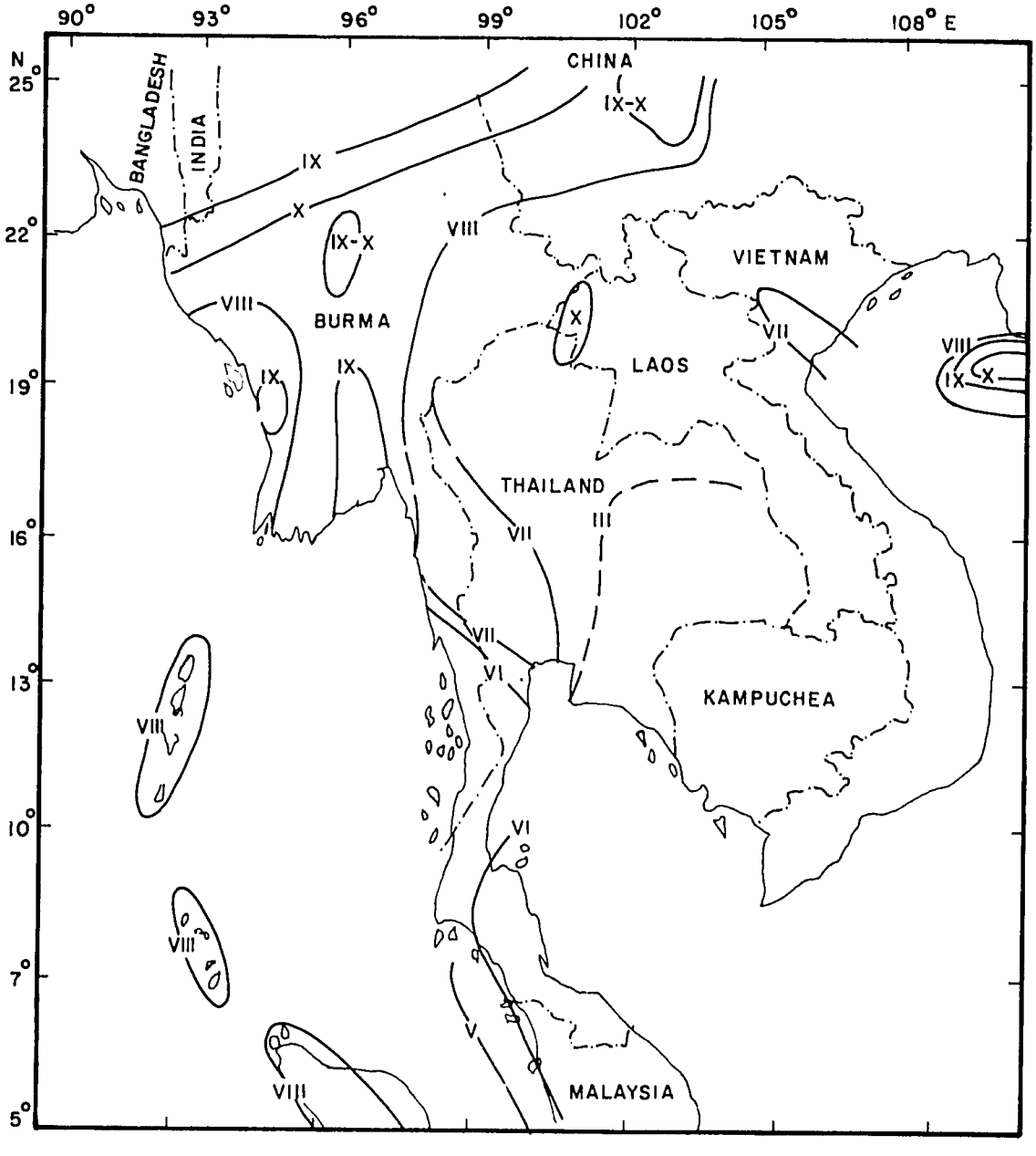

Fig. 11 Contours of maximum observed earthquake site intensities for Thailand and adjacent areas (see vol. II, Fig. 8, p. 147).

Contributions from Indonesia

Summary of Results

The catalogue of Indonesia earthquake intensity observations is presented here in two parts. The first is included in the Indonesian volume and is a list of "destructive" earthquakes from 1821 to the third quarter of 1984. The other part, which comprises English translations of a number of works presents earthquake observations from 88 A.D. to the end of 1941. It occupies about 3,000 pages of material and is published in microfiche form.

In the catalogue of destructive earthquakes in Indonesia, a maximum intensity is listed as well as the date of the earthquake and the felt effects. The only work known to exist but unavailable to the SEASEE Indonesian team was Visser (1922). An international search for this work was mounted but to no avail at the time of compilation but has recently (1986) been found.

The English language used in the Indonesian reports is somewhat different from that in the other national reports, but this local usage of English in no way detracts from the actual information presented. That is to say, there is no ambiguity of meaning whether you call landslides "groundslides" as they do in the Indonesian reports or whether one uses the rather archaic "mediterranean" meaning ashore or surrounded by land.

What is interesting about the Indonesian list of destructive events is their relatively small number compared to those observed in the Philippines for the same time period. This is most surprising since most of that part of Indonesia which is subject to earthquakes is far more densely populated than is the Philippines and domestic structures in particular are far weaker in Indonesia than in the Philippines. The only conclusion that this author can come to is simply that there are far poorer reporting practices in Indonesia than in the Philippines. One must also note that the text for each entry in the destructive list is taken from one and only one source rather than all of those that are available. One would have thought that a combination of all sources available would have been used in the destructive list.

Also presented is an analysis of the decay of site intensity with distance for 20 earthquakes in Java and Sumatera, most of the earthquakes used being located in Sumatera.

Discussion of Results

The greatest problem facing any prospective user of the earthquake catalogue compiled by this project is the identification of a large percentage of the localities mentioned. The reasons for the inability to identify the localities are given in the introduction to this section: language changes, changes of administration, resettlement of one village in another place, etc. A cursory examination of place names in the catalogues reveals that nearly 50 percent of the place names are unidentifiable when compared to a definitive modern atlas of Indonesia. It is recommended that a gazetteer of these place names be compiled and compared with governmental records to see if this percentage can be reduced. Further, a full gazetteer of all place names mentioned should be compiled giving the name of the locality, the island on

which it probably exists, and its geographic coordinates. The author knows of several sources of information which could be of help in this compilation but which have not so far been tapped.

With respect to the development of an attenuation function o 'ıtensity for earthquakes in Indonesia, the method was as follows: It was assumed that intensity as a function of distance is given by

$$I(x) = I_o \cdot e^{-bx} \qquad (2)$$

where
$I(x)$ = intensity level at x km epicentral distance
I_o = intensity level at the epicentre
b = attenuation coefficient.

This representation was given by Bolt and Abrahamson (1982). It in no way takes account of geometrical spreading as is given by equation 1 above for the Philippine case. This probably makes little difference since the data used are fairly crude and the contribution of the spreading term is small especially for shallow earthquakes. Twelve earthquakes were judged to have sufficient data to fit the above equation and they are listed in table 7. All of the earthquakes are either near the west coast of Sumatra or the south coast of Java. This is not surprising since this is where most of the Indonesian people live and therefore where damage to structures as a function of distance can be most easily observed. If one groups events 1-7 and 11 together as subduction earthquakes regardless of whether the epicenter itself is at sea or ashore and events 8, 9, and 10 together as shallow focus earthquakes in the forearc, the attenuation coefficients are quite understandable and make a considerable advance in our knowledge of this region. An example of the results for each of these groups is shown as figures 12 and 13. They are Cartesian plots of intensity as a function of epicentral distance.

Two things could be done, however, to improve these calculations. The first is to recalculate the focal parameters for the older earthquakes so as to obtain the best estimates of focal depth. Secondly, one should recalculate the attenuation coefficients using focal distance rather than epicentral distance. One should also provide at least one more decimal place in the attenuation coefficient.

Instrumental Location of Earthquakes

A catalogue of instrumentally located events is a fundamental requirement of modern seismological investigation. Instrumental locations are far more accurate than those from macroseismic data and the accuracy of instrumentally located events is almost equally accurate whether the epicentre is at sea or ashore. The use of instruments allows one to accurately measure the relative size of earthquakes through a parameter of the focus called magnitude which is related to seismic energy released. The use of magnitudes also allows one to relate earthquake source, energy release, and maximum peak acceleration or velocity at a site removed some distance from the epicentre, thus making possible the last step of this programme: the construction of seismic hazard maps.

The instrumental earthquake locations that have been collected comprise several thousand events between the years 1904 and 1983 within the area

TABLE 7
ATTENUATION FUNCTION OF INTENSITY FOR EARTHQUAKES IN INDONESIA

No.	Earthquake	Epicentre	Magnitude (R.S)	Depth (km)	Attenuation rate	Correlation coefficient	Data Source
1.	Banda Aceh 1 Apr 1964	5.9°N-95.7°E Submarine	5.2	132	0.006	0.87	GN, 1964
2.	Tapanuli 1 Apr 1921	2.4°N-98.8°E Inland	6.7	-	0.002	0.76	VPE, 1921
3.	Kotacane 9 Sept 1936	3.8°N-97.5°E Inland	7.2	-	0.003	0.95	VPE, 1936
4.	Simuk 16 Feb 1861	0.1°S-97.9°E Submarine	-	-	0.001	0.86	AW, 1861
5.	Pasaman 9 Mar 1977	0.4°N-99.7°E Inland	6.0	30	0.007	0.96	BMG-SR, 1977
6.	Pahae Jae 27 Aug 1984	1.5°N-98.9°E Submarine	4.8	53	0.006	0.68	BMG-SR, 1984
7.	Sibolga 4 Feb 1971	0.4°N-98.5°E Submarine	6.3	33	0.003	0.91	BMG-EI, 1971
8.	Bengkulu 15 Dec 1979	3.5°S-102.4°E Inland	6.0	25	0.021	0.73	BMG-SR, 1980
9.	Sukabumi 10 Feb 1982	6.9°S-106.9°E	5.3	10	0.015	0.87	BMG-SR, 1982
10.	Sukabumi 9 Feb 1975	6.7°S-106.7°E Inland	5.2	27	0.010	0.82	BMG-EI, 1975
11.	Jogyakarta 27 Sept 1937	8.7°S-110.8°E	7.2	-	0.003	0.92	VPE, 1937
12.	Podjon 20 Oct 1958	9.5°S-112.5°E	6.7	100	0.88		BMG-EI, 1958

Sources: (see references at end of text)
GN/Meteorological and Geophysical Agency, Geophysical notes.
BMG-SR/Meteorological and Geophysical Agency, Earthquake survey report.
BMG-EI/Meteorological and Geophysical Agency, Earthquakes in Indonesia.
VPE/Koninklijk Magnetisch en Meteorologisch Observatorium at Batavia, Volcanic phenomena and earthquakes in the east-Indian archipelago.
AM/Wickman, A. (1922).

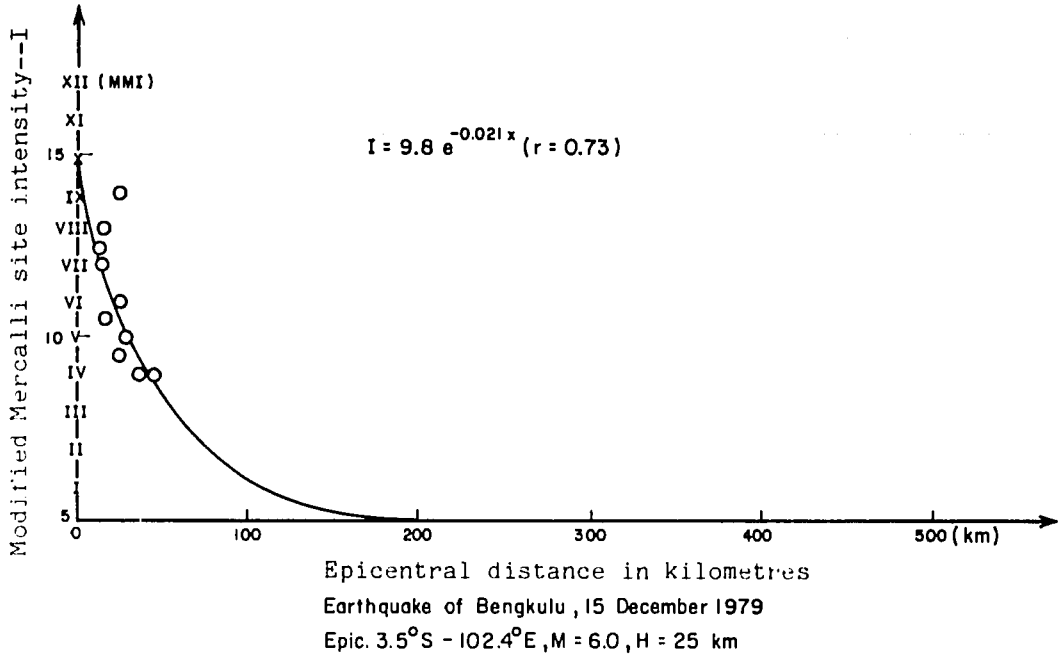

Fig. 12 Site intensity as a function of epicentral distance for the earthquake of 15 December 1979 near Bengkulu, western Sumatera. This earthquake is representative of shallow activity in this region.

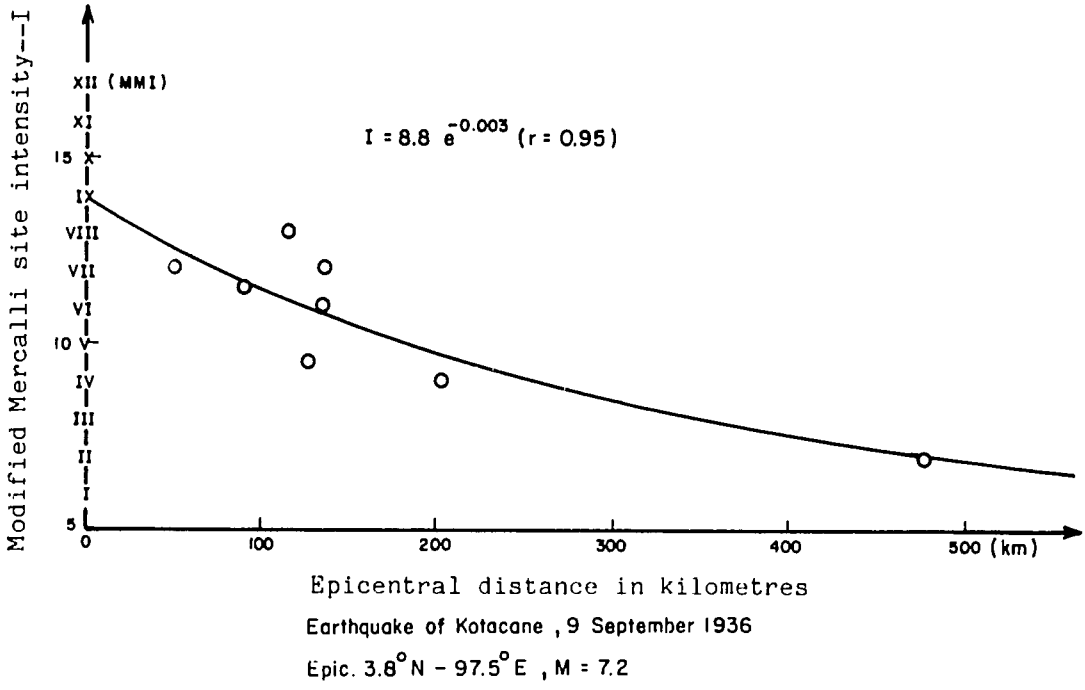

Fig. 13 Site intensity as a function of epicentral distance for the earthquake of 9 September 1936 near Kotacane, northwestern Sumatera. The depth of focus is indeterminate but has a distribution of intensities characteristic of deeper activity than that shown in figure 15.

bounded by 10°S. to 30°N. latitude and 90°E. to 155°E. longitude. Because of the volume of information this catalogue contains, it was felt that it would be too expensive to publish it in the usual printed form, so it is supplied as a magnetic tape along with a FORTRAN program to manipulate it which includes being able to print the entire catalogue. A list of the information sources and their abbreviations appears as a separate file on the tape.

All of the estimates of the focal parameters for earthquakes which are ascribed to the SEASEE member organizations were computed from their own seismographic observations with a computer program designed by the author during the UNDP programme (Arnold, 1976). It is unnecessary to go into all of the details of this programme as most of the programmes used to relocate earthquakes both in time and space are very similar one to each other, but this programme has one unique feature. It is particularly well suited for use with small networks and small earthquakes.

For events for Richter local magnitudes (M_L) in the range $4.0 \leq M_L \leq 5.2$, it is unusual to obtain more than five or so clear observations of first arrivals or P-phases. Since one wishes to solve for origin time, latitude, longitude, and depth of focus, this leaves only 1, 2, or perhaps 3 degrees of freedom if one is fortunate. These same seismograms, however, will yield a few clear observations of S-phases. The problem then is to combine these with the P-phases in such a way as to increase the number of degrees of freedom. Even for relocating earthquakes by first arrivals only, this program, as many others, employs the Method of Uniform Reduction invented by Jeffreys (1932) and improved by him later (Jeffreys, 1963). Buland (1986) has developed a method for estimating location errors more accurately than Jeffreys (1963). It is not used in the location program here because it was developed later. Simply put, uniform reduction recognizes that seismological observations do not obey the normal (Gaussian) law of error when one considers the residuals, the difference between the observed and the expected arrival times. The frequency of small residuals, 1 or 2 seconds or so for P-waves, does suggest a normal distribution but for 3, 4 and 5 second residuals, the frequencies are far larger than the normal law would predict. The same applies to S-waves but for different values of residuals. Jeffreys then derived a function of residual such that, when applied to the various observations, it makes the weighted residuals appear to be normally distributed. This is known as a weighting function and is given below. This means that when these weights are applied to the equations of condition, the Method of Least Squares, which is then used to find the unknown parameters of the focus, behaves properly and yields a maximum likelihood solution for the unknowns. The weighting function is

$$w_i^{-1} = 1 + \mu \exp \{h^2(\xi_i - \alpha)^2\} \qquad (3)$$

where

$$h^2 = \sigma^{-2} = \Sigma\, w_i / \Sigma\, w_i\, (\xi_i - \alpha)^2 ,$$

$$\alpha = \Sigma\, w_i\, \xi_i / \Sigma\, w_i ,$$

and $i = 1, 2, \ldots, n$ for n observations.

In general the value of σ for P-waves is about 1 second or somewhat less and for S-waves about 1.5 seconds or a bit more. Both of these parameters are solved for during each iteration in finding the solution. The coefficient μ, which is the ratio of the frequency of residuals on the flanks to the excess at the center of the distribution has typical values of .05 for P-waves and .1 or even more for S-waves. For this particular application, the coefficient μ, is taken to be a constant and set to the preceding values for the P- and S-wave observations.

Besides adding to the number of degrees of freedom in the conditional equations, the ability to use S-waves has the advantage of being better able to find depths of focus because, if one were to use P-arrivals only, depth of focus is made by comparing near and far observations, the latter being absent in the case of small networks.

Since each of the four national networks were equipped with the same programme for relocating earthquakes, and were taught during the UNDP programme to read their seismograms and process their data in exactly the same way (Hodgson et al. 1977), it is unnecessary to give a country by country summary here. The relocated earthquake epicentres are shown on each sheet of the accompanying seismotectonic maps.

Focal Mechanism Collection, Computation, and Interpretation

Introduction

The solution to focal mechanisms, that is determining from instrumental data for any given earthquake the type of faulting that has occurred, for example, normal, thrust, or strike-slip, produces an estimate of the directions along which the strains were released in a particular event. Knowing the focal mechanism for many earthquakes in a given region is an extremely useful tool in defining seismotectonic provinces and hence source zones. In an area as tectonically complex as Southeast Asia, it is necessary to use all the information available in analysing the tectonics of the region. This is particularly true in this region where in situ stress measurements along tectonic features are either impossible to obtain, very sparse, or even nonexistent.

Since focal mechanism solutions depend on instrumental data, they are restricted to events in this century. Furthermore, since they also require a good station distribution, both in azimuth and distance, most of the events considered in this study date from after the Second World War although a few large events from before the war are also considered. The procedure used by each of the national agencies was the same. Firstly, all of the existing literature was searched for reliable focal mechanism solutions which are then simply reproduced. Secondly, all of the existing earthquake data were searched for those events likely to yield good results. Then a computer-aided procedure was used in the focal mechanism solution. In this procedure, the computer program yields azimuths and distances which are plotted on a projection of the lower focal hemisphere. The traces of the two nodal planes are then chosen manually so as to divide the focal hemisphere into four groups of alternate compressions and dilatations. The intersection of the pressure and tension axes with the focal hemisphere are then plotted. In all cases the focal mechanism is assumed to be of the double-couple type.

Indonesia

The Meteorological and Geophysical Agency (BMG), the Indonesian member agency for SEASEE, has provided the most complete compendium of focal mechanism solutions for Indonesia that has ever been produced. Of the 900 solutions presented, nearly 700 of them were completely new and produced by the SEASEE-agency (BMG). This was a very prodigious effort indeed.

An example of the use of focal mechanisms is the following: referring to figure 14 for the earthquakes in the forearc system to the west of the island of Sumatera, most of the epicenters have pressure axes which trend in a northeasterly-southwesterly direction; that is, perpendicular to the trench and parallel to the direction of plate convergence. This is precisely what one would expect in a subduction zone. Note, however, that as the trench system turns to become almost parallel to the south coast of Java the situation changes abruptly. As discussed in the next section, there is an abrupt decrease in the seismicity and the maximum compressive stress axes for these earthquakes rotate to become parallel to the trench axis. The seismicity again resumes to the south of the Lesser Sunda islands and the maximum compressive stress axes are again, in the aggregate, normal to the trench. Understanding of the tectonics of the trench system south of Java, because of Java's huge population, is crucial to an earthquake mitigation programme. The author will not speculate here as to the reason for this change in the character of the seismicity along the subduction system. Whether or not great earthquakes can occur south of Java as have occurred along most of the rest of this zone is a question that must be answered in the future.

The Philippines

On the seismotectonic map accompanying this report. the Philippine agency has plotted 182 focal mechanisms in the Philippine region as shown in table 8, on its sheet of the seismo-tectonic map. These were selected as representative of the 371 solutions listed in Volume IV. Presumably, the selection was made so as not to clutter the map.

These focal mechanisms show the expected pattern of thrust faulting in the forearcs of trench systems and strike-slip faulting along the Philippine fault and other fault systems. The focal mechanism solutions substantiate the seismotectonic interpretations in Volume IV.

Thailand and Malaysia

Since earthquake activity on Malaysian territory only exists in northeastern Sabah State, the few epicenters shown on the Malaysian sheet also appear on the Philippine sheet, the solutions being supplied in both cases by the Pilipinos. Little need be said about them except that they seem to confirm the interpretation that the northeastern Sabah seismicity is an extension of the Sulu trench-arc system. In the case of Thailand, even though the area covered is very large indeed--more than just Thailand itself--surprisingly few focal mechanism solutions were found or determined. Data for new ones seem to be very sparse indeed. Most of the solutions are from events in Burma, mostly along the Sagaing fault system and in the Andaman Sea. It establishes the Sagaing fault, which has had a large number of major to great

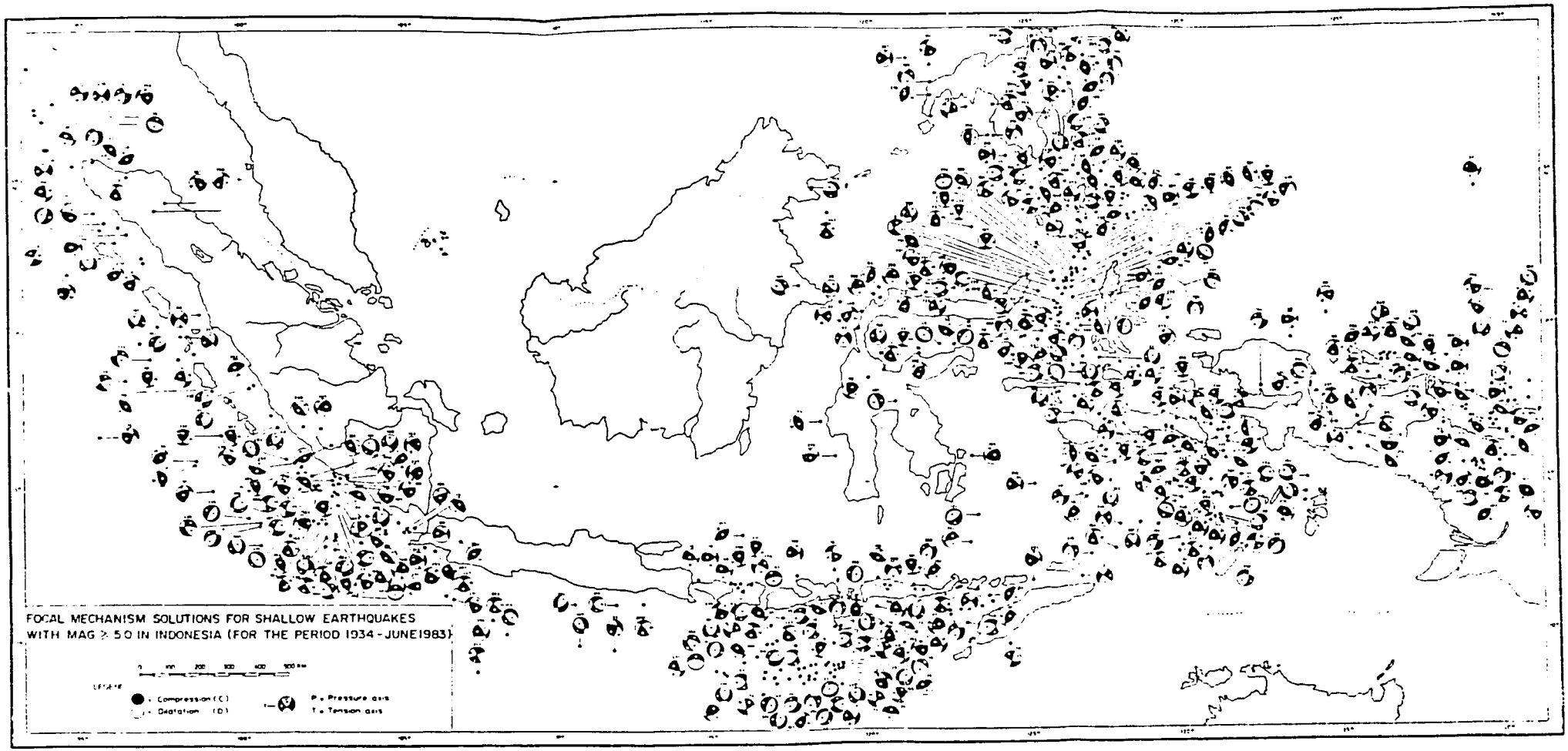

Fig. 14. Earthquake focal mechanisms for shallow earthquakes with M≥5.0 in Indonesia for the period 1934 to June 1983.

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TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
1	20 10 71	08 40 19.9	21.94	121.40	43	5.6	173.00/57.00	316.00/28.00	150.00/17.00	278.00/67.00	055.00/18.00	H29
2	07 01 77	19 36 46.9	21.20	120.25	36	5.7	072.00/44.00	224.00/42.00	153.00/75.00	058.00/01.00	327.00/15.00	H27
3	08 06 72	09 14 05.0	21.08	120.17	7	5.6	312.00/22.50	129.00/67.47	314.12/67.48	131.12/22.49	221.56/01.06	***
4	26 04 65	22 15 42.0	21.00	120.68	29	5.8	109.00/72.00	276.00/18.00	270.00/64.00	098.00/28.00	006.00/04.00	KS10
5	28 01 72	16 18 26.7	20.96	120.07	33	5.5	146.50/44.50	000.50/40.15	067.05/72.10	164.11/02.27	254.83/17.75	***
6	08 01 72	05 27 53.7	20.94	120.26	36	6.1	042.00/44.00	278.00/30.00	326.00/58.00	071.00/10.00	168.00/31.00	SK5
7	18 11 74	18 03 03.5	20.54	121.22	38	5.5	003.50/35.50	181.50/54.48	182.67/09.49	008.46/80.46	272.83/00.95	***
8	27 10 82	10 30 13.2	20.483	121.53	40	5.5	070.50/11.50	249.50/78.50	250.33/33.50	070.76/56.50	340.46/00.20	***
9	02 08 83	02 17 41.0	20.43	122.10	158	6.1	303.50/41.00	051.00/19.08	003.00/45.00	264.00/18.00	160.00/42.00	***
10	03 07 83	02 49 27.9	20.16	122.38	220	6.1	223.00/60.00	048.00/29.91	054.74/74.78	226.17/15.06	316.75/02.16	***
11	28 12 82	13 49 29.0	19.95	121.40	34	6.0	102.00/34.88	339.50/37.62	310.50/88.50	220.00/56.50	046.00/56.00	***
12	17 04 82	09 20 57.8	19.871	120.526	10	6.2	290.00/07.50	020.50/33.51	332.00/22.00	070.00/22.00	188.00/56.00	***
13	09 11 64	18 43 36.1	19.36	121.22	11	5.5	215.00/11.00	034.50/79.00	215.12/56.00	034.92/34.00	124.98/00.09	***
14	03 02 72	03 37 52.0	19.36	122.06	54	5.8	280.00/33.00	079.00/55.00	092.00/11.00	314.00/75.00	184.00/10.00	CIK1
15	07 01 81	21 36 22.8	19.173	121.151	39	5.7	104.50/23.50	006.50/18.77	146.04/03.12	054.19/30.63	241.27/59.17	***
16	02 12 74	06 34 07.6	19.15	121.22	50	5.6	308.00/04.00	041.00/02.00	086.00/02.00	355.00/04.00	181.00/88.00	***
17	25 06 73	07 19 45.9	19.11	121.19	36	5.8	101.00/32.00	265.00/56.00	275.00/13.00	130.00/75.00	006.00/08.00	H22
18	26 08 79	14 31 25.8	19.07	122.10	15	6.1	084.00/20.00	350.00/11.00	129.00/06.00	036.00/21.00	235.00/67.00	H21
19	19 11 74	03 55 21.0	19.00	121.39	40	5.7	127.00/32.00	292.00/58.00	301.00/13.00	148.00/26.00	032.00/08.00	H20
20	08 10 76	21 05 31.4	18.98	121.27	57	5.6	005.00/04.00	181.00/86.00	005.00/49.00	185.00/41.00	095.00/00.00	H19
21	03 02 74	10 08 47.4	18.93	120.13	30	5.8	090.00/50.00	270.00/40.00	270.00/85.00	090.00/05.00	000.00/00.00	CIK2

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TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP--Continued

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
22	22 11 81	15 05 20.5	18.75	120.80	24	6.2	089.50/29.00	191.54/59.12	318.00/68.00	179.00/16.00	084.50/12.00	***
23	03 09 74	05 55 09.7	18.26	119.2	41	5.9	098.00/55.00	313.00/30.00	119.00/13.00	355.00/69.00	213.00/17.00	H17
24	17 08 83	12 17 56.9	18.231	120.86	39	6.2	261.00/23.00	081.00/67.00	261.00/24.00	080.00/67.00	170.00/00.00	***
25	26 08 70	15 11 54.9	18.02	120.48	50	5.5	244.00/16.00	085.00/73.00	068.00/29.00	235.00/61.00	336.00/06.00	CIK3
26	16 09 83	23 10 47.8	17.974	120.766	33	5.6	276.00/24.00	030.00/42.41	323.72/49.87	066.94/10.91	165.62/38.04	***
27	17 10 67	21 05 23.9	17.27	121.83	41	5.5	037.00/11.00	135.00/33.88	180.44/15.03	080.21/31.95	292.04/53.90	***
28	29 08 77	14 23 40.5	17.44	119.87	12	6.0	067.50/31.50	252.50/58.40	248.00/16.00	070.00/64.00	160.00/01.00	***
29	06 12 75	05 13 11.7	17.42	119.68	19	5.8	156.00/72.00	336.00/18.00	336.00/63.00	156.00/27.00	066.00/00.00	SK23
30	21 07 77	13 45 54.4	16.86	122.39	29	6.0	074.00/66.00	264.00/24.00	081.00/21.00	272.00/69.00	161.00/06.00	H15
31	19 03 77	19 35 08.0	16.80	122.34	40	5.6	070.00/59.00	268.00/30.00	082.00/15.00	291.00/73.00	173.00/08.00	H14
32	18 03 77	21 43 52.4	16.773	122.327	37	6.2	068.00/62.00	272.00/25.00	084.00/18.00	296.00/70.00	178.00/10.00	H13
33	22 05 72	06 04 01.0	16.60	122.19	41	5.9	095.00/66.00	275.00/24.00	095.00/21.00	275.00/69.00	005.00/00.00	CIK5
34	03 08 68	06 25 07.4	16.45	122.31	52	6.1	113.50/48.00	341.50/29.07	140.00/14.00	032.50/64.00	235.00/26.50	***
35	01 08 68	20 19 21.5	16.30	122.11	30	5.9	280.00/20.00	065.00/66.00	089.00/24.00	299.00/63.00	185.00/12.00	F44
36	31 03 80	12 41 47.7	16.13	12[illegible].96	43	5.9	326.00/36.00	207.50/33.30	357.30/01.57	265.18/53.49	088.47/36.46	***
37	07 04 70	05 34 06.2	15.78	121.71	50	6.5	056.00/47.00	288.00/30.00	085.00/09.00	338.00/60.00	180.00/27.00	F51
38	21 05 77	05 35 22.5	15.69	120.82	189	5.7	279.00/35.00	041.50/37.50	338.58/56.72	070.75/01.43	161.69/33.24	***
39	07 04 70	06 11 52.8	15.68	121.85	22	5.5	099.00/25.50	195.00/12.36	149.50/27.12	054.96/08.80	308.56/61.26	***
40	04 07 71	11 30 53.8	15.60	121.85	46	5.5	108.00/85.00	288.00/05.00	108.00/40.00	288.00/50.00	018.00/00.00	CIK9
41	28 08 68	20 42 20.2	15.55	122.02	25	5.7	060.00/50.00	256.00/40.00	069.00/04.00	304.00/81.00	160.00/07.00	F53
42	07 04 70	06 34 19.2	15.53	121.86	33	5.5	108.50/14.00	210.00/38.65	254.30/15.70	151.71/37.78	002.45/47.95	***
43	07 04 70	05 53 48.6	15.50	122.40	47	5.6	295.00/27.15	035.00/18.71	253.50/05.50	347.13/33.33	155.26/56.10	***

TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP--Continued

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
44	08 04 70	21 23 54.0	15.43	121.75	7	5.7	236.00/40.00	064.00/50.00	060.00/05.00	195.00/84.00	329.00/04.00	CIK11
45	15 04 70	13 14 26.7	15.11	122.71	31	5.6	264.00/14.00	028.00/66.00	068.00/28.00	288.00/55.00	169.00/19.00	CIK12
46	12 04 70	04 01 44.6	15.08	122.01	25	5.8	073.00/02.00	341.00/28.00	032.00/23.00	294.00/16.00	169.00/61.00	SK3
47	14 08 68	07 56 37.0	15.08	122.51	15	5.5	314.00/27.00	135.00/63.00	134.34/18.00	312.96/72.00	044.21/00.40	***
48	21 11 70	12 19 40.1	15.01	120.13	53	5.5	345.50/33.00	116.50/45.29	143.29/06.74	040.11/62.58	236.66/26.44	***
49	06 10 69	12 48 05.8	14.99	120.11	66	5.6	230.00/28.00	108.50/44.50	075.84/09.42	180 00/55.85	339.78/32.48	***
50	19 08 76	19 04 04.6	14.45	123.68	26	5.5	136.00/30.00	233.00/10.00	091.00/13.00	188.00/29.00	340.00/59.00	H1
51	07 06 76	07 36 55.4	14.08	124.80	33	6.1	291.00/09.50	185.00/58.74	135.00/30.00	250.00/38.00	025.00/28.00	***
52	24 01 82	06 08 56.6	14.18	124.34	37	5.6	225.50/24.00	066.00/64.58	045.00/19.50	208.00/68.50	319.00/08.00	***
53	10 12 76	23 05 27.2	14.00	124.89	33	5.5	254.50/39.50	092.00/49.16	082.52/04.89	201.46/79.98	351.77/08.73	***
54	19 02 74	03 30 22	13.98	122.17	19	5.7	136.50/37.00	235.00/11.10	192.54/34.17	090.70/16.82	338.92/50.81	***
55	11 01 82	06 49 18.9	13.945	124.407	33	5.9	124.50/17.50	034.00/01.59	077.89/13.43	170.58/11.13	298.99/72.42	***
56	19 03 80	08 45 46.5	13.892	120.725	43	5.9	298.50/34.00	057.50/36.22	356.39/53.91	088.56/01.58	179.71/36.04	***
57	11 01 82	06 10 06.4	13.752	124.358	46	6.0	166.00/53.50	033.50/26.56	188.00/75.00	072.00/65.00	284.00/19.00	***
58	17 03 73	03 30 53.2	13.41	122.87	44	5.9	028.00/38.00	120.00/04.00	080.00/28.00	337.00/24.00	214.00/52.00	CIK16
59	25 04 72	19 30 08.0	13.33	120.34	37	6.4	330.00/22.00	068.00/18.00	288.00/02.00	020.00/30.00	193.00/61.00	CIK17
60	15 08 66	02 45 34.0	13.28	121.36	23	5.5	080.00/30.00	182.00/25.00	040.00/03.00	135.00/38.00	307.00/57.00	F43
61	05 07 73	22 46 15.0	13.18	124.65	20	5.5	338.00/25.00	146.00/65.00	348.00/69.00	154.00/20.00	247.00/04.00	CIK19
62	24 11 64	12 40 56.3	13.12	124.58	25	5.6	057.00/69.00	258.00/20.00	072.00/25.00	270.00/64.00	166.00/05.00	F40
63	25 08 76	12 29 56.6	13.10	124.48	39	5.7	355.00/76.00	176.00/14.00	356.20/31.00	177.00/58.99	086.41/00.35	***
64	24 05 65	23 21 13.6	13.10	124.50	54	5.7	288.50/29.50	044.00/37.27	077.87/04.59	342.19/50.93	171.55/38.69	***

TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP--Continued

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
65	15 02 76	01 54 19.0	12.98	124.74	0	6.2	263.50/13.00	039.50/72.21	278.00/56.00	074.00/31.00	170.00/12.00	***
66	27 12 64	17 43 17.4	12.92	125.37	1	5.6	261.00/08.00	048.00/81.00	076.00/36.00	267.00/53.00	170.00/04.00	F39
67	15 11 75	20 39 29.8	12.91	125.88	35	6.0	031.00/31.00	254.00/50.00	343.00/66.00	229.00/10.00	135.00/22.00	CIK23
68	28 02 79	22 36 30.6	12.829	124.599	26	5.6	079.50/84.50	259.50/05.50	259.50/50.50	079.50/39.50	349.50/00.00	***
69	29 04 71	19 56 14.0	12.63	122.27	19	5.6	032.50/15.00	123.50/03.73	347.08/07.88	078.95/13.22	227.10/74.52	***
70	05 02 70	22 05 58.5	12.58	122.09	8	5.9	292.00/08.00	198.00/24.00	247.00/23.00	152.00/10.00	038.00/64.00	F54
71	06 11 75	12 36 17.3	12.50	126.06	30	6.1	227.00/30.00	084.00/54.00	185.00/68.00	061.00/12.00	327.00/18.00	CIK25
72	31 10 75	08 28 02.4	12.47	126.01	49	6.5	239.00/26.00	059.00/64.00	239.00/71.00	059.00/19.00	329.00/00.00	CIK24
73	25 07 71	12 51 43.5	12.44	123.71	42	5.7	217.00/00.00	307.00/00.00	082.00/00.00	352.00/00.00	000.00/90.00	***
74	03 07 73	06 37 35.4	12.27	125.32	37	5.5	068.00/72.00	276.00/16.00	089.00/29.00	288.00/60.00	184.00/08.00	CIK27
75	03 07 73	07 03 47.1	12.21	125.29	36	6.0	067.00/62.00	247.00/28.00	067.00/17.00	247.00/73.00	337.00/00.00	CIK28
76	09 01 65	13 32 50.0	11.88	126.26	27	5.6	047.00/37.00	274.00/43.00	246.00/64.00	250.00/04.00	160.00/26.00	F38
77	27 11 77	02 19 52.3	11.80	125.472	33	5.5	156.00/29.00	299.50/38.83	265.70/05.77	003.09/51.83	171.24/37.57	***
78	13 11 70	14 16 21.7	11.78	123.97	18	5.5	180.00/30.00	000.00/60.00	180.00/75.00	000.00/15.00	270.00/00.00	CIK35
79	21 10 75	23 06 22.0	11.65	121.58	20	5.5	164.00/60.00	344.00/30.00	344.00/75.00	164.00/15.00	074.00/00.00	SK21
80	18 08 73	08 25 47.0	11.45	121.38	22	5.7	326.00/18.00	220.00/46.00	282.00/42.00	178.00/14.00	074.00/44.00	CIK37
81	12 07 70	09 18 04.6	10.84	125.41	77	5.5	260.00/30.00	048.00/56.00	296.00/70.00	066.00/13.00	161.00/15.00	CIK33
82	19 08 67	15 28 08.5	10.36	125.87	55	6.0	068.00/46.00	295.00/34.00	093.00/06.00	350.00/64.00	187.00/25.00	F37
83	17 08 76	01 11 10.3	10.09	125.09	33	6.0	310.00/42.50	072.00/30.04	018.00/56.00	278.00/06.00	184.00/33.00	***
84	23 08 75	15 06 42.4	10.04	125.86	66	5.8	066.00/55.00	280.00/30.00	086.00/13.00	318.00/68.00	180.00/16.00	CIK30
85	14 01 82	11 36 03.9	9.994	124.25	606	5.6	084.00/18.00	303.50/67.16	063.25/60.48	275.17/25.67	178.50/13.58	***

TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP--Continued

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
86	04 09 81	11 15 13.6	9.96	124.04	645	6.0	063.00/29.00	333.00/00.00	013.00/21.00	112.00/20.00	240.00/62.00	***
87	17 02 70	05 46 03.7	9.80	125.91	72	5.8	048.00/50.00	237.00/40.00	276.00/84.00	052.00/05.00	144.00/04.00	F49
88	14 12 75	20 49 14.7	9.7	122.56	49	5.5	005.00/39.00	246.50/30.51	300.80/53.51	037.51/04.93	13[illegible].11/36.04	***
89	04 07 72	10 16 13.1	9.42	122.54	64	5.7	224.00/39.00	345.00/42.46	193.17/03.76	288.66/55.54	100.61/34.20	***
90	19 06 80	14 14 52.1	9.353	126.55	36	5.5	192.00/27.00	096.00/10.00	236.00/11.00	140.00/27.00	350.00/57.00	S
91	20 09 73	20 43 39.8	9.23	123.92	542	5.9	311.00/05.50	113.00/16.00	313.00/53.00	128.00/39.00	221.00/02.00	***
92	08 11 70	14 58 57.4	9.16	126.41	41	5.6	288.00/15.00	065.00/70.00	097.00/29.00	305.00/58.00	195.00/12.00	CIK32
93	13 04 80	05 41 44.4	9.00	126.27	49	5.9	226.00/40.50	078.00/44.80	061.00/04.00	160.00/74.00	330.00/16.00	***
94	31 03 71	09 41 05.0	8.98	125.72	34	5.5	021.50/09.00	289.00/15.40	244.59/04.42	345.97/17.36	140.77/72.05	***
95	31 03 71	10 53 24.8	8.97	125.66	0	5.4	041.50/58.50	181.50/25.15	147.87/64.61	015.93/17.60	280.12/17.70	***
96	19 02 83	20 14 22.8	8.735	124.039	568	5.8	254.00/25.50	106.00/74.49	267.00/60.00	074.00/30.00	344.00/02.00	***
97	20 03 69	16 18 57.5	8.69	127.35	43	6.1	109.00/22.00	229.00/51.00	150.00/55.00	264.00/16.00	005.00/31.00	F55
98	01 12 78	17 10 29.5	8.665	122.206	40	5.8	195.00/22.00	096.00/20.00	236.00/02.00	145.00/31.00	328.00/26.00	S
99	22 11 78	09 32 19.9	8.586	126.038	33	5.5	348.00/25.00	094.00/30.59	039.04/41.20	132.11/03.50	226.08/48.59	***
100	22 06 78	06 37 51.5	8.514	126.63	59.3	5.5	162.00/26.00	342.00/54.00	342.00/08.00	162.00/82.00	252.00/00.00	S
101	21 08 66	05 00 24.0	8.48	126.62	39	5.8	248.00/24.00	068.00/64.00	068.00/19.00	248.00/71.00	349.00/00.00	F35
102	07 11 76	17 09 06.1	8.48	126.38	60	6.0	270.00/24.00	090.00/66.00	090.00/21.00	270.00/69.00	000.00/00.00	CIK41
103	16 03 71	20 35 15.0	8.43	127.23	51	5.8	217.00/50.00	098.00/22.00	141.00/53.00	253.00/16.00	353.00/32.00	CIK42
104	14 06 78	13 34 09.6	8.238	122.381	79	5.9	017.00/10.00	109.00/10.00	063.00/16.00	153.00/00.00	247.00/76.00	S
105	02 12 69	17 57 05.0	8.13	126.23	94	5.7	173.00/30.00	283.00/30.00	228.00/45.00	138.00/00.00	048.00/46.00	CIK44
106	30 10 78	13 43 14.6	8.051	122.286	33	5.7	212.00/10.00	116.00/39.00	168.00/26.00	072.00/13.00	318.00/60.00	S

TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP--Continued

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat.(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
107	23 02 75	02 58 41.8	8.02	124.06	634	5.6	267.00/16.00	110.00/72.00	256.00/62.00	092.00/28.00	359.00/07.00	CIK45
108	10 05 71	11 53 53.8	7.99	126.95	37	5.9	250.00/04.00	070.00/86.00	250.00/49.00	070.00/41.00	340.00/00.00	CIK46
109	01 10 72	23 49 37.5	7.46	123.77	636	6.0	117.00/60.00	290.00/30.00	285.00/75.00	112.00/15.00	022.00/03.00	CIK47
110	16 08 76	23 49 39.8	7.35	123.42	44	5.8	035.00/51.50	199.50/37.47	158.86/79.60	026.31/07.08	295.36/07.59	***
111	17 08 76	07 53 31	7.26	123.32	16	5.6	123.50/22.50	300.00/67.46	125.98/67.47	302.47/22.49	032.99/01.24	***
112	17 08 76	04 19 27.6	7.25	122.94	22	6.2	080.00/00.00	350.00/00.00	035.00/00.00	305.00/00.00	000.00/90.00	SC2
113	02 05 77	21 53 56.5	7.186	123.258	24	5.7	152.00/76.50	332.00/13.50	332.00/58.50	152.00/31.50	062.00/00.00	***
114	16 09 65	13 50 12.2	7.13	126.58	169	5.9	026.00/34.00	274.00/31.00	060.00/02.00	328.00/48.00	152.00/42.00	FM21
115	16 08 76	18 16 20.2	7.05	123.71	40	5.5	212.00/18.29	111.00/30.00	069.33/07.56	164.69/35.13	328.87/53.82	***
116	24 06 65	07 45 13.9	7.00	126.25	51	5.7	129.50/31.50	008.50/40.05	337.26/04.90	074.44/55.53	243.93/34.02	***
117	07 11 76	20 49 14.0	6.98	123.83	32	5.9	199.50/10.00	008.00/08.44	053.62/13.10	143.87/01.09	238.53/76.85	***
118	18 08 76	20 27 33.4	6.89	123.68	45	5.6	329.00/41.50	229.50/10.57	015.78/19.81	270.18/36.74	128.14/46.57	***
119	01 03 77	00 35 00.8	6.867	123.976	45	5.5	100.00/67.50	280.00/22.50	280.00/67.50	100.00/22.50	010.00/00.00	***
120	21 11 77	11 39 40.1	6.83	123.58	601	5.5	090.00/66.00	292.00/23.00	106.00/21.00	303.00/67.00	199.00/08.00	S
121	25 09 76	03 30 03.9	6.83	123.80	47	5.7	100.50/35.00	352.00/24.38	138.44/06.53	042.04/44.22	235.02/45.04	***
122	10 01 70	12 07 18.6	6.80	126.75	68	5.9	081.00/42.00	298.00/42.00	098.00/00.00	006.00/81.00	190.00/18.00	F48
123	04 04 78	06 58 00.0	6.783	123.783	43	5.6	216.00/43.50	057.00/11.37	269.47/20.33	016.78/38.77	158.30/44.27	***
124	30 03 70	16 46 46.2	6.78	126.86	63	5.8	062.00/30.00	280.00/54.00	256.00/13.00	019.00/66.00	162.00/18.00	F50
125	08 09 76	09 15 01.7	6.75	124.00	59	5.5	046.00/22.00	148.50/28.18	095.45/36.78	188.41/03.96	283.67/52.93	***
126	01 10 78	13 23 50.5	6.682	123.982	46	5.6	298.00/00.00	020.80/00.00	073.00/00.00	163.00/00.00	000.00/90.00	***
127	08 11 75	14 53 32.6	6.66	126.79	81	5.6	282.00/16.00	102.00/74.00	102.00/30.00	282.00/60.00	012.00/00.00	CIK56

TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP--Continued

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
128	08 07 80	04 39 29.4	6.63	125.77	173	5.9	261.50/10.00	046.28/77.82	076.00/35.00	268.00/54.00	170.00/04.00	***
129	04 08 68	11 41 23.8	6.6	126.77	109	5.9	262.00/20.00	082.00/70.00	082.00/25.00	262.00/65.00	352.00/00.00	CIK57
130	26 10 75	10 41 33.2	6.54	126.81	66	5.9	275.00/34.00	084.00/56.00	090.00/11.00	298.00/78.00	181.00/06.00	CIK52
131	10 07 75	18 29 15.8	6.51	126.65	82	5.9	279.00/50.00	066.00/35.00	260.00/07.00	014.00/71.00	168.00/16.00	CIK53
132	17 08 76	05 18 49.3	6.47	123.90	32	5.5	098.00/22.00	003.00/12.17	048.65/24.26	141.89/06.65	246.06/64.54	***
133	02 12 72	00 19 52.0	6.41	126.62	73	6.0	066.00/35.00	295.00/43.00	269.00/04.00	007.00/63.00	176.00/26.00	CIK54
134	29 02 80	11 13 00.0	6.33	126.90	102	6.0	224.50/47.00	062.00/41.65	233.00/18.00	115.00/81.00	324.00/08.00	***
135	09 03 73	10 06 37.7	6.32	127.38	55	6.0	106.00/26.00	234.00/52.00	149.00/61.00	266.00/14.00	002.00/26.00	CIK59
136	16 08 76	16 11 07.3	6.26	124.02	33	6.4	080.00/20.00	237.00/68.00	254.00/24.00	094.00/65.00	347.00/08.00	SC1
137	26 10 76	12 51 29.8	6.24	126.30	80	5.6	290.00/25.00	110.00/65.00	110.00/20.00	290.00/70.00	020.00/00.00	CIK60
138	14 03 73	01 57 03.7	6.138	126.885	81.6	5.5	306.00/22.00	198.00/38.00	258.00/44.00	159.00/10.00	062.00/42.00	S
139	24 10 68	15 51 16.0	6.06	126.97	43	5.5	078.00/50.00	309.00/29.00	107.00/11.00	356.00/61.00	204.00/26.00	F46
140	02 01 80	20 58 45.5	6.00	126.13	75	6.0	313.00/83.50	135.00/06.50	135.00/52.00	316.00/40.00	044.50/00.00	***
141	19 11 79	22 17 20.2	5.861	125.295	85	6.1	120.00/37.00	300.00/53.00	300.00/08.00	120.00/82.00	030.00/00.00	S
142	13 05 81	01 39 54.82	5.83	127.008	145	6.0	101.00/46.00	215.00/22.00	0[illegible].00/12.00	171.00/50.00	324.00/37.00	S
143	02 04 64	15 56 52.5	5.77	125.73	168	5.5	078.00/84.00	258.00/06.00	078.00/39.00	258.00/57.00	168.00/00.00	FM20
144	19 02 79	20 35 46.3	5.683	124.696	61.3	5.5	344.00/33.00	228.00/38.00	196.00/02.00	290.00/54.00	101.00/35.00	S
145	12 02 83	08 47 42.7	5.669	126.297	51	5.7	246.00/30.00	358.50/33.54	033.00/03.00	302.00/48.00	126.00/42.50	***
146	15 04 79	22 14 52.3	5.66	123.59	555	5.9	284.00/23.00	144.50/60.83	254.00/64.00	119.00/19.00	023.00/18.00	***
147	14 07 83	19 47 46.5	5.56	126.45	43	5.8	042.00/18.50	298.00/35.87	258.00/11.00	357.00/41.00	157.00/48.00	***
148	20 02 83	10 49 54.1	5.55	126.25	61	5.9	102.00/20.00	001.00/38.77	060.00/44.00	319.00/11.00	219.00/44.00	***

TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP--Continued

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
149	03 04 80	16 34 24.6	5.345	125.365	212.3	5.6	225.00/10.00	075.00/80.00	255.00/55.00	075.00/35.00	345.00/00.00	S
150	15 03 83	19 58 30.4	5.33	126.57	41	5.7	202.00/48.00	340.50/37.79	180.00/08.00	286.50/66.50	087.00/22.50	***
151	16 05 65	11 35 52.1	5.26	125.57	36	5.6	038.00/31.00	258.00/48.00	240.00/10.00	349.00/62.00	145.00/26.00	F33
152	07 02 79	21 02 06.8	5.21	127.295	129	6.2	288.00/22.00	174.00/39.00	137.00/05.00	236.00/48.00	036.00/34.00	S
153	13 12 70	23 50 12.8	5.15	123.50	524	5.5	270.00/13.00	090.00/72.00	270.00/63.00	090.00/27.00	000.00/00.00	CIK65
154	20 03 70	11 07 38.4	5.07	125.35	61	5.7	090.00/45.00	270.00/45.00	090.00/00.00	000.00/90.00	000.00/00.00	CIK67
155	10 06 64	22 16 39.0	5.02	127.43	86	5.7	148.00/40.00	328.00/50.00	328.00/05.00	148.00/85.00	058.00/00.00	FM23
156	03 02 69	21 41 43.4	4.81	127.54	46	6.1	291.00/44.00	053.00/26.00	260.00/10.00	003.00/56.00	162.00/31.00	F69
157	30 01 69	10 29 40.3	4.77	127.50	72	5.9	064.00/20.00	270.00/68.00	251.00/25.00	048.00/53.00	156.00/04.00	F67
158	27 03 69	12 41 36.3	4.72	127.65	31	5.8	270.00/48.00	051.00/35.00	248.00/06.00	256.00/69.00	156.00/20.00	CIK72
159	25 04 78	04 24 53.7	4.718	124.593	42.9	5.9	345.00/20.00	230.00/50.00	302.00/51.00	191.00/17.00	088.00/34.00	S
160	11 06 78	10 22 05.1	4.693	126.613	77.6	5.6	264.00/20.00	160.00/35.00	120.00/10.00	217.00/39.00	019.00/53.00	S
161	17 10 81	20 04 15.42	4.60	122.662	624.6	5.8	198.00/56.00	291.00/02.00	139.00/33.00	261.00/37.00	022.00/34.00	S
162	13 08 78	10 12 50.3	4.55	126.63	112.8	5.5	000.00/15.00	093.00/20.00	047.00/26.00	139.00/14.00	232.00/67.00	S
163	31 01 69	00 44 15.1	4.18	128.14	49	5.5	038.00/50.00	282.00/20.00	076.00/17.00	323.00/52.00	178.00/32.00	F68
164	04 06 82	15 21 33.1	4.09	124.523	328	5.7	340.00/12.00	243.00/30.00	199.00/11.00	296.00/32.00	088.00/57.00	S
165	05 03 69	13 52 08.0	4.04	128.11	38	5.5	053.00/65.00	270.00/20.00	079.00/23.00	293.00/62.00	174.00/14.00	CIK75
166	11 06 72	16 41 02.7	3.86	124.26	332	6.2	139.00/75.00	270.00/10.00	257.00/54.00	100.00/33.00	002.00/11.00	CIK[illegible]
167	17 02 69	00 43 03.0	3.69	128.40	37	5.6	125.00/60.00	242.00/14.00	082.00/26.00	212.00/53.00	339.00/26.00	F70
168	21 05 76	04 11 15.2	3.63	125.08	173	5.8	270.00/13.00	090.00/77.00	270.00/58.00	090.00/32.00	000.00/00.00	CIK82
169	20 02 69	09 55 29.0	3.58	128.16	2	5.6	222.00/25.00	042.00/65.00	222.00/70.00	042.00/20.00	312.00/00.00	CIK78

TABLE 8

FOCAL MECHANISM SOLUTIONS FOR PHILIPPINE EARTHQUAKES ON ACCOMPANYING SEISMOTECTONIC MAP--Continued

	Date Dy Mo Yr	Time Hr Min Sec	Epicentre Lat(N)	Long(E)	Depth Km	Mag MB	Pole of 1st Nodal Plane Trend/Plunge	Pole of 2nd Nodal Plane Trend/Plunge	Axis of Compression P Trend/Plunge	Axis of Tension T Trend/Plunge	Null Axis B Trend/Plunge	Ref
170	03 05 78	02 29 54.8	3.573	127.246	42.6	5.7	317.00/20.00	052.00/14.00	274.00/06.00	004.00/22.00	183.00/63.00	S
171	12 08 76	20 53 49.1	3.55	124.32	357	5.8	298.00/08.00	118.00/82.00	298.00/53.00	118.00/37.00	028.00/00.00	CIK83
172	23 12 79	08 33 59.1	3.502	126.846	33	5.8	250.00/70.00	056.00/19.00	240.00/24.00	050.00/65.00	147.00/04.00	S
173	26 03 81	21 30 04.7	3.412	127.998	60.5	6.1	350.00/20.00	170.00/70.00	170.00/25.00	350.00/65.00	080.00/00.00	S
174	14 02 81	07 31 33.69	3.333	128.128	154.9	5.6	280.00/20.00	024.00/34.00	065.00/08.00	327.00/39.00	168.00/47.00	S
175	01 11 64	12 26 07.5	3.11	128.06	74	5.8	128.00/39.00	241.00/26.00	094.00/07.00	192.00/48.00	356.00/40.00	F30
176	16 03 80	10 33 09.4	3.0594	126.94	45	5.6	230.00/50.00	340.00/16.00	300.00/48.00	186.00/20.00	082.00/36.00	S
177	12 10 64	15 42 55.1	3.02	126.50	68	5.5	270.00/18.00	032.00/60.00	070.00/22.00	301.00/56.00	172.00/24.00	F31
178	10 04 79	01 42 22.1	3.02	127.01	40	6.5	279.00/24.00	034.00/43.51	071.00/13.00	326.00/41.00	170.00/37.00	***
179	28 04 73	20 39 48.3	6.44	117.84	71	5.1	084.00/14.00	277.00/75.14	266.00/30.50	059.00/79.00	174.00/02.50	***
180	18 05 66	17 25 53.0	5.96	116.64	52	5.3	156.50/24.00	332.00/65.93	334.00/21.00	162.00/58.00	066.00/02.00	***
181	26 07 76	02 56 39.4	4.93	118.34	29	5.6	148.50/18.00	273.19/60.28	181.00/57.00	040.00/23.00	051.00/23.50	***
182	26 07 76	08 49 37.4	4.89	118.36	57	5.2	162.50/21.00	026.00/60.69	130.00/60.00	358.50/21.00	262.00/20.00	***

H, Hamburger, et al (1983); KS, Katsumata and Sykes (1969); SK, Seno and Kurita (1978); CIK, Cardwell, et al (1980); F, Fitch (1972); FM, Fitch and Molnar (1970); SC, Stewart and Cohn (1977); S, Soedarmo; ***, this study.

earthquakes on it in the past, as a very long continuous right-lateral strike-slip feature. Most of the events felt in Thailand, and which have caused damage, have come from the Sagaing fault or from the Tenassarim Ranges on the Thai-Burma frontier. It is unfortunate that no focal mechanisms have been found for the small earthquakes which have occurred on the Mae Tha fault, trace which actually passes through or near Chieng Mai, Thailand's second largest city.

Evaluation of Seismotectonic Studies

Introduction

For the purposes of estimating losses both to structures and to life, it is not sufficient just to know where earthquakes have occurred in the past, but also important are the sizes of these earthquakes and their relation to major tectonic features and active tectonic processes. A great deal of scientific material has been assembled for the seismotectonic sections of each of the four country reports. In addition to the written reports, there are seismotectonic maps produced in full-colour which accompany the respective volumes. The Philippine seismotectonic map on one sheet is accompanied by a translucent overlay containing the earthquake epicenters, contours of seismic flux, and contours of maximum observed intensity. The seismotectonic map of Indonesia is on four sheets with translucent overlays showing the same information as the Philippine one. The seismotectonic setting of Malaysia is displayed on one sheet and that of Thailand and its neighbouring area on two; both are without overlays. In all cases the base sheets contain the geology of the land areas, the bathymetry of the ocean areas; as many tectonic features as possible, some notably active and others apparently inactive; selected focal mechanisms for the larger earthquakes; sediment isopach contours; and the position of volcanos both active and inactive.

In the individual country summaries that follow, attention is only given to the major seismogenic features. Then, because this is a study of how earthquakes affect population and the works of man, only the seismogenic features which affect major population centres are discussed.

It must be pointed out that in the contours of seismic flux on the four Indonesian sheets of the seismotectonic map are derived from a different data set from that which is plotted as epicentres on the same overlays. The flux is derived from that part of the instrumental data from the years 1904 to 1976 whilst the epicentral data is from the years 1964 to 1983.

The Philippines

The tectonic setting of the Philippines is dominated by extensive subduction zones located on either side of the archipelago. In the east, subduction takes place from east to west across Luzon and Philippine trench-arc systems. In the west, subduction takes place west to east across the Manila trench, Sulu Sea and Negros trench systems which subduct from west to east. All five of these subduction zones are very active and earthquakes produced by subduction zone processes have severe effects ashore. In addition to these subduction zones, a major left-lateral, strike-slip fault, the Philippine fault extends almost the entire length of the archipelago.

The most active of these major tectonic features is the Philippine trench system which, in the years between 1964 and 1983, accounted for over 60 percent of all earthquake activity in the Philippines. This feature begins in the north at about the same latitude as that of Manila and continues to Halmahara in Indonesia in the south. Many of the destructive earthquake in the Philippines are associated with this subduction system. Large destructive earthquakes have occurred in the populous Bicol region of Luzon, in Samar, Leyte and in eastern Mindanao. It has almost certainly produced earthquakes in Halmahara that have caused some destruction on that little-populated island. The number of destructive earthquakes associated with this particular feature are so numerous they cannot all be mentioned here; the reader is directed to the catalogue in the accompanying Volume IV. It is clear that this trench system is certainly capable of producing great earthquakes, that is, earthquakes with magnitudes in excess of 8.

The most threatening seismotectonic feature to major population centres is that associated with the forearc of the Manila trench system. As its name suggests it includes Manila, a city of about 9 million inhabitants situated on an thick alluvial plain where soil amplification should be large. The seismic activity is high, comprising about 12 percent of the earthquake activity in the Philippines and, even though there is some doubt as to whether this system is capable of a truly great earthquake, very considerable damage has been caused in the past from earthquakes associated with this subduction system as is attested to by the cover photograph on this volume. A part of the activity in the forearc of the Manila trench also extends the full length of western Luzon which includes an area along the coast that has a moderately high population density.

The Sulu-Negros arc system extends from the island of Panay in the north and includes Negros, the Zamboanga peninsula of Mindanao, and all of the Sulu Archipelago extending into Sabah in southeastern Malaysia. Its seismicity is relatively low but large major earthquakes have been associated with it and the area covered is moderately well populated.

Although less than 1 percent of the earthquakes occur on the Philippine fault, it is clear that this feature is capable of generating great earthquakes. Notably, the Mati, Mindanao earthquake of 14 April 1924 had a magnitude of 8.3 (Allen, 1962). Since this fault runs from northwest Luzon to the southernmost regions of Mindanao and beyond, it passes just to the west of the Bicol peninsula through central Leyte and eastern Mindanao. Hence, a moderately large population is at risk from its infrequent but sometimes devastating earthquakes.

Indonesia

The Indonesian archipelago is tectonically very complex but, if consideration is limited to those major features which pose the greatest threat to population, it becomes somewhat more tractable. It should be pointed out that nearly the entire population of Indonesia is located in the western islands. These comprise western Sumatera, the whole of the islands of Java, Madura, Bali, Lombok, and the Lesser Sunda islands. This then limits the discussion here to two major features. The first is the trench system representing the subduction of the Indian Ocean plate beneath the entire Sunda arc. The second is the Great Sumatera or Semangko fault system which runs the entire length of

western Sumatera and is believed by many to continue into the Andaman Sea and perhaps even northward into Burma.

The Sunda trench off the west coast of Sumatera is highly active and capable of very large earthquakes. McCann et al. (1979), using the size of aftershock zones, assigned $M_W>8$ for two earthquakes in 1833 and 1861. If one consults the catalogue of damaging earthquakes in Volume V of this report, one will see that the damage is quite consistent with this assessment. Many large earthquakes have been associated with the forearc of the Sunda trench in this region, as noted from the main catalogue accompanying this report.

Slightly southwest of the Sunda strait, this trench system makes an abrupt change in direction from northwest-southeast trending opposite Sumatera to nearly east-west south of Java and the Lesser Sunda islands. Importantly, the seismicity decreases sharply at this point such that the number of earthquakes south of Java and associated with this trench system is quite small in comparison to that opposite Sumatera. The regional distribution of seismicity seems to form a gap opposite central Java. Whether or not this zone is capable of great earthquakes or for that matter even major earthquakes ($6.5 \leq M_S \leq 7.9$) constitutes a critical problem for any earthquake hazard study in Indonesia. With between 80 and 100 million people living on Java, even small earthquakes cause a lot of damage and life loss due to weak domestic buildings. A major or great earthquake could be catastrophic. This area south of Java was identified by McCann et al. (1979) as a gap for great earthquakes but, as can be seen from the seismotectonic map accompanying this report, even small earthquakes are relatively rare. There can be two explanations for this; one is that the Sunda arc and the subducting plate have somehow become decoupled (Newcomb and McCann, 1986) and that since no great earthquakes have been recorded for the past 200 years there is no reason to believe that the present lack of them in Java and the western Sundas will not continue. The other possible explanation, to which this author gives greater credance, is that the subducting and overriding plates are very highly coupled and strain in fact is accumulating. This latter indicates that great earthquakes are possible and, indeed, probable in the future. Neither of these explanations are anything more than hypotheses, perhaps not even that; they merely illustrate the extremes of a number of hypotheses which could be put forth. The important factor, however, is that much more work is required to better understand subduction tectonics in this region.

The other Indonesian tectonic feature of interest is the Great Sumateran or Semangko fault which extends from the Sunda strait along the west coast of Sumatera and runs to sea near Banda Aceh on the Andaman Sea. It links with a complicated system of both strike-slip and transform faults and eventually becomes the Sagaing fault in western Burma. On Sumatera it has been responsible for a large number of major but not great earthquakes. It appears odd that there does not seem to have been a truly great earthquake on a fault system that could be as much as 4,000 km long, perhaps the world's longest strike-slip system. The Semangko fault is a right-lateral system. Numerous authors, e.g., Hamilton (1979), have either assumed or derived from interpretations of aerial photographs that this fault is continuous; that is, unsegmented. If so, one could indeed expect great earthquakes to have rupture lengths on the order of a few hundred kilometres. One of the truly original parts of the SEASEE study was a new geological mapping of the Semangko fault zone in Sumatera proper. It was found that, far from being continuous, it was

a series of 18 nearly co-linear segments arranged en echelon. Each segment is about 200 km or less in length. This situation would certainly explain why truly great earthquakes have never been experienced on this fault and why none might be expected in the future.

Thailand and Malaysia

As was stated earlier, the material in Volume II concerning the seismotectonics of Thailand and its neighbours, unlike the other national contributions, was distributed throughout Part C devoted to the delineation of seismic source zones. The treatment here follows that pattern and will be found in the next section. In the case of Malaysia, the treatment in Volume III covers less than two pages and the reader is directed to Volume II, Part C. Inasmuch as Malaysia has few earthquakes occurring within its national boundaries, this seems reasonable.

Defining Seismic Source Zones

Introduction

The major use of a seismic zone mapping is in the construction of hazard maps. A seismic zone can be defined as follows, paraphasing Algermissen et al. (1982), Thenhaus (1983), and Thenhaus et al. (1982):

1. A seismic source zone has seismicity which can be characterized by the following parameters: the location of earthquakes within the zone can be considered as uniformally distributed; that is, earthquakes can be considered equally likely to occur anywhere in the zone. The recurrence of earthquakes in the zone can be considered constant as can be the so-called "b-value" from the Gutenberg-Richter law relating the frequency of occurrence with the magnitude of events (Richter, 1958).
2. A seismic source zone or seismogenic zone is delimited by a seismotectonic structure or a zone of similar structures. In the absence of a seismotectonic feature, the zone may be based solely on historical seismicity.

The zones may be large or small, linear or rectangular, depending upon how well the tectonics are known and the degree to which completeness and accuracy of the historical record allow for associations of seismicity with specific geological structures. It is also highly desirable to be able to define a maximum credible earthquake in each zone. By maximum credible is meant that earthquake whose magnitude is likely to be an upper-bound event in the prevailing tectonic regime.

Drawing the boundaries of seismic source zones requires considerable judgement and in many instances are plainly subjective (Thenhaus, 1983). One is usually guided not just by the geological or seismogenic feature involved but also by the limits of the historical seismicity. If there is a large strike-slip feature involved, one usually will draw the containing zone as a long thin rectangle including an area about 25-50 km on each side of the fault. This is because, even with the most modern seismographic network, location errors of 25-50 km are not uncommon. In addition, if the fault is known to bifurcate, the source zones are expanded to cover the bifurcation and

resulting fault splays and the historical seisimicity distributed over the entire area. Earthquake focal mechanism solutions for events on or near a fault which geologically show strike-slip displacement will help in assigning a width to the source zone as well as aid in the identification of fault segments that are responding to prevailing crustal stresses in a notably different tectonic style, such as zones of compression or extension across a through-going strike-slip fault.

On the other hand, there are areas such as northern Thailand that are highly faulted, and attempting to associate the distributed seismicity with particular faults would be highly presumptuous considering the lack of geological and seismic faulting investigations. In such a case, distributing the earthquakes uniformally throughout the area of similar geological structure is called for.

In general, the source zones associated with subduction under the land areas of concern are also large areas. These source zones are in general projections of the descending slab on the surface of the earth. There are two problems in defining source zones for subduction areas. The first is where to draw the limits of the zone landward of the trench. Earthquakes become progressively deeper as the island arc is approached and concomitantly smaller and farther from a given site on the surface. However, the effects of deeper earthquakes are generally more widely felt; that is, they have less attenuation with epicentral distance than do shallow earthquakes. Just where to draw the inland boundary of a seismic source zone which runs parallel to the trench is therefore a matter of judgement. The second question, related to the first, is how to model deep focus earthquakes? How such earthquakes can be treated mathematically in the hazard model is a question outside the scope of this study but it is necessary to specify the zones in such a way that they may be mathematically modeled in an appropriate manner afterward. There are two ways of treating this problem and both are represented in papers in this document. The first is to model the cross section of the earth as being an upper plane having shallow earthquakes behind the trench at all distances and a sloping slab with earthquakes along its upper edge. The difficulty of this approach is in attempting to assign rates of occurrence and ground motion attenuation rates for the two zones from the historical record. It is not easy in the best of circumstances to detect small differences in depth of focus. The other method is to simply ignore all earthquakes below some value, 50 km say, because experience has shown that they generally are not associated with significant damage to structures and then to draw two zones parallel to the trench, one representing the activity in the fore-arc near the trench where great earthquakes generally nucleate and another farther from the trench representing the shallow activity in the overriding plate. Neither of these seismic zone assignments is fully satisfactory but they will yield, after computation, a good initial estimate of the seismic hazard.

Thailand and Malaysia

Since Malaysia has few earthquakes on its own territory, mainly in south and eastern Sabah, it was not felt that a seismic zoning of the country would be useful. Contours, however, of maximum observed intensity are displayed on the seimotectonic map of Malaysia. These contours show that in the population centres of Malaysia, Peninsular Malaysia in particular, some considerable damage can occur from earthquakes in western Sumatera.

In Part C of Volume II of this work, Burma, Thailand, and Indochina are divided into 12 seismic source zones, the ones of great interest all being based on linear tectonic features except for a zone in northern Thailand which is nearly rectangular. The zones of interest to this programme are those which threaten Thailand in particular. The authors have labeled the seismic source zones A through L and the ones of interest are C, F, G, K, and L. The zones are mapped in figure 15. Source zone C labeled the east-central Burma basin is based primarily on the highly active right-lateral strike-slip feature which is usually called the Sagaing fault. Earthquakes associated with this fault system have reached a magnitude of 7.5 in historical times and are located very close to the northwestern Thai frontier. Because Bangkok is located on upwards to 1 km of saturated sediments, earthquakes of this size have been known to have caused damage there to the taller and weaker structures. Large shocks in the southernmost reaches of this fault zone would certainly cause great damage in Chieng Mai.

Zone F, called the Tenasserim range by the authors, is a highly complicated collection of faults in a zone which includes the Thai-Burmese frontier from approximately 22° N. to the neighbourhood of 14° N. Earthquakes of a magnitude of at least 7.9 have occurred in this zone in instrumental times. This probably means that great earthquakes can occur. If and when a great earthquake occurs in the southern reaches of this zone, which is but 100-200 km from Bangkok, much destruction there might be expected. Although earthquakes over 5.5 may never be experienced in zone G, labeled Northern Thailand, considerable damage could be caused in and around Chieng Mai; this valley is the most populous place outside the central valley of Thailand.

To the author's certain knowledge, some damage was experienced in Bangkok from an earthquake in the northern Andaman Basin (zone K) on 19 February 1978 having a magnitude of between 5.5 and 5.9. There is a distinct possibility, considering the length of the structure on which zone K is based, that earthquakes of at least 7.5 could occur there.

The Philippines

The zoning of the Philippines, which is shown in figure 16, divides the islands of the country into seven major zones and then subdivides those, save for zone 3, the Philippine fault, into two to four subzones. The major zones are based strictly on tectonic features whereas the subdivisions seem to be based primarily on the record of historical seismicity in the form of contours of seismic energy flux and contours of Gutenberg-Richter b-values.

An attempt has been made in zone 7 to distinguish between two overlapping structural features. Zone 7a is shallower than 7b and represents the Cotabato Trench and Fore-arc System characterized by high seismicity and thrust type earthquakes. The lower zone (7b) is identified with the Molucca Sea Plate and characterized by intermediate and deep earthquakes. Since most of the shallow activity in this region is used in calculating the attenuation curve shown in figure 9, it is due primarily to zone 7a and since the earthquakes in 7b are almost entirely below 71 km and rather small, zone 7b is of little interest to a seismic hazards assessment. The only exception that one may take with zoning in figure 18 is the representation of the Philippine Fault System (zone 3) as a single continuous line. This is of little consequence however if the right earthquakes are associated with it and a reasonable recurrence rate for earthquakes along it can be assigned.

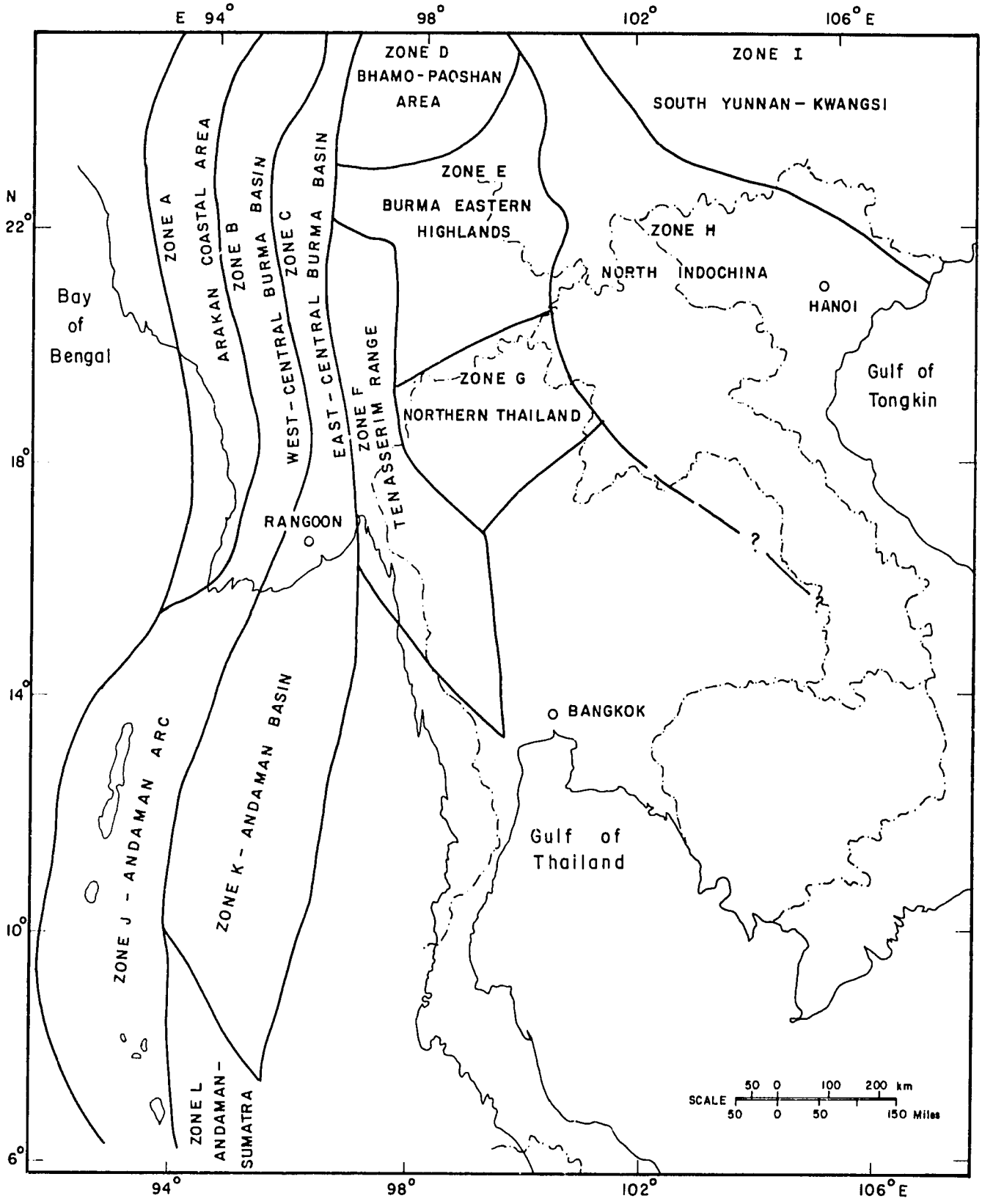

Fig. 15 Seismic source zones for the Burma-Thailand-Indochina region.

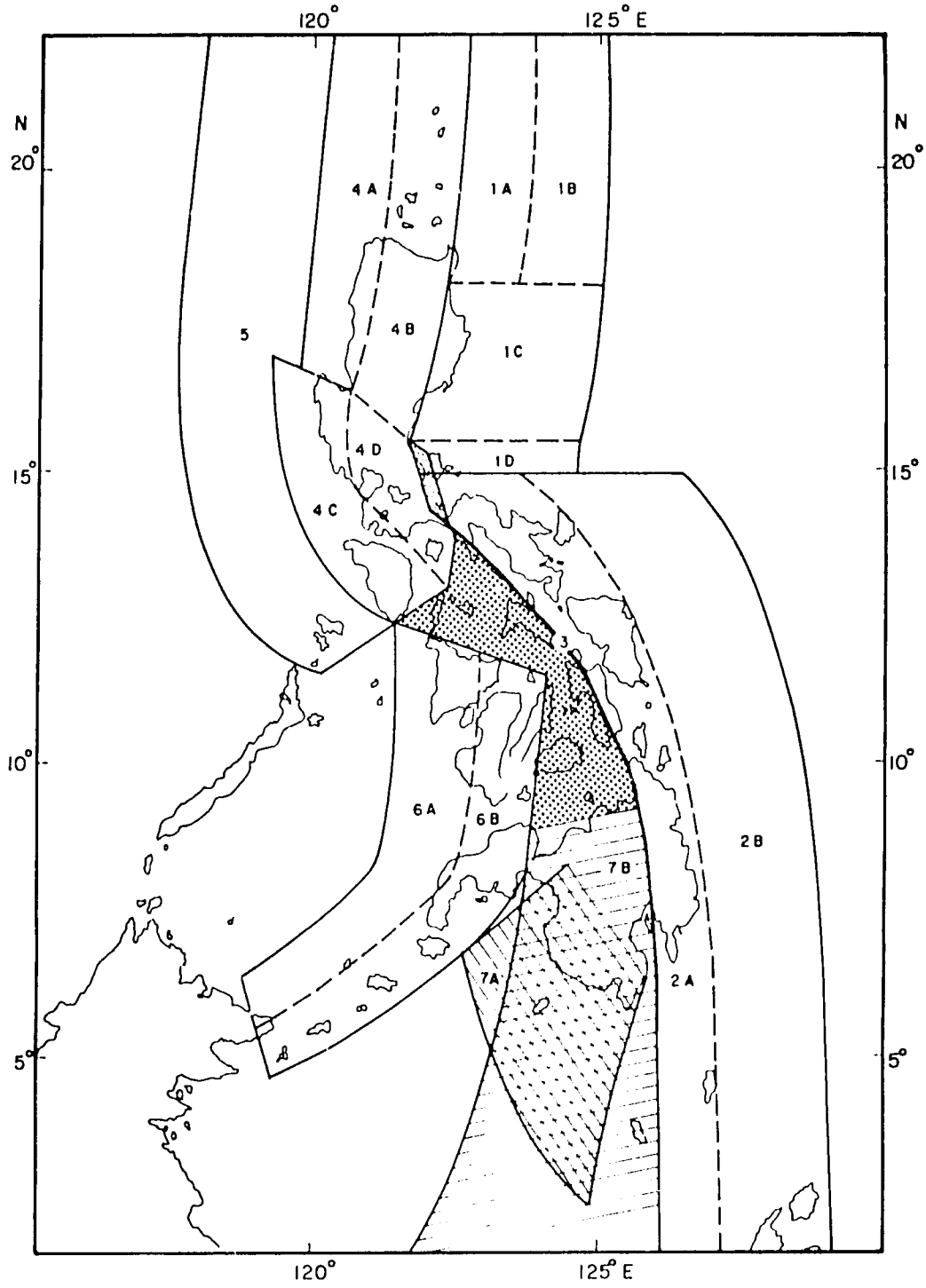

Fig. 16 Seismogenic or seismic source zones for the Philippine archipelago. The zone numbers are named in table 4. They are divided into sections in some cases with dashed lines depending upon depth of focus of the earthquakes in them or on tectonic features explained in vol. II Part G. Zone 3 is a line source extending from the Gulf of Davao northwards along the Philippine fault zone to Luzon. The area in the central Vizayas shown stippled with large dots is treated as aseismic. The small parallelogram in central Luzon (stippled with small dots) reflects an uncertainty in the tectonics of the area.

Indonesia

The construction of the seismic source zoning for Indonesia, as shown in figure 17, was based on the method used by Beca, Carter, Hollings, and Ferner Limited (a New Zealand firm of structural engineers). New data on seismicity, focal mechanisms, etc., were added to the original work. The procedure used is as follows:

1. The entire region was divided into areas thought to have the same maximum credible earthquake magnitude and the same Gutenberg-Richter b-value.

2. The region was further divided into areas of the same frequency of past geological deformation. This is also credited to Beca, Carter, Hollings, and Ferner (1980a and 1980b).

3. The region was divided into areas according to maximum acceleration for a return period of 20 years. Again, this is credited to Beca, Carter, Hollings, and Ferner.

4. The plate tectonic system in Indonesia was given full consideration.

5. The final zoning also took into account the distribution of shallow earthquake epicenters of magnitude above 6.0 for the period 1897-1984, a distribution which was unavailable to the New Zealand team.

6. Finally, zones of activity were derived by expressing the frequency of felt earthquakes in square degree areas during the period 1976-1983, again unavailable to the New Zealand team.

The procedure outlined above is generally valid although the procedure lacks a strong basis in shallow geological structure. Experience has shown that it is the clarification of the role of upper crustal geological structure in the earthquake generating process that has lead to significant refinements of hazard estimates in regions of active tectonics. The procedure used results, as seen in figure 17, in a zoning that one might expect from reading the entire exposition in Volume V. The numbers attached to the various zones (fig. 17) refer not to geographical areas but rather to the level of seismic activity. Other authors may have drawn zones somewhat differently but again zones tend to be a matter of judgement. This author, for instance, would probably not have drawn a zone 2 designation along the south coast of Java as the Indonesian authors have done but this does not invalidate their results. Most needed in this particular case is a resolution of the issue of whether very large or great earthquakes can occur from 106° to 112° E. along the Sunda Trench.

Upgrading the Southeast Asia Seismic Network

Introduction

The SEASEE seismic network, as it was left by the UNDP programme, was very simple. Each station was completely self contained in that the seismometer site was within 25 m of the recording house which contained most of the electronics, batteries, power supplies, radio receivers, etc. In many cases

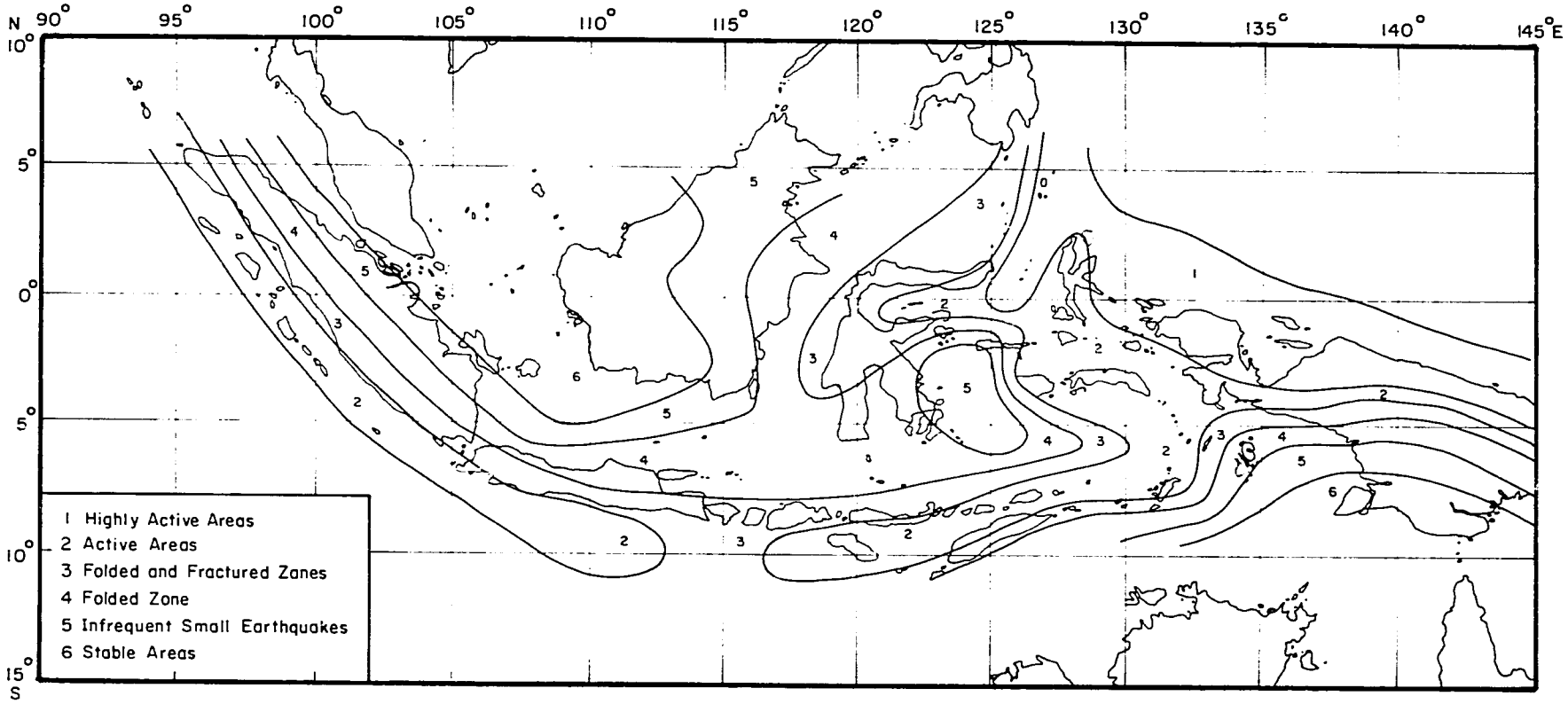

Fig. 17 Seismic source zones in Indonesia.

the seismic station was located near an existing weather station so that the same personnel could change the records, read them, and service the instruments. The weather stations, however, tend to be in more populous areas which are not usually ideal for seismic observation because of cultural noise. In some cases, a more remote site was selected, which is all to the good, but since the observer had to live on the premises this situation too had its drawbacks, as discussed in the section on telemetry below. Individual observatory personnel received the least training in the interpretation seismograms of all the SEASEE staff.

In addition to the above difficulties (difficulties shared by all seismic networks world-wide), there is the remaining problem of knowing where each of the stations is on a world-wide geodetic grid. That is to say, to locate earthquakes accurately there must be only a very small uncertainty in station position. With the exception of stations in Malaysia, the positions for stations in Southeast Asia were usually obtained by estimating positions on a topographical map. The number of errors that can be incurred by such a procedure are legion and in the aggregate can cause errors in station position on the order of kilometers. One method of solving this problem was to obtain the help of the national geodetic surveys in running a triangulation from a pair of close benchmarks to the selected station site. This was done in the case of Malaysia but it's a very expensive solution which the other national seismic centers were unable to afford.

It is necessary at this point to say something about counterpart funding. In order to demonstrate their genuine interest in seismological and earthquake engineering programmes, the SEASEE national agencies provided most of the funds necessary to execute the programme (this refers to the entire programme mentioned in this report) in the form of services in kind. This includes site acquisition, salaries for observers and headquarters staff, domestic travel arrangements of all kinds, buildings required both to house instrumentation and operators where required, and a multitude of other expenses. This also includes such items as national training programmes and travel for technicians to repair stations. A caveat must be added to this however in that, like most governments, these funds are not always instantly available because of the administrative difficulties in budgeting. This is particularly true for Indonesia where budgeting is done on a 5-year cycle. If one misses one 5-year period, one has to wait quite a long time. The author, as programme co-ordinator, was highly impressed by the effort expended by the national agencies to obtain the necessary counterpart funds as quickly as possible.

Because of the difficulties involved in operating a seismological network in Southeast Asia, both from the standpoint of station positions and that of logistic support, some relief from these problems was sought during the course of this programme as described in the following section.

Locating Stations

The problem of accurately locating a seismic station without resort to a geodetic survey was solved by the use of satellite navigators. The United States Navy operates a system of between five and seven satellites in polar orbit at an altitude of about 1075 km each orbiting with a period of 107 minutes. In conjunction with tracking stations the orbits of the satellites are very exactly known. Each satellite transmits signals at both 150 and 400

MHz that can be received world-wide. The satellites also have on board clocks which are reset by the ground stations on each pass maintaining very high accuracy indeed. The Dopler shift from the two frequencies is used to determine latitude and the accurate time for longitude. Although this system was released for commercial use in July 1967, it was only with the advent of microelectronics a few years ago that the user stations have become portable.

Two sorts of units can be used with the system to obtain ground position. The first, which is generally known as a satellite surveyor, uses both the 150 and 400 MHz signals and has two advantages. It can make an estimate of the error due to the ionospheric refraction and is accurate enough to define the altitude above mean sea level. The second, which is generally known as a satellite navigator, uses only the 400 MHz signal and is therefore subject to greater error and, since it is designed to be used with small boats and ships, does not find altitude.

The budget for this programme included enough money for either one surveyor or four navigators. Because of the difficulty expected from customs and finding the money for international shipments of equipment, it was decided that each of the national centers should have their own satellite navigator which was purchased for them and delivered by the U.S. Geological Survey. Happily some of the errors associated with the use of a single frequency are random and by taking a number of observations the errors can be significantly reduced.

The satellite navigators were delivered to the SEASEE national agencies in the middle of 1983 and the surveys were completed by the end of 1984. Much travel had to be done on the part of the technicians from national centers with all of the attendant scheduling arrangements. The Malaysian stations were used as a control in gauging the accuracy of the final results; in nearly all cases the navigators gave positions that were the same as the surveyed positions to within 0.4 seconds of arc. This was judged to be very satisfactory considering that many stations in the region had their positions moved by a kilometer or more and, in one case, by as much as 10 km. The satellite navigator is also a useful instrument if, in the case of a large damaging earthquake, a portable network is to be set up for aftershock monitoring and if new permanent stations are to be established. All of the earthquakes for which data had been gathered by the national networks were relocated using the new station locations. These are the locations plotted on the seismotectonic maps. The re-locations date from 1976 to the present and exhibit less scatter than using the earlier station positions.

Installation of Telemetry

Two types of logistical problems have plagued the Southeast Asia network since its establishment. The first is that to place a station near a meteorological observatory usually means placing it near the sea in a deep alluvial valley and usually in a city with high levels of cultural noise. All of these obviate the use of even moderate magnifications. If one is to put an observer with a self-contained station in a good observation site it usually means marooning the observer in the jungle for a week or more at a time and additionally must incur the expense of building living quarters on site. In the latter case, we found that even with high unemployment it is very difficult to find sufficiently well trained and educated personnel to occupy these remote

sites. The obvious answer to this problem is radio telemetry. Usually a good site can easily be found within a short distance, 50 km or less, of a population center so that radio telemetry can be used. The observing site need only have the seismometer, voltage controlled oscillator, transmitter, antenna, battery, and a small solar power unit. The receiving site, an urban meteorological station, would have antenna, receiver, discriminator, and recorder along with a clock and a radio receiver for setting accurate time. This method has been opted for by the two island regimes of Indonesia and the Philippines, the Philippines opting for VHF radio, Indonesia because of interference on VHF from civilian band activity has opted for UHF radio links. A list of sites is given in table 9 for the entire region.

The second logistical problem is that which can best be described as "speedy response". For seismic stations to be of use in disaster work, one must obtain their information as quickly as possible. If a potentially damaging earthquake occurs, one must be able to obtain information in a matter of minutes rather than hours. The Malaysian and Thai organizations opted for longer distance telemetry using dedicated telephone circuits from existing stations. This is much like the system used by the U.S. Geological Survey's National Earthquake Information Center in the United States where 63 stations are telemetered into the center at Denver. In July 1984 SEASEE took delivery of the telemetry equipment and in April 1984 one person from each of the SEASEE member agencies attended a maintenance and installation course in Pasadena, California. To reinforce this training programme, the most experienced technician toured the region in March-April 1985, supervising the actual installation of a number of telemetered stations. In addition, he trained three technicians each from Thailand and Malaysia and two from Indonesia, all of whom were unable to attend the course in California. Stations are listed in table 10. The delays in the final installation of telemetering for the stations given in table 9 are due to either land acquisition, access road construction, or securing the necessary dedicated telephone circuits.

Other Activities

Meetings and Symposia

Except for the introduction of a quarterly SEASEE newsletter at the beginning of 1986, most of the other activities engaged in, in conjunction with this project, were meetings and seminars. These were usually held in conjunction with SEASEE Executive Committee meetings and typically consisted of project coordination meetings and instructional seminars. The coordination meetings were an opportunity for each of the SEASEE national organizations to report their progress and exchange views on the problems they have encountered. In all cases funding was shared between project funds, UNESCO, and SEASEE member agencies. The details of each meeting are as follows:

1. SEASEE Executive Committee Meeting, 4 November 1981, Bali, Indonesia. Participants: Dr. R. L. Kintanar (Philippines), Dr. C. Sutrisno (Indonesia), Mr. Ho Tong-Yuen (Malaysia) Sumeth Hinsheranan (Thailand, Mr. R. G. Valenzuela (SEASEE secretary). Guests: Dr. E. P. Arnold (USGS), Mr. F. M. Cole (USAID), Mr. J. P. Herakonich (UNESCO)

TABLE 9. SEASEE SEISMIC TELEMETRY NETWORK

STATION	SEISMOMETER SITE	DISTANCE OF SEISMOMETER TO RECORDER	CURRENT MAGNIFICATION	EXPECTED MAGNIFICATION	REMARKS
A. INDONESIA					
1. Kupang, Timor Barat[1]	10°11'52"S. 123°35'18"E.	<50 kms	28,000	≥112.5 K	Requires solar power.
2. Dili, Timor Timur[1]	8°34'40"S. 125°33'39"E.	<25 kms	---	≥112.5 K	New station; requires solar power; VHG radio.
3. Ugung Pandang,[1] (Makasar), Sulawesi	05°13'04.2"S. 119°28'11.4"E.	<50 kms	28,000	≥112.5 K	Requires solar power.
B. MALAYSIA					
1. Ipoh, Perak	04°34'46.2"N. 101°01'31.8"E.	160 kms	225,000	225.0 K	Requires solar power; Data transfer via telephone line to Kuala Lumpur.
2. Kluang,[2] Johor	02°00'56.4"N. 103°19'08.4"E.	120 kms	56,000	56.0 K	As above.
C. THAILAND					
1. Pak Chong	14°40'51"N. 101°24'39.6"E.	100 kms	450,000	450.0 K	Requires solar power; Data transfer via telephone line to Bangkok.
2. Nakhon[2] Sawan	15°40'21.6"N. 100°07'58.5"E.	200 kms	112,500	112.5 K	As above.
D. PHILIPPINES					
1. Montalban, Rizal	14°42'00"N. 121°08'24"E.	15 kms	---	≥112.5 K	New station; requires solar power; VHF radio.
2. Mt. Samat,[1] Bataan	14°36'28.6"N. 120°30'32.4"E.	60 kms	---	≥112.5 K	As above.
3. Tagaytay, Cavite	14°06'53.1"N. 120°57'37.0"E.	60 kms	---	≥112.5 K	As above. Forms a tripartite array when recorded in Manila

[1]Awaiting site acquisition.
[2]Awaiting telephone circuits.

TABLE 10. PRESENTLY TELEMETERED SEISMIC STATIONS IN SOUTHEAST ASIA

STATION	COORDINATES LAT°N	LONG°E	DISTANCE OF SENSOR TO RECORDER	PREVIOUS MAGNIFICATION	CALCULATED TELEMETRY MAGNIFICATION	REMARKS
MALAYSIA Kluang (KGM)	2°00'56.4";	103°19'08.4"	200 km	56 K @ 3 Hz	62 K @ 10 Hz	Telephone line to Kuala Lumpur.
THAILAND Pak Chong (PCT)	14.7°;	101.43°	187 km	450 K @ 3 Hz	137 K @ 10 Hz	Telephone line to Bangkok.
INDONESIA Tuntungan (TSI)	Approx. 3.35°;	98.39°	10 km	28 K @ 3 Hz	≅20 K @ 3 Hz (expected magnitude)	(Temporary) Radio link to Balai Regional Centre, Medan, Sumatera; was used as a training site for installation of telemetry equipment while site acquisition for permanent stations is underway.
PHILIPPINES Montalban	Approx. 14°06'53.1";	120°57'37.0"	15 km	New	70 K @ 3 Hz	Radio link to Geophysical Observatory Diliman, Quezon City.
Tagaytay	14°06'53,1";	120°57'37.0"	60 km	New	112.5 K @ 3 Hz	As above.

2. SEASEE Earthquake Disaster Mitigation in Southeast Asia Seminar, 5-6 November 1981, Bali, Indonesia.
Participants: Indonesia: Mr. C. Sutrisno, Mr. R. Susanto, Mr. Agan Hariman, Mr. Hartono, Mr. Soetardjo, Mr. Darmoatmodjo, Mr. Sudarmo. Malaysia: Ho Tong-Yuen, Leyu Chong-Hua, Ong Tiong-Cheong. Philippines: Dr. R. L. Kintanar, Mr. T. G. Macalincag, Mr. E. A. Uy, Mr. R. G. Valenzuela. Thailand: Mr. Sumeth Hinsheranan, Mr. Sugit Yensuang, Ms. Buppha Pongsawat. Resource Speakers: Dr. E. P. Arnold, Dr. J. H. Hodgson, Mr. D. M. Perkins, Fr. S. Su S.J. Guests: Mr. F. M. Cole, Mr. J. P. Herakovich, Mr. O. Soekirto.

   Papers presented: (A) Country reports on current earthquake disaster mitigation practices: Presentors - Indonesia: R. Soetardjo; Malaysia: Mr. Ong Tiong-Cheong; Philippines: Mr. T. G. Macalincag; Thailand: Mr. Sugit Yensuang; Canada: Dr. John H. Hodgson. (B) Determination of maximum possible M_b, by Fr. S. S. Su S.J. (C) Effect of changing return periods on probabilistic ground motion, Mr. D. M. Perkins. (D) The possibility of tsunami warning in southeast Asia, Dr. J. H. Hodgson.

3. SEASEE Executive Committee Meeting, 16 November 1982, Bangkok, Thailand.
Participants: Mr. R. Soetardjo, Mr. R. P. Sudarmo, Mr. Ho Tong-Yuen, Mr. Ong Tiong-Cheong, Mr. R. L. Kintanar, Mr. R. G. Valenzuela, Ms. L. C. Garcia, Mr. J. D. Cordeta, Mr. Boonsorn Boonsukha, Mr. Twee Montivade, Mr. S. Hinsheranan, Mr. Sugit Yensuang, Ms. Sumalee Samootsokorn, Ms. Buppha Pongsawat, Mr. V. Chandranom. Guests: Dr. E. P. Arnold (USGS), Mr. S. T. Malling (UNESCO).

4. SEASEE Executive Committee Meeting, 14 November 1983, Kuala Lumpur, Malaysia.
Participants: Dr. R. L. Kintanar, Mr. Ho Tong-Yuen, Mr. Soetardjo, Mr. S. Hinsheranan, Mr. R. G. Valenzuela, Ms. L. C. Garcia. Guests: Dr. E. P. Arnold, Mr. F. M. Cole, Mr. R. P. Dionne.

5. SEASEE Project Advisory Meeting, 15-16 November 1983, Kuala Lumpur, Malaysia.
Participants: Dr. K. V. Steinbrugge, Dr. G. E. Brogan, Mr. P. C. Thenhaus, Dr. E. M. Fournier d'Albe, Dr. E. P. Arnold, Mr. S. T. Malling, Mr. F. M. Cole, Mr. V. Karnik, Dr. R. L. Kintanar, Dr. A. L. Lazaro III, Mr. R. G. Valenzuela, Ms. L. C. Carcia, Mr. J. D. Cordeta, Mr. E. A. Uy, Mr. Soetardjo, Mr. R. P. Sudarmo, Mr. Sulaeman Ismael, Mr. A. S. Danuatmodjo, Mr. Iyos Subki, Mr. S. Hinsheranan, Mr. S. Yensuang, Mr. T. Brikshavana, Dr. P. Nutalaya, Mr. T. Mahasandana, Mr. Ho Tong-Yuen, Mr. A. David, Mr. Leyu Chong-Hua, Mr. Ong Tiong-Cheong, Mr. Lim Yang-Teh, Mr. Goh Hee-Leng. Papers presented: Country Progress Reports.

6. Seminar on Seismic Safety for Critical Facilities and Lifelines, 17-18 November 1983, Kuala Lumpur, Malaysia. Papers presented: (A) Earthquake Risk Analysis, the Problem of Vulnerability, Dr. E. M. Fournier d'Albe. (B) Probabilistic Modelling of Multiple Seismotectonic Hypotheses, Mr. P. C. Thenhaus. (C) Hazards Evaluation and Assessment for Nuclear Power Plants: A Geologic Consideration, Dr. G. E. Brogan. (D) Lifelines and Earthquakes, Dr. K. V. Steinbrugge. (E) Aims of the Office of U.S.

Foreign Disaster Assistance by Mr. F. M. Cole. (F) Structural Response of Buildings to the 17 August 1983, Laoag City Earthquake, Dr. A. L. Lazaro III.
Participants same as above with the following additions: Mr. Abdul Malik, Mr. Tussin Santhira, Mr. Segaran Wahid, Mr. Omar Jafar, Mr. Bin Sahari, Mr. Shu Yeoh-Khoon, Mr. John Kuna, Mr. Raj Ariffin, Mr. Bin Hassan, Mr. Samsudin Bin, Mr. H. J. Taib, Mr. Z. M. Bartolome.

7. SEASEE Executive Committee Meeting, 8-9 December 1984, Quezon City, Philippines.
Participants: Mr. Ho Tong-Yuen, Dr. R. L. Kintanar, Mr. Nipon Rananand, Dr. C. Sutrisno, Mr. R. G. Valenzuela, Ms. L. C. Garcia. Guests: Mr. S. T. Malling (UNESCO), Mr. Patrick Shem (official observer, Hong Kong), Mr. E. V. Calpo (official observer), Mr. Soetardjo (official observer), Ms. Sumalee Samoothsakorn (official observer), Ms. Agnes E. C. Dabi (official observer).

8. SEASEE Project Advisory Committee Meeting and Co-ordination Sessions, 4-10 March 1985, Manila, Philippines.
Participants: Prof. A. H. S. Ang, Dr. E. P. Arnold, Dr. G. R. Balce, Dr. T. Boen, Mr. T. Brikshavana, Dr. G. E. Brogan, Mr. A. Canuatmodjo, Dr. E. M. Fournier d'Albe, Ms. L. C. Garcia, Mr. Ho Tong-Yuen, Mr. E. Kertapati, Dr. A. L. Lazaro III, Mr. Leyu Chong-Hua, Dr. P. Nutalaya, Mr. R. Sharpe, Dr. Shu Khoon-Yeoh, Mr. K. Siribhakdi, Mr. Soetardjo, Fr. S. S. Su, Dr. P. C. Thenhaus, Mr. E. A. Uy, Mr. R. G. Valenzuela, Dr. R. L. Kintanar, Mr. A. Malixi, Mr. B. George (USAID), Mr. W. Carter (USAID), Dr. E. Tabujara.
Papers presented: Country Progress Reports.

Regional Progress in Mitigation

In addition to the meetings related to the scientific work of this project, a number of other important events took place. These are of particular interest to emergency planning.

The first and most important event was the affiliation of SEASEE to the ASEAN organization. In consequence each ASEAN country has recognized SEASEE as their prime advisor on the subject of earthquake hazard. In almost all cases, the governments of each of the ASEAN countries has sent representatives of the agency responsible for emergency planning to the annual SEASEE meetings. In each case substantive talks were exchanged between the emergency planners and their scientific and engineering counterparts. As a consequence, the following events took place:

(1) The Thai cabinet approved the formation of the National Earthquake Committee of Thailand on 10 September 1985. This committee is chaired by the President of the Thai Engineering Association and the Vice-Chairman is the Director-General of the Meteorological Department (the SEASEE constituent agency for Thailand). It contains representatives from the Department of Public Works, the Department of Mineral Resources, the Department of Local Administration, the Hydrographic Department, the Bureau of the Budget, the National Environmental Board, the National Economic and Social Development Board, the Electricity Generating Authority of Thailand, the Engineering Advisory Board, and academic experts from various universities in Thailand. The formation of this committee was very much at the behest

of SEASEE and the Meteorological Department of Thailand. The Committee actually existed before its Cabinet approval and has been at work devising earthquake provisions for the National Building Code. This work has been completed and has been submitted to the Ministry of the Interior for its publication as a ministerial regulation which will implement it. The author has been assured that this will happen in the autumn of 1986. At present the Committee is drafting projects it will carry out during the 6th National Economic and Social Development Programme. These projects will include the production of a seismic zoning and risk [sic] map of the country*, a building period study and site amplification study, planning a strong motion network, various geological studies of active faults, a program on community protection and earthquake hazard mitigation, and a program for possible revisions of the ministerial regulation controlling building construction.

(2) The National Society of Seismology and Earthquake Engineering of the Philippines (NSSEEP) has consented to become the national body for SEASEE as specified in the SEASEE constitution. NSSEEP is composed of members from both governmental and nongovernmental agencies and enterprises, notably its membership includes many structural engineers interested in earthquake engineering.

(3) In Malaysia it was decided a few years ago to design some sort of earthquake protection into the Penang bridge which links Penang Island with the mainland of Peninsular Malaysia. Unfortunately the details of the design have not been made public for proprietary reasons but the Science University of Malaysia has been co-opted to instrument the bridge with strong motion accelerographs when it is complete . It should be added that Penang and Butterworth are the two localities usually most affected by earthquakes in northern Sumatera.

(4) In Indonesia, the National Coordination Board for Natural Disaster Relief (BAKORNAS PBA) was established in 1979 and has regularly sent representatives to SEASEE meetings. They are looking to SEASEE as the main source of information on earthquake hazard mitigation.

Regional Problems Concerning the Implementation of Building Codes

In consultation with many engineers from the region, a number of problems have been found with the implementation of building codes where they exist, primarily Indonesia and the Philippines. These problems are common to both countries (and probably to all the lesser developed world) and were best summarized by Cesar Caliwara, president of NSSEEP and a practicing structural engineer (private communication, 1986):

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*It should be noted that the basic data collection for producing the zoning and hazard maps is complete, some basic derived parameters will have to be developed such as b-values, attenuation functions, upper-bound magnitudes and occurrence rates.

"1. Some engineers who have been given responsibilities either in the structural design or supervision of construction are not as conversant as they had ought with the latest NBC [National Building Code] provisions especially those involving seismic requirements. Many engineers have not even read the Code.

"2. Some building officials entrusted with the enforcement of the Code may not be too strict -- whether this is intentional or inadvertent is of course a matter of conjecture.

"3. Some architects design buildings/structures then sign and seal building plans without the benefit of consultation with competent structural engineers on seismic resistance of those structures.

"4. Inadequate quality control systems and methodology during the construction phase of the project are among the major problems.

"5. Seismic instrumentation requirements are not strictly followed if at all, probably due to cost involved and of course laxity in enforcement. It is alleged that there is no specific implementing circulars or rules to do so."

All is not quite so bleak as the above suggests. A prominent Indonesian engineer has produced a manual for the construction of small buildings in seismic areas (Boen, 1978) designed to instruct small town and village builders in practical ways of strengthening their buildings. A programme of education for builders based on this manual is being carried out by BAKORNAS to some effect. The author visited northeastern Bali after the earthquake of 17 December 1979 and noted that not a masonry structure in the village of Culik (population ~6000) was habitable afterwards. He was able to visit it about two years later and was impressed by the improvement in the type of construction being used in rebuilding the village.

PART D CONCLUSIONS, RECOMMENDATIONS, AND ACKNOWLEDGEMENTS

Conclusions

This highly active seismic region has never before been as extensively and uniformly studied from the standpoint of earthquake activities. The closest approach to this was made by Hamilton (1979) but his study was more directed toward the geology and tectonics of the region rather than that of earthquake hazards. In addition, one of the goals of this programme was to interest national and even private agencies within the region in earthquake hazard mitigation and to create local expertise. This was to be done by a process of on-the-job training. The following is a list of the accomplishments of this program thus far and should be looked upon as providing the raw material for a complete earthquake hazard mitigation programme in Southeast Asia:

1. An earthquake history of very long duration has been compiled for the first time. It has been translated into English from its original sources and is as complete as one could hope for. It is homogeneous in many details but most particularly all assessments of damage have been put into the Modified Mercalli Intensity Scale.

2. Curves representing the attenuation of intensity with epicentral distance have been made in Indonesia and the Philippines.

3. A complete collection of instrumentally located earthquakes from the year 1904 to 1984 has been completed and is available on magnetic tape.

4. The seismotectonics of the region have been compiled and presented on accompanying full-colour maps. They are to the same scale and projection and contain important new contributions.

5. A substantial upgrade of the existing southeast Asia seismic network has been made by the provision of satellite navigators to locate the existing stations and to provide telemetry equipment to make possible better seismometer sites that are logistically easy to service. Ten sets of telemetry gear were provided; five have already been installed.

6. Nearly a thousand new focal mechanism solutions have been computed during the course of this programme in order to aid the seismotectonic interpretations and to delimit seismic source zones.

7. Seismic source zones for the Philippines, Indonesia, and Thailand (and adjacent areas) have been drawn, and Gutenberg-Richter b-values have been assigned where possible.

8. A number of meetings and other activities have been held. These were principally for the purpose of "cross fertilization" amongst the working-level principals in the programme and to provide instruction for them.

9. From numerous discussions over the years, problems in the implementation of seismic provisions of national building codes, where they exist, have been unearthed and, in the case of Thailand, through

urging from SEASEE and others, seismic design provisions for the building code are awaiting implementation.

10. Since Southeast Asia is a predominantly rural region, it can be concluded from this study that the major risk to the Philippines and Indonesia is not only to its largest cities but also to the myriad towns and villages they comprise. On the other hand, in Malaysia and Thailand, the large cities are most at risk due to long period effects of earthquakes at some distance from them.

Recommendations

1. Now that all the raw materials, but not all of the derived parameters, exist for the creation of seismic hazard maps, the first and most important recommendation is that this work be continued. This will allow SEASEE within a year or two to provide the governments of the entire region with seismic hazard maps and with probabilistic loss estimations for particularly vulnerable regions of their various countries. A proposal for accomplishing this is included here as Appendix B.

The steps necessary to accomplish this goal are as follows:

a. Further develop attenuation-relations for the various seismic zones in the area. This is not as easy as one might expect since no one as yet has devised a convenient method for treating subduction zones where both shallow and deeper earthquakes occur. In Thailand data exists for attenuation relations to be developed. It was agreed early on that Malaysia would contribute to and use Indonesian relations.

b. Develop estimates for a maximum credible earthquake in each zone.

c. Develop a distribution of earthquakes in time. Normally this distribution is taken to be Poissonian if only the larger shocks are included. This is normally a good working hypothesis, but since smaller shocks can cause damage in Indonesia and the Philippines, this distribution must be tested to see if it holds for earthquakes at the threshold of damage in specific areas of interest.

d. Gutenberg and Richter "b-values" must be developed for source zones for which this has not already been accomplished.

e. Seismic hazard maps of large, vulnerable sections of Indonesia and the Philippines should be generated by local personnel under the supervision of USGS staff experienced in this field of work. The remainder of each country can then be done by the local scientists and engineers.

f. Seismic zoning maps should also be produced under the same conditions as e above.

g. A building inventory and consequent loss estimation in two significant cities in Indonesia and the Philippines should be under-

taken. Originally, Yogyakarta and Manila were suggested but perhaps Manila is not such a good choice in light of recent studies.

h. A co-ordinated plan should be developed for a strong ground motion seismograph network in Southeast Asia.

i. In the case of Thailand and Malaysia, a building period survey should be undertaken to more clearly define the hazard to tall structures in these countries.

j. A soil amplification study should be accomplished in each of the countries but especially in Thailand and Malaysia to determine the site response of the distinctive soils on which all Southeast Asia cities are built.

2. It is the author's experience that in a multi-national project such as this one, a great deal more "on-the-spot" co-ordination is necessary to ensure good results in a timely manner than was able to be devoted to this project. It is, therefore, recommended that for any continuation of this programme a project co-ordinator either live in the region and make frequent trips to the other countries or spend no less than 6 months each year doing so. This would be the case even for a project covering single country; the logistical problems in supervising a programme at a distance of 10,000 miles are enormous.

3. It is recommended that SEASEE, as an organization, be vigorously urged to broaden its base of expertise in each country as is provided for in its own statutes. At present, only the meteorological and geophysical agencies are involved with some consultation with national geological surveys. Some attempts have been made from time to time to bring in representatives from universities and engineering societies. These efforts ought to continue and be intensified.

4. It is also recommended that a number of deficiencies in the present work be corrected. These deficiencies are listed in the body of Part C of this report and need not be listed in detail here. An example, however, is that a gazetteer of Indonesian place names appearing in their full catalogue should be compiled with the aid of Mr. I Made Sandy, the Director of Geographical Place Names in the Indonesian government.

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Gratitude is also extended to the Directors-General of the National Weather Bureaux in each of the SEASEE countries for their cooperation in expediting this programme. Thanks also go to the SEASEE secretariat especially to Mrs. L. C. Garcia and Mr. R. G. Valenzuela and to all staff members who have contributed to the successful outcome of this project.

References

Acharya, H. K., Aggarwal, Y. P. 1980. Seismicity and tectonics of the Philippine Islands: Journal of Geophysical Research **85**, 3239-3250.

Acharya, H. K., Ferguson, J. F., and Isaac, V. 1979. Microearthquake surveys - The central and northern Philippines: Seismological Society of America Bulletin **69**, 1809-1930.

Algermissen, S. T., Perkins, D. M., Thenhaus, P. C., Hanson, S. L. and Bender, B. L. 1982. Probabilistic estimates of maximum acceleration and velocity in rock in the contiguous United States: U. S. Geological Survey Open-File Report 82-1033, 99 pp.

Allen, C. R. 1962. Circum-Pacific faulting in the Philippines-Taiwan region: Journal of Geophysical Research **67**, 4795-4812.

Arnold, E. P. 1976. A manual of [seismic] computer operations: UNDP/UNESCO Regional Seismological Network for Southeast Asia. Manila, Philippines (revised 1979).

Beca, Carter, Hollings, and Ferner, Ltd. 1980a. Earthquake risk in Indonesia: **2**, unpublished, Wellington.

Beca, Carter, Hollings, and Ferner, Ltd. 1980b. Seismic zones for building construction in Indonesia: **3**, unpublished, Wellington.

Boen, T. 1978. Detailer's manual for small buildings in seismic areas: Privately published; available from T. Boen, Jakarta Hilton Annexe, Jakarta, Indonesia, 117 pp.

Bolt, B. A. and Abrahamson, N. A., 1982. New attenuation relations for peak and expected accelerations of strong ground motion, Seismological Society of America Bulletin, **72**, 2307-2321.

Brown, J. C. 1914. The Burma earthquakes of May 1912: Memoirs of the Geological Survey of India, **42**, part 1, 1-147.

Brown, J. C. and Leicester, P. 1933. The Pyu earthquakes of 3rd and 4th December 1930 and subsequent Burma earthquakes up to January 1932: Memoirs of the Geological Survey of India, **62**, part 1, 1-140.

Buland, R. 1986. Uniform reduction error analysis, Seismological Society of America Bulletin, **76**, no. 1, 217-230.

Cardwell, R. K., Isacks, B. L., and Karig, D. E. 1980. The spatial distribution of earthquakes - Focal mechanism solutions and subducted lithosphere in the Philippines and northeastern Indonesian islands, Hayes, D. E., ed.: American Geophysical Union Monograph No. 23, Washington, D.C., 1-35.

Cordeta, J., Valenzuela, R. G., and Garcia, L. C. 1985. Focal mechanism solutions for Philippine earthquakes with $M_L \geq 5.0$ 1964-1983, unpublished manuscript: Available from SEASEE Secretariat, c/o PAGASA, 1424 Quezon Avenue, Quezon City, Philippines, 363 pp.

Fitch, T. 1970. Earthquake mechanisms and island arc tectonics in the Indonesian-Philippine region: Seismological Society of America Bulletin **60**, 565-591.

Fitch, T., and Molnar, P. 1970. Focal mechanisms along inclined earthquake zones in the Indonesia-Philippine region: Journal of Geophysical Research **75**, 1431-1444.

Hamburger, M. W., Cardwell, R. K., and Isacks, B. L. 1983. Seismotectonics of the northern Philippines isalnd arc: Department of Geological Sciences, Cornell University, Ithaca, New York, 14853.

Hamilton, W. 1979. Tectonics of the Indonesian region: U.S. Geological Survey Professional Paper 1078, 345 pp., 2 plates.

Hodgson, J. H., and Arnold, E. P. 1977. Manual of [seismological] headquarters operations: UNDP/UNESCO Regional Seismological Network for Southeast Asia, Manila, Philippines (revised 1979).

Howell, B. F. and Schultz, T. R. 1975. Attenuation of modified mercalli intensity with distance from the epicenter, Seismological Society of America Bulletin, **65**, no. 3, 651-666.

Ismail, S., 1985. Energy release and frequency of earthquakes in Indonesia 1900-1978, unpublished manuscript: Available from Meteorological and Geophysical Agency, Jalan Arief Rachman Hakim 3, Jakarta, Indonesia, 15 pp..

Jeffreys, H. 1963. An alternative to the rejection of observations: Proceedings of the Royal Society, **137**, 78-87.

Jeffreys, H. 1932. The theory of probability: Oxford University Press, London, 447 pp.

Katsumata, M., and Sykes, L. R. 1969. Seismicity and tectonics of the western Pacific: Izu-Mariana-Caroline and Ryukya-Taiwan Region: Journal of Geophysical Research **74**, 1923-5948.

Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia, 1887-1938. Volcanic phenomena and earthquakes in the east-Indian archipelago: Published annually (translated by SEASEE into English), Jakarta.

Krause, D. C., 1966. Tectonics, marine geology and bathymetry of the Celebes Sea-Sulu Sea Region: Geological Society of America Bulletin **77**, 813-832.

Lewis, S. D., and Hayes, D. E. 1983. The tectonics of northward propagating subduction along eastern Luzon, Philippine Islands, Hayes, D. E., ed.: American Geophysical Union Monograph No. 27, Washington, D. C.

Lomnitz, C., 1974. Global tectonics and earthquake risk; Elsevier, Amsterdam, 329 pp.

McCann, W. R., Nishenko, S. P., Sykes, L. R. and Krause, J. 1979. Seismic gaps and plate tectonics: seismic potential for major boundaries: Pure Applied Geophysics, **117**, 1082-1147.

Meteorological and Geophysical Agency (BMG-GN), 1949-present. Geophysical Notes, Jakarta, published quarterly.

Meteorological and Geophysical Agency (BMG-EI), 1965-present. Earthquakes in Indonesia, Jakarta, published annually.

Meteorological and Geophysical Agency (BMG-SR), 1949-present. Earthquake survey reports, Jakarta, published after all damaging earthquakes.

Newcomb, K. R., McCann, W. R. 1986. Seismic history and seismotectonic of the Sunda arc: Unpublished.

Oldham, T. 1883. A catalogue of Indian earthquakes from the earliest time to the end of A.D. 1869: Memoirs of the Geological Survey of India, **19**, part 3, 48 pp.

Philippine Commission on Population, 1985. The Philippine population data sheet: Available from Commission on Population, MCPO Box 1841, Makati, Rizal, Philippines, 1 oversized sheet.

Repetti, W. C. 1946a. Catalogue of Philippine earthquakes, 1589-1899, Seismological Society of America Bulletin, **36**, no. 3, 133-322.

Repetti, W. C. 1946b. Seventy-five years of seismology in the Manila Observatory, Transactions, American Geophysical Union, **27**, 15-18.

Richter, C. F. 1958. Elementary seismology: W. H. Freeman & Co., San Francisco, 768 pp.

Rutland, R. W. R., 1968. A tectonic study of part of the Philippine fault zone: Quarterly Journal of the Geological Society of London **123**, 293-325.

Seno, T., and Kurita, K. 1978. Focal mechanism and tectonics of the Taiwan-Philippine region: Journal of Physical of the Earth, **26**, Suppl., S249-S263.

Stewart, G. S., and Cohn, S. N. 1977. The August 26, 1976 Mindanao Philippine earthquake...Evidence for a subduction zone south of Mindanao: American Geophysical Union Monograph No. 58, 1194.

Su, S. S. 1980. Attenuation of intensity with epicentral distance in the Philippines, Seismological Society of America Bulletin, **70**, 1287-1291.

Su, S. S. 1984. A case study of the August 17, 1976 Moro Gulf earthquake and its aftershocks: A paper presented during the Regional Seminar Workshop on Preparedness for Geologic Disasters in Southeast Asia and the Pacific, Dec. 4-10, 1984, Manila, Philippines.

Sudarmo, R. P. 1983. Focal mechanism solutions - Collection evaluation and reprocessing for the earthquakes in Indonesia with M=5.0 for the period 1934-1982: Unpuolished manuscript, available from Meteorological and Geophysical Agency, Jalan Arief Rachman Hakim 3, Jakarta, Indonesia, 491 pp.

Sudarmo, R. P., 1985. Focal mechanism solutions, collection, evaluation, and reprocessing for earthquakes in Indonesia with $M_s \geq 5.0$ 1934-1982, unpublished manuscript: Available from Meteorological and Geophysical Agency, Jalan Arief Rachman Hakim 3, Jakarta, Indonesia, 243 pp.

Thenhaus, P. C., Ed. 1983. Summary of workshops concerning regional seismic source zones of parts of the conterminous United States, convened by the U.S. Geological Survey 1979-1980, Golden, Colorado: U.S. Geological Survey Circular 898, 36 pp.

Thenhaus, P. C., Algermissen, S. T., and Perkins, D. M. 1982. A new seismic source zone map for the conterminous United States (abs.): Geological Society of America Abstracts with Programs, **14**, no. 7, 630.

United Nations Statistical Office 1985. Demographic yearbook for 1983: Available from Publishing Division, United Nations, New York, NY 10017, 1092 pp.

Visser, S. W. 1922. Inland and submarine epicenters of Sumatra and Java earthquakes: Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia, Verhandelingen 9, 14 pp.

Wichman, A. 1922. Die erdbeben des indischen archipels von 1858 bis 1877., Verhandelingen der Koninklijke akademie van wetenschappen, v. XXII, 209 (in German translated into English by SEASEE team 1983.)

APPENDIX A

This document is the final report of a planning mission carried out by the present author to determine the state of hazard analysis, emergency planning, awareness of the dangers of earthquakes on the part of governments, etc., and to plan a programme of work to help in formulating a strategy for mitigating the earthquake hazard in the ASEAN countries.

The report gives a non-exhaustive inventory of structures at some degree of risk, and the human resources and organizations available to combat the earthquake hazard. It also gives a more detailed plan of action to achieve a mitigation programme than given in the body of this report.

Final Report

Planning Study
Earthquake Hazard Mitigation
Program
in Southeast Asia

U.S. Department of the Interior
Geological Survey
Office of Earthquake Studies

Golden, Colorado
October 1981

Introduction

On 2 February 1980, the President of the Southeast Asia Association for Seismology and Earthquake Engineering* (SEASEE) delivered to the Director of the Office of Foreign Disaster Assistance, Agency for International Development (OFDA/AID) a request for assistance in carrying out an earthquake hazard mitigation program in the Southeast Asia region. Specifically, the region is to include those States which belong to the Association of Southeast Asian Nations (ASEAN). The request for assistance was accompanied by a preliminary project proposal. As a result of that request, OFDA sponsored a planning study by the U.S. Geological Survey which would form the basis of further involvement by OFDA in earthquake hazard studies in the region. The travel portion of this study was performed between 16 February 1981 and 18 April 1981.

1. Travel to each ASEAN country (Malaysia, Indonesia, Singapore, Thailand and the Philippines) to locate, identify, and meet with professionals, experts, technicians, organizations, and groups that could contribute to the development and implementation of a regional ASEAN program for earthquake hazard mitigation. The experts mentioned above would necessarily include engineers, electronics technicians, computer programmers, seismologists, geophysicists, and experts in risk and hazards analysis.

2. Identify, examine, and determine the usefulness of existing catalogs of earthquakes and historical seismicity in each country with a view toward assessing the quality and quantity of seismicity data available for hazard analysis studies.

3. Determine the extent and relative usefulness of existing studies in geological hazards, tsunami analysis, seismotectonics, and risk analysis for each country in the region.

4. Determine and evaluate the level of contribution which could be provided by individual experts and organizations to the regional program and within each ASEAN member-state.

5. Provide evaluation of possible suitable site(s) for program coordination center.

6. Determine level of commitment for counterpart funding to be provided by ASEAN member-states and/or other regional sources.

This report begins with a narrative description of governmental and nongovernmental interest in an earthquake hazard assessment program for the region. This is followed by an assessment of the state of seismology in the region, both from the point of view of observation and the level of existing expertise on which a program can be based. A third section outlines the objectives of an earthquake hazard mitigation program and a fourth gives

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* The constitution of this organization is given as Attachment to this report.

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strategy for carrying out the objectives of this program and includes specific recommendations drawn from the regional tour. Finally, a work plan, schedule, and budget are included.

Governmental Interest in Earthquake Hazard Assessment

The answer to the question, "Do the governments of Southeast Asia have an interest in the risk from earthquakes in their country?", is a resounding "yes" but there seems to be a good deal of doubt, in their minds, as to how they should proceed. There is, therefore, a very good case for conducting a familiarization course in risk analysis for government officials of these countries to acquaint them with just what can be expected from this science.

During the planning mission, many persons involved in the construction industry, public works ministries, the petroleum industry, the electric power generation industry, and others were interviewed as to their present practices and as to what measures they felt were necessary. The following is a summary, by categories of risk, of these factors.

Engineering Structures

Since Indonesia and the Philippines have more earthquakes than the other three ASEAN countries, the interest in controlling earthquake risks in these was the greatest. Of these two countries, the Philippines has by far more large engineering structures, that is large buildings, factories, offices, etc., than does Indonesia. A uniform building-code exists for all the Philippines which does include earthquake provisions. This code, however, is the only uniform code in the entire ASEAN region. Unfortunately, there is no commonly accepted risk analysis of the Philippines and the design earthquake is taken to be the 1940 El Centro quake. Metropolitan Manila, including the financial capital of Makati, has a population of some 8 million or so inhabitants and contains innumerable buildings over four stories in height. Many of these are along the five-mile stretch of Roxas Boulevard which borders Manila Bay on or near reclaimed land where the water table is less than a metre below the surface. It is well recognized that the El Centro earthquake is quite inapplicable as a design earthquake because the soil types in the Imperial Valley of California and the humid tropics are as different as could possibly be imagined. Yet nothing better exists!

Although Manila is not the only concentration of population in the Philippines (Cebú and Davao as well as Baguio have a significant number of large engineering structures), Manila represents the majority of risk from earthquakes in the Philippines. To the East lies the Manila fault, a normal fault with unknown seismicity due to a lack of instrumentation in previous years. One might add that instrumenting this fault would shed a great deal of light on the level of risk in Manila. It was suggested in one meeting by Mr. Andres Hizon, the President of the National Society for Seismology and Earthquake Engineering of the Philippines, that an organization devoted to seismology and earthquake engineering of the Metropolitan Manila area should be set up in the Governor's Office. This suggestion was heartily endorsed by Colonel Rafael Rueda who represented the Metropolitan Manila Commission at this meeting. Colonel Rueda was, in fact, the personal representative of the Governor, Mrs. Imelda Marcos. Colonel Rueda volunteered to contact the Governor on this question.

Although there are no fewer earthquakes in Indonesia than in the Philippines, the situation is quite different. There is no uniform building-code whatsoever although one is being planned. It is possible that it will be enacted into law in the next few years and may have earthquake provisions in it. Although the number of high-rise buildings per capita in Indonesia are far less than they are in the Philippines, this situation is changing daily. This state of affairs provides an excellent opportunity to be able to influence the future by instituting at least a rudimentary building- and land-use-code program as soon as possible.

One encouraging factor in Indonesia is that the Government of New Zealand hired a firm of consulting structural engineers, amongst other things, to construct risk and zoning maps for Indonesia. Unfortunately, and by their own admission, these maps were based on earthquake data before 1974, the date that the UNDP program began recording earthquakes from its greatly enhanced network. Before that year, the reporting threshold was somewhere between magnitude 5 and 5.5. There was practically no knowledge of the seismicity of smaller magnitude earthquakes, nor was there much account taken of surface features. The maps are therefore very generalized especially in the region of the islands of Java, Bali, and Lombok, the major concentration of Indonesian population. They were, however, a good "first-cut" as an assessment of Indonesian zoning but by no means completely adequate.

The situation in Thailand is far worse. Most municipalities have no building code of any kind and, in the codes that do exist, in Bangkok and especially in Chieng Mai, contain no provisions for earthquakes, or for that matter any other sort of lateral forces on buildings. Most earthquakes on Thai territory run along a feature from the southwest to the northeast very close to Chieng Mai. The Thai seismic network is not dense enough to accurately locate these earthquakes very well, if at all. There have been damaging earthquakes both at Chieng Mai and Chieng Rai in the past. The author noted that there was a large number of high-rise buildings on this mission when compared to his last journey to Chieng Mai exactly ten years before. Obviously the risk seems to have increased almost exponentially.

The situation in Bangkok is quite different. Bangkok is a sprawling metropolis of nearly six million inhabitants built on the alluvial fan of the Chao Praya River about two meters above sea level. The alluvium appears to be many hundreds of meters deep and is totally saturated with water. This indicates a very high soil amplification factor and a high soil liquifaction potential. The author on a previous trip to Bangkok remembers an earthquake which occurred in the Andaman Sea some 500 kilometers away which caused considerable consternation to the occupants of high-rise buildings and cracked not a little glass. The earthquake was a mere magnitude 5.6. This was due to a well known effect concerning the response of tall structures. As earthquake waves leave the source, the higher frequency waves are attenuated more quickly than the lower. Most persons and small buildings are sensitive only to the higher frequencies and it is these, whose period is around one-half second, that do most damage near an earthquake source. At greater distances, only structures with long natural periods will be affected. Particularly high aspect ratio buildings, such as high-rises, can sustain very heavy damage from earthquakes at some distance and at the same time will pass unnoticed by people in small buildings or out-of-doors. These are generally termed "long-period effects". Although there has been a fairly long instrumental record of

large shocks in the Andiman Sea, it is only recently that these have been noticed in Bangkok. The reason is simple; it is only recently that very tall buildings have been built there. The local government authorities in Bangkok have now become alarmed (alarmed may be too strong a word) over the possibility of severe damage to the now numerous tall buildings. An evaluation of this hazard is certainly necessary.

The risk to tall buildings in Kuala Lumpur in Malaysia and in Singapore seems to be totally unrecognized. Singapore and Malaysia have the highest economic growth rates in the Southeast Asian region and there appears to be a rather friendly rivalry between Kuala Lumpur and Singapore as to who has the tallest buildings. As far as one can determine there are no seismic provisions in either of the building-codes even though both cities lie about three hundred kilometers from the West Sumatera fault. This fault is, judging by its length, quite capable of producing magnitude 8 and greater earthquakes. If such an earthquake should happen on this fault, tall buildings in both Kuala Lumpur and Singapore would be badly damaged.

A cheap and very efficient way to measure the hazard in Thailand, Malaysia, and Singapore to long-period effects would be to measure the natural period of many of the tall structures and compare them with the energy spectrum in already recorded earthquakes. This procedure is highly recommended, not only for these countries, but for the whole region.

One bright spot in this situation is that the seismic hazard was considered in the design of the new bridge that will connect mainland Malaysia with the island of Penang. Just how it was considered is, however, unknown.

Domestic Buildings

Domestic architecture in most of Southeast Asia consists of two types. The first is essentially a bamboo or timber frame structure usually but not always one story with various forms of roofing materials. These can often be very substantial structures indeed and are inherently earthquake resistant. Even in the poorer areas of the Southeast Asian cities one can find a large number of well built houses. As for the less well built timber houses, it is doubtful whether any of the Southeast Asian governments could control building practices in these areas in any case.

The second sort of domestic structures is the "single family" masonry house. Since these structures are small, no threat either to life or the economy exists in Malaysia or Singapore where building standards are high anyway, nor in most of Thailand. In the Philippines and most particularly in Indonesia the situation is very different. In the urban areas of these two countries, construction standards are fairly high; the quality of workmanship and materials being comparable to southern Europe, say. It appears that no earthquake resistant precautions have been taken for most of these buildings. The greatest threat to life and limb in these two countries and most particularly in Indonesia is the collapse of masonry houses in rural areas. Since both are primarily agricultural countries, most of the population is in rural areas. The materials and the workmanship are both of very low quality and no account for the effect of earthquake forces, either fortuitously or by design, is incorporated in the design of these structures. As a consequence, even small earthquakes (magnitude 5.5 and greater) can cause extensive damage, loss

of life, and casualties. The governments of both countries fully realize the extent of this risk. They do not, however, have the funds nor the expertise to tackle this problem on a uniform national level. Here the case for a sophisticated earthquake zoning map is at its clearest. The existence of a fairly detailed zoning map would allow these governments to focus their efforts on the areas of the highest risk thus turning an intractable problem into one which can be realized in the foreseeable future.

A third type of "domestic" architecture could be added to the list in these two countries. This is the combination commercial-residential building, a very common sight in cities and large villages. These generally take the form of shops on the ground floor with living quarters on the upper floors and can sometimes be as tall as about four stories. These are most often reinforced concrete frame buildings of reasonably high standard although certainly not up to those of industrialized nations. No study has been made of the performance of these buildings during earthquakes which is somewhat questionable because the usual practice is to have a completely open wall on the lower story thus displacing the center of gravity from the center of torsion of the building. This risk should definitely be investigated because of the prevalence of this sort of building.

All in all, the potential risk to both the lives of people and the economy of the Philippines and Indonesia from the collapse of domestic masonry structures is very high. But there is a secondary risk involved that the governments of these two countries have not considered. The inhabitants of these buildings are generally of the middle classes, the mainstay of their local economies, a portion of whose services will be lost at least for a time in the event of a destructive earthquake. Thus a case may be made for conducting a loss analysis of this effect.

Nuclear Power Generating Facilities

Thailand, Indonesia, Malaysia, and the Philippines already have plans in some stage of development for nuclear power stations. Considering the cost of such plants and the various constraints upon them, such as proximity to water borne transport (none of these countries have a road or rail system of a size sufficient to transport a prefabricated pressure vessel very far from the sea), the question of siting is paramount. From the point of view of the seismic hazard, the problem of siting is as follows: one must select a place where the Safe Shutdown Earthquake (SSE) is of such a magnitude that designing for it does not inordinately increase the cost of the station. The probability that the SSE is exceeded must be very low indeed because the cost to the economies of these countries of an idle plant could very well lead to both economic and, possibly, political disaster.

In the case of Indonesia, the projected power station is still in the siting stage and the Meteorological and Geophysical Agency has been asked to conduct a micro-earthquake study on a site to the north and east of Jakarta. One of the difficulties encountered in siting studies on volcanic island arcs is that any fault systems that might exist in the proximity to a proposed site are generally covered to great depths by volcanic debris or alluvium. This limits the tools that are available to determine a SSE. The rather poor instrumental record of earthquakes in Southeast Asia makes the problem even

more difficult. This application alone could make a case for an increased density of seismic stations in Java, Bali, and Lombok.

In Thailand, the Electrical Generating Authority of Thailand (EGAT) is considering a site near the eastern shore of the Gulf of Thailand and is searching for an alternative one on the western shore. The difficulty in selecting any site is that the instrumental record of earthquakes in the Gulf of Thailand is zero. The density of stations in and around the Gulf is so low that the reporting threshold would have to be assessed, probably, at something around magnitude 6. This is the case even considering the increase in station density brought about by the UNDP program. There is evidence, however, that earthquakes do exist there, because petroleum surveys have indicated that the entire floor of the Gulf is highly fractured. Again the application of seismology to nuclear power plant siting makes a case for an increased number of seismic stations in Thailand.

The problem of siting a reactor in the Philippines near Manila follows much the same lines as those in Indonesia and Thailand but is far more politically sensitive even on an international scale since the latest proposed site is only a few miles from the U.S. Naval Base at Subic Bay. This site, on the Bataan Peninsula, has a known seismicity far greater than any probable sites in Indonesia or Thailand. This situation is bound to increase the costs of construction and the operating uncertainties.

It is known that there are areas in the world where the superficial rock is quite weak and limits the size of earthquakes which will occur. These are generally known as "low strain release" areas and some may very well exist in Southeast Asia. The existence of low strain-release areas certainly would help in the siting problem as well as helping to delineate the general risk. Finding such areas would certainly be part of any hazard and risk program for the region.

Oil and Gas Sites and Pipelines

Both Indonesia and Malaysia are significant producers of petroleum and related products, Indonesia being a member of OPEC. In Malaysia, earthquakes do not represent a substantial threat except for northeastern Sabah where there is a substantial amount of earthquake activity. In Indonesia, there may very well be a threat to pipelines in Sumatera but it could not be learned whether or not Petromina (the national petroleum company) was interested or not.

The Petroleum Authority of Thailand (PTT) was very interested indeed in any earthquake threat to their gas platform about 400 km south of Bangkok in the Gulf and to the pipeline which connects it with that city. The highly fractured nature of the sea floor (qv) would suggest that at least small earthquakes occur in this area. These would probably be more of a hazard to the buried pipeline than to the production platform itself but the question must somehow be resolved.

Irrigation and Agriculture

Contrary to generally received knowledge, agriculture is not immune to the effects of earthquake damage. This is nowhere more true than in Southeast

Asia! Rice culture is dependent on intricately channelled water, and as a consequence, is highly dependent on these channels remaining open and undiverted. These conditions are most important in Indonesia but are nearly equally so in the Philippines as well. In the Sukabumi earthquake in 1972, many billions of Rupiah of damage to crops were suffered due to the collapse of irrigation canal walls.

This project, to protect the poor from disaster, should also undertake an investigation of the effects of earthquakes on agriculture. Perhaps the International Rice Research Institute, headquartered in Manila, could undertake part of this burden or at least serve as a contractor.

Irrigation also means water supplies for larger cities and electrical generating facilities when considering large dams. These too are worthy of consideration in this project.

Landslides

A risk from landslides certainly exists in the Philippines and Indonesia but, because of the lack of knowledge of the dynamical properties of humid-tropical, volcanic soils, the risk is quite unknown. The extent of this risk can be approached in two ways; first by using reports on landslides associated with historical events and, second, by conducting laboratory experiments on soil samples. In the latter case, the geological surveys in the region can be expected to help.

Tsunamis

The Philippines is naturally subjected to seismic sea-waves in the Pacific Basin, but PAGASA is already working in conjunction with the International Oceanographic Commission of UNESCO which gives sufficient warning in the case of remote tsunami-genic earthquakes. Indonesia as well as the Philippines also is subjected to risk from smaller earthquakes in their own region which produce local sea-waves. By far the greatest hazard is the production of tsunamis in the "inland seas" of the region. In this case, as well as in the case of local tsunamis, no warning is possible since the effects follow the earthquake by five minutes or less. Here a tsunami potential map would be a great help to land-use planners in these two countries.

The Status of Seismology in Southeast Asia

This section is devoted to all aspects of seismological activity both past and present in Southeast Asia and is subdivided by country. This will include both the present knowledge of the seismicity of each country and the state of the present infrastructure.

One item, however, must be repeated; probably due to the inherently earthquake resistant character of its indigenous architecture, seismology, as an academic pursuit, has a very short history in this region. This applies to all the countries in the ASEAN region although there is evidence that this situation is now improving. Individual improvements will be discussed below.

Observational seismology did not begin in earnest in Southeast Asia until the early 1960's when the then United States Coast and Geodetic Survey

installed seven stations of the world-wide Standard Seismograph Network (WWSSN) in the region. One should be reminded that the Southeast Asia region is about the same size and dimensions as the lower 48 states of the United States. The design of the instrumentation in these stations was primarily directed toward recording teleseisms rather than local or regional activity. It did however lower the detection threshold in the region a good deal and increase the accuracy of earthquake locations. It was not until about 1974, when the UNDP program began installing high magnification stations with a response more suitable to detecting local and regional earthquakes of lower magnitude that the data necessary for an assessment of seismicity in the region became available. In general, the UNDP program was highly successful but certainly did not leave the region with the most desirable network possible. This was no fault of the management of the UNDP program but merely a lack of funds and the inability of the various governmental agencies to absorb aid in a rather arbitrarily allotted time.

Philippines

The Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) now operates a network of 17 seismological stations; all are of the UNDP type except for one six component WWSSN station at Manila. The names and locations of the Southeast Asian network can be found in Appendix I attached. PAGASA also operates a network of 15 strong-motion accelerographs mostly in Metro-Manila but with some in more outlying areas. Additionally, the National Irrigation Administration has 3 instruments at Pantabangan Dam. Manila Observatory which is part of Ateneo de Manila operates two World-Wide stations one at Baguio and one at Davao. In general, the network in the Philippines is well and conscientiously run but is still plagued with some persistent logistical problems. The first of these is as follows: The UNDP instrumentation was originally set up with local registration, that is to say, the recording device was within a few meters of the sensor. This of course, was for the purpose of simplifying maintenance. Unfortunately, in the more remote areas (where the best sites are), it is very difficult to find station operating personnel willing to live under these conditions even at the relatively low salaries paid in the ASEAN countries. The obvious solution to this problem is telemetering, whereby the seismometer and a very small power supply is placed in a remote site and recording instruments removed to a more populace area. The second difficulty is that of spare parts. In general, parts for all of these instruments are freely available as is an adequate allocation of foreign currency with which to buy them. There are a few components, however, which are peculiar only to these instruments for which importing agencies impose minimum orders far in excess of requirements. A good example is film for the strong motion instruments. The importer requires a minimum order of two years' supply. The film only lasts one under tropical conditions. The obvious solution to this problem is direct buying in the United States and the use of diplomatic pouch to obviate the need for an importer.

In the Philippines, the study and teaching of Seismology is confined to the activities of Father Sergio Su whose research is widely published and is of world class. His students however are very few in number as is typical of the region. Some general geophysics is also taught at the University of the Philippines but what there is seems to be directed toward the exploration industries.

Indonesia

The Meteorological and Geophysical Agency (BMG) operates 18 stations in Indonesian territory and is exceedingly conscientious in both maintaining the stations themselves and reporting the output therefrom. The BMG also operates a network of 11 strong-motion accelerographs throughout the islands. However, some of the same logistical problems that exist in the Philippines also exist in Indonesia. Some difficulties exist in obtaining spare parts but the solution indicated above will probably cure this problem. The problems of operating remote sites has been solved in Indonesia in a slightly different way by installing stations near population centers but operating them necessarily at very low magnifications. Here again telemetry is the obvious solution and should be employed because, in almost every case, good sites can be found within 35 to 50 kilometers of the present stations.

The greatest problem for the Indonesian seismological network is its lack of density. Whereas in the other ASEAN countries the UNDP program goal of reducing the reporting threshold to M_L of 4.0 has been met, in Indonesia it has not or at least not uniformly so. One must remember that Indonesia is a very far flung country whose east-west dimension is about the same as that for the United States with a seismicity at least 10 times that of the United States. The most populace islands of Java, Bali, and Lombok have only four high gain seismic observatories. If one were to add Sumatera the number would only climb to eight. This is simply inadequate! The success of any risk or hazard assessment program depends heavily on knowing the earthquake history of any given region in as much detail as possible. The earlier that additional stations can be installed the earlier answers will be available. The BMG has planned to put in four more stations in its five year plan, of course at its own expense. It is suggested that help from USAID could accelerate this program.

The BMG presently has deployed six strong-motion accelerographs mostly in the Jakarta region. It has however, recently, taken delivery of 30 which are not as yet deployed. Advice on the deployment of these instruments is a place where the USGS could be of great assistance in an ongoing program. It is very important to the success of any mitigation program to obtain accelerograms of an earthquake in a tropical setting which will reflect the behavior of its characteristic soils.

The BMG has a unique method for recruiting technical employees. It recruits secondary school graduates. These recruits then complete a course in an academy run by the BMG on the premises of their headquarters in Jakarta which in the United States would be considered a junior college. The BMG has recently entered into an agreement with the physics department at the University of Indonesia to establish a course for academy graduates which would take them to a Bachelor's level standard. USAID could help establish this university program by supplying through the BMG such items as library acquisitions and teaching equipment for its geophysics program. This would help to accelerate the supply of university level personnel that the BMG so badly needs.

Graduate-level geophysics is the exclusive province of the Bandung Institute of Technology. Only a small amount of their work, however, is directed at seismological studies. Since a long-range program in earthquake hazard mitigation cannot exist without an adequate supply of graduate level seismologists, it would seem that assistance to the ITB would be in order.

One of the primary pieces of data necessary for the assessment of earthquake hazard and risk is intensity data from historical events. These have been collected by the BMG in conjunction with the Geological Survey of Indonesia for many years. These are collected for each event and published as a report. Unfortunately, these reports are in the Indonesian language and will have to be collected and translated before they can be used by both Indonesian and United States scientists. There are also some intensity reports for events before the Second World War that are written in Dutch which will also have to be translated.

Malaysia

The Malaysian Meteorological Service (MMS) operates three seismological stations in peninsular Malaysia and one in Sabah in northern Borneo. They have plans to install two more stations in Borneo which should become operational very soon. The MMS also operates one strong-motion accelerograph at their headquarters in Kuala Lumpur. The MMS is very conscientious indeed in operating its stations even though the level of earthquake risk is far less than it is in the Philippines or Indonesia. This does not mean, however, that problems do not exist. Again, the problems tend to be logistical but more closely resemble those of more developed countries. Since Malaysia is far more prosperous than the other ASEAN countries with the exception of Singapore, it is difficult to justify keeping highly paid personnel at individual stations as operators. Here the case for long-distance telemetry comes into its own. If the entire network were telemetered via telephone channels into Kuala Lumpur and recorded there much as the NEIS telemeters its United States network into Golden, two advantages would accrue. First, far fewer personnel would be needed and secondly locations of nearby earthquakes could be found within minutes rather than days which would help to justify the maintenance of a network in the face of relatively low Malaysian risk and whose existence is primarily of help to another country, Indonesia.

As in any other nation, to carry on a long-range program in seismology, there must be a supply of trained personnel which can interpret the results. In this regard Malaysia is probably the best equipped of all the ASEAN countries because courses in seismology are taught at the Malaysia University of Science at Penang, at the University of Malaya at Kuala Lumpur and at the Malaysia University of Technology also in Kuala Lumpur. Some assistance for these institutions should be considered.

Thailand

The Meteorological Department operates a four-station network which includes a Seismological Research Observatory and a World-Wide Standard station. The Electricity Generating Authority of Thailand (EGAT) operates five strong-motion instruments at two dams in the country. The Meteorological Department which like its neighbors is very conscientious in its seismological program has had a long history of co-operation with both its neighbors and the U.S. Geological Survey (and the U.S. Coast and Geodetic Survey before it). Like Indonesia however the network in Thailand is not dense enough to accurately locate earthquakes either in northern Thailand or in the Gulf. Like its neighbors logistical problems exist which could be solved by short range telemetry.

The Physics Department of the University of Chieng Mai does include some instruction in seismology and should be encouraged by some assistance.

While in Bangkok during this mission, it was fortuitous that the Director General of the Meteorological Department at Rangoon was also present. Although Burma is not a member of ASEAN, observations from Burmese territory would certainly help locate earthquakes in the Andaman Sea which are a threat to Thai cities. Assistance to Burma in establishing some stations should be considered.

Singapore

At present Singapore operates no seismic stations but there is willingness on the part of the Meteorological Service of Singapore to do so. Because of its prosperity, Singapore would probably not require any financial assistance but would welcome expert advice both in establishing a network and in participating in a hazard and risk analysis program.

Hong Kong

Hong Kong although not a member of ASEAN is an official observer within the SEASEE organization. Since the location of earthquakes is primarily a geometrical problem, Hong Kong aids in the location of earthquakes within the ASEAN area. The Royal Observatory, Hong Kong has a long history of co-operation with its Southeast Asian neighbors and has expressed its desire many times to continue its association with them. Because they are officially a part of the United Kingdom, they cannot accept financial aid. They would, however, appreciate advice and technical expertise.

Objectives of an Earthquake Hazard Mitigation Program in Southeast Asia

The ultimate aim of any earthquake hazard mitigation program is to provide the required information for governments to frame building- and land-use codes and for engineers and others to design structures. Moreover, such a program should develop an institutional framework within each country for continued earthquake hazard assessment. The program proposed in this document will strive to meet these objectives. The following is a description of the basic elements of any 18 month program beginning on 1981 July 1. This program is designed as a first step in a longer program.

1. The first task will be to collect as complete as possible a seismological data base. This will be in two parts. The first will be to collect a complete catalogue of instrumental epicenters for as long a time period as is possible. Many of these epicenters will have to be relocated in the light of new station positions. It may also be possible to develop, at least for selected locales, a new velocity model which will further help to increase the accuracy of the locations.

   The best source for the raw data necessary for this task is the International Seismological Centre in the United Kingdom. It has the most

complete collection for a time period ending two years after the present. USGS and SEA data could fill the resulting gap.

To assess the effects of earthquakes, intensity surveys for as many historical events as possible must be collected. This will entail collecting as much original information as is possible, translating it into English if necessary, drawing isoseismal maps if possible and finally collecting it into a catalogue of earthquakes for the region. Finally, all of these data should be combined to provide the input parameters for the delineation of the seismic hazard as outlined in 3 below.

In order to further refine the zoning of Southeast Asia in the future it will be necessary to augment the present network of seismological stations and strong-motion instruments. This will take several forms: (1) Completely new stations, (2) The introduction of telemetry with existing stations in order to obtain higher magnifications thus lowering the detection thresholds and (3) adding some long-period instrumentation throughout the network so as to better define earthquake focal-mechanisms.

2. Seismo-tectonic Assessment. The objective is to prepare regional seismo-tectonic maps that will provide a framework for the correct interpretation of the historical seismicity and seismic hazard.

One of the most important relations to establish for successful seismic hazard assessment and zoning is the relationship between geologic structure, geological evidence of earthquake occurrence (for example, fault slip) and historical seismicity. If relationships of this kind can be established, the historical record of earthquake occurrence can be greatly supplemented and areas of currently only moderate or low seismicity can be identified as potentially seismogenic.

3. Delineation of Seismic Hazard. The principal objective is to delineate the ground shaking on a regional basis with special attention to site conditions in important urban areas that might significantly affect the ground shaking hazard. An attempt will be made to identify areas where geologic effects might be severe and where tsunamis may be a significant threat.

The results of earthquakes can be classified in the following manner:

a) Primary faulting: Faulting associated with the mechanism of the earthquake.

b) Ground shaking: The vibrational effects of earthquakes.

c) Geologic effects: Ground shaking frequently causes geologic effects, such as liquifaction, differential compaction and landsliding.

d) Tsunamis: Large submarine earthquakes (usually with magnitudes greater than 7) frequently cause seismic seawaves or tsunamis that may cause great damage.

The delineation of seismic nazard requires the estimation of a number of seismological and geological parameters such as:

a) The historical seismicity.

b) The nature of the earthquake focal mechanism (direction and mode of faulting, depth of focus of earthquakes, etc.).

c) Attenuation of seismic waves.

d) Site conditions (thickness and engineering properties of surficial geologic formations) in locations of special interest (urban areas and areas of planned development).

4. Once hazard and zoning maps are available it will be necessary to develop recommendations for additions to building-codes and land-use provisions thereto. These must be developed in close cooperation with Southeast Asian engineers and scientists in order that they may be both practicable and enforceable. It is at this point where most programs fail. Building-code provisions which do not conform to local practice or which are too expensive to implement are both next to useless. Recommended changes should be made with respect to both engineering and domestic structures especially in Indonesia and the Philippines.

5. Development of an institutional framework for continued earthquake hazard assessment. Every effort will be made to develop an institutional framework in the region for continued work in this field. This will take the form of training, the handing over of new instrumental and computing expertise and the opening of avenues for even greater cooperation amongst the ASEAN countries.

In a program of only 18 months duration it is doubtful whether steps 3 and 4 above can be carried out for the entire region. In consequence, it is proposed that representative areas of high seismic hazard will be considered in each country and the rest of the region finished in a subsequent program.

Work Plan

Duties and Responsibilities

Under the administration, management, and professional leadership of the Office of Earthquake Studies of the U.S. Geological Survey, the Southeast Asia Association of Seismology and Earthquake Engineering (SEASEE) will work toward and accomplish the following objectives:

1. Collect and catalogue, on a consistent basis, the historic and instrumental information available from past seismic events in each country; this includes the epicenter location, the determination of magnitudes and/or intensities of reported historical events and the revision and

updating of recent catalogues and published bulletins. When possible, important earthquakes will be relocated.

2. Collect and summarize the geological and tectonic information of the Southeast Asian region for the evaluation of seismic hazard and risk.

3. Seismic hazard maps will be produced for the area of the project for various probability levels and for various parameters. If there are alternative hypotheses, for example, with reference to the location of potential seismic source areas, hazard estimates consistent with each hypothesis will be produced. The emphasis will not be to recommend the "best" hypothesis, mapping parameters and probability levels, but to produce maps that are consistent with the differences in economies, building codes, and design philosophies of the several countries and regions involved. To this end, structural engineers and building authorities will be consulted in each country, before and during the production of the seismic hazard maps, so that those who ultimately will use the maps can have a part in defining the specific variables and information to be included in maps to be produced by the project. As indicated above, all of the basic information used in the analysis of the seismic risk will be published with the object of documenting the hazard maps and also to facilitate the interpretation of the results. Estimates of seismic risk (earthquake losses) will be undertaken on a limited basis in areas where the potential for disastrous losses are deemed to be very high and where risk evaluations will be an aid to disaster preparedness planning.

   A major objective of this program will be to pin-point the locales where the loss to area ratio is near maximum for all countries so that any of the governments involved can spend their monies most effectively.

4. Carry out a feasibility study of a Southeast Asian satellite-relay network capable of locating with a small number of stations, all events of magnitude 5 or greater within 6 hours after the occurrence of the event and those of magnitude between 4 and 5, within the next 24 hours. The feasibility of local arrays of telemetered stations will also be evaluated.

Implementation Plan

This project is funded by the Agency for International Development, OFDA, through the U.S. Geological Survey for the Southeast Asia Association of Seismology and Earthquake Engineering (SEASEE). SEASEE has greatly contributed to an integration of seismological data acquisition, collection and research in the Southeast Asia region and is a logical focal point for such a program. U.S. Geological Survey will provide both the administrative and technical advice to SEASEE, review the accomplishments of the project, and report to OFDA on progress. The general objectives of the project, selection of key personnel such as managers, technical consultants, etc., will be made by SEASEE with the concurrence of U.S. Geological Survey and OFDA co-ordinators. Neither USAID or U.S. Geological Survey will enter into the day-to-day operation of the project, but the U.S. Geological Survey will keep SEASEE activities under close supervision and will report progress to OFDA on a periodic, mutually agreeable basis.

General Outline of Work Plan

a. Initiation of Project:

1. U.S. Geological Survey transfers funds to SEASEE.

2. Advisory and Coordinating Committee selected; Project Manager selected.

3. OFDA Coordinator, U.S. Geological Survey Co-Managers, Advisory Committee, Coordinating Committee, and Project Director meet; country proposals submitted to SEASEE; Advisory Committee recommends course of action to SEASEE based on country proposals.

4. SEASEE, U.S. Geological Survey, and OFDA agree on specific technical details of project.

5. Project work begins.

b. Project Implementation

1. SEASEE implements projects in participating countries.

2. SEASEE acquires Consultants with USGS approval.

3. Second meeting of OFDA Coordinator, USGS Co-Managers, Advisory Committee, etc. (as in a.3 above).

4. Third meeting of OFDA Coordinator, USGS Co-Managers, Advisory Committee, etc., as in b.3 above approximately two months before completion of project.

c. Completion of Project

1. SEASEE reports on achievements of project to USGS/OFDA.

2. General Conference held to allow presentation of technical results of project.

3. Proceedings of conference published by SEASEE.

Technical Products

(Dates given are from initiation of project)

a. Report on feasibility of satellite relay telemetry seismograph network: 1 year.

b. Recommendations on number, requirements and costs for upgrading of a limited number of teleseismic stations in the ASEAN region: 3 months.

c. Upgrading of stations selected from b above completed: 16 months.

d. Seismicity catalogue of Southeast Asian region earthquakes completed: 1 year.

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e. Preliminary seismic hazard assessment and report for the Southeast Asian region completed: 16 months.

f. Selected risk assessments completed (report): 16 months.

g. Selection of training programs and persons to be given training: 6 months.

h. General report of the technical achievements of the project: 18 months.

Organization

An organization chart, illustrating the way the project will be handled appears on the next page. Below is an explanation of some of the critical elements of the organization.

Project Director

The Project Director would be employed by SEASEE and would be responsible for the day-to-day technical direction of the project. Preferably, the Project Director would be an experienced scientist from either inside or outside the ASEAN region. He should not, however, be an employee of one of the member organizations as this would provide balance and perspective to the project. The director would be responsible for co-ordinating the tasks performed within each country.

Advisory Committee

This committee would be made up of four to six experts in earthquake engineering, seismic hazard and risk analysis, instrumentation and seismotectonics, preferably from outside the ASEAN region. The Committee would meet no less than three times during the project and would provide recommendations for the technical content of the program to the Project Director, SEASEE and the Technical Co-Managers, U.S. Geological Survey.

Consultants

Experts in various technical aspects of the project would be engaged by SEASEE as appropriate with USGS approval. Where practicable, consultants will be from within the USGS itself.

Task Supervisors

Within each ASEAN country, one person from the SEASEE member organization will, with USGS Co-Manager approval, be appointed to supervize all aspects of the project conducted in his country.

Support Staff

Employees of the member organizations would provide the majority of the work force.

Headquarters

During the tour associated with this study, each Director-General was given the opportunity to offer space in his buildings for a headquarters for this project. All of them were delighted to make such an offer and each of the four situations had much merit. On the whole, however, Manila seemed to be the best place, first, because SEASEE was headquartered there and, second, because USAID conducts its ASEAN affairs from there.

Attachment

SOUTHEAST ASIA ASSOCIATION OF SEISMOLOGY AND EARTHQUAKE ENGINEERING (SEASEE)

CONSTITUTION AND BY-LAWS

PREAMBLE

We, the members, of the Southeast Asia Association of Seismology and Earthquake Engineering, in the pursuit of establishing a progressive regional cooperation, enhancing exchange of information on research and developments in seismology and earthquake engineering, and committing ourselves to the welfare of human society, do hereby promulgate this Constitution and By-Laws.

ARTICLE I - THE NAME

The organization shall be called the Southeast Asia Association of Seismology and Earthquake Engineering (SEASEE), hereinafter referred to as the Association.

ARTICLE II - ORGANIZERS

The Association was established by the participating agencies to the UNDP- assisted Regional Seismological Network in Southeast Asia Project Terminal Tripartite Review/Coordinating Committee Meeting held in Manila, Philippines from 29 - 31 August, 1979.

ARTICLE III - GOALS AND OBJECTIVES

Section 1 Main Objectives

a) To encourage the development of cooperation in seismology and earthquake engineering among the member countries of ASEAN.

b) To help develop a more thorough understanding of the science of Seismology and Earthquake Engineering with ASEAN countries.

c) To fulfill the role of Seismology and Earthquake Engineering as an endeavour concerned with human welfare.

Section 2 Specific Goals

a) To ensure the continued optimum operation of the seimological and strong-motion networks in Southeast Asia through the sharing of data and expertise.

b) To ensure the fullest utilization of the data derived from these networks through the encouragement of research into:

i) Precise location of earthquakes and the determination of magnitudes;

ii) The deep structure of the area and the earth processes active in it;

iii) Improved seismic zoning;

iv) Improved anti-seismic provision in building codes;

v) Earthquake prediction.

c) To enhance the development of earthquake disaster preparedness measures.

d) To encourage field studies of affected areas following major earthquakes or tsunamis.

e) To encourage the exchange of reports on research and development in seismology and earthquake engineering through the holding of annual meetings and the publication of a Newsletter.

f) To act as an agent for the solicitation and receipt of funds or other farms of aid in support of its aims.

g) To foster cooperation with regional and national organizations of seismology and earthquake engineering in other parts of the world.

ARTICLE IV - MEMBERSHIP

Membership of the Association shall be the agencies in the ASEAN countries which are engaged in their national seismological activities, namely:

1. Meteorological and Geophysical Agency, Republic of Indonesia

2. Malaysian Meteorological Service, Malaysia

3. Philippine Atmospheric, Geophysical and Astronomical Services Administration, Republic of the Philippines

4. Meteorological Department, Thailand

5. Equivalent agencies in other ASEAN countries.

ARTICLE V - RIGHTS AND DUTIES OF MEMBERS

Rights and Privileges of Members

a) Every member shall have full deliberative and voting rights on all matters concerning the Association.

b) Every member shall have access to the documents of the Association which include official acts, decisions, transactions, accounting of funds, and minutes of the meetings.

ARTICLE VI - ORGANIZATIONAL STRUCTURE

Section 1 The Officers

a) The Association shall have a President and a Vice-President duly elected by the Executive Committee.

b) A Secretary and Treasurer shall be appointed by the President.

Section 2 The Executive Committee

The Executive Committee shall be composed of the directors-general or their designees of the member agencies which shall be headed by the President. It shall have general supervision and control of the projects and affairs of the Association.

Section 3 National Body

Each member may form a national body of agencies interested in seismology to be headed by the director-general of the member. Such national bodies shall adopt their own rules and regulations not inconsistent with this Constitution.

Section 4 Meetings

Meetings of the association shall be held annually, if possible. Such meetings shall be held in a venue to be determined by the Executive Committee

ARTICLE VII - PRINCIPAL OFFICE OF THE ASSOCIATION

The Association shall have its principal office at the office of the incumbent President of the Association.

ARTICLE VIII - ELECTION AND TERMS OF OFFICE

Section 1 Elections

a) Officers of the Association shall be elected by a majority vote of one-half plus one (1) of the total number of votes cast.

b) Election of officers shall be held at the annual meeting of the Association.

Section 2 Terms of Office

a) The officers of the Association shall have a term of office ending at the close of the meeting where a set of new officers have been elected.

b) Any officer may be re-elected into office but may not hold the same position for more than two (2) consecutive terms.

ARTICLE IX - DUTIES OF OFFICERS

Section 1 The President

a) Shall preside at all regular and special meetings of the Executive Committee; decide all questions of order; sign all resolutions and communications for, and in the name of the Association; and perform such other duties as the Executive Committee may authorize.

b) Shall be the official Spokesman and respresentative of the Association.

Section 2 The Vice-President

a) Shall assist the President in the implementation of the latter's functions.

b) Shall assume the President's responsibilities and obligations whenever the President becomes unable or ineligible to carry out the functions of his office for any cause.

Section 3 The Secretary

a) Shall keep a complete written record of the minutes of the meetings and shall prepare the official letters to be signed by the President.

b) Shall take charge of keeping and safeguarding the documents and records of the Association.

c) Shall handle the communications within the Association, including the publication of the SEASEE Newsletter.

Section 4 The Treasurer

a) Shall take custody of the funds of the Association and shall handle the business transactions of the Association duly approved by the Executive Committee.

ARTICLE X - SUCCESSION OF POWER

Section 1 Offices that are vacated before the end of the terms of office shall be appointive, except for that of the President which shall be automatically assumed by the Vice-President until the next regular elections of officers.

ARTICLE XI - AMENDMENTS

Any provision of this Constitution may be amended by a majority vote of one-half plus one of the total number of votes cast.

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APPROVED in behalf of the Members:

C. SUTRISNO
Director General
Meteorological and Geophysical Agency,
INDONESIA

HO TONG YUEN
Director General
Malaysian Meteorological service
MALAYSIA

ROMAN L. KINTANAR
Director General
Philippine Atmospheric, Geophysical and
Astronomical Services Administration
PHILIPPINES

KAJIT BUAJITTI
Director General
Meteorological Department
THAILAND

31 October 1981
Quezon City, Philippines

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Appendix B

This document is a proposal for truly winding--up this truncated programme. It is useful because it sets out in detail the items yet to be completed.

APPENDIX B

EARTHQUAKE HAZARD MITIGATION PROGRAM IN SOUTHEAST ASIA

A Proposal for the Final Work Step

INTRODUCTION

In the Final Report of the Planning Study, Earthquake Hazard Mitigation Program in Southeast Asia submitted by the U.S. Geological Survey, Office of Earthquake Studies, in October 1981, a complete plan was outlined for a hazard mitigation program in this region. The region was confined to the ASEAN group of countries. This proposal outlines in somewhat more detail, and with some modification, a fifth and final step toward its execution. The main topics to be covered during this period of work will be a seismic zoning map for the islands of Luzon and Java, which will serve as a pilot program for subsequent studies which the member states of SEASEE will conduct on their own, and the publication of the results of previous years of work. Other items as detailed below in the plan of work will round out the program. As before, this program will be carried out in conjunction with a Southeast Asia Association of Seismology and Earthquake Engineering presently headquartered in Manila and comprising organizations in the Philippines, Indonesia, Malaysia, and Thailand. It is requested that a PASA be applied for here run for 18 months but able to be modified for another six months if necessary.

OBJECTIVES AND WORKPLAN

Under the administration, management, and professional leadership of the U.S. Geological Survey (USGS), the Southeast Asia Association of Seismology and Earthquake Engineering (SEASEE) will accomplish the following in the period referred to above. The various items described below are given in no particular order of importance for they are all equally important to the ultimate outcome of the project.

1. Augmentation of Intensity Scale -- The definitions of the standard Modified Mercalli intensity scale will be augmented to suit local conditions in each of the countries of Southeast Asia. The need for such an augmentation is to include the local building types unique to the region; i.e., those building types which do not exist in either North America or Europe where most of the intensity scales were invented and where most of the measurements of acceleration and velocity have been made. This is particularly important since it will be necessary during this period of time to translate the relationship between the attenuation of intensity with distance to the attenuation of acceleration and velocity with distance, and this can only be done with functions derived from other areas of the world. It is necessary to be certain that the intensity-acceleration-velocity data are compatible with other areas and these relationships are transferable only provided that the intensity data are interpreted through Southeast Asia with due regard to the characteristics of local construction and that this local construction finds its appropriate place in the Modified Mercalli scale. These characteristics will be accounted for in this study. In other words, it will be possible for us to standardize the Modified Mercalli intensity scale in yet another region of the world. This standardization has wider scientific value.

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2. Zoning of Luzon and Java -- A seismic zoning will be completed for the islands of Luzon and Java as a pilot study for the subsequent zoning of all of Southeast Asia. These zoning maps would tell the designers of structures (either engineers or architects) how they should modify their designs to take into account the seismic hazard. These zoning maps, however, should not be confused with a microzoning map which in effect gives you the same information in far greater detail over smaller areas. These zoning maps can be constructed from:

   a. Hazard maps which give the probabilistic maximum acceleration and velocity of ground motion. These maps are developed using the seismic source zones already constructed under the current PASA, from the previous seismicity, and the functions relating the attenuation of acceleration and velocity with distance, and

   b. The judgment of engineers as to how maximum acceleration and velocity affect the construction of a particular structure whether it be a large engineered structure, domestic architecture, or dams.

   This item and the next are the reasons that this proposal stipulates an 18-month project rather than a one-year project because it will take a lot of time and attention to detail. But, these items illustrate the true output of this entire program. In addition to providing the basis for a revision of existing building codes, it will also provide the data required for land-use planning and emergency management.

3. Loss Estimation in Manila and Yogyakarta -- SEASEE will provide a loss estimation for portions of Manila and Yogyakarta which will give the losses as a result of the maximum credible earthquake in each area. This will require an inventory of buildings in each city which although time consuming is fairly easy to do, along with the hazard maps cited above. In the time allotted, it will probably only be possible to zone a small portion of each of these cities but it will serve the useful purpose of (a) instructing SEASEE personnel in the techniques involved and (b) giving government agencies and decision makers a far better idea of the risk their country faces from earthquakes than they have ever had before.

4. Planning of Strong-Motion Network -- A plan will be drawn up for increasing the size and density of the strong-motion accelerograph network in Southeast Asia. As was stated above, the relationship between intensity and acceleration can be got by using (carefully) the relationships derived in other parts of the world, notably in California. This will indeed suffice for a first approximation but it is always well to get actual observations of strong ground motion from the region of interest. It is therefore necessary at some time in the future to increase the size and density of the rather scanty networks of strong motion instruments which already exist there. The objective is a rational plan which will maximize the number of observations measured by this network while minimizing both initial investment and the cost of maintenance. The USGS would advise SEASEE as to how this can best be done. The execution of such a plan is to be left until later and possibly funded by several aid-giving organizations with the host countries providing the usual counterpart funding.

5. Building-Period Study -- The building period study begun last year would be continued during this amendment to the PASA with renewed efforts to get the experimental data as originally sought. This part of the program would be executed at no additional cost to AID.

6. Site Amplification Study -- To completely define the hazard facing tall buildings in those great cities of Southeast Asia that are not proximate to regions of high seismicity; i.e., regions of a high frequency of at least moderate earthquakes occurring near the site in question, but rather in regions where there is a serious threat of great earthquakes at distances of 250 to 400 km, at least one more parameter or set of parameters is necessary. It will be necessary to determine the site magnification as well as the site-response spectrum for one of the cities in question. Perhaps the best place to use is Bangkok for a number of reasons. First of all, the Department of Geology at the Asian Institute of Technology is interested in such a program and, secondly, Bangkok has a geological foundation which is reasonably typical of other great Southeast Asian cities. It is founded on a great graben or down-dropped block, which over geological time has filled with over a kilometer of alluvial deposits. This is very much like Rangoon, Manila, etc.

   The method for conducting such an experiment would be to use portable seismographs of high-magnification which are very much like the ones used in standard seismological observatories, installed in buildings in and around Bangkok, "looking" at earthquakes in the Andaman Sea and northern Sumatra, which are thought to be the source of great earthquakes that could affect Bangkok. One, of course, should not have to wait for a great earthquake to occur to complete this experiment but rather use the scaled results from the plethora of small to moderate earthquakes which occur on this fault system. The instrumentation can be moved from site to site within Bangkok and then compared with that obtained from seismometers already installed on hard rock near dam-sites close by.

   It is thought that, since these instruments will be looking at events at a great distance, building owners will not feel threated and allow this instrumentation to be installed in their buildings.

7. Publications -- When the original PASA was written, an amount of $19,000 was set aside for the publication of results. As will be evident from the progress reports thus far, there is far more information to be published than at first was estimated. This budget item is included to augment the original amount so that within this PASA's time period all results may be published including the macroseismic data, the various maps described in Modification 1 of this proposal, and various papers which will be the direct result of this work. The very act of publishing the results of this work is perhaps the most important item in this proposal, since without a publication no one else can use the information.

8. Project Advisory Panel Meeting -- SEASEE will hold a project advisory panel meeting in conjunction with its annual executive committee meeting in either November or December of the specified year. The advisory panel meeting will consist of a number of distinguished scientists who will meet with SEASEE project leaders to review their progress and advise them on how best to proceed.

SEASEE is canvassing a number of other international organizations including UNDRO, UNESCO, and UNDP for partial sponsorship of a seminar to be held in conjunction with this meeting on the seismic aspects of land use planning. This is a particularly timely subject for most of the ASEAN countries since they are all planning a number of new communities termed "new economic zones." To place them in areas of high seismic hazard would, of course, lead to a possible future disaster, both to their economy and lives. In the interest of savings, it would be highly desirable that the members of the project advisory panel stay on to deliver papers at this symposium and a budget item is included therefor.