UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A WORKSHOP ON "GEOLOGIC HAZARDS IN PUERTO RICO"

APRIL 4-6, 1984
SAN JUAN, PUERTO RICO

SPONSORED BY

U.S. GEOLOGICAL SURVEY
FEDERAL EMERGENCY MANAGEMENT AGENCY
NATIONAL BUREAU OF STANDARDS

Editors
Paula L. Gori and Walter W. Hays
U.S. Geological Survey
Reston, Virginia 22092

Open File Report 84-761

Compiled by
Carla J. Kitzmiller and Lynne N. Downer

Reston, Virginia
1984

TABLE OF CONTENTS

PLANNING AGAINST GEOLOGIC HAZARDS IN PUERTO RICO

by

Hilda Diaz-Soltero
Puerto Rico Department of Natural Resources
San Juan, Puerto Rico

INTRODUCTION

It is my privilege to welcome you, in the name of the Governor of Puerto Rico, the Honorable Carlos Romero Barcelo, to this conference/workshop on geologic hazards in Puerto Rico. We are indeed grateful to the United States Geological Survey and to the Federal Emergency Management Agency for sponsoring this activity, which is designed to promote an awareness of certain hazards that have always been with us, but that we have been in the habit of disregarding. Through this activity, we hope to reach government officials, leaders of business and industry, and the key individuals representing professional, civic, service, and voluntary groups. We also appreciate the assistance of the Agency for International Development, which made it possible for representatives from other Caribbean nations to participate in this conference.

During his years of service as Mayor of San Juan and subsequently as the chief elected official of Puerto Rico, Governor Carlos Romero Barcelo has come to appreciate the value of being prepared to respond to a variety of natural catastrophes. During the past few years, Puerto Rico has been faced with the battering effects of waves generated by North Atlantic storms and with the heavy rains and floods created by passing tropical disturbances, including some hurricanes that did not strike the island directly. Since 1967, the government of Puerto Rico has had to expend $53 million from its emergency relief funds, of which $7.9 million were for severe drought conditions, $41 million were for floods, and the remainder were for special spraying programs to combat an epidemic of dengue fever, oil spill cleanups, and public safety measures during major strikes and international athletic events.

Since direct Federal disaster assistance was first received in 1971, Puerto Rico has received \$108 million for flood disasters and \$220 thousand for oil spill cleanup from agencies of the United States Government.

CAUSE FOR CONCERN

When we review the historical data and realize that during the past 40 years Puerto Rico has not suffered a land-falling hurricane, nor a severe earthquake, and we realize further that the major urban growth of the island occurred during that period, we can begin to understand the rising concern about the fact that our recent development, with its high-rise structures and extensive use of glass for curtain walls, has yet to be tested under extreme conditions of wind and earth motion.

We have read about the relatively small earthquake that occurred in Coalinga, California, in May 1983. We have reproduced a preliminary assessment of the situation at Coalinga for distribution at this conference, to help to make you aware of the devastating effect such an event can cause. In a town of about 7,500 people, strong ground motion caused \$31 million in damages to private property and another \$6 million in damage to public property. Only some \$300,000 of that damage was directly covered by earthquake insurance. The entire business district of the town was rendered unfit for occupancy, and destroyed. That curtailed the municipal revenues, which were strongly dependent upon a sales tax. None of the schools, hospitals, or other public facilities were insured. Both of the town's banks, which were branches of statewide banking enterprises, were able to resume business again within 2 weeks. The banks granted 60- to 90-day emergency extensions on loan payments and credit card installments, and began to process emergency loans for repairs to houses or for replenishing business inventories. The banks made effective use of the local radio stations to advise people about their ability to do business and the availability of emergency loans. Luckily, the main highway connections serving Coalinga were not damaged by the quake, and relief supplies were brought in quickly by motor vehicle. Much needed repair and service vehicles were also able to arrive without delay.

In view of the severe effects that strong shocks have generated in Managua, Nicaragua, in Guatemala, in the Dominican Republic, in the Virgin Islands, and other nearby areas, we have to stop and wonder what could happen in a similar situation in Puerto Rico, under present circumstances. We must be grateful that such events have not happened here, but we must not close our eyes and minds to the possibility that they may happen in Puerto Rico. We are mindful that the San Juan Geophysical Observatory, now located in Cayey, which is now operated by the Center for Energy and Environment Research (CEER) of the University of Puerto Rico, is collecting information on microseismic events. The data published periodically by CEER reveal that Puerto Rico is in the midst of continuing seismic activity, with small, unnoticed shocks occurring on the average of two or three times a day. They are so deep and so attenuated by the thickness and structure of the Earth's crust that most people never feel them. We cannot let a sense of complacency dull our awareness of the seismic situation or our ability to prepare ourselves to reduce the effects of such events upon life and property. We are also grateful for the continuing research into seismic activity in the Caribbean by the Lamont Doherty Geological Observatory of Columbia University, which has provided valuable guidance to both CEER and staff of the Department.

HAZARD MITIGATION PLANNING

Governor Romero's Executive Order Number 366 of August 1979 was the first to make note of a requirement for hazard mitigation planning in the case of flood emergencies. Within 2 weeks of its publication, Hurricane David and Tropical Storm Frederick poured intense rains over most areas of Puerto Rico and caused severe flooding. A Federal disaster emergency was declared by the President, at first applicable to only six municipalities, but eventually covering 72 of the island's 78 towns. The provision for mitigation planning, and the assignment of responsibility for that activity to the Department of Natural Resoruces was not clearly understood until the FEMA disaster team set up shop in San Juan. They knew that hazard mitigation was a requirement of the disaster assistance agreement, but the local officials were not aware of the new executive order. It took only a few days for the word to reach the responsible parties and for action to be initiated.

The Coastal Management Program of the Department of Natural Resources had been approved in September of 1978. It included a continuing task related to coastal flooding, and a team had been organized to consider that problem, under the guidance of an excellent consultant. My predecessor created an interagency task force, including representatives of 12 Federal and local agencies. The task force's working committee visited the locations of major flood damages, made a preliminary assessment of the extent and severity of the problems, and developed a priority list for future action. An Overview report on coastal flooding and the Puerto Rico Flood Hazard Mitigation Plan were published during 1980. The mitigation plan for the coastal portion of the Rio Grande de Loiza was assigned the top priority.

The Flood Hazard Mitigation Plan for Coastal Areas of the Rio Grande de Loiza was published in September 1980. An implementation program was initiated quickly, but it required several years of debate before the Legislative Assembly approved a joint resolution last September authorizing the assignment of over $36 million over a period of 5 years to resolve the major problems in that river basin. Some 1,400 families will be relocated out of the floodway. With assistance from the National Weather Service, a flash flood warning system will be installed to warn the operators of the Carraizo Dam to open or close their flood gates to provide greater flood storage capacity. The main channel and the overspill floodway will be cleaned and widened to provide greater flood capacity. Old dikes protecting developed areas will be restored and new ones will be built to protect other areas. We believe that this is the largest project of such a nature in the United States. Now we are making plans to request funding for the second priority mitigation program in the Rio de la Plata valley west of San Juan.

When the Department's experience at hazard mitigation is combined with the fact that it maintains a scientific inventory of natural, cultural, and environmental resources, covering the entire island, in its computer center, it is understandable why the Department has been assigned the task of dealing with the vulnerability analyses for earthquakes and hurricanes, under FEMA's new programs. Using the data already in the inventory, and filling in certain gaps, a geomorphologist is being contracted to identify the areas that appear to be most susceptible to geologic hazards such as landslides. In cooperation with the National Weather Service, and using a special grant from FEMA, we have contracted with the Department of Marine Sciences of the University of Puerto Rico at Mayaguez to apply the Service's SLOSH model for estimating the storm surges generated by hurricanes along the coasts of Puerto Rico and the Virgin Islands.

All of the bits and pieces of information, gathered from various other sources and evaluated by the specialists in the Department, will make it possible for us to provide better advice to other government agencies, such as the Planning Board, the Highway Authority, and the State Civil Defense Agency, for example, concerning areas to be avoided when considering public investment, where it is appropriate to sponsor new development, and where natural disasters may be expected to cause the most damage when they occur. I used the word <u>when</u> rather than <u>if</u>, because Puerto Rico has experienced such strong earth motion in the past, and the probability is that they will occur again. Unfortunately, the art of earthquake prediction has not yet been elevated to a precise science. We can only hope that we will have time to consider our situation and take appropriate countermeasures to reduce the level of potential damage.

QUESTSIONS THAT SHOULD BE CONSIDERED

Here are some examples of the matters that might be considered. It is by no means a comprehensive list, but should give you an idea of specific areas of concern that may apply to you as individuals, as heads of families, as plant managers, administrators, or persons with a responsiblity for the safety of children, patients, or employees.

1) Is the average household prepared to meet a major emergency, with adequate supplies of water, food and other equipment? Does everyone know where to take shelter? Is there a plan to meet at the home of a friend or relative if family members become separated?

2) Do our school administrators and teachers know what to do in case of emergency? Are there regular drills to prepare children to respond to disaster situations without panic?

3) Do the managers of industrial plants and businesses know how to secure their equipment and protect their inventories against ground motion so as to minimize the disruption of production and business activity? Are their employees assigned responsibilities for emergency situations, with periodic drills to prepare them to respond in a reliable manner?

4) Do our hospitals have appropriate training to respond to major emergencies? Do they have emergency power systems and special supplies? Are there plans to distribute responsbilities among public and private facilities in case one or more medical facilities is damaged?

5) Are our major communications systems equipped with appropriate emergency power? Are they in safe and adequate structures? Are presses, transmitter equipment, and other machinery appropriately secured against being thrown out of alignment or off their racks?

6) Do government agencies have adequate knowledge of potential geologic hazards in all areas, so as to be able to discourage development in some areas or to assure that adequate extra reinforcement is provided if it is necessary to permit construction in them?

7) Have our bridges and overpasses been inspected for seismic resistance, so that measures may be taken to reinforce them against potential failure?

8) In view of the tremendous capital investment in industrial structures, in houses, condominiums, office buildings, and the quality of life, a major question is whether the mortgage holders have adequate insurance to protect themselves against damages due to a devastating earthquake? Are government facilities insured?

9) Are businesses protected against loss of income due to the disruption caused by a natural catastrophe? Is the government protected against loss of revenues?

10) Are our utility services prepared to cope with natural disasters so as to assure continuity of essential services, such as water and electricity?

11) Do our hotels have a disaster emegency plan so that they can provide shelter and food to local residents?

12) Is the insurance industry prepared to provide appropriate protection to property owners at reasonable, realistic rates? Are there adequate numbers of adjusters with appropriate training to deal with the structural damage caused by natural disasters other than floods?

These are among the questions that I believe should be raised in your minds as you begin to comprehend the potential impacts of a natural catastrophe upon our current structure of government, business, and society in general.

Since I majored in geology while in college, I am especially pleased to note that the value of that field of specialized knowledge is becoming more and more understood and appreciated, particularly as a vital element of the process of preparedness planning.

I regret that the pressures of my office will not permit me to remain with you throughout the conference and its workshops. However, the Department is represented on several panels, so I will be well informed about the results of your deliberations, and believe me, I will do my utmost to assure that your recommendations receive adequate consideration in our mitigation planning.

My best wishes for a successful conference.

INTRODUCTORY REMARKS: THE ROLE OF THE WORKSHOP FOR IMPROVING THE STATE-OF-PREPAREDNESS IN ADDRESSING GEOLOGIC HAZARDS

by

Samuel W. Speck
Associate Director
State and Local Programs and Support
Federal Emergency Management Agency
Washington, D.C. 20472

INTRODUCTION

It is a pleasure to be here with you at this workshop. Having joined the Federal Emergency Management Agency (FEMA) last year, this is the first of the joint U.S. Geological Survey (USGS)/FEMA workshops which I have been able to attend. As one whose Directorate has responsibility for chairing the Federal Earthquake Policy Coordinating Committee as well as the Earthquake Committee of the Emergency Mobilization Preparedness Board, I appreciate this opportunity to address you and look forward to receiving your postworkshop position reports.

Integrated Emergency Management

Emergency management, which is what this workshop is all about, is a team effort. This is clearly seen in a disaster response situation where you have city managers; fire and police personnel; communications experts; medical units; utility company personnel; building experts; State and perhaps Federal technical, financial, and emergency management people; and private volunteer groups such as the Red Cross. Each component has a job to do that depends on the integration and coordination with others of the total response effort.

An integrated emergency management approach can be applied to all levels of government and the private sector. It also can be applied to the full spectrum of potential hazards and emergency activities: mitigation, preparedness, response, and recovery. Consequently, we must bring together all these team elements up front in the planning stage in order to prepare adequately for any sort of a crisis.

In December 1982, FEMA adopted an Integrated Emergency Management System (IEMS) as a means of more effectively administering its programs and intergovernmental coordination responsibilities. The system structures all FEMA activities into a unified national process that applies common management functions to the degree of capability needed to manage any emergency conditions that threaten public health and safety, irrespective of the nature or cause. The use of IEMS in the planning process allows FEMA to focus on the integration of Federal preparedness programs, on improving coordination among the Federal agencies involved in the response to various emergencies, and on the linkage between Federal, State and local preparedness in such areas as resources management, continuity of government, and resource mobilization for major domestic and national security emergencies. The system, therefore, builds on the foundation of existing emergency plans, systems, and capabilities toward applications that are achievable, practical, effective, efficient, and predictable.

Hazard Identification and Assessment

In preparing for any and all emergencies, the Federal Government for the most part identifies hazards and determines their occurrence probabilities. This work is done by conducting research to better understand the physical processes, developing methodologies and techniques used in risk assessment and mitigation, and promoting public awareness and education. In carrying out that research and risk assessment function, we at FEMA rely on you in your State and local planning and response role as well as the assistance of academic institutions and various professionals, e.g., State geologists and hydrologists.

Since some hazards like ground failure are associated with both flooding and earthquakes, measures to deal with such a problem should consider all factors and causes. At FEMA we are applying the IEMS concept of integration and coordination beyond the traditional way to plan for a single-hazard program.

Our planning is being designed to encompass all potential hazards and take advantage of common elements in the response and mitigation of similar problems.

An Integrated Approach to Earthquakes

In establishing the national Earthquake Hazards Reduction Program (NEHRP), Congress was fully cognizant of the need for scientists, academicians, and emergency management planners and managers from both the public and private sector to work together in an integrated and coordinated multihazard program.

Enacted in 1977, NEHRP provides a comprehensive, integrated national program to reduce losses of life and property resulting from earthquakes. Although nearly all Federal agencies contribute to the NEHRP, four principal agencies are charged to provide a central focus for leading, coordinating, and conducting earthquake research, hazard mitigation, and disaster preparedness. These principals are FEMA, USGS, National Science Foundation, and National Bureau of Standards.

FEMA's assistance to State and local earthquake preparedness programs focuses on the preparation of response plans that address the extraordinary problems caused by major earthquakes in high-risk, high-population areas. Earthquake response planning follows a logical sequence of tasks: assessments are done on past and potential seismic activity in the area, vulnerability analyses (loss studies) are made to estimate primary and secondary earthquake effects, and calculations and projections are carried out regarding the numbers of possible casualties and injured requiring hospitalization as well as potential damage to critical and (or) special facilities and lifelines needed for immediate response.

Using data from the analyses, FEMA assists State and local governments in determining the resources required for lifesaving and other emergency operations and in developing response plans. The plans include implementation measures such as guidelines, procedures, and specific assignments. The final phase of the planning efforts consists of scheduled training exercises.

Although this program specifically addresses earthquake preparedness, success will ultimately depend on the integration of local planning efforts.

Workshops as a Component of Preparedness

These particular joint USGS/FEMA workshops provide an opportunity to bring together all interests, public and private, to form a better perspective on the overall problem of disaster preparedness. They have become a significant part of our NEHRP awareness, education, and planning programs because of the diverse fields of interest represented. To date, joint workshops have been held in Knoxville, Tennessee; St. Louis, Missouri; Charleston, South Carolina; Boston, Massachusetts; and Little Rock, Arkansas. All have proved informative and productive.

Among the many benefits derived from these workshops has been the information presented at the meeting, later contained in the publication of its proceedings, and continued through dialogue among people from various fields of interest which takes place on regional seismic safety panels and consortiums. The awareness of the topics resulting from discussions at these workshops will contribute significantly to the preparedness planning process at all levels of government.

CONCLUSION

Walt Hays, his staff, and all of you who have participated in the planning of this workshop have done an outstanding job of providing many stimulating topics for discussion--not to mention the congenial environment--while we are here. I look forward to meeting you all during the workshop and working with you in the months ahead to reduce the potential for losses from geologic and other natural (and manmade) hazards in this region.

BACKGROUND AND SUMMARY OF THE WORKSHOP ON "GEOLOGIC HAZARDS IN PUERTO RICO"

by

Walter W. Hays and Paula L. Gori
U.S. Geological Survey
Reston, Virginia

BACKGROUND

The workshop, "Geologic Hazards in Puerto Rico," was held in San Juan, Puerto Rico, on April 4-6, 1984. The U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the National Bureau of Standards (NBS), and the Department of Natural Resources of Puerto Rico sponsored the workshop, which was the twenty-fourth in a series of workshops and conferences devised in 1977 under the auspices of the Earthquake Hazards Reduction Act. The workshop was also supported by the Assistant Secretary for Territorial and International Affairs, Department of Interior, as a part of the President's Caribbean Basin Inititive. The purpose of the workshop was to strengthen the capability of the public officials and the scientific-technical community of Puerto Rico to undertake the multidisciplinary tasks of research, mitigation, response, and recovery in order to reduce potential losses from geologic hazards. The strategy employed in the workshop was to identify the base of existing knowledge on geologic hazards in Puerto Rico and to foster a process that would improve current research on these hazards and the utilization of the research results in emergency management and other activities. Also an effort was made to devise an integrated short- and long-term process which would link knowledge producers and users (sometimes referred to as a network) and to strenghten the use of the existing network.

The workshop brought together 105 participants having varied backgrounds in earth science, social science, architecture, engineering, and emergency management. The participants (see Appendix A for a list) represented industry, volunteer agencies, and academic institutions of the Commonwealth of Puerto Rico, as well as representives of the government of Puerto Rico, Federal Government, other States, and the private sector. Collectively the Commonwealth participants represented a major part of the resources of Puerto Rico needed to prepare for and to respond to the earthquake hazards of ground shaking, earthquake-induced ground failures, surface faulting, tectonic deformation, and tsunamis.

HISTORICAL SEISMICITY IN THE PUERTO RICO AREA

Puerto Rico, a part of the Greater and Lesser Antilles, is located in one of the most earthquake-prone regions of the world--the zone of seismicity corresponding the Carribean plate (Figure 1). The Caribbean plate, one of the

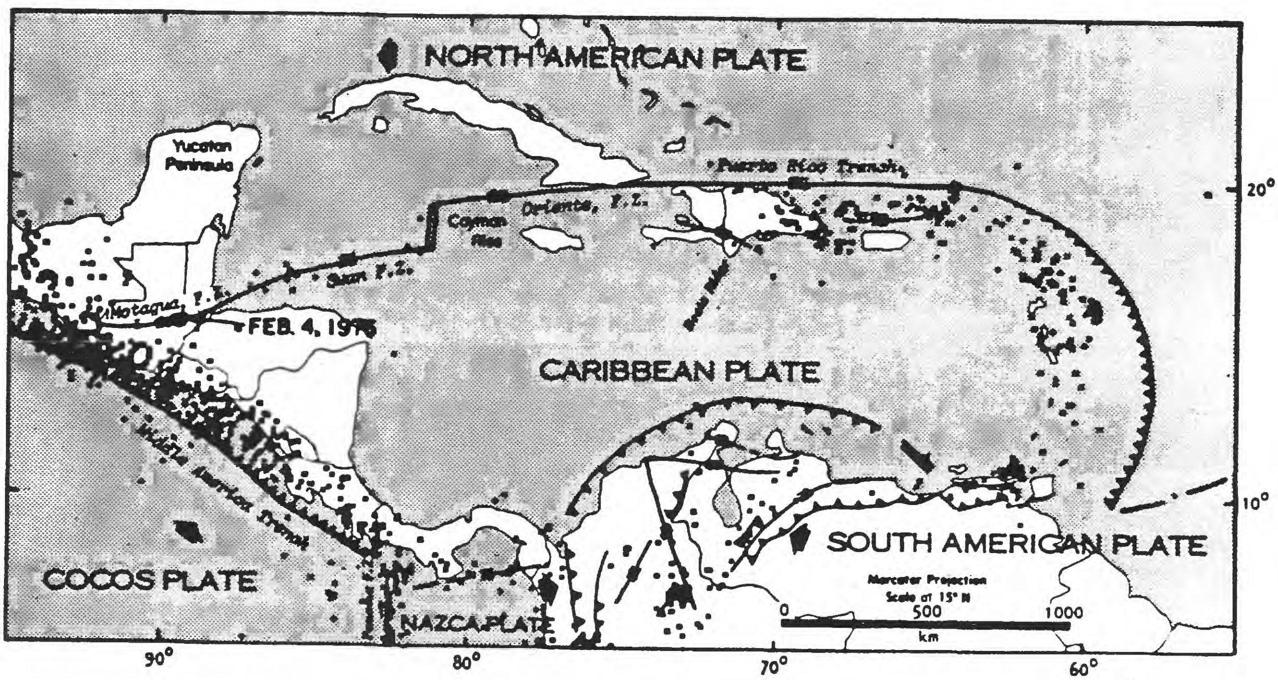


Figure 1.--Diagram showing the relation of the Caribbean plate to the North and South American plates. The North American plate is moving westward at a rate of approximately 0.8 inches per year relative to the nearly stationary Caribbean plate.

major 50 to 60 mile thick rigid plates or segments of the Earth's crust and upper mantle that move slowly and continuously over the interior of the Earth, is marked by a high rate of seismicity (Figure 2). Damage from historical earthquakes in the Puerto Rico area has occurred at least 40 times in the past 450 years. Because many of the causative faults are offshore or deeply buried, the location of some of the older earthquakes is not precise. The most important historical earthquakes are listed below in terms of Modified Mercalli intensity (MMI), a subjective index of the physical effects of an earthquake on structures.

DATE (GMT)	LOCATION	MAXIMUM MM INTENSITY
Apr 20, 1824	St. Thomas, Virgin Island	VII
Apr 16, 1844	Probably north of Puerto Rico	VII
Nov 28, 1846	Probably Mona Passage	VII
Nov 18, 1867	Virgin Islands	VIII also tsunami
Mar 17, 1868	Location uncertain	VIII
Dec 08, 1875	Near Arecebo, Puerto Rico	VII
Sep 27, 1906	North of Puerto Rico	VI-VII
Apr 24, 1916	Possibley Mona Passage	VII
Oct 11, 1918	Mona Passage	VIII-IX also tsunami

Source: Algermissen (1983)

A destructive tsunami was associated with the 1867 and the 1918 earthquakes. The 1867 earthquake was located south of St. Thomas in the Virgin Islands and had an estimated magnitude of 7.5 and an epicentral intensity of IX. It caused intensities of VII (architectural damage) and VIII (structural damage) over a wide area in Puerto Rico and the Virgin Islands. The earthquake of 1918 was located about 9 miles of the northwest coast of Puerto Rico and had an estimated magnitude of 7.5 and an epicentral intensity of X. It caused economic loss estimated at $4 million (1918 dollars) and 116 deaths. Future damaging earthquakes of magntidue 7.5 or greater and tsunamis are expected to occur in the Puerto Rico area; however, the potential losses would be significantly greater now as a consequence of the increased building wealth.

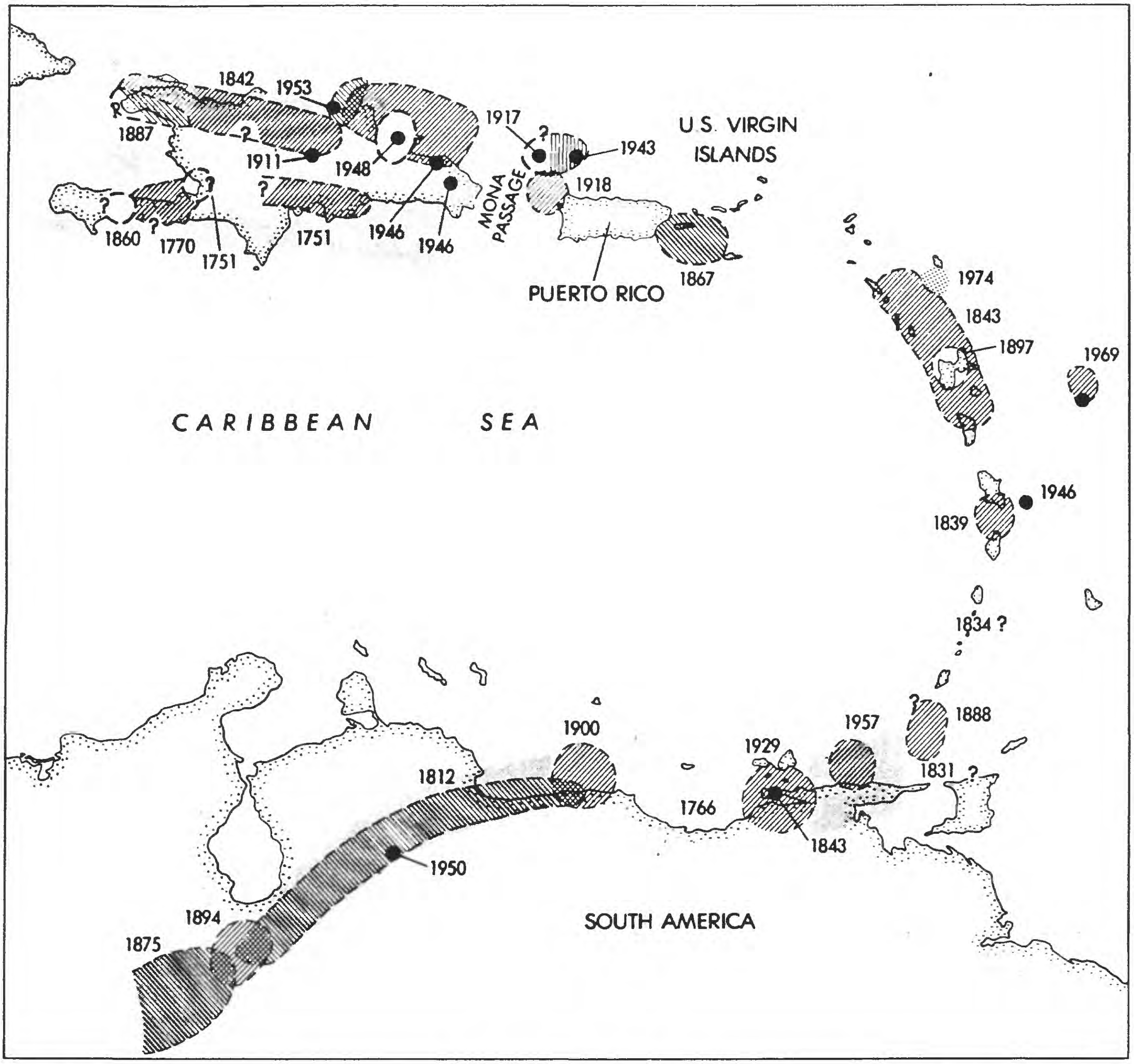


Figure 2.--Map showing location of Puerto Rico and rupture zones of Caribbean earthquakes since 1800. Areas having the highest potential for earthquakes of magnitude equal to or greater than 7 are shaded. The possibility of great earthquakes (magnitudes of 8 or greater) cannot be ruled out.

OBJECTIVES OF THE WORKSHOP

This workshop was designed to address the potential effects of earthquakes and other geologic hazards in Puerto Rico. The workshop was the sixth in a subseries specifically designed to define the threat from earthquakes in the Eastern United States and to improve earthquake preparedness. The five prior workshops on earthquake preparedness were sponsored by USGS and FEMA and brought together producers and users of hazards information with the goal of fostering local-State-Federal partnerships and effective use of existing information networks. Each of the prior workshops are summarized below to give insight into the overall process:

The first workshop, "Preparing for and Responding to a Damaging Earthquake in the Eastern United States," was held in Knoxville, Tennessee, in September 1981. The Knoxville workshop (described in USGS Open-File Report 82-220) demonstrated that policymakers and members of the scientific-engineering community can assimilate a great deal of technical information about earthquake hazards and work together to devise practical work plans. The workshop resulted in the creation of a draft 5-year work plan to improve the state-of-earthquake-preparedness in the Eastern United States and the birth of the South Carolina Seismic Safety Consortium.

The second workshop, "Continuing Actions to Reduce Losses from Earthquakes in the Mississippi Valley Area," was held in St. Louis, Missouri, in May 1982. It resulted in the identification of specific actions with a high potential for reducing losses that could be implemented immediately and the formation of the Kentucky Governor's Task Force on Earthquake Hazards and Safety. The workshop provided a basis that eventually led in 1985 to FEMA's Central United States Earthquake Preparedness Project. The results of the workshop (described in USGS Open-File Report 83-157) reaffirmed that practical work plans can be created efficiently by a diverse group of scientists and decisionmakers.

The third workshop, "The 1886 Charleston, South Carolina, Earthquake and its Implications for Today," was held in the Charleston area of South Carolina, in May 1983. The Charleston workshop had multiple objectives including: interpretation of scientific information, its use in the siting of critical facilities, and preparedness measures. The results of the workshop (described in USGS Open-File Report 83-843) emphasized the need for a comprehensive integrated research program on eastern seismicity.

The fourth workshop, "Continuing Actions to Reduce Potential Losses from Future Earthquakes in the Northeastern United States," was held at Massachusetts Institute of Technology, Cambridge, Massachusetts, on June 13-15, 1983. The workshop (described in USGS Open-File Report 83-844) identified a need for at least one regional seismic safety organization in the Northeastern United States to deal with earthquakes in the context of natural hazards.

The fifth workshop, held in North Little Rock, Arkansas, on September 20-22, 1983, was designed to accelerate the ongoing work of the Arkansas Office of Emergency Services. It provided a forum for discussion of their activities to prepare for and respond to a major earthquake such as a recurrence of the 1811-1812 New Madrid earthquakes. The results of this workshop (described in USGS Open-File Report 83-846) pointed out that no State or region of the United States is adequately prepared at this time to cope with the effects of a major earthquake.

DECISIONMAKING AND GEOLOGIC HAZARDS

This workshop in Puerto Rico emphasized the well known fact that understanding geologic hazards is essential when devising methodologies for reducing future economic losses and social impacts. The potential losses in Puerto Rico are increasing annually as a consequence of factors such as: 1) increased population density living in areas of high seismic risk and in landslide-prone areas, 2) increased building wealth as a consequence of construction of homes, schools, hospitals, high rise buidings, factories, utility systems, oil refineries, and other facilities, and 3) increased vulnerability of old existing buildings and lifeline systems that were not designed in accordance with present standards for earthquake resistance.

The choices facing decisionmakers are difficult for three reasons: 1) future geologic hazards occur fairly infrequently, at uncertain times and locations, and have great variation in severity and frequency of occurrence, 2) reducing losses requires integration of technical information in the planning process, and 3) loss reduction measures costs money and require local-Federal partnerships. The options for reducing losses from geologic hazards include:

1) Personal preparedness--prepare on an individual basis for the consequences that are expected to occur, taking advantage of efficiencies provided by preparation for other natural hazards such as hurricanes.

2) Avoidance--when the characteristics of the hazard are known, select the least hazardous areas for construction sites.

3) Land-use regulation--reduce the density of certain types of buildings and facilities or prohibit their construction within parts of the area characterized by a relatively high frequency of occurrence or severity of effects.

4) Engineering design and buiding codes--require buildings to have a lateral-force-resisting system that is appropriate in terms of the frequency of occurrence and the severity of the hazard expected in a given exposure time (e.g., an exposure time of 50 years corresponds with the useful life of ordinary buidings).

5) Distribution of losses--use insurance and other financial methods to distribute the potential losses expected in a given exposure time.

6) Response and recovery--plan response and recovery measures that will address all of the needs identified in realistic disaster scenarios.

Decisonmakers and scientists/engineers have different prespectives which affect decisionmaking. These differences have been summarized by Szanton (1981) and are as follows:

1) The ultimate objective of the decisionmaker is the approval of the electorate; it is the respect of peers for the scientist/engineer.

2) The time horizon for the decisionmaker is short; it is long for the scientist/engineer is long.

3) The focus on the decisionmaker is on the external logic of the problem; it is on the internal logic for the scientist/engineer.

4) The mode of throught for the decisionmaker is deductive and particular; it is inductive and generic for the scientist/engineer.

5) The most valued outcome for the decisionmaker is a reliable solution; it is original insight for the scientist/engineer.

6) The mode of expression is simple and absolute for the decisionmaker; it is abstruse and qualified for the scientist/engineer.

7) The preferred form of conclusion for the decisionmaker is one "best solution" with uncertainties submerged; it is multiple possibilities with uncertainties emphasized for the scientist/engineer.

These seven differences are the main reasons that the effort to increase the capability of a region to reduce losses from geologic hazards must have well coordinated short- and long-term objectives and involve both the scientific/technical community and policymakers.

WORKSHOP PROCEDURES

The procedures used in the workshop were designed to enhance the interaction between all participants and to facilitate achievement of the objectives. The following procedures were used:

PROCEDURE 1: Research reports and preliminary technical papers prepared in advance by the participants were distributed at the workshop and used as basic references.

The technical papers of the participants were finalized after the workshop and are contained in this publication.

PROCEDURE 2: Scientists, social scientists, engineers, and emergency management specialists gave oral presentations in six plenary sessions.

The objectives were to: 1) integrate scientific research and hazard awareness and preparedness knowledge 2) define the problem indicated by the session theme, 3) clarify what is known about geologic hazards in Puerto Rico and, 4) identify knowledge that is still needed. These presentations served as a summary of the state-of-knowledge and gave a multidisciplinary perspective.

PROCEDURE 3: The participants were encouraged to respond to the presentations of the speakers and panelists.

PROCEDURE 4: Discussion groups were convened following the plenary sessions to discuss the subject in greater detail and to generate recommendations for future research and loss-reduction measures.

PROCEDURE 5: Ad hoc discussions on topics not addressed during the plenary and discussion group sessions were encouraged to add a spontaneous dimension.

PLENARY SESSIONS

The overall theme of the workshop was developed in six plenary sessions. Three ways of reducing potential losses from earthquakes and other geologic hazards in Puerto Rico were stressed. They were: 1) increasing personal preparedness through increased home, school, and workplace safety, 2) increasing community preparedness through such actions as requiring appropriate building codes and their enforcement, and 3) identifying and obtaining Federal government resources for mitigating and responding to geologic hazards. Special emphasis was given to the discussion of building codes such as the 1978 Applied Technology Council's model code which provided a basis for comparison of the ground shaking hazard in Puerto Rico with other parts of the United States.

The themes, objectives, and speakers for each session are described below:

SESSION I: BACKGROUND, OBJECTIVES, AND GOALS OF THE WORKSHOP.

OBJECTIVE: Description of the background for the workshop and its objectives and goals.

SPEAKERS: Hilda Diaz Solerto
Sam Speck

SESSION II: THE NATURE AND EXTENT OF EARTHQUAKE AND GROUND FAILURE HAZARDS IN PUERTO RICO

OBJECTIVE: Presentations giving the geologic setting of Puerto Rico in the context of the Caribbean Basin. Topics included: a) historical seismicity in the Puerto Rico area, their frequency of earthquake occurrence and potential impacts, ground motions expected for various planning scenarios, and potential tsunami impacts, b) mass movements as geologic hazards, debris flows and other ground failures and their correlation with rain fall distribution, and sinkhole development in limestone areas.

SPEAKERS: William McCann
Walter Hays
Modesto Iriarti
Jose Molinelli
Bernardo Deschapelles-Duque
Alejando Soto
Fernando Gomez-Gomez

SESSION III: RESPONDING TO GEOLOGIC HAZARDS

OBJECTIVE: A panel discussion of the following subjects: a) current planning activites of local government, b) resources available from local government, c) FEMA, Department of Defense, and other Federal resources that could be committed to assist Puerto Rico, d) ways the National American Red Cross and other volunteer agencies would support individual and family assistance, e) the role of utilities in preparing for an recovering from a major earthquake, and f) the role of industry in preparing for and recoverning from a major earthquake.

SPEAKERS: Antonio Munero
Jane Bullock
Phillip McIntire
Borris Oxman
Miguel Puig
Graziella Seijo

SESSION IV: FORMULATING PLANS TO DEAL WITH GEOLOGIC HAZARDS IN PUERTO RICO

OBJECTIVE: Suggestions for improving public education, increasing hazard awareness, and implementing geologic information in land-use and emergency response planning.

SPEAKERS: Risa Palm
Joyce Bagwell
Boris Oxman
Earl Brabb
Alejandro Soto

SESSION V: FORMULATING PLANS TO REDUCE LOSSES FROM GEOLOGIC HAZARDS IN PUERTO RICO

OJBECTIVE: Suggestions for improving earthquake-resistant design of structures and lifelines and for developing a community program to prepare for and respond to a major earthquake.

SPEAKER: Leandro Rodriquez
Charles Culver
Samuel Diaz
Claire Rubin
Julia Malave

SESSION VI: PUERTO RICAN AND FEDERAL GOVERNMENT PLANS FOR DEALING WITH GEOLOGIC HAZARDS

OBJECTIVE: Identification of plans for reducing losses from geologic hazards in Puerto Rico.

SPEAKERS: Juan Lopez
Boris Oxman
Walter Hays
Jane Bullock
Charles Culver

DISCUSSION GROUPS

The following subjects were discussed in a small group setting. The goal was to stimulate interactive discussion of the problem and some of its solution. The topics included:

1) Plans for mapping of geologic hazards to meet the needs of land use and emergency response planning.

2) Plans to increase community preparedness.

3) Plans for implementation of loss reduction measures.

4) Plans to enhance information transfer and personal preparedness.

5) Plans for increasing awareness of geologic hazards.

In the discussion groups the participants identified individuals or groups that could have the responsibility for implementing the recommendations.

CONCLUSIONS AND RECOMMENDATIONS

Throughout the workshop the concept of the "Rule of the Six P's" was adopted as the working principle and formed the basis for specific recommendations which are listed below. The "Rule of the Six P's" is Proper Pre-earthquake Planning Prevents Poor Post-earthquake Performance. The following actions were proposed:

1) Individuals in Puerto Rico should adopt personal measures to increase earthquake preparedness, such as making their homes, schools, and workplaces safer from earthquakes through low cost actions such as strapping the water heater to the wall, bolting the house to the foundation, and formulating and exercising family response plans.

2) Formation of a "Puerto Rican Seismic Safety Council." Miguel Puig of the Purto Rico Telephone Company, volunteered to direct the initial activities of this ac hoc group.

3) A resolution calling for the adoption of the proposed seismic provisions of the Puerto Rican building code. This resolution will be forwarded to the Puerto Rican Building Permit Administration urging immediate action.

4) Construction of probabilistic ground-shaking hazard maps like those in the Applied Technology Council's model buiding code. These maps would provide a direct correlation with other parts of the United States.

5) Mapping of areas susceptible to landslides, subsidence, and liquefaction.

6) Assessment of the current economic base in Puerto Rico to determine the sensitivity, if any, of increased awareness of geologic hazards or the occurrence of a major event.

7) Creation of three to four geologic hazards libraries in Puerto Rico.

8) Another workshop on geologic hazards in April 1985 to continue the process initiated in this workshop.

ACKNOWLEDGMENTS

A special note of appreciation is extended to each of the following individuals for their contributions:

1) The Steering Committee of Philip McIntire, Boris Oxman, Ferdinand Quinones, Leandro Rodriquez, Luther Edwards, and Richard Wright assisted in the planning and organization of the workshop.

2) The participants who joined in the plenary sessions and the discussion groups were the key to the success of the workshop. Their vigorous and healthy exchange of ideas made the workshop practical and interesting.

3) Boris Oxman and Anselmo De Portu provided valuable technical assistance and coordinated the logistical support.

4) Carla Kitzmiller, Lynn Downer, Joyce Costello, Cheryl Miles, and Susan Kibler provided strong and capable administrative support.

REFERENCES

Algermissen, S. T., (1983), Introduction to the seismicity of the United States: Earthquake Engineering Research Institute Monograph, Berkeley, California, 149 p.

Applied Technology Council, (1978), Tentative provisions for development of seismic regulations for buildings: National Science Foundation, National Bureau of Standards, ATC 3-06, NBS SP 510, NSF 78-8, 514 p.

Szanton, Peter, (1981), Not well advised: Russell Sage Foundation and Ford Foundation, 81 p.

DRAFT PLANS FOR MAPPING OF GEOLOGIC HAZARDS TO MEET THE NEEDS OF LAND USE AND EMERGENCY RESPONSE PLANNING

by

Stanley McIntosh
Federal Emergency Management Agency
New York City, New York
and
Anselmo De Portu
Puerto Rico Department of Natural Resources
San Juan, Puerto Rico

FOREWARD

These draft plans and recommendations were developed by the participants of the workshop on "Geologic Hazards in Puerto Rico." They are intended to serve as a guide for public officials, scientists, engineers, social scientists, and emergency managers. Representatives of these disciplines can use the plans and recommendations in several ways: 1) to evaluate their current research, mitigation, response and recovery programs, 2) to devise new programs and plans and, 3) to create a seismic safety policy in Puerto Rico.

Dr. William MacCann of Lamont Doherty Geological Observatory of Columbia University, Dr. Earl Brabb of USGS, and Dr. Alejandro Soto of the University of Puerto Rico (Mayaguez Campus) provided special assistance in the formulation of the draft plan and recommendations. The membership of the discussion group included:

Luis Biaggi	Puerto Rico Planning Board
Heriberto Capella Acevedo	Department of Education of Puerto Rico
Orlando Cordero	University of Puerto Rico
Benicio Correa Matos	Civil Defense of Bayamon
Anselmo De Portu	Department of Natural Resources (Recorder)
Juan A. Deliz	U.S. Geological Survey--San Juan
Bernardo Deschapelles	University of Puerto Rico
Samuel Diaz Santiago	Engineering Consultant
Rafael Esteva	Puerto Rico Planning Board
Ellis FebresSiliva	Puerto Rico Civil Defense
Ralph Field	Ralph M. Field Associates, Inc.
Edgar J. Figueroa	Puerto Rico Ports Authority
Jose E. Hernandez	Center for Energy and Environment Research
Gilberto Isaac Valdes	Soil Engineering Office, Highway Authority
Rafael Jimenez Perez	Universty of Puerto Rico
Juan Luis Trias	U.S. Geological Survey, San Juan
Jussef M. Galib	Puerto Rico Chamber of Commerce
Jose Martinez Cruzado	University of Puerto Rico
Bill McCann	Lamont-Doherty Geological Observatory at Columbia University
Stanley McIntosh	Federal Emergency Management Agency (Moderator)
Jose Molinelli	University of Puerto Rico
Edgardo Pagan Anes	Soil Engineering Office, Highway Authority
Andres Paiva Liendo	Soil Engineering Office, Highway Authority
Cesar Pujols	Soil Engineering Office, Highway Authority

Nestor Ramirez	Public Building Authority
Leandro Rodriguez	University of Puerto Rico
Jesus Rodriguez	San Juan Department of Natural Resources
Emilio Rodriguez Esteban	Department of Commerce
Pedro Salicrup Rivera	Soil Engineering Office, Highway Authority
Ramon Santiago	U.S. Department of Agriculture
Alejandro E. Soto	University of Puerto Rico
Rodolfo Tardy Garcia	University of Puerto Rico
Thomas Thornton	U.S. Corps of Engineers
Heriberto Torres	U.S. Geological Survey--San Juan
Antonio Zaragoza Rodriguez	University of Puerto Rico

HIGHLIGHTS OF THE DISCUSSION

The group noted that a large amount of information published by USGS is presently available and can be used in the evaluation of geologic hazards. Specific comments included:

1) Most of the USGS Geologic Maps of Puerto Rico have been published or are on "open file." (Available from USGS Libraries in Reston, Virginia; Denver, Colorado; and Menlo Park, California.)

2) There is an urgent need to upgrade the information on landslides. Detailed maps at a scale 1:20,000 are needed. This effort could be accomplished by USGS and the University of Puerto Rico.

3) Fault inventory (land and sea) is incomplete and must be completed. This effort could be undertaken by USGS and Lamont-Doherty Geological Observatory.

4) Mapping the depth of the bedrock is critical and should be given a high priority because fundamental knowledge of the following factors are not well known in Puerto Rico: a) the relationship between the natural period of vibration of a specific structure and the dominant period of the soil under its foundation, and b) the effect of the local soil conditions underlying the building on the frequency content and duration of the vibrations induced in the building.

5) Identification of areas subject to liquefaction is a high priority task. Most of Puerto Rico's urban development is located in coastal areas with a relatively high water table. That is where major infrastructures are located, including airport and port facilities.

6) A preliminary study on liquefaction potential has been funded by the USGS for the San Juan Metropolitan Area and is due before the end of 1984.

7) Lamont-Doherty Geologic Observatory has specific interest in assisting Puerto Rico to improve its seismic information, especially with respect to: a) historical seismicity map, b) isoseismal maps, and c) upgrading its seismic network.

RECOMMENDED ACTIONS

Considering the availability of information, the discussion group recommended that the following actions be given high priority.

1) Produce a probabilistic map of the ground-shaking hazard for an exposure time of 50 years. Such a map would be consistent with the zoning map in Applied Technology Council's model building codes for other parts of the United States.

2) Update landslide inventory and identify areas that are potentially susceptible to landslides

3) Identify geologic hazards as well as other natural and for man made hazards in urban areas, quantifying the frequency of occurrence and the severity of effects.

4) Request the Puerto Rican Regulations and Permits Administration to assign a high priority to the review and amendment of the Puerto Rican building code with respect to seismic design and construction standards. The recommendations prepared by the local College of Engineers and Surveyors should be promptly evaluated and incorporated into the Building Code.

5) The Government of Puerto Rico should set forth its planning needs for mapping geologic hazards and should determine the extent to which the private sector is willing to provide part of the needed financial support.

6) A formal application should be submitted to the Federal Government (for example to FEMA or the USGS) for technical and financial aid for preparedness planning and hazard mitigation measures.

The activities identified above are designed to upgrade and refine knowledge of the spatial distribution of potential geologic hazards in urban areas. Presently a uniform standard is applied to seismic design, regardless of location on the Island. Accomplishment of these activities will ensure the achievement of the following rule of the "P's" and "S's:" "Proper preparedness planning seeks site specific surveys."

By the time of the next workshop on "Geological Hazards in Puerto Rico" (tentatively scheduled for April 1985) we believe that major accomplishments will have taken place and our knowledge of Puerto Rico's geologic hazards will be greatly enhanced.

DRAFT PLANS TO INCREASE COMMUNITY PREPAREDNESS

by

Risa Palm
University of Colorado
Boulder, Colorado
and
Olga Hernandez
University of Puerto Rico
Mayaguez, Puerto Rico

FOREWARD

These draft plans and recommendations were developed by the participants of the workshop on "Geologic Hazards in Puerto Rico." They are intended to serve as a guide for public officials, scientists, engineers, social scientists, and emergency managers. Representatives of these disciplines can use the plans and recommendations in several ways: 1) to evaluate their current research, mitigation, response and recovery programs, 2) to devise new programs and plans and, 3) to create a seismic safety policy in Puerto Rico.

The membership of the discussion group included:

Joyce B. Bagwell	Baptist College at Charleston
Andres Castillo Ortiz	Centro Unido de Detallistas de Puerto Rico
Jose A. Colon	National Weather Service Forecast Office
Charles Culver	National Bureau of Standards
Luz D. Diaz Rozado	State Civil Defense Agency
Jaime Fonseca	Cooperative de Seguros Multiples
Hildelisa Gonzalez	Department of Natural Resources
Paula Gori	U.S. Geological Survey
Olga Hernandez	University of Puerto Rico (Recorder)
Alba Martin	Department of Natural Resources
Jose Molinelli	University of Puerto Rico
Lizette Montaluo	Department of Natural Resources
Risa Palm	University of Colorado (Moderator)
Jesus Parrilla Calderon	University of Puerto Rico
Miguel Puig	Puerto Rico Telephone Company
Lourdes Rivera	Asociacion de Bancos de Puerto Rico
Ismael Roque	Continental Claim Services Inc.
Graciela Seijo	American Red Cross of Puerto Rico
Ismae Valazquez	Puerto Rico Telephone Company
Nara Zenoni	State Civil Defense Agency of Puerto Rico

HIGHLIGHTS OF THE DISCUSSION

The participants in the discussion group noted that there is a great need for community preparedness in Puerto Rico. However, the reality of the situation is that earthquakes are not the first priority problem; unemployment is.

The group pointed out the need to know how prediction of an earthquake and the actual occurrence of an earthquake might affect the economy of Puerto Rico (for example, the flow of money from companies as land values are decreased as a consequence of either the prediction or the actual event).

The question of possible overemphasis on earthquake hazards was raised by the group. The potential negative impact of "overkill" based on imprecise data dictates that earthquake hazards be studied very carefully in Puerto Rico to build a credible and well documented scientific data base that can be used in community preparedness activities.

RECOMMENDATIONS

The discussion group concluded that the information available at the present time was adequate to undertake a number of activities that would enhance community preparedness. The group recommended that the following subjects be given high priority:

1) Provide information on preparedness and mitigation strategies to the people of Puerto Rico.

2) Inform corporate executives about earthquake hazards and risk in Puerto Rico.

3) Provide information to the public about earthquake hazards and risk and practical actions the community can take to increase their preparedness.

4) Using this workshop as a starting point, provide the press (and others) with: a) correct and timely information on earthquake hazards and risk in Puerto Rico, b) carefully designed scientific information on selected topics (such as the ground shaking hazard, tsunamis, liquefaction, building codes, etc.), and c) popular articles which can be used in a public educational campaign that would give answers to the following types of questions:

   a) What is the hazard and what caused the hazard?
   b) What to do after the hazardous event?
   c) How are communities organized to respond to a hazardous event?

5) Promote educational campaigns to increase awareness and personal preparedness for geologic hazards in Puerto Rico seeking sponsorship from: a) the Department of Education (for example, incorporate information about the nature of geologic hazards and what to do to mitigate their effects in the curriculum and textbooks), b) churches (for example, provide puppet shows, etc.), c) civil defense organizations, d) volunteer groups, and e) civic and professional organizations.

6) Information should be prepared for target audiences.

7) Inform the Puerto Rican Permits and Regulation Administration of the need and strong support for their approval of the new building code.

8) Promote educational campaigns seeking sponsorship by: a) hotels, b) industry, c) public utility companies, d) insurance companies, and e) local and Federal agencies

DRAFT PLANS FOR IMPLEMENTATION OF LOSS REDUCTION MEASURES

by

Earl E. Brabb
U.S. Geological Survey
Menlo Park, California
and
Luis E. Biaggi
Puerto Rico Planning Board
Santurce, Puerto Rico

FOREWARD

These draft plans and recommendations were developed by the participants of the workshop on "Geologic Hazards in Puerto Rico." They are intended to serve as a guide for public officials, scientists, engineers, social scientists, and emergency managers. Representatives of these disciplines can use the plans and recommendations in several ways: 1) to evaluate their current research, mitigation, response and recovery programs, 2) to devise new programs and plans and, 3) to create a seismic safety policy in Puerto Rico.

The following participants attended this discussion group on implementation:

Luis E. Biaggi	Puerto Rico Planning Board (Recorder)
Earl Brabb	U.S. Geological Survey (Moderator)
Anselmo De Portu	Department of Natural Resources
Bernardo Deschapelles	University of Puerto Rico
Rafael Esteva	Puerto Rico Planning Board
Angel Figueroa	Puerto Rico Police
Esteban L. Fuertes	Citibank
Walter Hays	U.S. Geological Survey
Jose E. Hernandez	Center for Energy and Environmental Research
Gilberto Isasc Valdez	Highway Authority
Rafael Jimenez	University of Puerto Rico
Victor M. Marques	Highway Authority
Philip McIntire	Federal Emergency Management Agency
Stanley McIntosh	Federal Emergency Management Agency
Andres Paiva Paiva	Puerto Rico Highway Ing. Soils
Edgardo Pagan Anes	Highway Authority
Fernando L. Perez	Puerto Rico Electric Power Assoc.
Cesar Pujols	Highway Authority
Pedro Salcrup Rivera	Highway Authority
Heriberto Torres	U.S. Geological Survey, San Juan

HIGHLIGHTS OF THE DISCUSSION

The participants in this group discussed the following subjects:

1) The necessity to implement the amendments submitted to the Puerto Rican Administration of Permits and Regulations by a Seismic Committee of Engineers. These amendments will be reviewed in public hearings and after adoption they will be approved by the Puerto Rican Planning Board.

2) The need for the Department of Natural Resources to gather all available information from public and private enterprises and make an economic cost analysis of the impact of geologic hazards in Puerto Rico (for example, the effects of landslides on subdivisions, housing, and roads). The possibility exists that an executive order may be needed to implement this study.

3) Utilization of advisory services on soils and geologic hazards offered by the Department of Soil Engineering at the Puerto Rican Highway Authority by all government agencies involved in construction and planning.

4) The need for geologic reports for critical and important facilities such as hospitals, schools, and lifelines.

5) The need and possible requirement for federal agencies who fund construction (such as Veterans Administration, Federal Housing Authority, and Farmers Home Administration) to obtain site geologic reports in hazardous areas (for example, those areas shown in red on the USGS landslide maps).

6 The importance of continuing education for architects and other disciplines not represented at the workshop.

RECOMMENDATION

The members of the discussion group approved the following declaration:

> "Whereas, the Seismic Committee of Engineers Association has submitted to the Puerto Rican Building Permits and Regulation Administration an updated proposal for the earthquake resistant design of structures in Puerto Rico. Whereas, after nine months after the document has been submitted no action has been taken. Therefore, the participants of the workshop on Geologic Hazards in Puerto Rico strongly recommended the need for urgent action in the evaluation and implementation of the aforementioned updated seismic code."

Implementation of this declaration would reduce losses from geologic hazards in Puerto Rico.

DRAFT PLANS TO ENHANCE INFORMATION TRANSFER AND PERSONAL PREPAREDNESS

by
William Kockelman
U.S. Geological Survey
Menlo Park, California
and
Leandro Rodriguez
University of Puerto Rico
Mayaguez, Puerto Rico

FOREWARD

These draft plans and recommendations were developed by the participants of the workshop on "Geologic Hazards in Puerto Rico." They are intended to serve as a guide for public officials, scientists, engineers, social scientists, and emergency managers. Representatives of these disciplines can use the plans and recommendations in several ways: 1) to evaluate their current research, mitigation, response and recovery programs, 2) to devise new programs and plans and, 3) to create a seismic safety policy in Puerto Rico.

The membership of the discussion group included:

Heriberto Capella Acevedo	Puerto Rico Department of Education
Walter Cedeno Rivera	Center for Energy and Environment Research
Jacobo Colon Gutierrez	Puerto Rico Department of Civil Defense
Orlando Cordero	University of Puerto Rico
Ellis S. Febres Silva	Puerto Rico Department of Civil Defense
Ralph M. Field	Ralph M. Field Associates, Inc.
Chalres Gover	Puerto Rico Highway Authority
Jorge Hidalgo	Hidalgo & Associates
Luis Humberto Vega	Office of the Commissioner of Insurance of Puerto Rico
William Kockelman	U.S. Geological Survey (Moderator)
Jose Martinez Cruzado	University of Puerto Rico
William McCann	Lamont-Doherty Geological Observatory at Columbia University
Wilfredo Melendez	Puerto Rico Department of Civil Defense
Antonio V. Munera	Puerto Rico Department of Civil Defense
Boris Oxman	Puerto Rico Department of Natural Resources of Puerto Rico
Robert D. Prince	LANT NAVFAC (Navy)
Nestor Ramirez	Public Building Authority
Leandro Rodiquez	Puerto Rico Department of Civil Engineering (Recorder)
Jesus Rodriguez	Puerto Rico Department of Natural Resources
Ramon Santiago	U.S. Department of Agriculture, Soil Conservation Service
Alejandro Soto	University of Puerto Rico
Rodolfo Tardy	University of Puerto Rico
William Vazquez	International Charter Mortgage Corporation of San Juan
Antonio Zargoza Rodriguez	University of Puerto Rico

HIGHLIGHTS OF THE DISCUSSION

Information transfer is a complex subject; therefore, the members of the discussion group spent a great deal of time identifying the primary steps in the process. The process can be represented as follows:

> The community (people and programs) require geologic hazards information (maps, reports, etc.). The process of transferring the information to users in the community (scientists, engineers, architects, social scientists, emergency managers, public officials) is controlled by constraints (political-legal, safety, physical, economic, social, technological) which must be eliminated or minimized by creative activities (partnerships, incentives, reduction of costs, development of technology for solving discrete components of the problem, optimization of decisions, etc.). The activities designed to transfer information require demonstration of their value (publications, workshops, etc.) for evaluation and promotion of acceptance (ordinances, legislation, etc.).

In addition the group also discussed the following subjects:

1) The need to allocate resources to support "geologic hazards crusaders" who will carry the message to decisionmakers about the threat and the options for mitigation.
2) The opportunties to educate builders, engineers, architects, the financial sector, and others.
3) The emerging challenge of rehabilitation of existing buildings and the opportunity to test various techniques.
5) Design and construction problems in Puerto Rico.
6) Implementation of reasonable seismic design provisions of the building code.
7) The need for a seismologist in Puerto Rico.
8) Organization of a Caribbean Basin Geologic Hazards Conference to share information, to build networks, and to continue the effort begun at this workshop.
9) Personal preparedness; i.e., those actions which individuals can take to make their home, work place, and their children's schools safer from geologic hazards.

RECOMMENDATION

The members of the discussion group recommended two priority actions:

1) The adoption of the new seismic design provisions of the Puerto Rican Building Code.

2) Every participant find extraordinary ways to enhance transfer of information on geologic hazards to various users. The goal is to make the process become "routine" and a model for other regions of the world to follow.

3) Every participant identify "zero cost" actions which they can take to make their home safer from earthquake hazards. These actions include bolting the house to the foundation, tying down the water heater, reinforcing bookcases so that they will not fall, etc.

DRAFT PLANS FOR INCREASING AWARENESS OF GEOLOGIC HAZARDS

by

by Jane Bullock
Federal Emergency Management Agency
Washington, D.C.
and
Philip McIntire
Federal Emergency Management Agency, Region II
New York City, New York

FOREWARD

These draft plans and recommendations were developed by the participants of the workshop on "Geologic Hazards in Puerto Rico." They are intended to serve as a guide for public officials, scientists, engineers, social scientists, and emergency managers. Representatives of these disciplines can use the plans and recommendations in several ways: 1) to evaluate their current research, mitigation, response and recovery programs, 2) to devise new programs and plans and, 3) to create a seismic safety policy in Puerto Rico.

The membership of the discussion group included:

Joyce Bagwell	Baptist College at Charleston
Jane Bullock	Federal Emergency Management Agency (Moderator)
Carmen L. Burges	Department of Social Services
Luz Delia Diaz Rosado	State Civil Defense Agency
Walter Hays	U.S. Geological Survey
Bill Kockelman	U.S. Geological Survey
Philip McIntire	Federal Emergeny Management Agency (Recorder)
Antonio Munera	Puerto Rico Civil Defense
Boris L. Oxman	Department of Natural Resources
Miguel Pagan Mir	State Civil Defense
Fernando L. Perez	Puerto Rico Electrical Power Authority
Miguel Puig	Puerto Rico Telephone Company
Claire Rubin	George Washington University
Graciela Seijo	American Red Cross
Robert A. Shuman	Independent Insurance Broker
Mariano Vargas	Department of Natural Resources
Manuel Vazquez	Puerto Rico Electrical Power Authority
Nora E. Zenoni	State Civil Defense Agency
Hildelisa Gonzalez	Department of Natural Resources

HIGHLIGHTS OF THE DISCUSSION

The members of the discussion group identified a wide range of subjects in the context of increasing hazard awareness. They included:

1) The American Red Cross check-list for making homes, busineses, and industries safe from geologic hazards. The need to update this information and publish it in Spanish was noted.

2) Ways to achieve effective radio and T.V. spot announcements on geologic hazards.

3) Forming partnerships with business and industry.

4) Mobilization of organizations such as the scouts and others and civil defense personnel to carry information about geologic hazards to the home.

5) The location of existing shelters that could be used in the event of a damaging earthquake. The questions of being self sufficient for 48 hours (for example, food supplies, procedures for making water safe, first aid, communications, etc) were addressed.

6) Evacuation procedures for buildings; potential limitations on use of roads and other transportation lifelines.

7) Education of of school children, beginning at the earliest levels, on geologic hazards. Earthquake drills.

8) Training of local civil defense organizations; earthquake exercises; evacuation exercises; formulation of multihazards emergency management concepts.

RECOMMENDATIONS

The group recommended the following actions:

1) Increasing hazard awareness is a team effort. Each member of the team (scientists, engineers, architects, social scientists, planners, emergency managers, and public officials) has a job to do that depends on the intergration and coordination of their activities and programs with others. Therefore, a priority effort is needed in Puerto Rico to continue the work that has already begun to increase the level of awareness of geologic hazards. Identification of leaders, "geologic hazards crusaders," and other resources to achieve the short- and long-term goals of hazard awareness should be undertaken immediately and continued throughout this decade.

EVALUATION OF THE WORKSHOP ON GEOLOGIC HAZARDS IN PUERTO RICO

by

Ann FitzSimmons
University of Colorado
Boulder, Colorado 80309

At the conclusion of the workshop, program participants were asked to answer several questions: How well did the workshop succeed in reaching its goals? How useful were various workshop procedures in communicating? Did changes in their levels of awareness and concern occur as a result of having participated? The workshop was designed to define the threats posed by earthquakes and ground-failure in Puerto Rico, describe current capabilities for responding to geologic hazards in Puerto Rico, develop strategies to increase awareness and concern, and aid in the formation of plans to incorporate geologic information into local land use and emergency plans.

Responses were elicited on a five-point scale, 1 and 2 representing the lowest level of agreement, 3 moderate agreement, and 4 and 5 highest agreement, or a "yes" response (see Table 1). Since not all respondents answered all the questions, percentages are based only on those who submitted evaluations (see Table 2).

Evaluations returned by 55 participants indicate that the workshop was successful in meeting its goals. Eighty-two percent of the evaluators thought the workshop did a good job of defining the earthquake threat; 78% also thought that the workshop did a good job in defining the ground-failure hazard in Puerto Rico. The workshop's role in formalizing plans to increase awareness and concern for earthquake and other geologic hazards and to incorporate geologic information into planning activities were both well received. Over 50% of the respondents found the workshop successful in its description of earthquake response capabilities; 25% thought it moderately helpful; and 14% (the largest "low" percentage for question #1) viewed the workshop as marginally helpful in this regard.

In order to determine in what specific ways the meeting was useful to participants, questions addressed sources of information and how they provided a better understanding of geologic hazards in Puerto Rico. Eighty percent of the respondents gave the workshop high marks for providing new sources of information or expertise, and the remaining 14% were at least moderately happy with new sources suggested by the workshop.

Certainly a major achievement of the workshop was the extent to which it gave participants an appreciation of the problems faced by decisionmakers. Again, eighty percent said that the workshop was very successful in providing a better understanding of problems faced by decisionmakers, and 14% said that it was at least moderately successful.

To indicate which activities were viewed as the most useful, participants were asked to rate formal presentations, follow-up discussions, small group discussions, informal discussions, and materials such as notebooks and abstracts. The small discussion groups received the most enthusiastic evaluation; 91% of the respondents judged them to be highly useful. Formal presentations and discussions following the formal presentations were judged highly successful by nearly 80% of the respondents. The written materials were well received, with 85% of the respondents giving them high marks. Informal discussions were seen to be a valuable part of the meeting as well.

The importance attached to this workshop is shown in the response of 98% of those submitting evaluations that they would, knowing now what to expect, most definitely wish to attend again. Not one person indicated a reluctance to take part in similar future gatherings.

The most interesting and significant impact of the workshop has been its influence on heightening levels of awareness and concern. Significant numbers of participants (27%). reported their levels of awareness prior to the workshop would have been described as "low." Thirty-five percent rated their levels of awareness as "moderate," and 36% rated them as "high" before the workshop. Following the workshop, however, no participant felt his or her awareness was "low;" only 5% considered their awareness moderate, while 93% judged their awareness to be "high." Similarly, levels of concern were heightened significantly by participation. Before the workshop, concern was judged to have been low by one-half of the respondents, with 22% registering moderate concern and only 25% high concern. After the workshop, participants revised their perceptions of concern significantly; only 5% defined their levels of concern as low, no one said they were moderate, and 89% said they were highly concerned about the state of earthquake preparedness in Puerto Rico.

Another important judgment of the success or failure of a workshop can be made by looking beyond the impacts it had on attitudes, to ways in which it may have affected behavior. In order to determine whether the workshop had any long-term effect on the behavior of participants, the final question asked respondents to consider actions they might take to improve the awareness and concern of others or to implement mitigation activities in Puerto Rico. Response from 33 participants to this question was strikingly uniform.

Virtually all of the respondents were planning to become involved in some type of educational activity, either among their friends and social acquaintances or their co-workers. Many stated they were going to volunteer to share their new knowledge with local service organizations (Rotary, Lions, Masonic Lodges), private schools, or their agencies or businesses through workshops or seminars, and with the general public, via the media. One participant planned to write a comprehensive article in Spanish on the nature of earthquake hazards in Puerto Rico. Civil defense personnel saw their agencies adding earthquake information to their annual training program and conducting lectures for public and private agencies. Another participant planned to propose that the local Association of Engineers and Surveyors promote and participate in earthquake education for the general public.

Of the respondents who were planning steps besides educational activities, one mentioned working to convince the Federal Emergency Management Agency to increase funding for earthquake hazards planning in Puerto Rico. Numerous other respondents planned on working on the ad hoc earthquake committee formed during the workshop. One person anticipated working to ensure the coordination of efforts of persons who volunteered for committee work. It is evident from their lengthy responses that the workshop provided enough new information to cause participants to enthusiastically begin to pass on their expanded knowledge of geologic hazards to others in Puerto Rico.

Table 1
Evaluations of the Workshop by Individual Participants

	LOW 1&2	MED 3	HIGH 4&5 *
1. Did you find the workshop to be useful for:			
a. Defining the nature and extent of earthquake hazards in Puerto Rico?	--	8	45
b. Defining the nature and extent of ground-failure hazards in Puerto Rico?	1	9	43
c. Describing the current capabilities to respond to geologic hazards in Puerto Rico?	8	14	32
d. Formalizing plans to increase awareness and concern for earthquake and other geologic hazards?	2	11	39
e. Formulating plans to incorporate geologic information in land-use planning, emergency response planning, and earthquake-resistant design?	2	11	41
2. Did the workshop benefit you or your organization by:			
a. Providing new sources of information and expertise you might want to utilize in the future?	--	8	44
b. Establish better understanding of the problems faced by researchers and decisionmakers?	1	8	44
3. Did you find the following activities useful:			
a. Formal presentations?	--	10	43
b. Discussions following the formal presentations?	2	7	50
c. Small discussion groups?	1	2	50
d. Informal discussions during coffee breaks, lunches, and after hours?	5	8	38
e. Notebook and abstracts?	1	6	47
4. If the clock were turned back and the decision to attend the workshops were given you again, would you want to attend?	--	1	54
5. Should future workshops be planned to continue the work initiated at this meeting?	--	2	49
6. Prior to attending this workshop, I would rate my awareness of the earthquake threat in the Puerto Rico as	15	19	20
7. Prior to attending this workshop, I would rate my concern about the state-of-earthquake preparedness in the Puerto Rico as	28	12	14
8. I now rate my awareness as	--	3	51
9. I now rate my concern	3	--	49

10. Some steps I plan to take to increase others awareness, concern, and activities to lessen the effects of potential earthquakes in Puerto Rico.

*Evaluations were completed by fifty-five participants. Totals vary as not all respondents completed all questions.

Table 2
Evaluations of the Workshop by Percentages of Participants

	LOW 1&2	MED 3	HIGH 4&5 *
1. Did you find the workshop to be useful for:			
a. Defining the nature and extent of earthquake hazards in Puerto Rico?	--	14%	82%
b. Defining the nature and extent of ground-failure hazards in Puerto Rico?	2%	16%	78%
c. Describing the current capabilities to respond to geologic hazards in Puerto Rico?	14%	25%	58%
d. Formalizing plans to increase awareness and concern for earthquake and other geologic hazards?	4%	20%	71%
e. Formulating plans to incorporate geologic information in land-use planning, emergency response planning, and earthquake-resistant design?	4%	20%	74%
2. Did the workshop benefit you or your organization by:			
a. Providing new sources of information and expertise you might want to utilize in the future?	--	14%	80%
b. Establish better understanding of the problems faced by researchers and decisionmakers?	2%	14%	80%
3. Did you find the following activities useful:			
a. Formal presentations?	--	18%	78%
b. Discussions following the formal presentations?	4%	13%	80%
c. Small discussion groups?	2%	4%	91%
d. Informal discussions during coffee breaks, lunches, and after hours?	9%	14%	69%
e. Notebook and abstracts?	2%	11%	85%
4. If the clock were turned back and the decision to attend the workshops were given you again, would you want to attend?	--	2%	98%
5. Should future workshops be planned to continue the work initiated at this meeting?	--	4%	89%
6. Prior to attending this workshop, I would rate my awareness of the earthquake threat in the Puerto Rico as	27%	35%	36%
7. Prior to attending this workshop, I would rate my concern about the state-of-earthquake preparedness in the Puerto Rico as	51%	22%	25%
8. I now rate my awareness as	--	5%	93%
9. I now rate my concern	5%	--	89%
10. Some steps I plan to take to increase others awareness, concern, and activities to lessen the effects of potential earthquakes in Puerto Rico.			

*Percentages do not total 100% as not all respondents completed all questions.

ON THE EARTHQUAKES HAZARD OF PUERTO RICO AND THE VIRGIN ISLANDS

by

William R. McCann
Lamont Doherty Geological Observatory
Palisades, New York

INTRODUCTION

Puerto Rico and the Virgin Islands lie at the eastern edge of the Greater Antilles, a chain of islands composed of volcanic and sedimentary rocks deposited over the last 100 million years (Figure 1); they also lie near the northeastern corner of the Caribbean plate, a rigid block in motion with respect to North and South America, and the floor of the Atlantic Ocean. The ocean floor to the north and east of the islands, which is part of the North American plate, moves WSW with respect to the Caribbean; upon meeting the Caribbean plate it bends downward, descending into the mantle with a dip of 50 to 60 degrees (Figures 2 and 3) eventually reading depths as great as 150 kilometers (Molnar and Sykes, 1969; Schell and Tarr, 178; Frankel et al., 1980; Fischer and McCann, 1984). Convergence between the Caribbean and North American plates occurs at a rate of about 37 mm/year (Sykes et al., 1982).

Seismicity occurring along the margin of the Caribbean plate represents either relative motion between two plates (interplate) or between blocks within one plate (intraplate). Regardless of their origin, strong earthquakes near Puerto Rico and the Virgin Islands pose a hazard to local populations.

The historic record spanning 400 years is clear, strong damaging earthquakes have periodically stricken the islands. The location of their causative faults and the approixmate magnitude of these older shocks is not well determined. The first recorded damaging shock, in the 1520's, reportedly destroyed the home of Ponce de Leon, as well as other structures in western Puerto Rico (Anon, 1972). During succeeding centuries other strong shocks are reported affecting various sectors of the island. The most important shocks

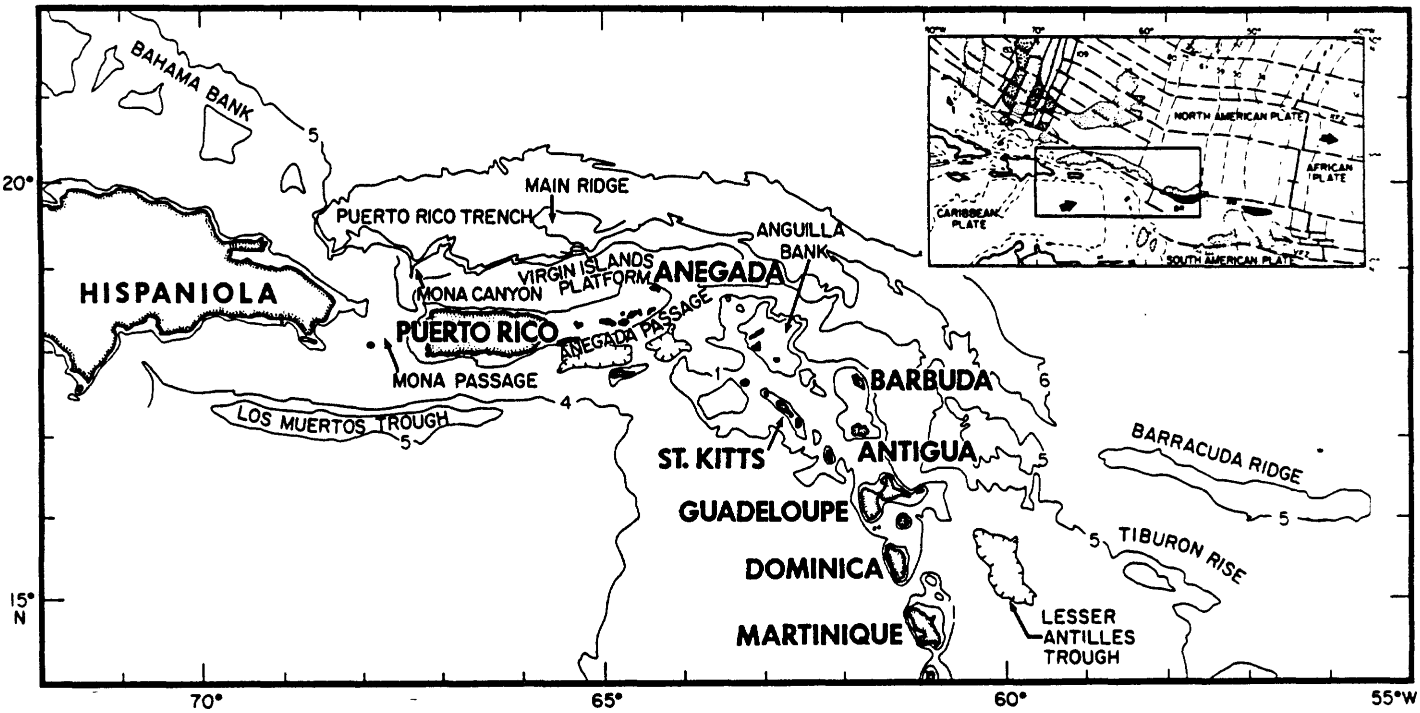


Figure 1. Place names and general bathymetry of northeastern Caribbean. Contours are in kilometers (after Case and Holcombe, 1980). Inset shows tectonic framework fo the eastern Caribbean and Central Atlantic Ocean. Arrows are directions of relative motion of African and Caribbean plates with respect to a fixed North American plate. Double lines represent seafloor spreading. Light dashed lines are magnetic anomalies, numbers are age of anomaly in millions of years. Close stipple pattern is region of Mesozoic anomalies. Heavy dashed lines are fracture zones. Barracuda and Researcher Ridges (BR and RR) are shown in black. Open stipple pattern shows extent of abyssal plains. Northeastern Caribbean is the site of subduction of North Atlantic seafloor. Note the northwesterly trend of fracture zones in the region. Recent motion of the Caribbean plate has carried it over several of these fracture zones. Other labels: VFZ, Vema Fracture zone; KFZ, Kane fracture zone; COR, Caicos Outer Ridge; from McCann and Sykes (1984).

being those of 1787, when destruction occurred everywhere but the south coast of Puerto Rico, and 1867 when a destructive seismic seawave (tsunami) ravaged the coast of southeastern Puerto Rico and various parts of the Virgin Islands (Anon, 1972; Reid and Taber, 1920).

Damage from large shocks in the Dominican Republic to the west, have also affected Puerto Rico. Dominican earthquakes in 1615, 1751, 1776 and 1946 caused considerable damage in the western part of Puerto Rico (Iniguez et al., 1975; Anon, 1972).

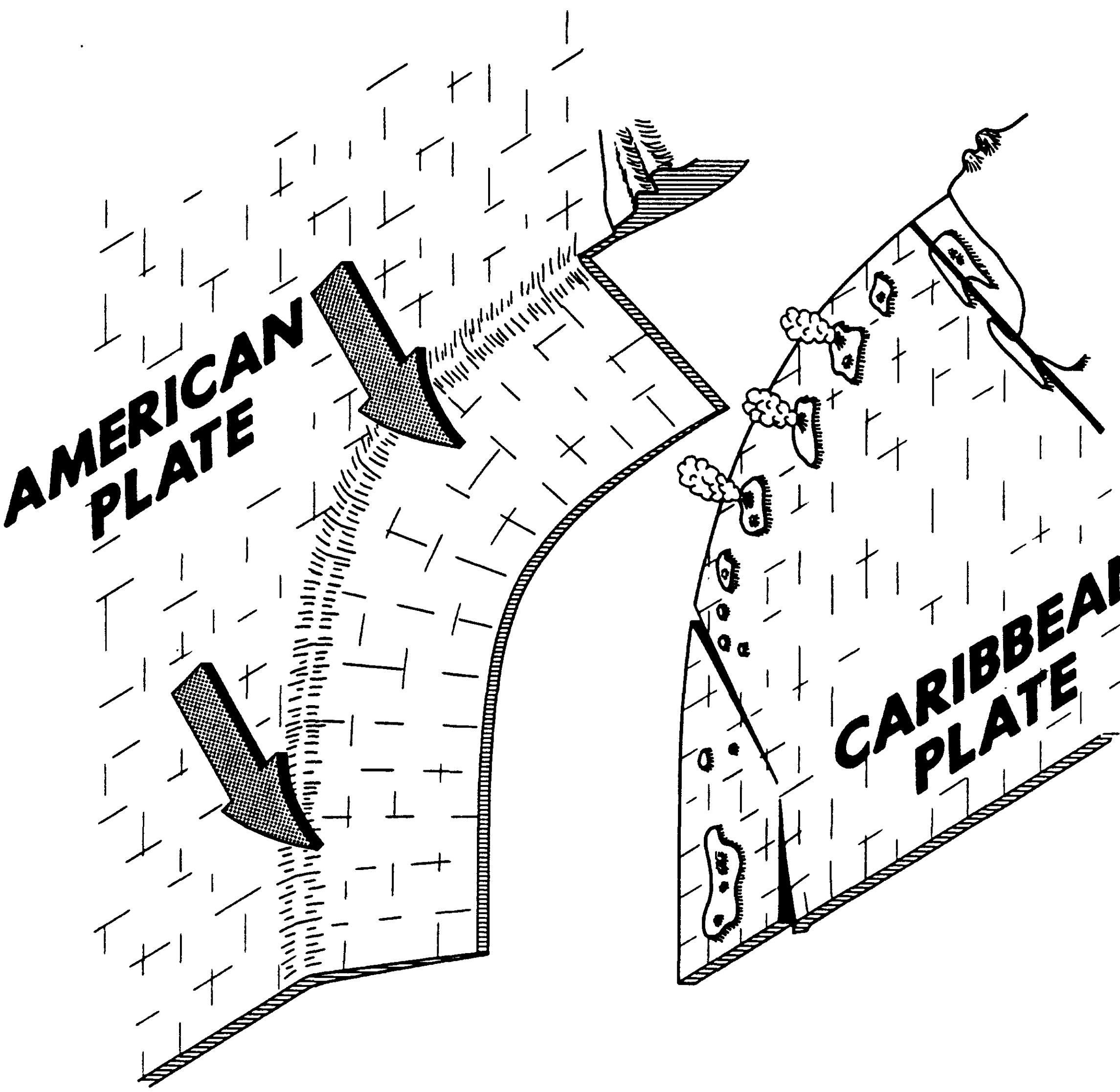


Figure 2. Plate tectonic sketch of eastern Caribbean. North American Plate moves WSW relative to the Caribbean plate. In the view shown here the plates are separated to allow viewing of downgoing section of North American plate. Puerto Rico and the Virgin Islands lie on a block that appears not to be rigidly attached to the Caribbean plate. Caribbean plate underthrusts western and central Puerto Rico; this motion is associated with active faulting south of the Virgin Islands.

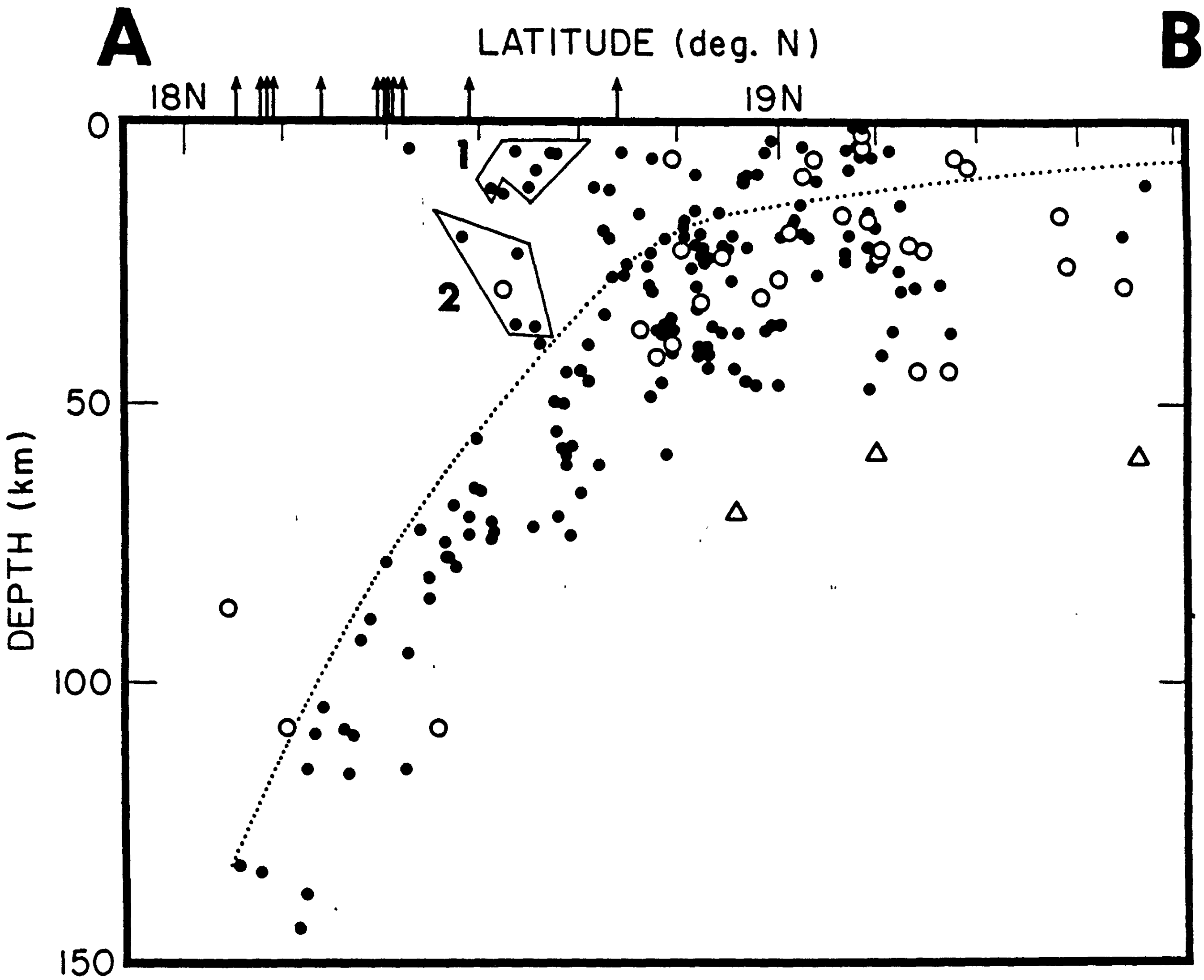


Figure 3. Vertical cross-section of 227 relocated hypocenters, obtained by projecting them onto a vertical plane striking N-S along 64 degrees 40' W in a direction perpendicular to Puerto Rico (only events within 100 km of this line are shown). Open symbols indicate events with residuals ≥ 0.3 sec; solid symbols show events with residuals ≤ 0.3 sec. The two groups of events outlined at the top are long possible intraplate faults. Arrows at top of figure indicate station locations.

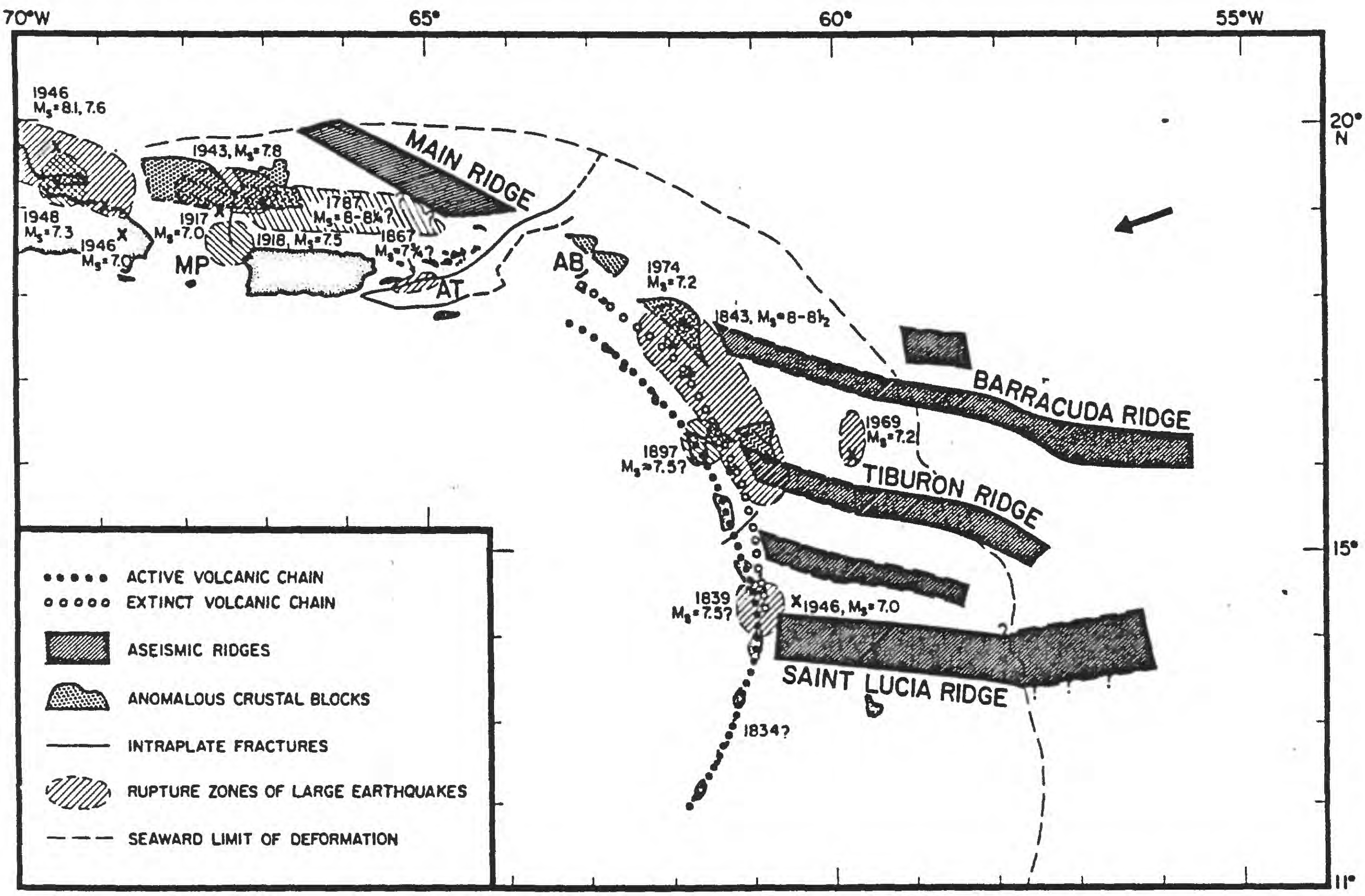


Figure 4. Rupture zones of large earthquakes ($M \geq 7$) in the eastern Caribbean and their relationship to features that bound end of rupture. Several bathymetric highs intersect the plate boundary dividing it into tectonic segments. Rupture during the 1787 event may have been limited by the Main Ridge and the features near Mona Passage (MP). Three anomalously shallow portions of the forearc (stippled areas) may be either exotic blocks accreted to the inner wall of the trench or blocks uplifted by the subduction of aseismic ridges. The large block northwest of Puerto Rico represents a part of the Bahama Bank that has been accreted to the Caribbean plate in the last few million years. AT, Anegada Trough; AB, Anguilla Bank (from McCann and Sykes, 1984).

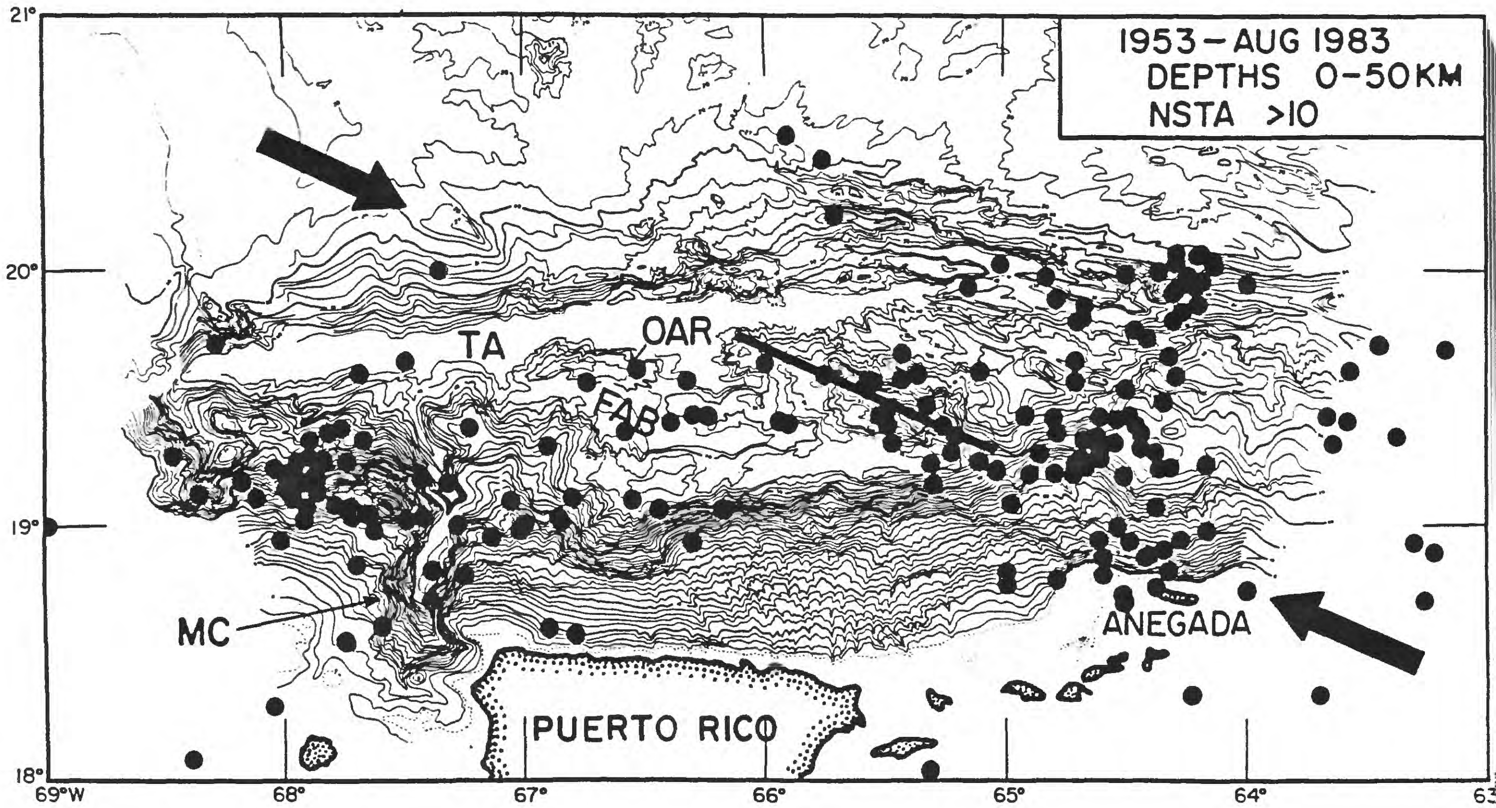


Figure 5. Detailed bathymetry of the Puerto Rico Trench north of Puerto Rico and the Virgin Islands (A. Leonardi, unpublished data). Contours are in hundreds of fathoms (1 fathom = 1.829 meters). Circles are epicenters are moderate-sized shocks from 1953 to 1983 with depths less than 50 kilometers. Only events located using more than 10 statins are shown (nsta >10). Note the clusters of earthquakes near the bathymetric feature northwest of Anegada and near the Mona Canyon (MC). The great earthquake of 1787 probably ruptured a fault segment bounded by these two regions of enhanced seismic activity. Arrows and heavy line lie along strike of Main Ridge. TA is axis of Puerto Rico Trench; OAR is Outer ARc Ridge, a feature composed of sediments deformed by the WSW motion of the North American plate; FAB is a basin of undeformed sediments.

With the advant of instrumental seismic recording (about 1900) information for large earthquakes becomes more complete. The largest shocks of this century (1918, M = 7.5; 1943, M = 7.75) occurred off the northwest coast of Puerto Rico, in the vicinity of the Mona Passage (Figure 4). Instrumental locations of small, more frequent shocks over the last 35 years have allowed a more precise identification of possible causative faults and the distribution of seismicity in general (Sykes and Ewing, 1965; Molnar and Sykes, 1969; Sykes et al., 1982).

Based on the record of historic earthquakes, Kelleher et al. (1973) defined segments of the Caribbean plate boundary most likely to produce large earthquakes in the near future. McCann et al. (1979) and McCann and Sykes (1984) further refined these estimates. They estimate a high seismic potential for a major fault in the Puerto Rico Trench north of Puerto Rico and the Virgin Islands. Recently, work by numerous other authors has helped to define the nature of the main seismic zone extending along Puerto Rico and the Virgin Islands, and to elucidate the relative motion between major tectonic blocks (Minster and Jordan, 1978; Murphy and McCann, 1979; Ascencio, 1980; Frankel, 1982).

This report integrates previous results with new data available from the region south of the islands and presents preliminary estimates of likely earthquake locations and sizes of strong earthquakes.

The conclusion of this report is that, while great earthquakes ($M \geqq 7.75$) will occasionally occur in the Puerto Rico Trench 50 to 100 km to the north of the islands, the historic record and regional tectonic framework suggest that major shocks ($M \simeq 7$-7.5) may occur on intraplate faults close to the islands just as frequently. This conclusion, based on a longer historic record than previously available as well as analysis of data from local seismic networks and marine seismic programs, should be taken as a plausible working hypothesis to be refined by further investigations. Clearly more work in several lines of research is needed before definitiave conclusions can be made.

Earthquakes and Structures Offshore

Puerto Rico Trench

The Puerto Rico-Virgin Islands (PRVI) platform is bounded north and south by two deep-sea trenches; to the north the Puerto Rico Trench, to the south the Muertos Trough. The most prominent offshore structure is the west-striking Puerto Rico trench (Figures 1 and 5). Its axis lies at a depth of 8 km about 100 km north of the Puerto Rico-Virgin Islands platform. Here the North American plate moves WSW underneath the sedimentary cover at the northernmost edge of the PRVI platform (Figure 5). The North American plate, as delineated by microearthquakes, dips southerly from the trench, reaching depths of 70 to 150 km beneath the islands (Figures 2 and 3). The shallow-dipping fault zone just to the south of the trench is likely to produce earthquakes with magnitudes as large as 8 to 8.25 (see dotted in Figure 5). In the last 35 years numerous shocks, though moderate in size, occurred in the vicinity of the trench. Most of these shocks are found beneath its south wall; there are two particularly active regions--one where the Mona Canyon meets the trench northwest of Puerto Rico, and the other near where the Main Ridge intersects the easternmost Virgin Islands (Figures 4 and 5).

A broad cluster of seismicity near the Virgin Islands occurs in a triangular region with each side about 100 km long (Figure 5). Seismic activity immediately to the west of this cluster is low. This quiet zone is also similar in structure to classicial subduction zones where rupture during occasional large earthquakes is separated by long periods of seismic quiescence. In contrast, the region typified by high seismic activity of moderate-size shocks lies beneath an anomalous submarine feature on the North American plate, the main ridge. Local network data shows that these earthquakes occur within the PRVI platform, within the downgoing North American plate, as well as the zone of contact between the two plates.

The cluster of activity NW of Puerto Rico lies near a submarine bathymetric high to the west of Mona Canyon. This feature, other submarine highs near it, and the narrow, deep Mona Canyon, are part of a complex tectonic element on the inner wall of the Puerto Rico trench. The geologic history of these features suggest that they are pieces of the Bahama platform carried into the region by the North American plate. Little is known about the details of the distribution of the shocks in this region.

Mona Passage

The regions east, west, and south of Puerto Rico and the Virgin Islands include many complex structures. Some of the structures off the west coast of Puerto Rico are subtle, complex, and difficult to interpret with currently available data. Down-dropped blocks (grabens) striking north or northwesterly are the most prominent features of this region; they extend from the Muertos Trough to the south and from the Puerto Rico trench in the north (Figure 6).

The most prominent of these grabens is the Mona Canyon. A destructive earthquake in 1918 (M = 7.5) probably occurred on one of the faults bounding this canyon (Reid and Taber, 1919). As a destructive seawave accompanied this earthquake, a significant vertical displacement of the seafloor must have occurred and the depth of the shock must have been one of fairly shallow depth, i.e. the upper 40 km. The canyon to the south is a more subtle feature, being less clearly defined bathymetrically than the Mona Canyon. Nonetheless its dimensions approach those of Mona Canyon. Both features should be considered likely sources for strong earthquakes as active faults are observed in seismic reflection records near both features although such shocks may be more frequent and larger near the prominent Mona Canyon.

The grabens do not intersect, but rather terminate against a shallow platform characterized by WNW trending structures. These structures appear to be submarine extensions of the Great Southern Puerto Rico fault zone. This shallow bank is structurally complex, and an estimate of the maximum size earthquake likely to occur there is difficult to determine with existing data.

Muertos Trough

South of Puerto Rico and Saint Croix lies the Muertos Trough. It is probable that, like the Puerto Rico Trench, it accommodates the convergence between two blocks. Along much of this trough the floor of the Caribbean Sea moves underneath the massif of Puerto Rico. So the "rigid" block upon which Puerto Rico and the Virgin Islands lie is at most 300 kilometers wide in the north-south direction and overrides converging seafloor from both north and south. Based on our knowledge of the seismic history, motion along the Muertos Trough appears to be a small fraction of that near the Trench to the north. So Puerto Rico, in fact, is perhaps not an integral part of the Caribbean plate (although nearly so), but is rather a smaller plate or block, separating the larger plates.

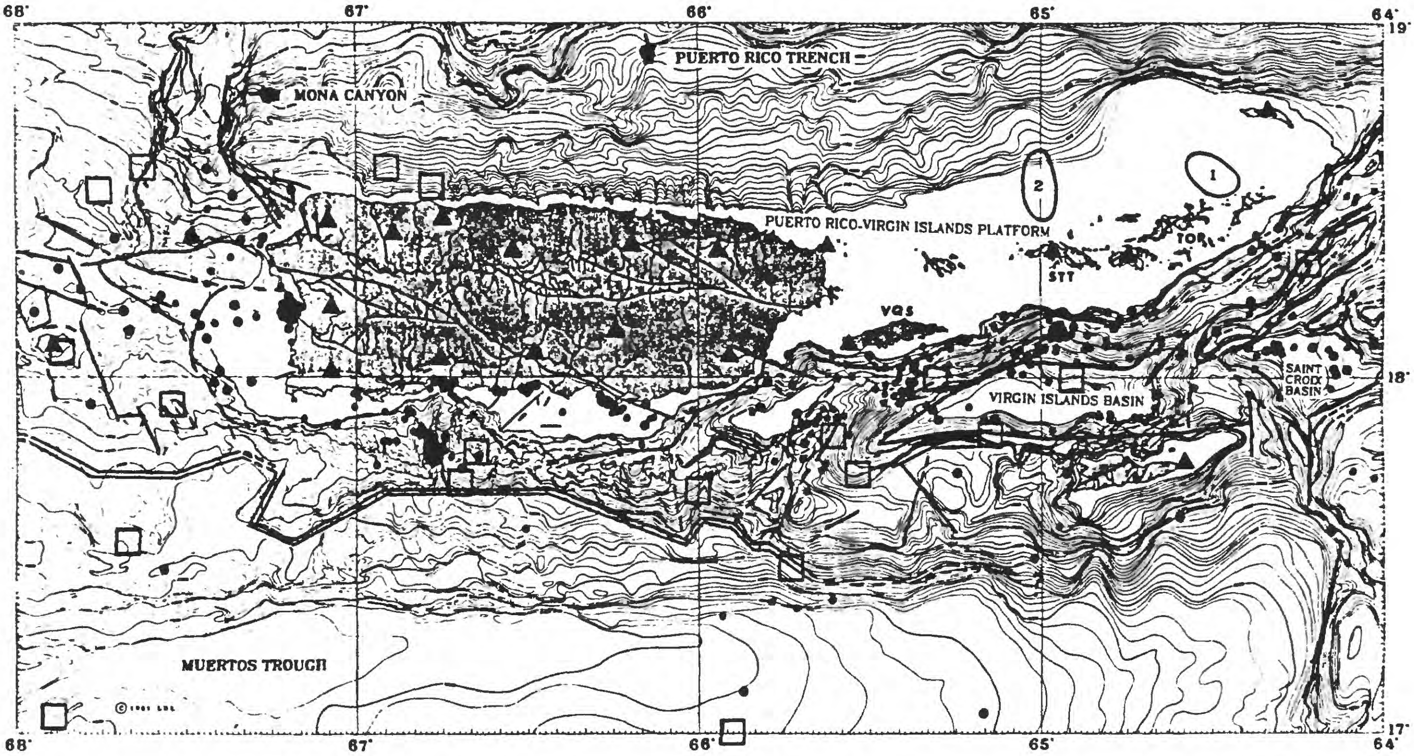


Figure 6. Major, recent tectonic features near Puerto Rico and the Virgin Islands. Contours, showing depth to seafloor in meters, delineate major morphologic features in the offshore region (from Trumbull, 1981). Puerto Rico and the Virgin Islands lie on a long, shallow platform. Saint Croix lies on a narrow bank separated from the PRVI platform by a major basin. The width of the shallow platform off Puerto Rico is highly variable, as is the slope down towards the axis of the Muertos Trough. Closed triangles are stations monitoring microearthquakes (i.e. Puerto Rico Seismic Network). Closed circles are locations of shallow microearthquakes (depth $\leq$ 50 km) south of 18.6 degrees N. east of 66 degrees W locations are from catalog of LDGO network; events occurred during the period 1977-1982; large circles have magnitudes $m \geq 2.5$, smaller circles represent smaller events; only events reported by 5 or more stations occurring south of the PRVI platform are shown. Events west of 66 degrees W are from catalog of early Puerto Rico network as reported by Dart et al. (1980); only offshore events are shown. Large circles are events with magnitudes $m \geq 2$. Regions labeled 1 and 2 on PRVI platform are shallow, seismically active faults noted by Fischer and McCann (1984) (see figure 3). Open squares are locations of moderate-sized shocks ($M \geq 4$) as reported by Sykes and Ewing (1965) and NEIS. Double line south of Puerto Rico is probable southern limit of crystalline rocks of Puerto Rico block. Solid lines are active faults, identified in single-channel seismic reflection records, and their continuation along the strike of obvious morphologic features. Data is from Lamont-Doherty ships VEMA and CONRAD and data reported by Garrison (1972). Beach and Trumbull (1981) and Rodriguez et al. (1977). Single, dashed lines are morphologic features that appear to be fault controlled. Junctures of complex fault systems are found east and west of the Virgin Islands Basin. Northerly striking faults from the Mona Canyon and a smaller graben west of southwestern Puerto Rico are truncated by a WNW trending set of faults.

Recent sediments on the slope south of Puerto Rico are disturbed by tectonic movements. This slope can be segmented into three regions based on seafloor morphology. In the southwest, the shelf varies in width and the slope is cut by numerous canyons. The central region has a broad shelf, south of which lies an easterly trending ridge-trough pair. The southeast region has a very narrow shelf; it slopes steeply into one of three basins south of the Virgin Islands. This basin is part of a network of complex structures primarily composed of uplifted and down-dropped blocks (horsts and grabens) bounded by short-intersecting fault segments. Of the three morphologic regions south of Puerto Rico, the western two appear to be more coherent blocks bounded by long faults. Therefore, these segments are more likely to generate major ($M \simeq 7.8$) earthquakes, albeit with a long repeat time, as faults segments are probably longer than those to the east. These faults may be nearly horizontal, being associated with motion between Puerto Rico and the seafloor of the Caribbean, or at high angles to the horizontal, representing motion with a part of the Puerto Rico block. In the eastern region earthquakes would probably be smaller in size because any falt breaking during a shock is either short or cut by another fault (Mogi, 1969).

The slope south of Saint Croix is markedly different in character than that south of Puerto Rico. It has a relatively uniform slope from the shallow shelf to the flat floor of the Caribbean Sea. Seismic reflections records of this region suggest a more stable environment than that near Puerto Rico, although high sedimentation rates in this region may mask the effects of slow tectonic movements. This margin can be treated as a coherent, relatively stable block, perhaps attached rigidly to the Caribben seafloor. Hence, it is clear that seafloor morphology, suggestive of active faulting south of Puerto Rico, does not continue along the southern flank of Saint Croix. Instead, active faults appear to pass north of that island into the region near the Virgin Islands Basin, passing to the northeast off the east margin of the PRVI platform, and eventually intersecting the Puerto Rico Trench.

Anegada Passage

Steep scarps characterize the margins of the deep Virgin Islands basin, and microearthquakes are found in association with these features (Figure 6). The large earthquake of 1867 presumably ruptured one of the faults along the northern flank of the basin (Reid and Taber, 1920). Reid and Taber (1920) compared the 1918 earthquake (M = 7.5) near northwestern Puerto Rico with the earthquake of 1867. They said: "The two main shocks had about the same intensity and were felt for about the same distance, namely, 500 or 600 kilometers, and the amounts of energy liberated in the two cases were about the same." Based on their report we assign a magnitude of 7.5 to the 1867 earthquake. The largest clusts of microearthquakes, south of Saint Thomas and Vieques, may lie near the fault which broke during that shock. The relatively simple structure of the Virgin Islands basin, being bounded by long fault segments, is a more likely source of strong shocks ($M \approx 7$-8) than the more complex structures to the west. Complex features separate the Virgin Islands Basin from the smaller Saint Croix Basin. At this complex region northeasterly trending faults extending from the Puerto Rico Trench intersect the westerly trending structures characterizing the series of basins between Saint Croix and the PRVI platform. This complex junction of faults is structurally similar to the region west of the Virgin Islands Basin and therefore is likely to pose a similar earthquake hazard.

The prominent, linear features forming the edges of the ridge-trough structures north of the Saint Croix Basin may pose a hazard similar to the major faults of the Virgin Islands Basin. A large shock in 1785, strongly felt in Tortola and the Northern Lesser Antilles to the east, may have occurred on one of these faults, but the location of this shock is very uncertain (Robson, 1964).

Earthquakes and Faults Onland

The bulk of the rocks comprising Puerto Rico and the Virgin Islands were deposited from 110 to 45 million years ago during a period of sustained convergence between the Caribbean and North American plates. During this time period, and the following 20 million years, two major fault systems, the Great Northern and Southern Puerto Rico fault zones were active, displacing rocks on either side in a left-lateral sense (Briggs, 1968, Seiders et al., 1972). These faults, clearly visible today in the morphology of Puerto Rico, extend into submarine areas to the northwest and southeast of the island, may be associated with the formation of the Mona Canyon and Virgin Islands basin, and are the most pominent, inherited zones of weakness in the platform on which Puerto Rico and Virgin Islands lie.

Geologic mapping suggest that little, if any, motion has occurred on these faults in the last 20 million years; none is documented in the last million years. Surprisingly, seismic activity is observed in association with the onland portions of these faults, espeically in Southwest Puerto Rico (Ascencio, 1980). As offshore expressions of these faults appear to be active, some of the onland faults may also be active. The apparent lack of recent faulting observed on land may result from high erosion rates coupled with low rates of slip of the faults. More mapping is needed to carify the relationship between onshore and offshore faults and to identify recent faulting onland if it exists. Nevertheless, most of the recent deformation associated with plate movement appears to occur in the offshore regions. As noted before, deformed sediments and displaced blocks of seafloor are found off all portions of the Puerto Rico-Virgin Islands platform.

Expected Long-term Seismic Activity

The observations presented above provide a tectonic framework in which to estimate the likely sources of strong earthquakes. The conclusions that follow should not be taken as definitive, but they do suggest a high level of hazard for the region; more research is needed to further define the hazard. The spatial distribution of recent seismic activity is remarkably similar for events in the magnitude range 2.0 to 4.0 recorded in the last 10 years and magnitudes 4.0 to 6.0 recorded in the last 30 years. Events during the first half of the century also show a similar pattern, but their locations are less precise (Sykes et al., 1982). Seismic activity is high along limited segments of the Puerto Rico Trench. These active segments are separated by zones of relatively little seismic activity. The relatively long period of time over which this consistent distribution of seismicity is observed (up to 80 years) and the ability to correlate the level of seismic activity with features on the inner wall of the trench strongly sugggests that the distribution of seismicity is not random, but rather is associated with long-term tectonic processes occurring near the plate boundary.

The Mona Canyon region and the Main Ridge are anomalous features that appear to concentrate stress along the major thrust faults in the Puerto Rico Trench. They are presntly seismically active and, because they are stress concentrators, are likely to be sites of large earthquakes ($M \geq 7$) more often than the large, seismically quiet region that separates them. This quiet region is probably the only region near the PRVI Platform capable of producing a great earthquake with a magnitude greater than 8.0. In the eastern, western, and southern regions off the PRVI Platform, some seismic activity correlates with known or suspected submarine faults. Seafloor morphology varies in these regions and therefore the margin can be subdivided into regions based on an apparent density of faulting. Figure 7 is a recent estimate of the long-term seismicity activity for the northeastern Caribbean. Neither figures 7 or 8 should be considered predictions of earthquakes. Figure 7 estimates the likely long-term character of seismicity activity indicating the likely maximum size of an earthquake in a regin, given the tectonic framework provided above.

The main seismic zone in the Puerto Rico Trench is characterized by variations in the expected frequency of moderate and large earthquakes. Those portions of the PRVI Platform interacting with the Main Ridge to the east of Puerto Rico, as well as the feature at the western end of the Puerto Rico trench may be expected to experience relatively short repeat times for moderate and large shocks. The intervening segment of smooth seafloor may tend to be relatively quiescent for shocks of similar magnitudes. This zone of little seismicity, as well as the adjacent active areas is likely to experience great earthquakes with rupture zones about 200 km (?) long and magnitudes about 8 to 8.25 perhaps every 200 years. An example of such an earthquakes is that of 1787. The estimated rupture lengths and magnitudes are probably maximum values, the repeat time is a minimum value. Maximum event size is likely to be limited by the distances between the seismically active areas on the main fault zone ($\sim$ 200 km).

The Mona Canyon west of Puerto Rico as well as the coherent blocks south of west and central Puerto Rico may generate shocks as large as 7.5 to 8.0. A graben southeast of Mona Island and the region south of eastern Puerto Rico and northeast of Saint Croix may generate shocks of magnitude 7.0 to 7.5. The

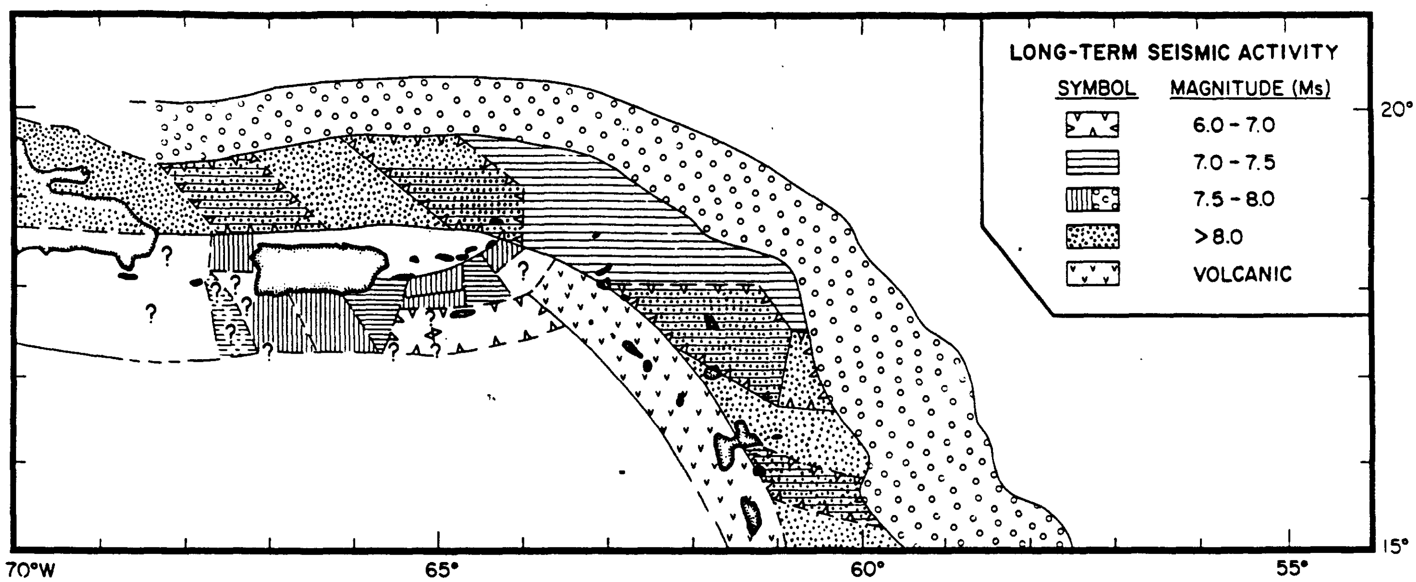


Figure 7. Estimate of long-term seismic activity of shallow focus along the Caribbean - North American plate boundary. Moderate-sized events ($M \simeq 6$-7) are expected to be more frequent along those portions of the seismic zone where bathymetric highs have entered the trench. Large shocks ($M \simeq 7.5$-8.0) may occur occasionally, but with long repeat times (i.e. thousands of years) in the deeper parts of the trench as the North American plate flexes to descend beneath the Caribbean plate. Large shocks can be expected to occur infrequently along the Anegada Passage; events with similar sizes may occur in the region of the Mona Canyon off NW Puerto Rico. Major blocks with some, as of yet poorly defined, seismic potential also exist along the southern flank of Puerto Rico. In total, the region including the Anegada Passage, Muertos-Trough and Mona Passage, but excluding the Puerto Rico Trench, may produce large shocks as frequently as the Puerto Rico Trench. Great shocks ($M \geq 7.75$) may rupture large sections of the fault zone south of the Puerto Rico Trench. The extent of rupture in great events would probably be limited by tectonic barriers such as those that may have delimited rupture during the large shock in 1787. Great shocks may not occur along the plate boundary in the transition region from normal underthrusting to oblique slip, where the Anegada trough intersects the subduction zone. Areas of seismic potential for great shocks appear to exist along the northern Lesser Antilles and to the north of Puerto Rico (from McCann and Sykes, 1984).

relatively large, steep walled Virgin Islands Basin and the linear structures leading to the Puerto Rico Trench from this basin may generate magnitude 7.5 to 8.0 earthquakes. Any given fault segment not on the main plate boundary near the Puerto Rico Trench may produce strong earthquakes every few thousand years rather than hundreds of years. The prominent Mona Canyon and Virgin Islands Basin, having produced shocks in historic times, may be more active than other, more subdued features. The larger number of off-plate boundary faults in this region suggests that, on average one fault may break every few hundred years.

Estimates of Seismic Potential

Estimates of the likelihood that a major fault will experience a large earthquake (seismic potential) can be made by use of the historic record and inferences of the likely sites of future shocks based on regional tectonics. McCann et al. (1979) estimates seismic potential based on the time elapsed since the last large earthquake. Regions of greatest seismic potential are those with the greatest elapsed time since the last large shock. McCann and Sykes (1984) revised those estimates (Figure 8). Better knowledge of the current tectonic deformation will further refine these results. Although more precise determinations of seismic potential can be made in regions with numerous historic or prehistoric events, the general lack of historic detail for this region prohibits the use of such techniques.

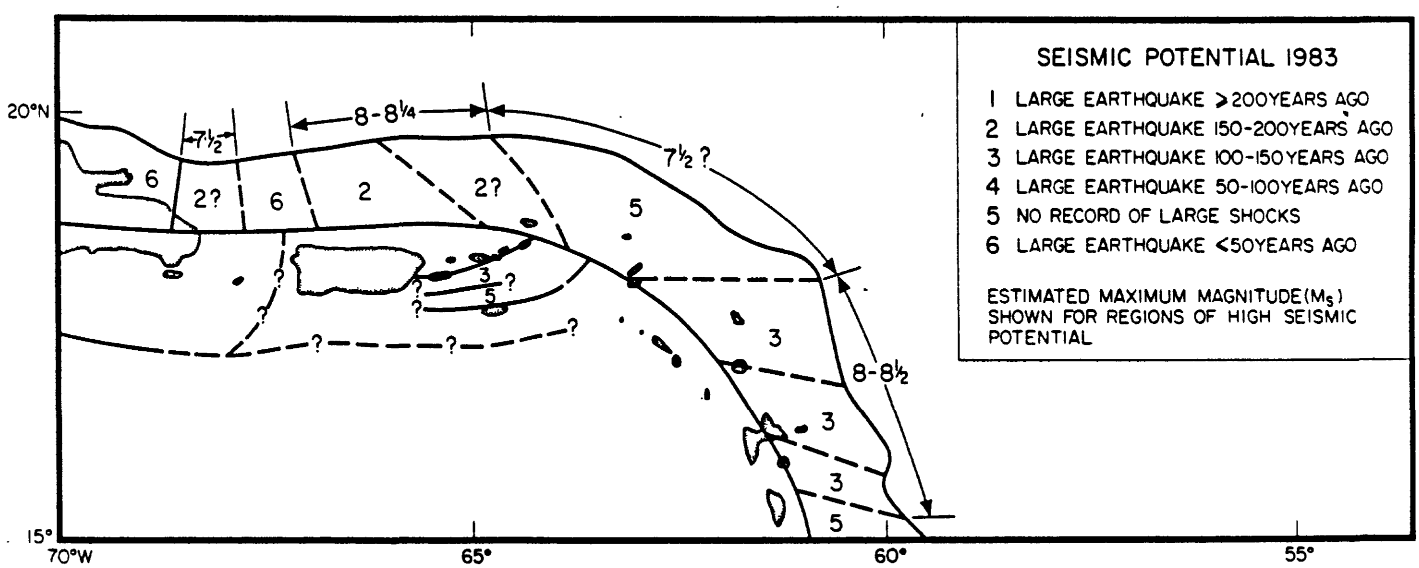


Figure 8. Estimate of seismic potential for the northeastern Caribbean. Potential for large or great shock to occur is estimated by the time elapsed since the last large earthquake. This method assumes repeat times throughout the region are about the same. Magnitudes of future shocks are estimated for those regions of high potential. Question markes (?) denote uncertainty in boundaries of seismic zone or level of seismic potential.

We implicitly assume that the repeat times for shocks of the same size are approximately the same. Whereas this may be true for regions where smooth seafloor abuts the Puerto Rico Trench, those regions interacting with features such as the Main Ridge and the features near the Mona Canyon are likely to have shorter repeat times for significant shocks ($6 < M < 7.5$). Most of the regions off the main plate boundary (i.e. Puerto Rico Trench) appear not to have experienced a large shock in historic times. The two that have, the Mona Canyon and the Virgin Islands Basin are the largest, most prominent features. Hence, because of a lack of historic information, it is probably too early to extend the seismic potential analysis, intended for more simple structures, into all of this region.

McCann et al. (1979) placed the Puerto Rico-Virgin Islands region in a neutral category for seismic potential. At that time it was not clear that this region was capable of producing large interplate shocks. Now with better understanding to the tectonic structure of the region, and with a more complete historic record, it is clear that this region does have the potential to produce strong and great earthquakes.

CONCLUSION

The earthquake of 1787 appears to have originated in the Puerto Rico Trench, 50 to 100 kilometers to the north of the islands. While the probable magnitude of this event ($M = 8 - 8.25$) makes this shock the largest in the historic record, more damaging quakes of somewhat smaller magnitude ($M = 7 - 8$) occurred much closer to land (10-50 km). A major shock on one of the many faults nearer to the islands may, on average, occur just as frequently as the great earthquakes in the Puerto Rico Trench. The main earthquake hazard in this region, therefore, may come not from great earthquakes to the north, but rather from major ones occurring closer to land.

The information collected in the last decade has clarified our understanding of the nature of the seismic zone near Puerto Rico and the Virgin Islands. Numerous active faults are located in the offshore region; some may extend onshore. The framework developed here represents a plausible working hypothesis for the evaluation of the earthquake hazard of the region. More research is needed to validate this hypothesis. Identification and detailed mapping of active faults, focal mechanisms and more precise locations of small earthquakes, more detailed investigations of the historic record and collection of geodetic data are a few of the areas of research deserving expanded effort.

ACKNOWLEDGEMENTS

Sincere thanks are expressed to Gerardo Suarez and Lynn Sykes for their comments on the manuscript and to Walter Hays and the workshop steering committee for inviting me to this conference. This research, supported by contract #21233 with the U.S. Geological Survey, is Lamont-Doherty Geological Observatory contribution no. 3675.

REFERENCES

Anonymous, Seismicity Investigation, 1972, Aguirre Nuclear Plant Site, Puerto Rico Water Resources Authority Amendment #11 to preliminary facility description and safety analysis report, Aguirre Plant #1, US AEC Docket #50-376.

Asencio, E., 1980, Western Puerto Rico seismicity, U.S. Geological Survey Open-file Report 80-192, 135 p.

Beach, D. and Trumbull, J., 1981, Marine geologic map of the Puerto Rico insular shelf, Isla Caja de Muertos area, U.S. Geological Survey Miscellaneous Investigation Series, Map I-1265.

Briggs, R., 1968, Large- and small-scale wrench faulting in an island-arc segment, Puerto Rico, Geological Society of America, Abstracts for 1967, p. 24.

Dart, R., Tarr, A., Carver, D., and Wharton, M., 1980. Puerto Rico seismic network data report of eathquakes located by the programs HYPO71 and HYPOELLIPSE July 1, 1975 - December 31, 1977, Geological Survey Circular 821.

Fischer, K. and McCann, W., 1984, Velocity modeling and earthquake relocation in the northeast Caribbean, Bulletin of the Seismological Society of America, v. 74, no. 4.

Frankel, A., McCann, W., and Murphy, A., 1980, Observations from a seismic network in the Virgin Islands region: Tectonic structures and earthquake swarms, Journal of Geophysical Research, v. 85, 2669-2678.

Frankel, A., 1982, A composite focal mechanism for microearthquakes along the northeastern border of the Caribbean plate, Geophysical Research Letter, 9, 511-514.

Garrison, L., 1972, Acoustic-reflection profiles - Eastern Greater Antilles, U.S. Geological Survey 72-004, 18 p.

Iniguez, H., Acosta, R., and Vicaino, J., 1975, Relacion de sismos ocurridos en la Isla de Santo Domingo, (1551-1975) UASD Sant Domingo, Dominican Republic, 45 p.

Kelleher, J., Sykes, L., and Oliver, J., 1973, Possible criteria for predicting earthquake locations and their applications to major plate boundaries of the Pacific and the Caribbean, Journal of Geophysical Research, 78, 2547.

McCann, W., Nishenko, S., Sykes, L., and Kraus, J., 1979, Seismic gaps and plate tectonics: Seismic potential for major plate boundaries, Pure and Applied Geophysics, 117, 1083.

McCann, W. and Sykes, L., 1984, Subduction of aseismic ridges beneath the Caribbean plate: Implications for the tectonics and seismic potential of the northeastern Caribbean, Journal of Geophysical Research, in press.

Minster, J. B. and Jordan, T., 1978, Present-day plate motions, Journal of Geophysical Research, 83, 5331-5354.

Mogi, K., 1969, Relationship between the occurrence of great earthquakes and tectonic structures, Bulletin of Earthquake Research Institute, 47, 429-451.

Molnar, P. and Sykes, L., 1969, Tectonics of the Caribbean and Middle America regions from focal mechanisms and seismicity, Bulletin of Geological Society of America, 80, 1639.

Murphy, A. and McCann, W., 1979, Preliminary results from a new seismic network in the nrotheastern Caribbean, Bulletin of the Seismological Society of America, 69, 1497-1514.

Reid, H. and Taber, S., 1919, The Puerto Rico earthquakes of October-November 1918, Bulletin of Seismological Society of America, 9, 95-127.

Reid, H. and Taber, S., 1920, The Virgin Islands earthquakes of 1867-1868, Bulletin of the Seismological Society of America, 10, 9-30.

Robson, G., 1964, An earthquake catalog for the eastern Caribbean 1530-1960, Bulletin of the Seismological Society of America, 54, 785-832.

Rodriguez, R., Trumbull, J., and Dellon, W., 1977, Marine geologic map of Isla de Mona area, Puerto Rico, U.S. Geological Survey Miscellaneous Investigation Series, Map I-1063.

Schell, B. and Tarr, A., 1978, Plate tectonics of the northeastern Caribbean Sea region, Geologie en Mijnbouw, 57, 139.

Seiders, V., Briggs, R., and Glover III, L., 1972, Geologiy of Isla Desecho, Puerto Rico, with notes on the Great Southern Puerto Rico fault zone and Quarternary stillstands of the sea, U.S. Geological Survey Professional Paper 739, Washington, D.C., 22 p.

Sykes, L. and Ewing, M., 1965, The seismicity fo the Caribbean region, Journal of Geophysical Research, 70, 5065-5074.

Sykes, L., McCann, W. R., and Kafka, A., 1982, Motion of Caribbean plate during last seven million years and implications for earlier Cenozoic movements, Journal of Geophysical Research, 87, 10656-10676.

Trumbull, J., 1981, Oceanographic data off Puerto Rico and the Virgin Islands, LBL Publication #360, Berkeley, CA.

EVALUATION OF THE EARTHQUAKE GROUND-SHAKING HAZARD

by

Walter W. Hays
U.S. Geological Survey
Reston, Virginia

INTRODUCTION

This paper describes current research that can be applied to evaluate the earthquake ground-shaking hazard in a region. Because most of the spectacular damage that takes place during an earthquake is caused by partial or total collapse of buildings as a result of ground shaking or the triggering of geologic effects such as ground failures and surface faulting, an accurate evaluation of the ground-shaking hazard is an important element of: 1) vulnerability studies, 2) specification of seismic design parameters for earthquake-resistant design of buildings, lifeline systems, and critical facilities, 3) the assessment of risk (chance of loss), and 4) the specifications of appropriate building codes. Although the physics of ground shaking, a term used to describe the vibration of the ground during an earthquake, is complex, ground shaking can be explained in terms of body waves (compressional, or P, and shear, or S) and surface waves (Rayleigh and Love) (See figure 1). Body and surface waves cause the ground, and consequently a building and its contents and attachments, to vibrate in a complex manner. Shear waves, which cause a building to vibrate from side to side, are the most damaging waves because buildings are more susceptible to horizontal vibrations than to vertical vibrations.

The objective of earthquake-resistant design is to construct a building so that it can withstand the vibrations caused by body and surface waves. In earthquake-resistant design, knowledge of the amplitude, frequency composition, and time duration of the vibrations is needed. These quantities are determined empirically from strong motion accelerograms recorded in the geographic area or in other areas having similar geologic characteristics.

In addition to ground shaking, the occurrence of earthquake-induced ground failures, surface faulting, and for coastal locations, tsunamis must also be considered. Although ground failures induced during earthquakes have caused many thousands of casualties and millions of dollars in property damage throughout the world, the impact in the United States has been limited, primarily to economic loss. During the 1964 Prince William Sound, Alaska, earthquake, ground failures caused about 60% of the estimated $500 million dollars total loss; and landslides, lateral spread failures, and flow failures caused damage to highways, railway grades, bridges, docks, ports, warehouses, and single family dwellings. In contrast to ground failures, deaths and injuries from surface faulting are unlikely; however, buildings and lifeline systems located in the fault zone can be severely damaged. Tsunamis, long Period water waves caused by the sudden vertical movement of a large area of the sea floor during an earthquake, have produced great destruction and loss

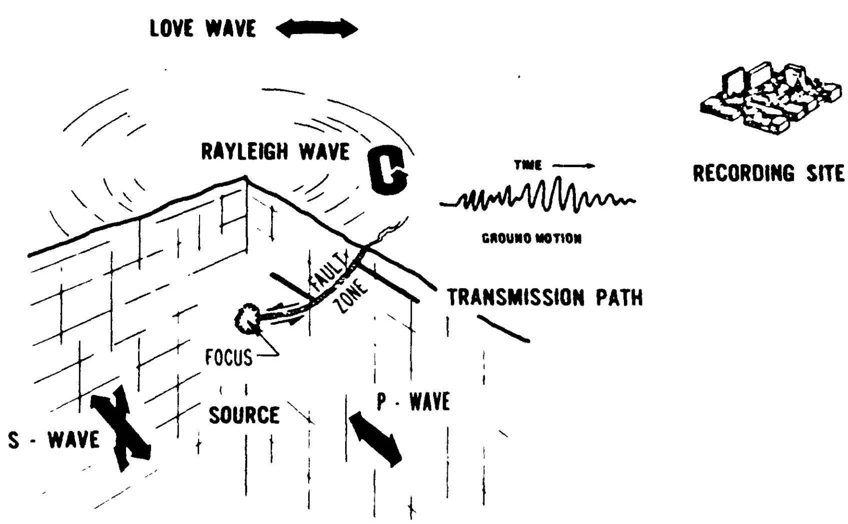


Figure 1.--Schematic illustration of the directions of vibration caused by body and surface seismic waves generated during an earthquake. When a fault ruptures, seismic waves are propagated in all directions, causing the ground to vibrate at frequency ranging from 0.1 to 30 Hertz. Buildings vibrate as a consequence of the ground shaking and damage takes place if the building is not designed to withstand these vibrations. P and S waves mainly cause high-frequency (greater than 1 Hertz) virbrations which are more efficient in causing low buildings to vibrate. Rayleigh and Love waves mainly cause low-frequency vibrations which are more efficient than high-frequency waves in causing tall buildings to vibrate.

of life in Hawaii and along the west coast of the United States. Tsunamis have occurred in the past and are a definite threat in the Caribbean. Historically, tsunamis have not been a threat on the East coast.

EVALUATION OF THE GROUND-SHAKING HAZARD

No standard methodology exists for evaluating the ground-shaking hazard in a region. The methodology that is used (whether deterministic or probablistic) seeks answers to the following questions:

1) Where have past earthquakes occurred? Where are they occurring now?
2) Why are they occurring?
3) How big are the earthquakes?
4) How often do they occur?
5) What are the physical characteristics (amplitude, frequency composition, duration) of the ground-shaking and the physical effects on buildings and other facilities?
6) What are the options for achieving earthquake-resistant design?

The ground-shaking hazard for a community (see Figure 2) may be presented in a map format. Such a map displays the special variation and relative severity of a physical parameter such as peak ground acceleration. The map provides a basis for dividing a region into geographic regions or zones, each having a similar relative severity or response throughout its extent to earthquake ground-shaking. Once the potential effects of ground shaking have been defined for all zones in a region, public policy can be devised to mitigate its effects through appropriate actions such as: avoidance, land-use Planning, engineering design, and distribution of losses through insurance (Hays, 1981). Each of these mitigation strategies requires some sort of zoning (see Figure 2). The most familiar earthquake zoning map is contained in the Uniform Building Code whose aim is to provide a minimum earthquake-resistant design standard that will enable the building to:

1) Resist minor earthquakes without damage,
2) Resist moderate earthquakes without structural damage, but with some nonstructural damage, and

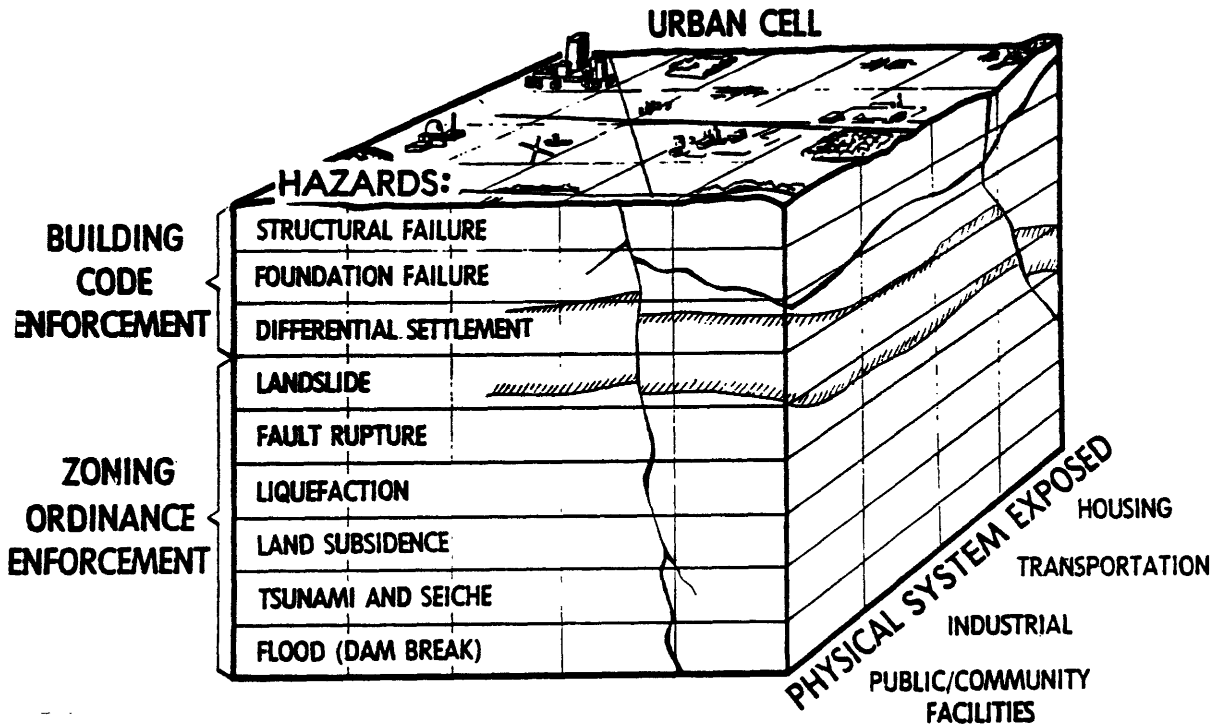


Figure 2.--Schematic illustration of a typical community having physical systems (public/community facilities, industrial, transportation, and housing) exposed to earthquake hazards. Evaluation of the earthquake hazards provides policymakers with a sound physical basis for choosing mitigation strategies such as: avoidance, land-use planning, engineering design, and distribution of losses through insurance. Earthquake zoning maps are used in the implementation of each strategy, especially for building codes.

3) Resist major earthquakes with structural and nonstructural damage but, without collapse.

HISTORY OF SEISMIC ZONING

Zoning of the earthquake ground-shaking hazard--the division of a region into geographic areas having a similar relative severity or response to ground shaking--has been a goal in the contiguous United States for about fifty years. During this period, two types of ground-shaking hazard maps have been constructed. The first type (Figure 3) summarizes the empirical observations of past earthquake effects and makes the assumption that, except for scaling differences, approximately the same physical effects will occur in future earthquakes. The second type (Figures 4-5) utilizes probabilistic concepts

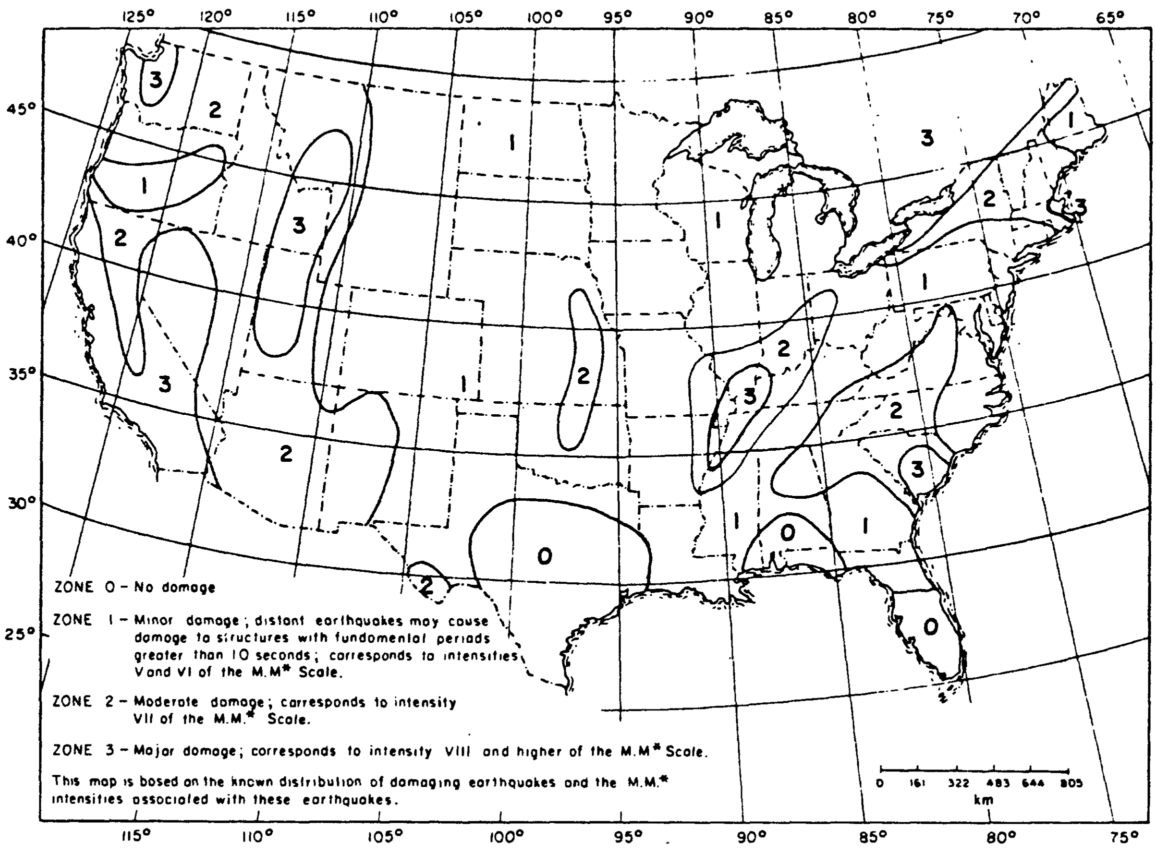


Figure 3.--Seismic hazard zones based on historical Modified Mercalli intensity data and the distribution of damaging earthquakes (Algermissen, 1969). This map was adopted in the 1970 edition of the Uniform Building Code and incorporated, with some modifications, in later editions. Zone 3 depicts the greatest hazard and corresponds to VIII and greater.

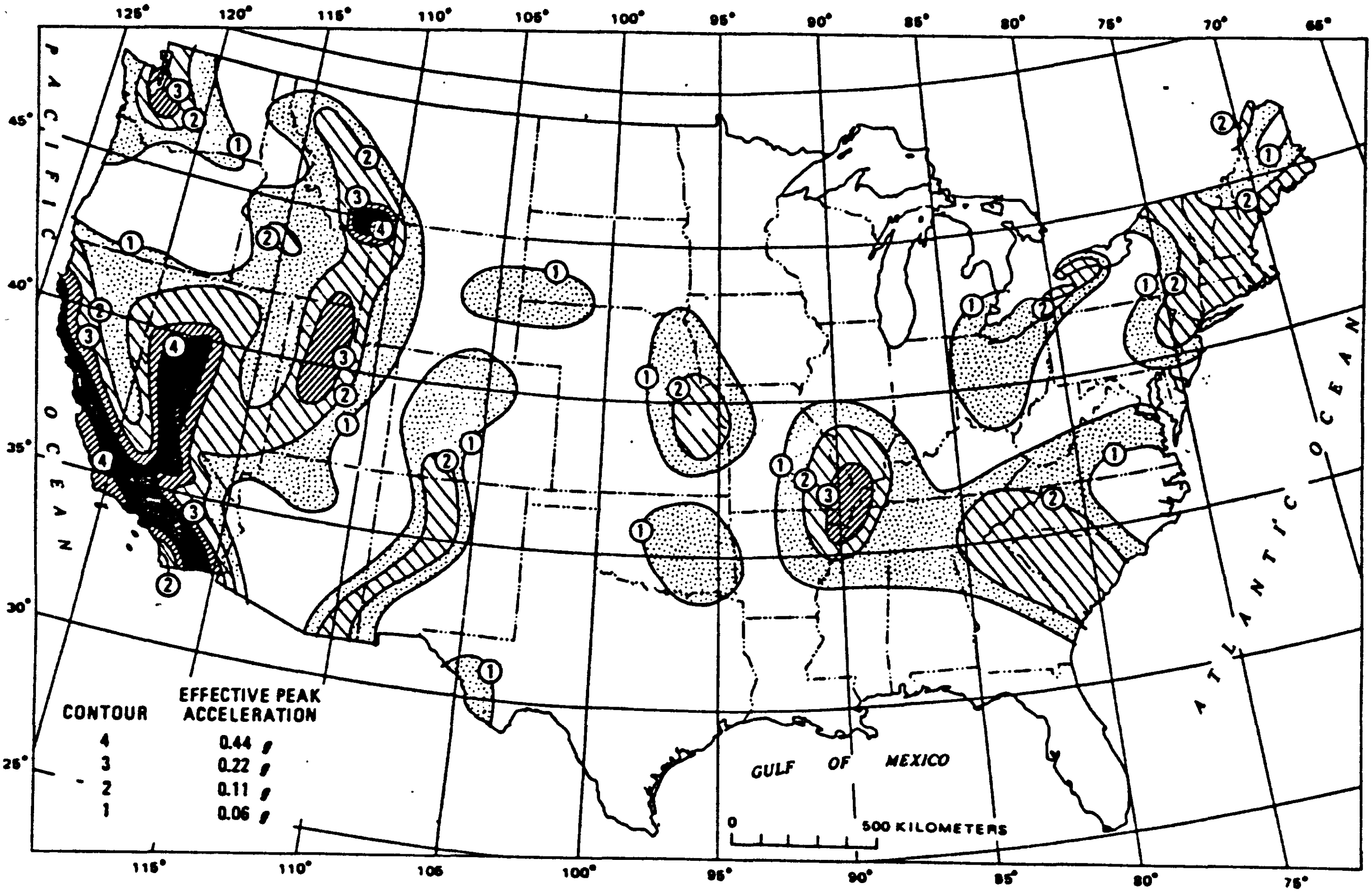


Figure 4.--Map showing preliminary design regionalization zones for the contiguous United States proposed by the Applied Technology Council in 1978 for its model building code. Contours connect areas underlain by rock having equal values of effective peak acceleration. Mapped values have a 90 percent probability of not being exceeded in a 50 year period. Zone 4 depicts the greatest ground-shaking hazard (0.44 g or greater) and Zone 1 represents the lowest hazard (0.06 g). Sites located in Zone 4 require site-specific investigations. This map was based on research by Algermissen and Perkins (1976).

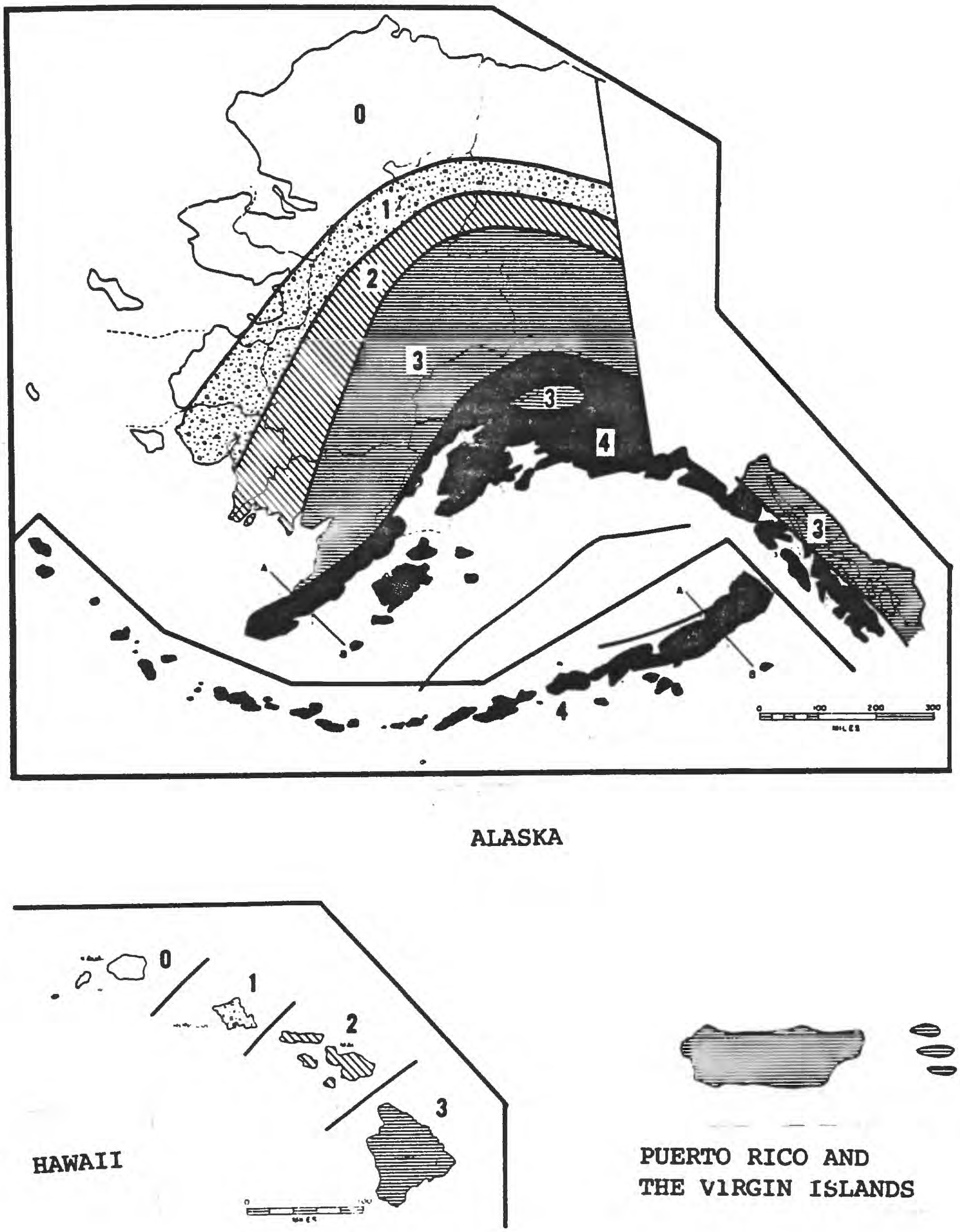


Figure 5.--Map showing preliminary zones of the ground-shaking hazard in Alaska, Hawaii, Puerto Rico, and the Virgin Islands. Puerto Rico and the Virgin Islands lie in zone 3; indicating the requirement for a peak acceleration of about 0.20 g. These maps can be improved with additional research.

and extrapolates from regions having past earthquakes as well as from regions having potential earthquake sources, expressing the hazard in terms of either exposure time or return period.

PROCEDURE FOR EVALUATING THE GROUND-SHAKING HAZARD

Construction of a ground-shaking hazard map requires data on:

1) seismicity,
2) earthquake source zones,
3) attenuation of peak acceleration, and
4) local ground response.

The procedure for constructing a ground-shaking hazard map is illustrated schematically in Figure 6. Except for probabilistic considerations a deterministic map would follow the same general procedure.

RESEARCH PROBLEMS

A number of complicated research problems are involved in the evaluation of the ground-shaking hazard (Hays, 1980). These problems must be addressed if more accurate specifications of the ground-shaking hazard are desired. The problems can be catagorized in four general areas, with each area having a wide range of technical issues. The following representative questions, which generally can not be answered with a simple "yes" or "no", illustrate the controversy associated with ground-shaking hazard maps.

1) Seismicity

- Can catalogs of instrumentally recorded and felt earthquakes (usually representing a regional scale and a short time interval) be used to give a precise specification of the frequency of occurrence of major earthquakes on a local scale?

- Can the seismic cycle of individual fault systems be determined accurately and, if so, can the exact position in the cycle be identified?

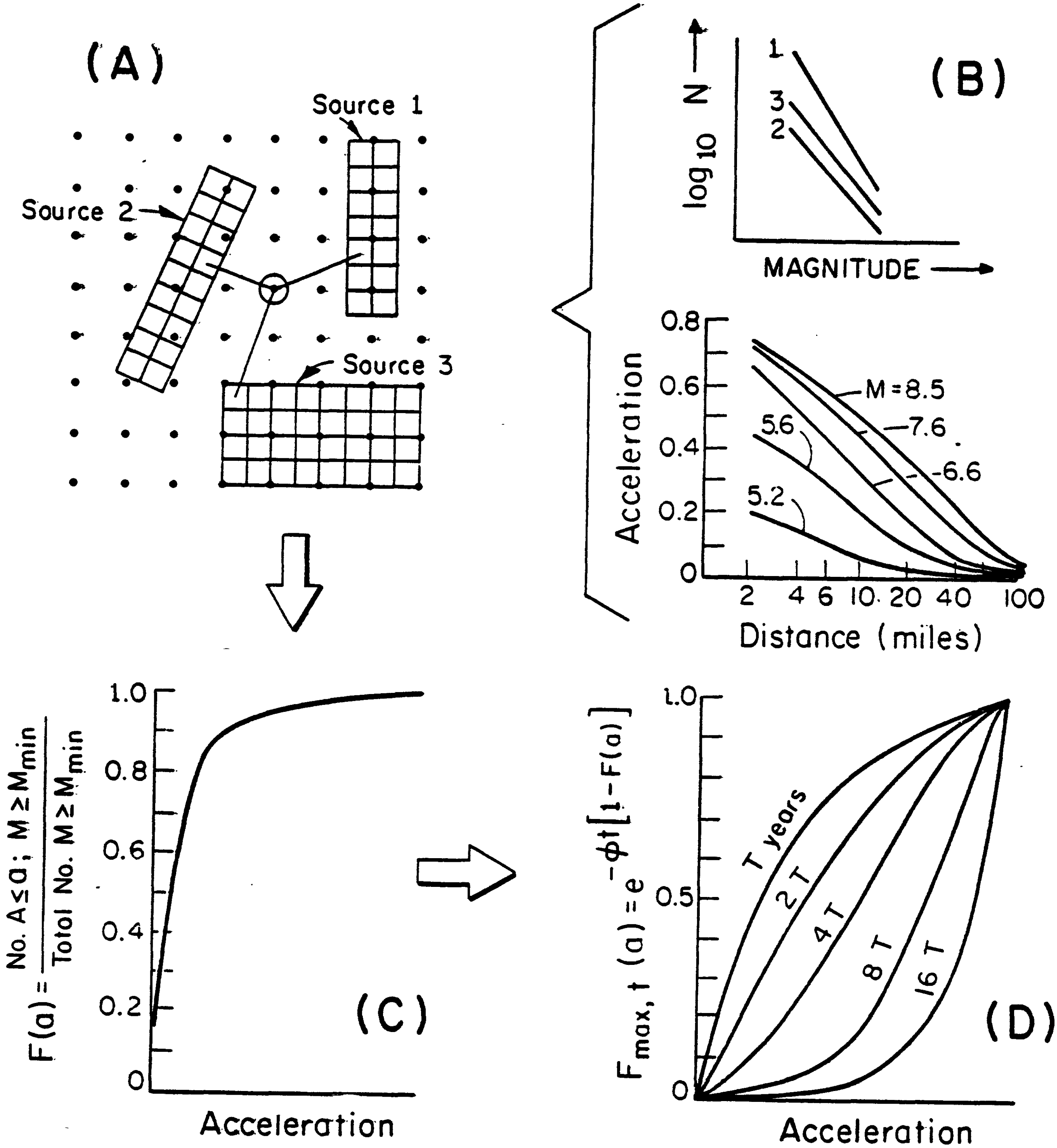


Figure 6.--Schematic illustration of the procedure for constructing a probabilistic ground-shaking hazard map. Inset A shows 3 typical seismic source zones and the grid of points at which the ground-shaking hazard is calculated. Inset B shows typical statistical distributions of historical seismicity for the 3 seismic source zones and an acceleration attenuation function for the region. Inset C depicts a typical cumulative probability distribution of ground acceleration at a selected site in the grid. Inset D shows the extreme probability for various levels of ground acceleration and exposure times, T, at the selected site. A contour map is created from values obtained in inset D.

- Can the location and magnitude of the largest earthquake that is physically possible on an individual fault system or in a seismotectonic province be specified accurately? Can the recurrence of this event be specified? Can the frequency of occurrence of small earthquakes be specified?

- Can seismic gaps (i.e. locations having a noticeable lack of earthquake activity surrounded by locations having activity) be identified and their earthquake potential evaluated accurately

- Does the geologic evidence for the occurrence of major tectonic episodes in the geologic past and the evidence provided by current and historic patterns of seismicity in a geographic region agree? If not, can these two sets of data be reconciled?

2) <u>The Nature of the Earthquake Source Zone</u>

- Can seismic source zones be defined accurately on the basis of historic seismicity; on the basis of geology and tectonics; on the basis of historical seismicity generalized by geologic and tectonic data? Which approach is most accurate for use in deterministic studies? Which approach is most accurate for use in probabilistic studies?

- Can the magnitude of the largest earthquake expected to occur in a given period of time on a particular fault system or in a seismic source zone be estimated correctly?

- Has the region experienced its maximum or upper-bound earthquake?

- Should the physical effects of important earthquake source parameters such as stress drop and seismic moment be quantified and incorporated in earthquake-resistant design, even though they are not traditionally used?

3) <u>Seismic Wave Attenuation</u>

- Can the complex details of the earthquake fault rupture (e.g., rupture dimensions, fault type, fault offset, fault slip velocity) be modeled to give precise estimates of the amplitude and frequency characteristics of ground motion both close to the fault and far from the fault?

- Do peak ground-motion parameters (e.g., peak acceleration) saturate at large magnitudes?

- Are the data basis adequate for defining bedrock attenuation laws? Are they adequate for defining soil attenuation laws?

(4) Local Ground Response

- For specific soil types is there a discrete range of peak ground-motion values and levels of dynamic shear strain for which the ground response is repeatable and essentially linear? Under what in-situ conditions do non-linear effects dominate?

- Can the two- and three-dimensional variation of selected physical properties (e.g., thickness, lithology, geometry, water content, shear-wave velocity, and density) be modelled accurately? Under what physical conditions do one or more of these physical properties control the spatial variation, the duration, and the amplitude and frequency composition of ground response in a geographic region?

- Does the uncertainty associated with the response of a soil and rock column vary with magnitude?

CONCLUSIONS

Improved maps of the earthquake ground-shaking hazard will come as relevant geologic and seismological data are collected and synthesized. The key to progress will be the resolution of the research problems identified above.

REFERENCES

Algermissen, S. T., (1969), Seismic risk studies in the United States:World Conference on Earthquake Engineering, 4th, Santiago, Chile, Proc., v. 1, 14 p.

Algermissen, S. T. and Perkins, D. M., (1976), A probabilistic estimate of maximum acceleration in rock in the contiguous United States: U.S. Geol. Survey Open-File Rept. 76-416, 45 p.

Applied Technology Council, (1978), Tentative provisions for the development of seismic regulations for buildings, ATC-3-06, 514 p.

Hays, W. W., (1980), Procedures for estimating earthquake ground motions: U.S. Geol. Survey Prof. Paper 1114, 77 p.

Hays, W. W., (1981), Facing geologic and hydrologic hazards-earth science considerations: U.S. Geol. Survey Prof. Paper 1240-B, 108 p.

CUSTOM MADE MICROCOMPUTER SEISMIC ACQUISITION AND DISPLAY SYSTEM FOR THE CAYEY OBSERVATORY

by

Modesto Iriarte,
Jose E. Hernandez Betancourt
and
Walter Cedeno
Center for Energy and Environment Research
San Juan, Puerto Rico

INTRODUCTION

In March 1982 engineers of the Center for Energy and Environment Research (CEER) began studying the possibility of replacing the 20-channel develocorder at the Cayey Seismic Observatory with a digital data acquisition system.

Under the develocorder system the data was recorded on a 48-hour film. This film was anlyzed at CEER at Rio Piedras using a film viewer. The analyst must locate and evaluate seismic and nonseismic activity from the film using a millimeter rule. He should pick from the screen the P- and S- waves arrival times with a precision of 0.05 seconds. It takes too much time looking at the film to find an event and pick all the necessary information to locate the event. Some of this information is: P- and S- arrival time, first motion weight and direction, coda duration, hour, and minutes for the event. The analyst then writes the information in a file using the editor and executes the following programs:

1) PREP - This program will find a trial hypocenter using four stations from the data.

2) HYPOINVERSE - This program takes the trial hypocenter found by PREP to find the final location using all the data.

From this solution, the analyst must determine if the location and the error residuals in the solution of the describing equations of the stations are good enough. In case the residuals are too large, the event must be repicked in order to reduce them and repeat the program.

CUSTOM MADE SYSTEM

With the advent of the low cost microcomputers the above functions could be performed more efficiently by digitizing the data and recording only the events on a magnetic tape. The equipment manufactured by Kinemetrics, Inc. of Pasadena, California, and others was studied and evaluated for this purpose. Finally, it was decided to build a custom-made system with the collaboration of Lamont-Dohergy Geological Observatory (LDGO), patterned after their Alaska and Virgin Islands systems.

The system would consist of a 32-channel, 12 bit analog to digital converter connected to three central Intel ISBC 80 Single Board Computer units, each with 4K bytes of RAM and 4K bytes of ROM. Also, it would have a 512K memory board, 32 antialias filters on 80 column printer, a video terminal, a digital magnetic tape recorder, and an analog event detection system. Procurement of components began in June 1982. This equipment will be located in Cayey.

The tapes recorded at Cayey would be taken to CEER at Río Piedras to be processed on a digital computer especially acquired for this purpose and for other research work in its idle time. Several popular microcomputers were considered, among them: IBM, Apple, Olivetti, Radio Shack, and Commodore Pet. They were discarded because of great limitations. Digital Equipment's PDP 11/23 was finally chosen for this work because it was a proven computer that underbid other similar minicomputers. This unit was finally placed in operation by the Digital in July 1983.

Delivery of equipment for the Cayey station began in August 1982. The first to arrive, the Zenith Z-19 Video Terminal, was tested and it soon developed a malfunction that was traced to a defective keyboard encoder which was replaced. The Epson printer also arrived in defective condition and had to be troubleshooted before it could be placed in operation.

Meanwhile, Dr. Ray Buland from the U.S. Geological Survey (USGS) at Denver, Colorado, visited CEER and installed the hypocenter inversion program on the Administration of Regional Colleges PDP-10 computer. Thus, CEER personnel could start processing a backlog of develocorder films. They were read on a Teledyne Geotech Film Viewer loaned by the USGS.

Field installation of the digital data acquisition system at Cayey was completed between April 27 and May 22, 1983, by Eng. David Lentrichia of Lamont Doherty Geological Observatory. A sample magnetic tape recorded by the Alaska microseismic network system was originally used at CEER to develop the software to read and display the tapes on the video terminal fo the PDP 11/23 computer. Unsuccessful attempts were made by others to read the Alaskan tape in the DEC 10 computer at the Regional Colleges Administration. A Digi-Data Model 174 tape transport was installed afterward and interfaced by CEER personnel on the PDP 11/23 computer. Use of Fortran software routines supplied by Digital proved unsuccessful in reading the tapes.

Success in tape reading was finally achieved by using the Operating System's Magnetic Tape Control Task. This had the disadvantage that the tape had to be read outside of the Fortran program that would perform the rest of the operations necessary for displaying the tape on the video terminal. However, it furnished a starting point for developing needed software.

It should be mentioned that Lamont Doherty has the software required to read and process the tapes. However, it is in the Celanguage for use with a Unix Operating System. CEER computer has an RSX-11M Operating System with a Fortran compiler. Meanwhile a Venix operating system (Unix version) and an additional Winchester disk drive have been ordered for implementation of the LDGO software at CEER.

The output of the CEER recently developed program is displayed on the VT-100 Video Terminal of the PDP 11/23 computer. To be able to do this, CEER engineers had to upgrade the terminal with a Matrox GT-600 Graphics Board. The board generated new difficulties which had to be resolved by CEER engineers. The problem was further complicated by the software drivers Pan, Scroll and Zoom which proved to be unsuitable for the large volumes of data processing. New programming had to be developed.

The first attempt to display a magnetic tape file on the screen was disheartening. It seemed that the reading of the data and displaying the curves would take forever. To speed up the program all the floating point operations were replaced by fixed point operations. Since this was not enough, Macroassembler Fortran-callable subroutines were developed for the critical parts of the program. After the first assembler subroutines were programmed, the program ran nine times faster. Encouraged by this improvement, further programming in assembler was performed until the program was running 65 times faster than the orinal Fortran program.

Additional time was gained by preparing an assembler subroutines to plot only the maximum and minumum values of those samples whose x-coordinate could be resolved by the video terminal. Programming the different modes of operation of the system followed. A way had to be found for moving efficiently forward and backward seismic files in time. To do this, the sample READ operations were changed from sequential to direct access.

To expand and contract the image, a subroutine labeled "Change Baseline Seconds" was developed. It enables to vary the time period of the baselines from 0.03 seconds to 320 seconds.

By this time, a set of Macro and Fortran subroutines, running under RSX-11M, was received from Dr. Ray Buland of USGS at Golden, Colorado. One of these subroutines made possible the reading of the magnetic tape from the Fortran program. This eliminated the disadvantage of having to read the tape outside of the program.

PRESENT CAPABILITY

At present, CEER has the following programs running under the RSX-11M system:

1) TPREAD - Fortran program to read the tape and identify a status block from a data file. It writes the file number, number of records and time of the first time mark that appears in a data file.

2) MKHDR - This program reads a status block and writes in an output file the number of active channels and the corresponding number of the channels.

3) CAT22 - Fortran program to display the data of a possible event with different options in order to pick the necessary information needed to locate the event using PREP and HYPOINV.

These programs permit the analyst to pick the P- and S-arrival times with a precision of 0.01 seconds. In this way the analyst can locate the event and relocate it very easily if the residuals are large.

When the Venix Operating System arrives, new programs will be prepared to minimize the analysts' work, improve the precision of the event location and increase the speed of the whole process. For this purpose, it is within CEER plans to use programs similar to the ones employed by Lamont Doherty Geological Observatory. These programs, with some modifications for the Puerto Rico network are:

1) TPREAD - The same as the one explained above.

2) OKPLOT - Program to see the first 60 seconds of the data and determine if it is an event.

3) DMUX - Program to demultiplex the data in the file in order to increase the speed of the program that plots the signals.

4) PICK - This program is the most important one and is used to plot the demultiplexed data to obtain the information necessary to locate the event. This information will include the details explained earlier, plus the amplitude of the greatest wave, first period of the P-wave and other information in order to increase the clarity in the description of the event.

5) LOCATE - Program to output the final locations of the hypocenters on a map with marks to differentiate the magnitudes of the events.

With the tape recording system, less time is lost trying to find an event and most of the work is concentrated in determining with precision the hypocenter of the event. This kind of program will help in the process of data analysis in order to give a better description of the seismic events in the proximity of Puerto Rico.

All the recorded seismic data by the new system has been processed through February 29, 1984. March 1984 data is now being processed. However, because of widespread interest in the March 19, 1984, seismic event, priority was given to the processing of this event. This event was calculated to be of magnitude 4.2 occurring north of the city of Fajardo, latitude 18 degrees 50.44 minutes, longitude 65 degrees 39.13 minutes at a depth of 15.66 km. Event was detected to have began at 12 hours 15 minutes 3.39 seconds on March 19, 1984. Figure 1 shows a plot and summary of the computer output.

CONCLUSION

In conclusion, it can be stated that CEER has recently contributed to the art of seismic data processing using low-cost minicomputers such as the PDP 11/23 DEC. This is the smallest and lowest cost computer of DEC LSI 11 bus series. This will be of great advantage to smaller institutions in the Caribbean which cannot afford purchasing large and costly computer systems.

CEER further intends, if funds can be made available, to undertake a new project for developing seismic data processing software systems by using still lower cost microcomputers such as IBM PC compatibles or Motorola 68,000 microcomputer systems such as Apple McIntosh. This was the original idea at CEER which was abandoned at a time when the 16 bit computer systems were just coming into the commercial market.

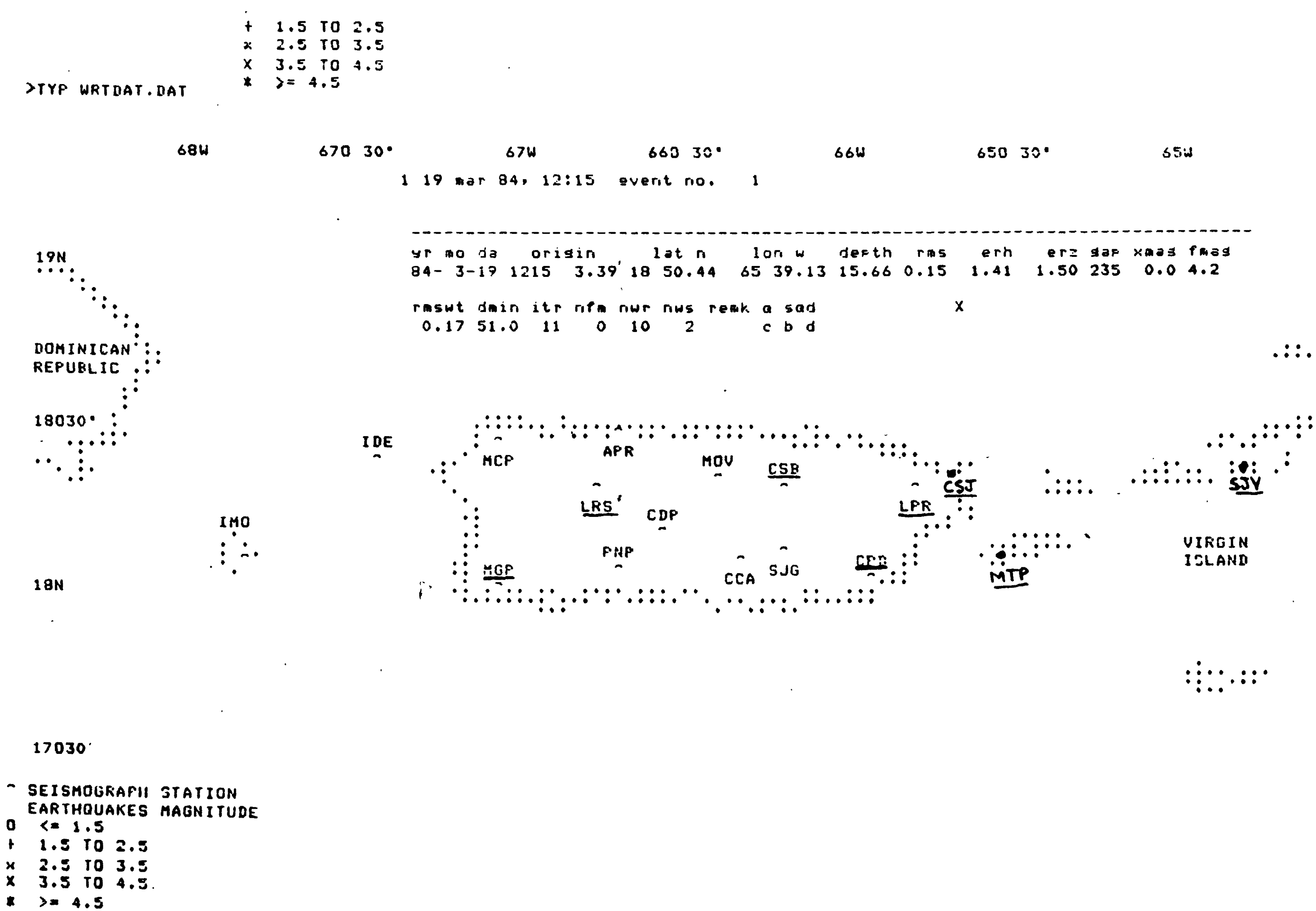


Figure 1. Plot and summary of the computer output.

RAPID MASS MOVEMENTS AS A GEOLOGIC HAZARD IN PUERTO RICO

by

Jose Molinelli
University of Puerto Rico
Mayaguez, Puert Rico

INTRODUCTION

Mass movements are the downslope movement of geologic materials under the direct influence of gravity. This geomorphic process becomes a geologic hazard when it can endanger life and property. Every year thousands of human lives are lost or affected by the rapid movement of large masses of rock and earth.

Rapid mass movements occur mostly in association with protracted periods of rain and earthquakes. In January 22, 1967, in Sierra Das Araras in southern Brazil an intense rainfall caused thousands of landslides that were accompanied by severe flooding that claimed the life of 1,700 people (1). A similar catastrophe was the 1969 flooding and associated debris flow caused by hurricane Camille in central Virginia. Of the 150 people that died in the event a substantial percentage were killed by mass movements (2).

Rapid mass movements triggered by earthquakes are one of the most potentially hazardous geologic event. The tremor is sudden and usually occurs with little or no warning. One of the greatest disasters in world history occurred in wind deposited silts (loess) in the Kansu province in China in 1920. More than 200,000 people were killed when the loess collapsed to the earthquake vibrations. More recently in 1970 an earthquake magnitude 7.75 with epicenter off the coast of Peru triggered a debris avalanche that descended on the slopes of Mt. Huascaran at an average speed of 320 km/hr (200 mph). The village of Ranrahirca and Yungay were buried and more than 18,000 people lost their lives.

FORCES PRODUCING INSTABILITY

Slope stability depends on the interaction between the forces that tend to move the geologic materials downslope (shear stress) and those that resist the movement (shear strength). Mass movements occur when the shear stresses exceeds the shear resistance.

In general terms the stability of a slope is defined by a safety factor F where:

$$F = \frac{\text{shear strength}}{\text{shear stress}}$$

When the shear stress is greater than the shear strength a mass movement takes place. Several factors can increase or decrease the shear forces at a particular slope site. Factors leading to an increase in shear stress that control the downslope force are:

1) Hillslope gradient: It determines the downslope component of the soil weight ($W \sin \theta$) which acts to shear the soil along the potential surface of sliding.

2) Removal of lateral or underlying support: Is caused by geomorphic processes such as undercutting by stream and wave action as well as the weathering of weaker strata at the toe of slopes. Cuts, excavations, and the draining of lakes or reservoirs are manmade factors that can generate unstable slope conditions.

3) Loading of the upper end of the slope: Overloading is generally associated with construction activities especially roads and residential developments in steep areas. Here the material removed from the cut is side cast into the lower slope as fill material to widen the road bed. In addition overloading is frequently caused by the placement of buildings, houses, dumps, and spoil heaps in potentially unstable locations.

4) Vibrations generated by earthquakes: Earthquakes produce horizontal ground accelerations that increase the shear stress or driving moment of the geologic materials. If the slope is close to the point of failure, these additional pulsating stresses can cause slope movement (3). Studies conducted by Simonett in the Bewani and Torricelli Mountains in New Guinea showed that most landslides are generated by large earthquakes. The number of slides decreased away from the epicenter following a logarithmic function (4).

Factors that control the shear strength

1) The nature of the geologic materials: rock type and structure (joints, faults, dip, basal surface of weathering), and the nature of the weathering products.

2) Weathering changes: weathering reduces the effective cohesion and lowers the angle of shear resistance.

3) High pore water pressures: high pore water pressure is generally caused by long and intense periods of precipitation from water pipes, septic tanks, canals, etc. In addition, when some geologic materials such as silt, clay, and loose sand are subjected to a high level of cyclic stresses, high pore water pressure can be generated resulting in liquefaction.

MASS MOVEMENT CLASSIFICATION

Several classifications are available in the geologic and engineering literature. The most complete being the one developed by Varnes is presented here (5).

In general slope movements are classified according to the type of movement and materials. The types of movements are falls, topples, slides (rotational and translational), lateral spreads, flows and complex. The materials are classified into bedrock, debris and earth. The system is simple to use and very useful because it combines different materials with different mass movement types. Thus a rotatinal slide can be a rock slump, debris slump or earth slump.

The most hazardous of these are translational slides and flows. The large translational component of these movements results in the destruction of life and property on their path. The zones affected by mass movement hazards include not only potentially unstable geologic materials but the valley slopes, terraces, and floodplains where the material can finally come to rest.

FACTORS THAT AFFECT THE DISTRIBUTION OF MASS MOVEMENTS IN PUERTO RICO

Mass movements take place when the shear stress exceeds the shear resistances. Delimitation of areas susceptible to mass movements requires the spatial delineation of slopes whose factor of safety (F) can be lowered by events such as earthquakes and rainfalls. In Puerto Rico unstable areas are related to rock type and its weathering characteristics, terrain steepness and man activities.

The island of Puerto Rico consists of a central, mountanous upland composed of volcanic and intrusive rocks together with sedimentary rock of Early Cretaceous to Eocene age. The central upland is surrounded to the north and south by a belt of middle Tertiary age limestone. The coastal plains are mainly depositional environments composed of sand, gravel, and clay. These make up Quaternary age beach, swamp, dunes, alluvial plain and fan deposits (6).

The intense chemical weathering processes characteristic of the humid tropics transform the geologic materials affecting their shear strength (7). Most of the materials derived from the volcanoes of andesitic composition weathers into a highly resistant red clay of low erodibility. These areas are of moderate susceptibility to landsliding.

The weathering of plutonic intrusive rocks produces a sandy regolith characterized by the abundance of corestones. They are likely to move downhill during earthquakes and intense rains. In addition unstable slopes are produced when a sharp basal surface of weathering is exposed in cuts and excavations. The limestones are characterized by a strong tendency to develop underground drainage systems. They are formed by the dissolving action of acid rain upon the limestone. Underground caves are enlarged to a point where the cave roof cannot hold its own weight collapsing under the actions of gravity or when triggered by earthquakes and intense rainfalls. In spite of its solubility limestone is very stable. When the rock is exposed to the direct actions of rain the calcium carbonate is dissolved and rapidly precipitates again over the surface reducing its solubility and hardening the slope (8).

The distribution of landslides and areas susceptible to these movements have been mapped by Monrose. In general mass movement susceptibility is related to terrain steepness. The most susceptible areas are characterized by slopes 50 percent while areas of low susceptibility are nearly flat on underlain by stable slightly weathered rock.

Monroe found that the areas of highest susceptibility are those where the Lares Limestone Formation underlies the unstable, clayey San Sebastian Formation at the contact between the sedimentaries and the volcanics. Similar slides but of smaller magnitude occur to the north where the Aguada limestone overlies the clayey Cibao limestone. In addition areas where deeply weathered volcanic are underlain by intrusive rocks in northeastern Puerto Rico are very unstable.

Areas classified as moderate susceptibility dominates the central mountainous upland. In general they are stable under most circumstances except where slopes are steepened by excavations and cuts.

Man has become an important geomorphic agent in Puerto Rico. The number of potentially unstable areas have increased as man incremented its power to moify the surface of the Earth. Thus, man has become an important factor contributing to the hazardousness of mass movements. Areas of moderate susceptibility to slides can become very unstable when roads and houses are constructed mainly due to undercutting, slope steepening and overloading. This is a common phenomena specially along roadside the central upland. The conditions are worsened when cuts and excavations are made in naturally unstable terrains. This is the case of a cut built on deeply weathered hydrothermally altered clay material along Puerto Rico 52 southeast of Cayey. In addition when fill slopes are placed on ground water discharge areas, high pore water presures are produced within the fillreducing its stability (e.g. Puerto Rico 52 Beatriz section, between Caguas and Cayey). Eventually the fills could fail and slide downhill onto the valley floor if subjected to strong vibratory stresses caused by an earthquake.

It is concluded that mass movements have the potential to cause severe damages to life and property in Puerto Rico. To reduce the hazard it is necessary to understand the spatial and temporal distribution of the factors that affect slope stability. In this way land use planning can properly zone and regulate man's activities in hazardous areas.

REFERENCES (Numbers are cited in text)

1) Jones, F. O., 1973, Landslides of Río de Janeiro and the Serra das Araras escarpment, Brazil, U.S. Geological Survey Professional Paper 697, 42 pp.

2) Williams, G. P., and Guy, H. P., 1973, Erosional and despositional aspects of hurricane Camille in Virginia, 1969, U.S. Geological Survey Professional Paper 804, 80 pp.

3) Sangrey, D. A., 1972, Changes in strength of soils under earthquake and other repeated loading in Earthquake Engineering (Cherry, S., ed.), Proceedings of 1st Canadian Conference on Earthquake Engineering, University of British Columbia, Vancouver, pp. 82-96.

4) Simonett, D. S., 1967, Landslide distribution and earthquakes in the Bewani and Torricelli Mountains, New Guinea. In: J. N. Jennings and J. A. Mabbutt (eds.), Landform Studies from Australia and New Guinea, University Press Cambridge.

5) Varnes, D. J., 1978, Slope movement types and processes, In: Schuster, L. R., Krizek, J. R. (eds.), Landslides: Analysis and Control Special Report 176, TRB, NRC, National Academy of Sciences, Washington, D.C.

6) Briggs, R. P., and Akers, J. P., 1965, Hydrogeologic map of Puerto Rico and adjacent islands: U.S. Geological Survey Hydrologic Inv. Atlas HA-197.

7) Thomas, F. M., 1974, Weathering processes and products, Chapter 1, In: Tropical Geomorphology, Macmillan Press LTD.

8) Monroe, W. H., 1976, The Karst landforms of Puerto Rico: U.S. Geological Survey Professional Paper 899, 69 p.

9) Monrose, W. H., 1979, Map showing landslides and areas of susceptibility to landsliding in Puerto Rico: Miscellaneous Investigations Series Map I-1148.

VULNERABILITY OF MANMADE STRUCTURES TO EARTHQUAKES AND GROUND FAILURE

by

Bernardo Deschapelles
University of Puerto Rico
Hato Rey, Puerto Rico

INTRODUCTION

The response of a structure to earthquake ground motions depends to a large extent on how close the dominant period of vibration in the soil motion and the fundamental period of vibration of the structure are when both are subjected to seismic excitation. If both periods are equal, resonance phenomena cause large amplifications of acceleration in the upper part of the structure. Therefore, the evaluation of both these periods is of great importance in the prediction of structural response to a prescribed ground motion.

If the motion at some specific location underlain by rock is registered by appropriate instruments, (i.e., an accelerograph) no matter how erratic it may appear, a Fourier analysis can be performed on the obtained data to assess its frequency content and to determine the dominant period of the motion. It has been found that this value increases with the earthquake magnitude. Also, and very importantly, the propagation of seismic waves through rock formations is known to be accompanied by an increase in the dominant period of the motion. In other words, the propagation of earthquake waves through the Earth's mantle implies attenuation of kinematic parameters and filtering of high frequency components.

VULNERABILITY CONSIDERATIONS

In relation with a manmade structure, the squared value of its natural period of vibration is inversely proportional to its lateral stiffness and directly proportional to its mass. Pertinent calculation can be achieved using standard numerical procedures of structural dynamics.

Observed damage after an earthquake has confirmed the relationship between building vulnerability and the ratio obtained dividing the natural period of vibration of the structure by the dominant period of the soil motion under its foundation. The 1972 Managua, Nicaragua, earthquake had its epicenter relatively close to the city and the dominant period of soil motion under the building was rather short, similar to the natural period of vibration of one-story buildings. Accordingly, these buildings had a very strong response, many of them to the point of collapse, and since they formed the vast majority of the city structures, the overall effect was one of widespread destruction. Two tall concrete buildings in the city downtown, having a much longer period of vibration, suffered some structural damage but did not collapse.

An inverse situation occurred in the 1967 Caracas, Venezuela, earthquake. In this case, the epicenter was located in the Caribbean Sea, relatively far away from Caracas and some filtering of high frequency components of the earthquake waves took place before they hit the city. Moreover, local soil conditions at the building site further modified the frequency content of the motion because deep soft soil formations tend to increase even more the dominant period of the motion. In the zone of the Caracas valley known as Los Palos Grandes the alluvium stratum reaches a depth on the order of 300 feet. Accordingly, in that part of the city the soil motion at the Earth's surface had a rather long dominant period, on the order of 1.2 seconds, very close to the natural period of vibration corresponding to buildings in the range of 10 to 15 stories. Several buildings having this dynamic characteristic suffered collapse immediately, while taller and lower buildings withstood the seismic action. No widespread destruction took place in the city after the event and serious damage was mainly restricted to the zone having deep soft soil deposits and buildings of 10-15 stories.

It should be emphasized that the vulnerability arising from the aforementioned resonance phenomena does not lead necessarily to structural failure. However, because of the stronger building response, the lateral load analysis should be performed using higher values for the horizontal loads that simulate the seismic inertia forces. This situation is taken into account in current building codes by means of a soil amplification factor, S.

It is important to observe that a building period of vibration, T_1, close to but below the dominant period of the earthquake motion, T_s, represents a more vulnerable condition than the case a building whose period of vibration is equally close to T_s but larger than it, that is, $T_2 > T_s$ and $T_s - T_1 = T_2 - T_s$. The reason for this is that a strong building response causes some stiffness deterioration leading to an increased period of vibration. If $T_2 > T_s$, then T_2 increments takes the building away from the resonance danger, opposite to what occurs in the other case, when $T_1 < T_s$.

Strong response of a structure cannot be economically maintained within the elastic range of behavior of typical construction materials. This fact is implicitly admitted in all building codes and implies that the structure must develop large plastic deformations without a significant decrease in its ultimate strength. Accordingly, ductility is an essential characteristic for adequate resistance to a major seismic event. While some structural materials like mild steel and wood have constitutive ductility, other materials like concrete and stone tend to fail in a brittle form. Judicious use of reinforcing bars can transform the concrete into a reasonably ductile material. Lack of the appropriate technology for achieving ductile behavior in the concrete, both in design and construction phases, leads to structures extremely vulnerable to strong earthquake motions. In some instances, the interior integrity of the structure is not destroyed by its seismic response but the soil underneath the foundation fails, causing a rigid body movement of the building. A typical example of this problem is represented by the so-called soil liquefaction, which occurs when the earthquake motions cause an increase in pore water pressure in saturated cohesionless materials and lead to an effect similar to a quicksand condition. In the 1967 Niigata, Japan, earthquake some buildings experienced a severe tilting due to loss of bearing capacity in the supporting granular soil. In other cases, the cohesionless soil maintains its bearing capacity but settles significantly due to the compaction effect caused by the ground vibrations. If the soil mass directly below the structure does not settle uniformly, differential vertical displacements in the structure are usually responsible for heavy damage.

However, in general terms, the most vulnerable condition for a manmade structure is its inability to develop ductile behavior rather than the possibility of local soil failures because the former situation leads to a type of catastrophic collapse not usually encountered when soil properties are altered by seismic action.

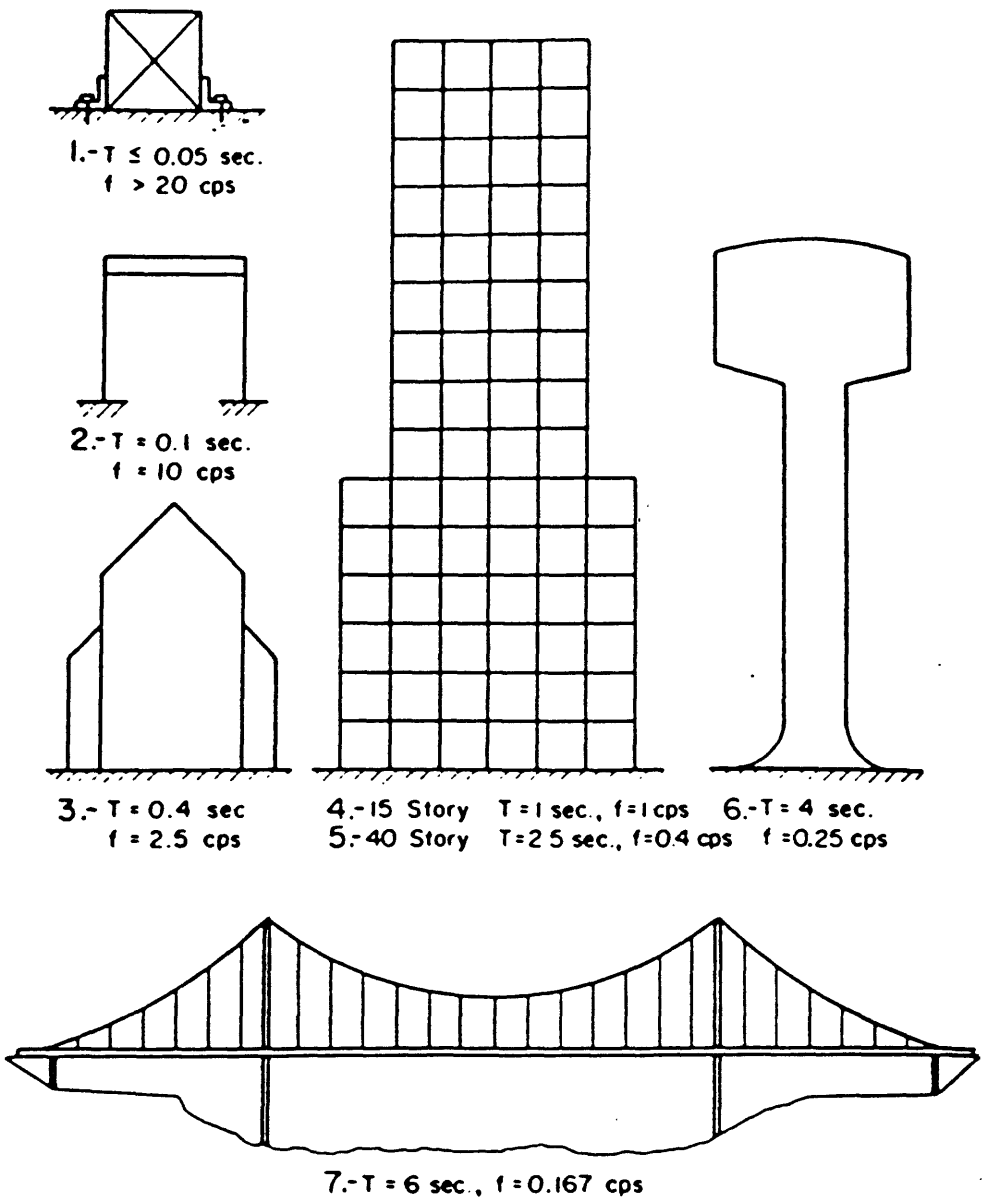


Figure 1. Schematic illustration of various types of structures subjected to earthquake ground motions. Each type of structure has a fundamental period of vibration.

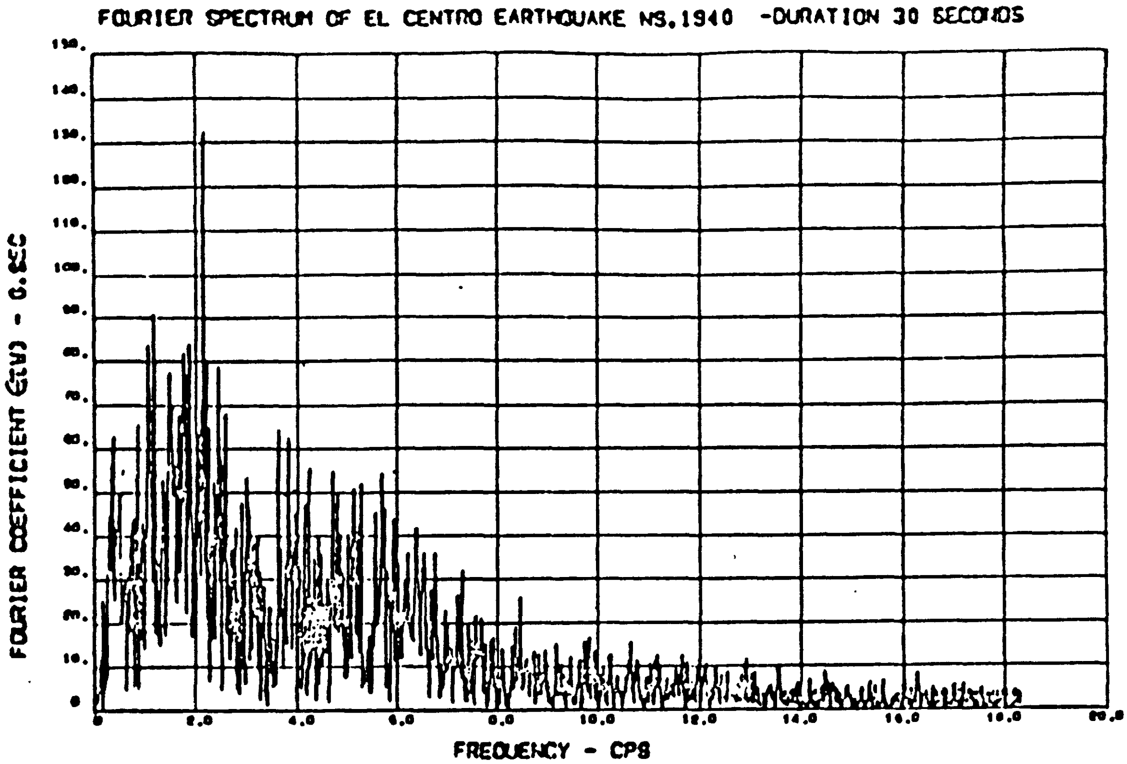


Figure 2. Fourier spectrum of 1940 El Centro earthquake ground acceleration.

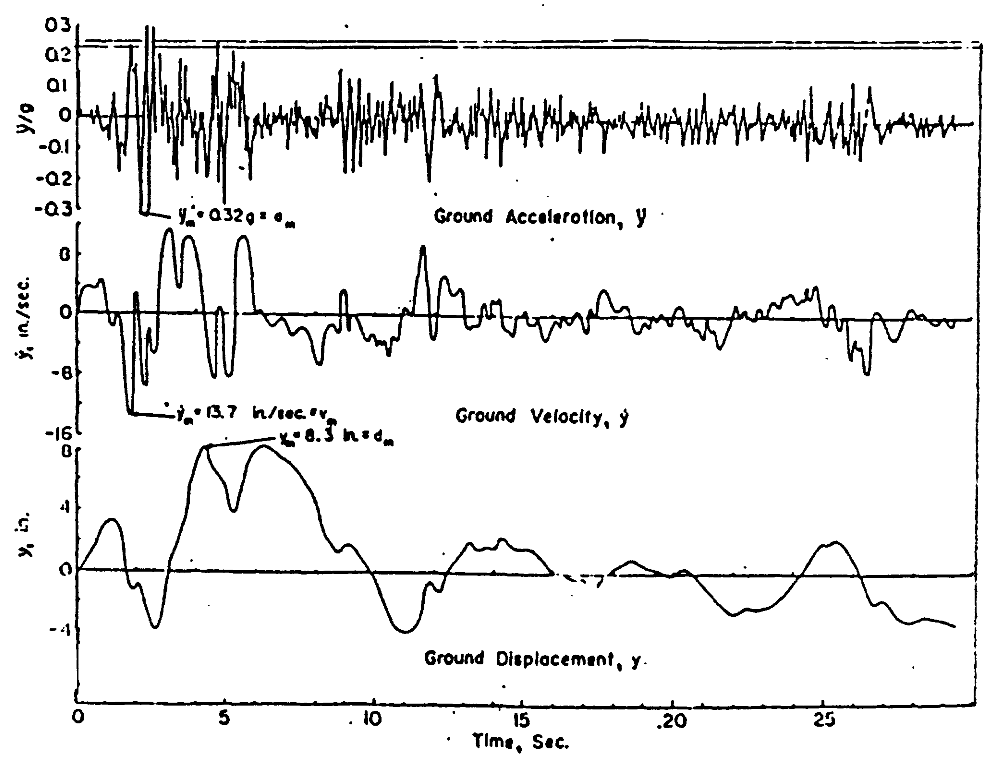


Figure 3. El Centro, California, earthquake of May 18, 1940, NS component

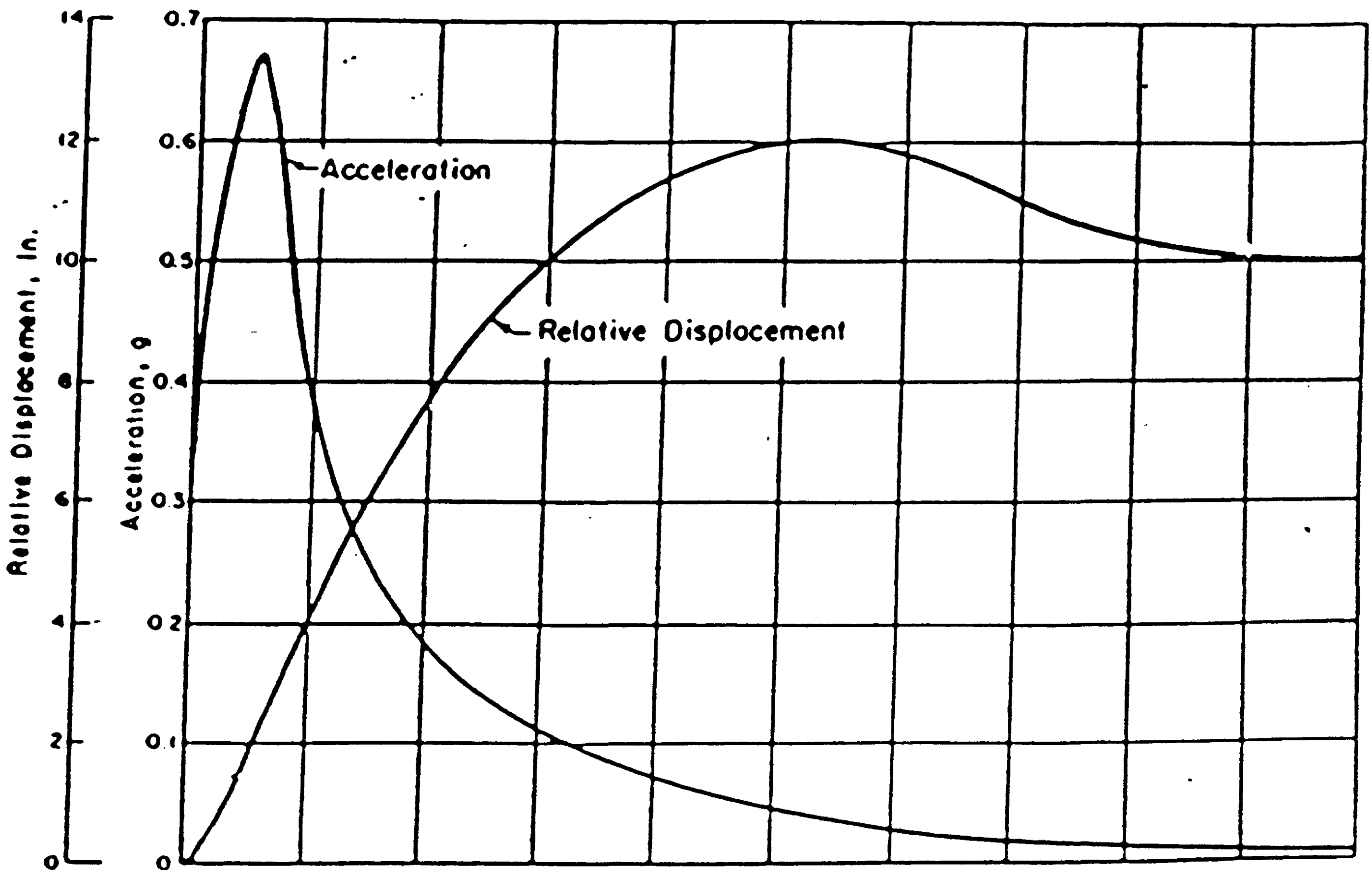


Figure 4. Arithmetic plots of response

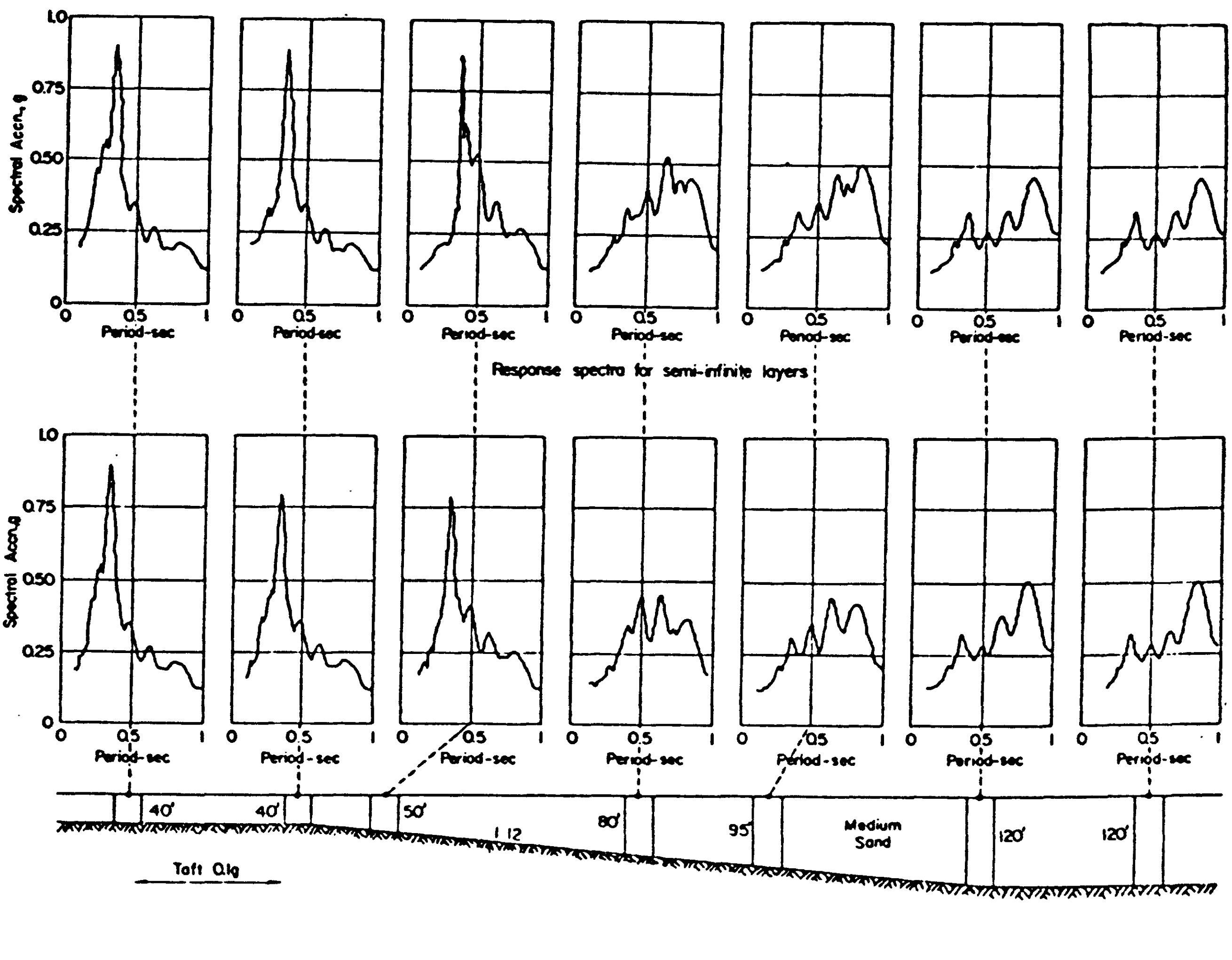


Figure 5. Comparison of frequency distributions at surfaces of soil columns within a deposit underlain by sloping rock surface with those for corresponding semi-infinite layers. (From Dezfulian[1], H., A.M. ASCE, and H. Bolton, Seed,[2] M. ASCE, in Journal of Soil Mechanics and Foundations Div., Proceedings of the Am. Soc. of Civil Eng., 1970.)

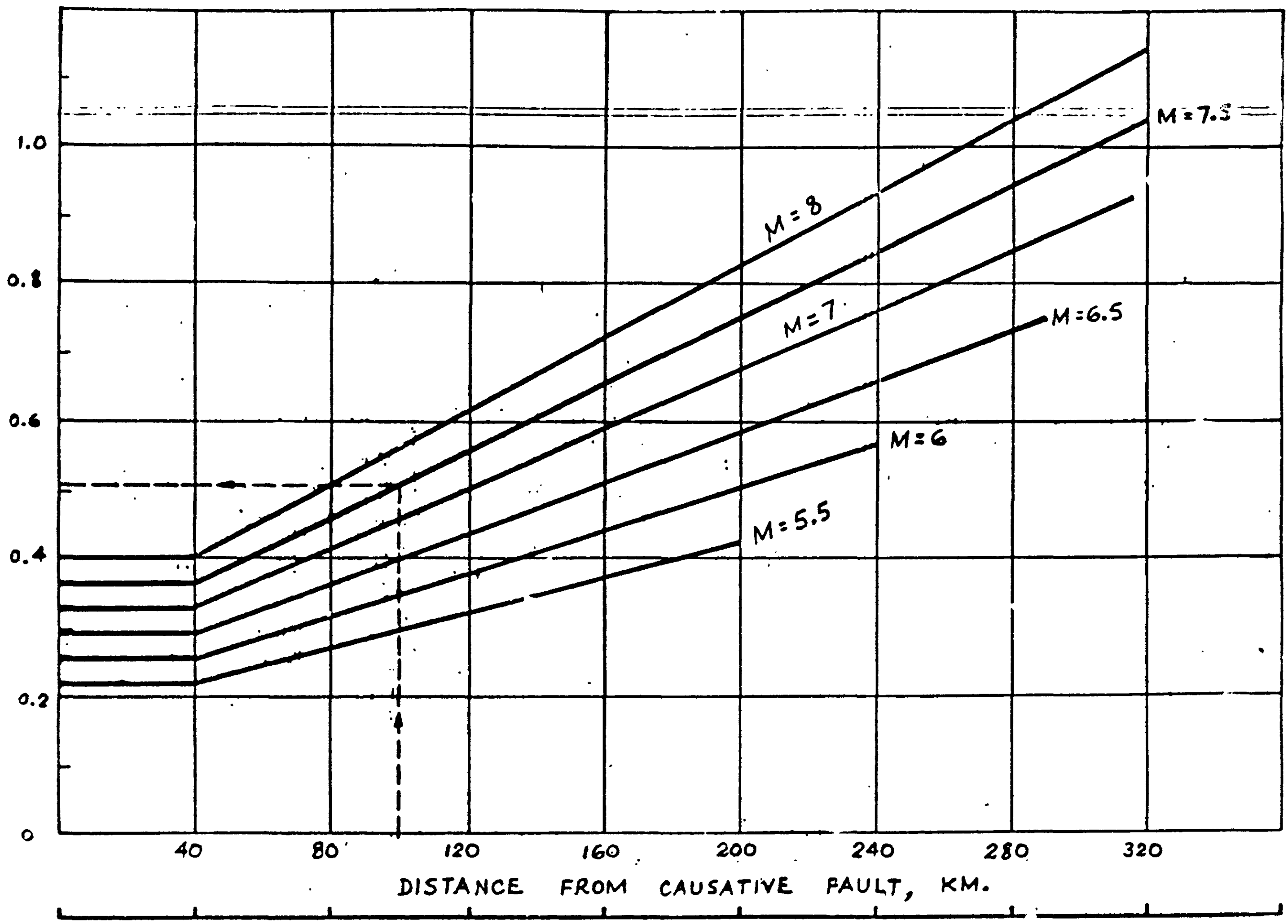
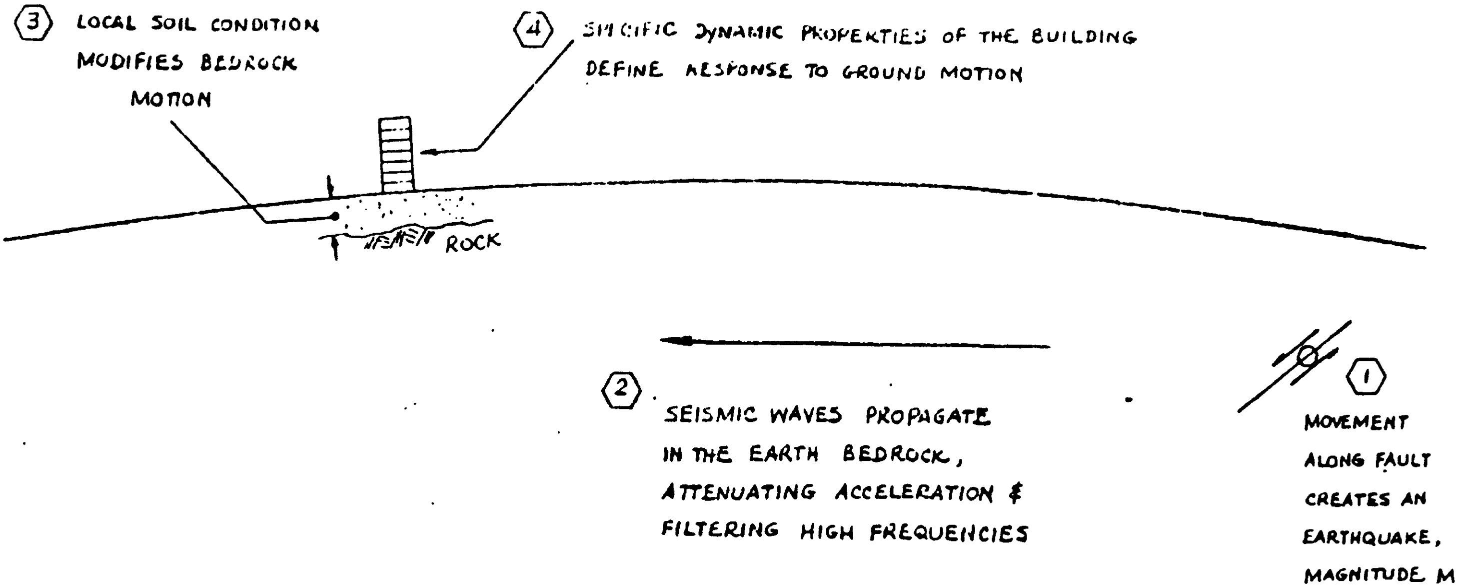


Figure 6. Predominant period for seismic motions in rock.



Parameters 1 & 2 (Seismology)--Considered when defining the building design earthquake spectrum.

Parameter 3 (Soil Mechanics)--Considered when defining the building design earthquake spectrum.

Parameter 4 (Structural Dynamics)--Model analysis and spectrum response to estimate building inertia forces.

Figure 7. Parameters involved in seismic design.

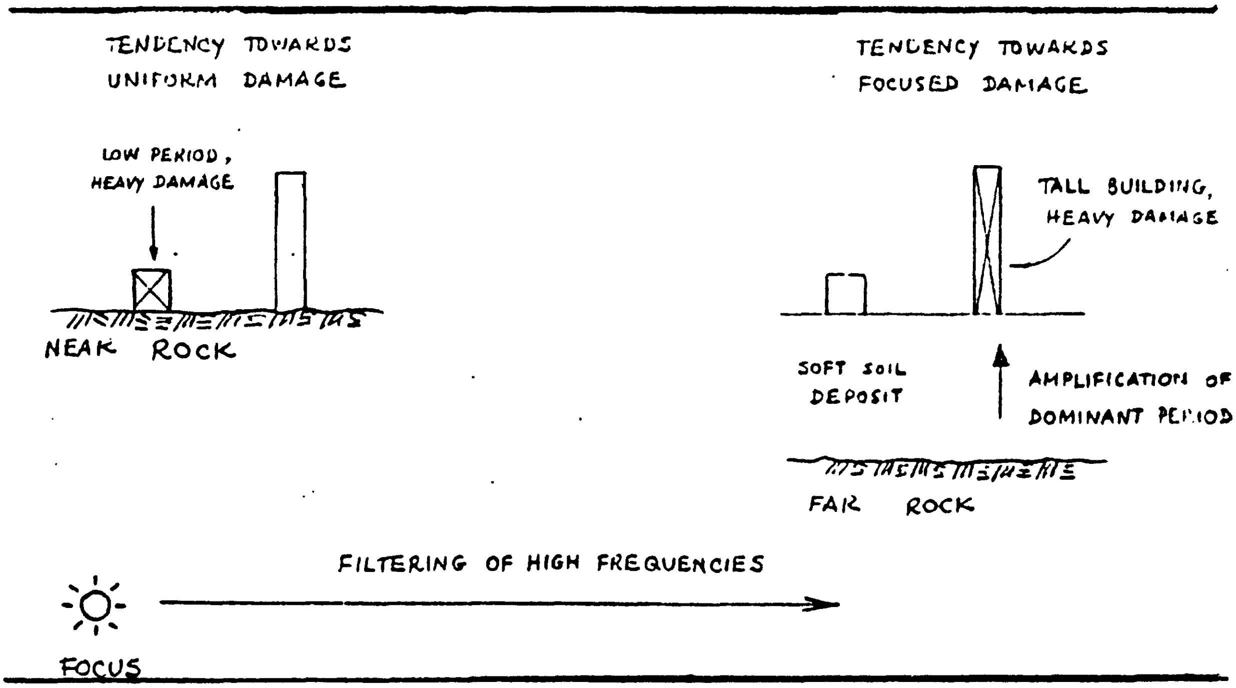


Figure 8. Schematic effect of epicentral distance and soil amplification.

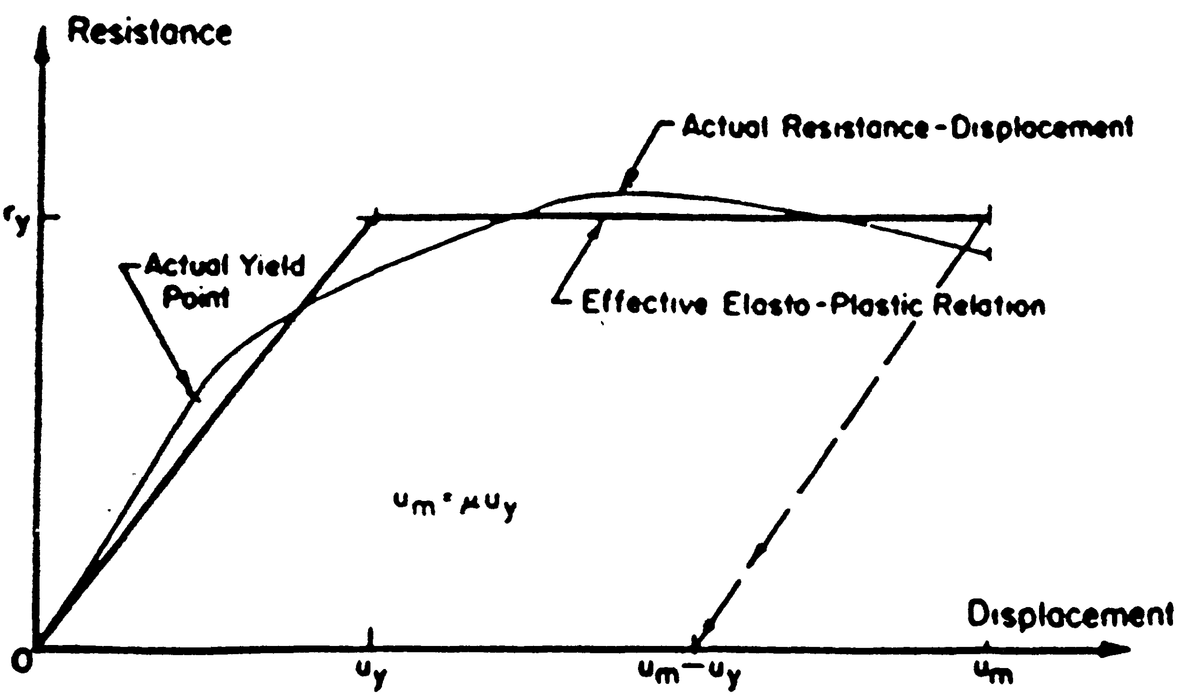


Figure 9. Resistance-displacement relationship

GROUND FAILURE IN PUERTO RICO

by

Alejandro E. Soto
University of Puerto Rico
Mayaguez, Puerto Rico

INTRODUCTION

Ground failure may be defined as any movement or displacement of ground which disrupts human activity or imposes restrictions on land use. In Puerto Rico ground failure is widespread and takes many forms. It includes: landsliding, the downward and outward movement of masses of soil or rock from slopes under the influence of gravity; sinkhole collapse, the subsidence of surficial soil or rock into subterranean passages formed by the dissolution of limestone bedrock, and; rapid erosion by storm runoff and storm waves. Less widespread and less dramatic are failures related to the expansion and contraction of clayey soils in response to changes in soil moisure content.

LOSS DATA

At present there are no reliable figures on the losses to the Puerto Rico economy due to ground failure. Costs may be direct, as those attributable to the physical destruction of man-made facilities, or indirect, such as those due to disruption of normal human activity and the long-term effect of loss of agricultural land. Cost data are currently being compiled. Preliminary estimates indicate that the losses from the various modes of ground failure may amount to millions of dollars per year. A single landslide may produce millions of dollars in damage. For example, a large landslide in the Las Delicias Urbanization in Ponce is slowly destroying over 20 residential structures. Although the damage in some of the structures is minor at present, unless repair and stabilization measures, which may be too costly, are undertaken a large number of families will loose the largest investment of their lives. Because the incidence of most forms of ground failure increases during periods of intense precipitation and, or ground shaking, losses attributable to ground failure during a future hurricane or earthquakes on the island may reach hundreds of millions of dollars.

PROCESSES CAUSING GROUND FAILURE

The processes responsible for ground failure in Puerto Rico are natural geologic processes which have been actively shaping the island's landscape for hundreds of thousands of years. A study presently underway in the Department of Geology-RUM has identified over a hundred collapse sinkholes and related depressions in the area between Vega Alta and Arecibo, an area underlain by limestone, a soluble rock. Numerous landslide scars in the mountainous central part of the island attest to the frequency of landslide occurrence. The area is underlain by rocks locally riddled with fractures which are planes of weakness along which sliding may occur. Relatively high temperatures and abundant precipitation and vegetation facilitates the chemical decomposition of the rock to produce thick residual soils which mantle moderate to steep slopes. Erosion by storm generated runoff undercuts the slopes leading to landsliding.

The failure modes mentioned so far are influenced by the presence of water and show a strong correlation to rainfall and rainfall intensity-duration characteristics. The role of water in forming collapse sinkholes will be discussed in another paper presented during this workshop. Suffice it to say here that rainfall infiltrating the subsurface carries surficial soils into open channels in the underlying limestone. With time a cavity develops in the soil above the limestone. As the cavity is enlarged the roof thickness decreases to the point it can no longer support its own weight and collapse ensues, usually during or shortly after precipitation events.

Water promotes landslides in two ways. Landslides represent a departure from equilibrium in the sense that movement occurs when the forces driving the mass exceed the forces which act to keep the mass in place. The resisiting forces are due to soil or rock strength and slope geometry. The driving forces are due to the weight of the slide mass. Saturation increases the weight of the soil or rock mass. Thus saturation increases the driving force. Saturation also causes a reduction in soil or rock strength. When these effects are combined with erosion by runoff (changes in slope geometry) it becomes apparent that most landslides will occur during or shortly after precipitation events.

By definition, failure from rapid erosion occurs during storm events. Lugo and others (1980) have shown that Puerto Rican rivers discharge up to 70 percent of their yearly sediment load during a few days of high intensity precipitation.

Correlation of failure due to the expansive nature of some clay soils with storm events is not good. The expansion-contraction behavior of the soils follows seasonal fluctuations in available moisture. Damage results from differential movement of structures founded on such soils, as would occur when a structure has only part of its foundation on expansive clay, or when it rests on clay deposits of variable thickness. Damage is more a function of previous soil moisture conditions and not of storm intensity or duration. A large storm will have little effect on the expansion of previously saturated soil whereas normal rainfall events following a period of drought may produce widespread damage.

EFFECT ON MAN

Althogh ground failures are natural geologic processes, man frequently alters conditions in a way which tends to accelerate these processes. Lugo and others (1980), for example, attribute high erosion rates on the island to poor soil management practive. Deforestation invariably leads to accelerated erosion often followed by landsliding. Construction frequently alters natural drainage conditions resulting in erosion, landsliding, and sinkhole collapse. Failures of oversteepened cut slopes are common.

EARTHQUAKE-INDUCED GROUND FAILURES

Puerto Rico is located within an active seismic belt. Destructive earthquakes have occurred in recent history, the last two occurring in 1867 and 1918. Ground shaking due to the passage of seismic waves can induce sliding in hillsides (increases the driving force) or the collapse of soil or bedrock roofs leading to the formation of sinkholes. Earthquakes shaking can lead to other types of ground failure. Differential compaction of alluvial sediments was widespread during the 1918 earthquake (Reid and Taber, 1919) leading to the formation of numerous cracks due to differential settlement. Liquefaction, defined as the transformation of granular material from a solid to a liquid by an increase in the pressure of fluids (water) in soil pores, is also possible. Although records of the 1918 earthquake make no mention of liquefaction phenomena, there are descriptions of increased flow in streams and ditches indicating the explusion of groundwater under pressure. This means that excess pore pressures were developed during the shaking and liquefaction may have occurred. Some of the ground settlement attributed to differential compaction may have in effect resulted from liquefaction. The writer is currently involved in a study of liquefaction potential in the San Juan Metropolitan area funded by the U.S. Geological Survey. Preliminary results show the existence of liquefiable materials (defined as fine-medium grained clean sand deposits located below the groundwater table) particularly near the coast and in large river valleys.

POSSIBLE FUTURE IMPACTS

Beginning in the 1950's Puerto Rico underwent a transformation from a primarily rural-agricultural society to a dominantly urban-industrial society. Much of this development occurred under building codes that have subsequently been revamped. The old building codes were particularly unsatisfactory in relation to earthquake-resistant design. Landslides, sinkholes, erosion, and expansive soils have caused much damage in the past and will continue to do so in the future. The problem will be greatly enhanced when the next hurricane passes by the island, or when the earth begins to shake during a future large earthquake. Damage from the latter would be compounded by differential ground settlement and liquefaction as well as other seismic effects. It boggles the mind to think that the island could suffer both hurricane and earthquake within a short period of time. This worst possible scenario is not impossible.

In an environment where ground failure is an integral part of the natural processes at work it is necessary to integrate available knowledge on the distribution and mechanisms of different failure modes in the planning, construction, and maintenance of the works of man. A concerted, island-wide effort to better define the potential losses to society from such events and to formulate solutions to reduce these losses is needed. This workshop is a step in the right direction.

REFERENCES

Lugo, A. E., Quinones Marquez, F., and Weaver, P. L., 1980, La erosion y sedimentacion en Puerto Rico: Caribbean Journal of Science, v. 16, p. 143-165.

Reid, H. F., and Taber, S., 1919, The Porto Rico Earthquake of 1918, with Descriptions of Earlier Earthquakes: Report of the Earthquake Investigation Commission, U.S. Government Printing Office, Washinton, D.C., 74 p.

SINKHOLE DEVELOPMENT IN LIMESTONE AREAS AS RELATED TO RAINFALL AND GROUND WATER DEVELOPMENT IN PUERTO RICO

by

Fernando Gomez-Gomez
U.S. Geological Survey
San Juan, Puerto Rico

INTRODUCTION

Documentation of the occurrence of sinkholes or collapses within the limestone areas of northern Puerto Rico are essentially nonexistent. The formation of sinkholes is becoming more conspicuous, but up to this date there have been no catastrophic incidents as have been documented in Florida. Our attention on the subject, "the possible relationship of intensive rainstorms or groundwater withdrawals with collapse incidents," actually started in 1982. It was brought about after a record setting rainfall event on December 12-15, 1981. Various collapses were reported to have occurred in the municipalities of Manati, Barceloneta, and Arecibo during the storm event or shortly after. The mechanisms leading to the collapse features at these sites could be explained by the local hydrogeologic conditions and comparison to documented studies in Alabama (Newton, 1976).

MECHANISMS FOR SINKHOLE FORMATION

Before going into the specific island situations it is worthwhile to review the mechanisms which could account for most collapses documented. They are:

1) Collapse caused by failure in unconsolidated deposits--There are two major mechanisms of this type; those caused by water table fluctuations or by seepage of runoff. Most sinkhole formation can be attributed to one or both of these. Water tables fluctuations lead to collapses by the "wet and dry" cycles which residual clay deposits are subjected to.

2) Collapse caused by failure of bedrock--Collapses from this mechanism are rare. The most important causal factor is possibly by loss of bouyancy in caverns beneath the water table. If the roof cannot sustain the increased load resulting when the bouyancy effect is lost through the lowering of the water table (potentiometric surface) a collapse occurs. Such extreme lowering of the water table is usually related to mining dewatering effects or severe droughts.

Failure of bedrock may lead to a collapse in a less relevant manner. Locally the evolution of subterranean conduits may cause fracturing of the bedrock. Some of these collapses may be visible above land surface along exposed bedrock outcrops. If a considerable amount of runoff or rainfall is conveyed along these features, a collapse may occur within unconsolidated deposits adjacent to the outcrops.

As can be seen, intensive rainstorms can trigger the conditions that eventually lead to a collapse. Not only through the generation of significant amounts of runoff, but also by raising the water table (potentiometric surface). An an example, the event of December 12-15, 1981, raised the water table an average of 7 feet throughout most of the limestone aquifer on the north coast of Puerto Rico. This particular event is rare, and may have its greatest impact on inducing collapses which are caused by runoff. The water table oscillations which would excert the greatest impact on inducing sinkhole development are mainly those with a higher frequency of occurrence (seasonal).

Areas having the greatest potential risk are those that are: 1) underlain by unconsolidated blanket deposits, 2) characterized by the depth to the water table of about 100 feet (unconsolidated deposits rarely extend 100 feet below land surface), and 3) underlain by bedrock that has developed a high degree of secondary porosity.

REGIONAL SUSCEPTIBILITY

On a regional basis in Puerto Rico the limestone formations that are most susceptible to sinkhole formation are: 1) Aymamon Limestone, 2) Aguada

Limestone, 3) Cibao Formation and Lares Limestone. These limestones are part of the North Coast limestone formation. Thus, areas which meet conditions 1 and 2 and are underlain by Aymamon or Aguada Limestone would have a high potential for water table induced collapse.

The "wet and dry" water table induced cavity formation in unconsolidated deposits can be accelerated through ground-water withdrawals. In the vicinity of pumping wells this cycle can be put into effect at sites where such conditions did not exist. On a regional basis, large-scale ground water development will cause major shifts of the water table (potentiometric surface). This lowering of the water table would consequently have the following effects:

1) Regional change of the "wet and dry" affected areas; on north coast limestone essentially a southward migration of this boundary.

2) Ground water recharge within areas which under natural conditions rejected infiltration due to high water table (full storage); this would induce runoff infiltration and increase the potential for "scour holes" or slumping of the land surface. In general on north coast limestone the induced recharge area would be that near the southern limit of the blanket deposits.

The potential for collapse of the type in which significant water table lowering may cause failure of an underground cavern system is essentially nil in Puerto Rico. Cavernous limestones with relatively shallow water tables exist within the Aymamon Limestone Formation. Its proximity to the sea and high transmissivity would more properly induce sea-water intrusion that water table declines.

REFERENCES

Newton, J. G., 1976, Early detection and correction of sinkhole problems in Alabama, with a preliminary evaluation of remote sensing applications: State of Alabama Highway Department, HPR Report No. 76, 83 p.

RESPONDING TO GEOLOGIC HAZARDS

by

Philip McIntire
Federal Emergency Management Agency, Region II
New York City, New York

INTRODUCTION

The Federal Emergency Management Agency and its predecessor, the Federal Disaster Assistance Administration, have on several occasions responded to large-scale natural disasters in Puerto Rico. There were severe storms and flooding in 1974; Hurricane Eloise in 1975 and Hurricanes David and Frederick in 1979. Total Federal financial assistance after these disasters totaled several hundreds of millions of dollars. Over 20 Federal agencies were mobilized to provide financial and other assistance to the disaster victims.

Before describing specific types of Federal assistance that can be made available after a severe natural disaster, I would like to briefly explain the philosophy and organization of disaster relief activities for the United States and its possessions. Disaster relief is a local responsibility. In the case of Puerto Rico, the Commonwealth Government has the obligation of providing relief after disasters. I would like to point out that over the years the Commonwealth Government has fulfilled this responsibility in an exemplary manner.

If the event is beyond the capabilities of the Commonwealth Government, the Governor, and only the Governor, may request that the President declare Puerto Rico an area of major disaster. To assist the President in making this decision, the Federal Emergency Management Agency will make an on-site assessment of the effects of the disaster and prepare a report regarding the severity, magnitude and impact upon the citizens and the government of the event. Based on this information, the President makes a determination of whether or not to declare a major disaster.

FEDERAL DISASTER RELIEF AUTHORITY

With the declaration of a major disaster, the full resources of the Federal Government are potentially available. Immediately after a declaration by the President, a Federal Coordinating Officer (FCO) is appointed. This individual's primary responsibility is to coordinate the assistance efforts of all Federal agencies and the private relief organizations, such as the Red Cross and Salvation Army. The FCO works closely with the Commonwealth Coordinating Officer (CCO) appointed by the Governor.

Federal disaster assistance is supplemental to Commonwealth assistance. That is, all relief efforts are closely coordinated with the Commonwealth Government. A major disaster declaration does not mean that the Federal Government takes over control of Commonwealth functions. The FCO's responsibility is to coordinate Federal resources to compliment the relief and recovery effort of the Puerto Rican government.

FEMA also has the authority to direct Federal agencies to undertake recovery activities and pay the cost of these actions from the President's Disaster Relief Fund. Through these two activities--coordinate of other agencies' statutory authorities for providing disaster assistance, and FEMA's authority to direct and pay other Federal agencies to undertake relief activities authorized by the Disaster Relief Act of 1974, PL 93-288--the full resources of the Federal Government are potentially available for relief and recovery.

POTENTIAL RESOURCES IN THE EVENT OF AN EARTHQUAKE AFFECTING PUERTO RICO

In the event of a serious earthquake in Puerto Rico, FEMA Region II personnel would make plans to travel to Puerto Rico. If conditions were such that commercial airline service was not availalble, we have standby contracts with air charter companies and agreements with the military to provide transportation.

Upon arriving in Puerto Rico, FEMA team would immediately make contact with Commonwealth authorities and be briefed on the situation. The FEMA team would also contact Federal agencies located in Puerto Rico for their initial assessments. If the earthquake were so destructive that it was immediately evident that the severity and magnitude was beyond the capability of the Commonwealth Government, this information would be relayed immediately to the FEMA Regional Office in New York and then to Washington D.C. In the case of a serious earthquake, a Presidential declaration could be made within a few hours of the occurrence.

The first priority in such a case would be to save lives and protect property as well as prepare the population for future aftershocks. Puerto Rico is fortunate that the Roosevelt Roads Naval Station is on the island. The Department of Defense (DOD) would be the primary Federal agency to carry out emergency protective actions. If additional DOD resources were required, they could be deployed in an expedited manner in accordance with current plans.

Basically, all disaster response operations are the same. What is required of the emergency responders is to quickly ascertain the needs generated by the disaster and then take actions, by commiting resources, to alleviate these needs. It is these requirements, generated by each disaster, that vary and a different mix of resources must be deployed by the emergency responders.

There is no doubt that a serious earthquake in Puerto Rico would be beyond the capability of the Commonwealth Government. There would be a declaration by the President. Such an event would severely test the ability of FEMA and the Federal Government to respond to all the needs in a timely and effective manner. That is one of the primary reasons FEMA has allocated monies for earthquake preparedness in Puerto Rico. The goals of this program are to minimize the impact of a serious earthquake; prepare the Commonwealth and Federal Governments to respond to the emergency needs of the people of Puerto Rico and expeditiously recover from the impact of the earthquake while mitigating the effects of future earthquakes.

In summary, both the Commonwealth Government and the Federal Government are preparing for a serious earthquake in Puerto Rico. The authority of the President of the United States and the full range of resources of the Federal Government would be available for the recovery effort.

THE PUERTO RICO TELEPHONE COMPANY INVOLVEMENT IN EARTHQUAKE DISASTER

by

Miguel Puig
Puerto Rico Telephone Company
San Juan, Puerto Rico

INTRODUCTION

The Puerto Rico Telephone Company (PRTC) sincerely thanks the sponsors of this interesting workshop for the invitation extended to us and for the opportunity given to share with all of you ideas and strategies that we will put into effect to restore normality into our communities after a major earthquake.

As we all know, when a major disaster occurs, good communication is the common denominator for the success of any recovery plan. Without proper communication, the normal confusion will be raised to chaos and reasonable thinking will be neutralized.

In order to provide reasonable service after a major disaster, the Puerto Rico Telephone Company has developed our own disaster restoration guide as part of our general emergency plan, which also provides for hurricanes, flooding, and others.

The emergency plan procedures are controlled by a special committee composed by the vice presidents and directed by our president.

An executive emergency center has been installed for this purpose, but also different alternatives are present in case the established center is unreachable.

All the restoration jobs for the entire island are coordinated through the emergency center, which in addition to directing the operations, also gathers data for further analysis.

The center offers 24-hour service until the conditions are restored to normal.

Basically there are two types of communications that we at PRTC will have to ensure continuation.

Intraisland telephone service will have to be restored by correcting failures in our outside or inside plant, or by rerouting the trunk service to avoid affected routes.

Communication will also have to be restored with the mainland and the rest of the world, if some is partially or totally affected.

OPERATIONAL RESTORATION PLAN

The telephone company took three major areas into consideration in order to develop an operational restoration plan as follows:

1) Outside plant, which is the hardware including poles, cables, lines, terminals and others, installed from the central office to the customer and equipment.

2) Central office building which houses our switching systems, long-distance service, and directory assistance services.

3) The transmission towers which are the ones that carry the microwave radio transmission.

For the emergency restoration of the outside plant, PRTC has offered special training to our forces, and maintain in our warehouses equipment and materials to reasonably repair or replace damaged hardware. It is also worth mentioning that the engineering design of the outside plant provides reasonable flexibility to resist over strength normal conditions. This is related to the plastic behavior condition previously mentioned.

Our manholes and cable vaults are constructed with concrete poured over reinforced steel frames. We have been replacing our lead cables with polyethylene insulation. We are using PVC conduits and most of our plant is being designed underground where possible.

PRTC central office buildings are constructed following earthquake design load specifications which include properties of the building structure, such as rigidity, mass, energy-absorption characteristics and geometrical configuration.

In case of a major disaster where a central office building is totally lost, PRTC counted respond with two mobile switching units that could be relocated and telephone service could be transferred to them as required, on a priority basis.

Another aspect is the possibility of a major power failure. We are also well protected in this area. PRTC has 15 mobile power plants in addition to those installed in most of our premises, and by the end of 1984 every company building will be provided with their own power plant.

The third major area, as I mentioned before, is our microwave network for intraisland communications. Our microwave network includes towers with lined antennas, similar to the one you are looking at. Some of these towers pick up signals far outside of the island communication. Those signals are then retransmitted to an earth station, and from the earth station to a satellite that links us with the mainland and the rest of the world. All these towers and the earth station are erected in accordance with the most rigid parameters of construction. The footing of the structure must reach too bedrock, and are also filled with concrete poured over reinforced steel frames. Not withstanding, a major disaster could happen and could cause the construction to fail depending on the severity of the ground motion.

Due to the effect of an earthquake there are three possible conditions that could occur to a microwave tower.

1) A moderately intense ground motion could alter the established line of sight, interrupting the service. In this case, specially trained technicians will reach the tower and with electronic instruments realine the antennas, providing service until further corrective action is taken.

2) The ground motion could be strong, causing partial damage to the towers. In this case, brigades will correct the failure.

3) The ground motion could be so intense that it could cause the tower to fall, resulting in total lost. In this case PRTC could respond with portable aluminum alloy towers that could be set in place in a short amount of time.

The portable towers reach up to 300 feet and are provided with the required antennas to do the job.

In the other hand we also have a warehouse in the north part of the island, which includes towers piece parts, and will set a second one by this year in the south.

CONCLUSIONS

As you can see, PRTC is continuously adjusting and refining our methods and procedures and developing alternatives to ensure the continuation of telecommunication services in case of a major disaster. Although we all know that things could get quite bad after an earthquake, at least it is comforting to know that reasonable emergency plans have been made.

SESSION 2: RESPONDING TO GEOLOGIC HAZARDS

1. Current planning activities of local government

- There are only two levels of government in Puerto Rico

  Central (state)
  Municipal (78 municipalities)

- There are no special districts, such as school districts, fire districts, sewer districts, as on the mainland

- All lifeline services are provided by public authorities:

  Aqueduct and Sewer Authority
  Electric Power Authority
  Communications Authority
  Telephone Authority (Puerto Rico Telephone Company)

- All basic services are provided by central agencies:

  Department of Education
  Department of Health
  Department of Social Services
  Department of Sports and Recreation
  Police of Puerto Rico
  Fire Service of Puerto Rico

- All planning and land use control is at the central level:

  Planning Board
  Regulations and Permits Administration

- Municipal government powers include:

  Cemeteries
  Refuse collection
  Local streets
  Emergency response
  Powers conferred by HUD under community development block grants for development of housing and economic programs

- Characteristics - range

  Population: Total 1980, 3196K
  Density: 934 per sq mi
  Municipality area: Catano 5 sq mi
  Arecibo: 127 sq mi
  Municipality population: Culebra 1,265, San Juan 434-849

2. Resources available from local government

Planning Board	Planning and zoning regulations
Land use maps and data	
Socioeconomic data	
Flood-zone maps	
Regulations & Permits Administration	Permit records
Subdivision plats	
Building plans	
Department of Natural Resources	Scientific Inventory (computerized)
Land use	
Geology	
Soils	
Land slope	
Water	
Beaches	
Minerals	
Drainage basins	
Floodable areas	
Public buildings	
Water Planning Division	
Rainfall data	
Aquifer data	
Well records	
Flood data	
State Geologist	
Marine Geology	
Public Buildings Administration	Public facilities
Department of Education	Public school facilities
Enrollment in schools & colleges	
Department of Health	Hospital facilities
Health centers	
Medical professionals data	
Department of Social Services	Public institution facilities
Institutional population	
PR Industrial Development Company	Manufacturing plants
Governor's Office for Disabled (in development)	Special census of disabled

HOW TO DEVELOP AN EFFECTIVE PROGRAM OF PUBLIC EDUCATION AND INCREASED HAZARD AWARENESS

by

Risa I. Palm
University of Colorado
Boulder, Colorado

INTRODUCTION

One of the primary goals of a program of public education on natural hazards is the promotion of attitudes which would increase the perception of risk and the learning of appropriate responses. Before devising such a program, it is important to review the set of factors which seem to increase risk perception and the adoption of mitigation measures. Mileti (1980) has summarized relevant research in three categories: the first involves the causes of variation in risk perception and the impacts of such variation on mitigation policy; the second differentiates social units (such as governments or community organizations) on the basis of likelihood of adaptive responses to risk; and the third links individuals and collective risk perception and adaptation. Risk perception by individuals is affected by (1) the ability to estimate risk, (2) the assumed causes of the hazard (whether the earthquake has been caused by the will of God, an uncontrollable nature, or the occupance of a hazardous area due to social choices, (3) previous experience with the hazard, (4) propensity of the individual or unit to deny risk, (5) size of the unit, (6) access to information, and (7) extent to which existing adjustment policies have yielded a false sense of security.

Of course, hazards adjustments are also affected by factors which lie beyond an analysis of the individual or small group. Social units vary in risk-mitigating adjustment based on the capacity to implement policy. This, in turn, is affected by the extent to which power is concentrated in the hands of an elite, the extent to which adjustment would require a change in the existing organization or power relationships, and the resources (human and monetary) required for an adjustment. Social units also vary in perceived costs of adjustment, based on the extent to which the adjustment fits into other ongoing programs, as well as the strength and persistence of opposition to policy change.

Individuals and organizations will adopt mitigation measures only if systems exist to reinforce such decisions. Such systems must contain incentives to adopt adjustment strategies, as well as the ability to command or compel conformance.

This session is devoted to the response of individuals, particularly through the avenues of attitude change and public information. It is important however to remember the larger context of hazard adjustment as we consider the most appropriate ways to influence individual behavior and preparedness in Puerto Rico.

ELEMENTS OF A PUBLIC INFORMATION PROGRAM

How then should we be guided in the development of a public information campaign? Research in psychology and communication (summarized by Cook and Berrenberg, 1981) suggests that an effective program of public information involves:

1) The depiction of the severity of the hazard and the consequences of the occurrence of the disaster for the individual and the community.

2) The recommendation of specific and feasible actions for mitigation against the worst effects of the disaster.

3) A portrayal of costs and benefits involved in adopting mitigation measures.

The recommendations by Cook and Berrenberg are based on the findings of what has been a voluminous research literature on attitudes, behavior, persuasion, and action. Not all individuals will respond to any campaign of public information--no matter how carefully designed or well executed. Response seems to be affected by:

1) Characteristics of the earthquake hazard in a particular location:

   a) Its visibility (is there evidence of previous damage which is obvious to the casual observer?)

b) Recurrence intervals (do scientists predict an imminent disaster over the short run?)

2) Information source and quality

a) Consistency of information concerning predictions or effects of recurrence (what is the source credibility of any predictions or recommendations for response?)
b) Consistency of public policy concerning mitigation strategy recommendations (do salient information sources disagree with respect to appropriate response strategies?)

3) Characteristics of the individual:

a) Initial attitudes towards earthquake hazards.
b) Beliefs concerning possible impacts of an earthquake on individual comfort or economic security.
c) Acceptance of personal responsibility for mitigation against the effects of an earthquake or other environmental problem (locus of control).
d) Relative salience of the problem (as compared to poverty, crime, day-to-day survival issues).
e) Technological optimism/reliance on fixes by government or "science."

4) Ability of individuals to respond to earthquake risk information

a) Knowledge of appropriate responses.
b) Anticipated consequences of responses:
   1) financial gain/loss
   2) convenience or comfort gain/loss
   3) social approval gain/loss
   4) satisfaction - peace of mind

c) Does the political economic organization make it easy or difficult for the individual to respond (are there incentives in the tax structure, for example?)

CONCLUSIONS

The body of previous research on factors affecting the response of individuals and institutions to hazards (Baumann, 1983) lead to a small set of specific recommendations for the design of a public information campaign on earthquake hazards in Puerto Rico. First, probability statements concerning the likelihood of damage and its location should be provided, if possible. Second, information concerning the costs of adopting each measure should be provided along with detailed instructions about what individuals can do. Third, a variety of information sources, all providing similar messages, should be used. Information sources must be credible, and target audiences vary in their acceptance of given sources of information. While a parish priest may be the best source o finformation in one context, the university scientists may be the best in another. Coordination of information sources must be carefully arranged. Fourth, it is important to provide social reinforcement; news items on television and in the printed media might provide the idea that "everyone" is doing what is recommended as a mitigation measure. Fifth, if possible, it is best to provide external incentives in the form of positive reinforcements, for example, tax credits or social recognition as a reward for the adoption of mitigation measures will encourage preparedness, even in the absence of attitude change.

Of course, a major damaging earthquake is the event most likely to result in public policy as well as private response to the hazard. Let us hope that enlightened local officials will take action to encourage the adoption of mitigation measures before such an event occurs.

REFERENCES

Baumann, Duane (1983), Floodplain resident notification project: Assessment of public information programs, report submitted to Illinois Department of Transportation, Division of Water Resources, March 4, 1983, mimeo.

Cook, Stuart W., and Berrenberg, Joy L., 1981, Approaches to encouraging conservation behavior: A review and conceptual framework, Journal of Social Issues, 37:73-107.

Mileti, Dennis S., 1980, Human adjustment to the risk of environmental extremes, Sociology and Social Research, 64:327-347.

HOW TO PLAN AN EFFECTIVE PROGRAM OF PUBLIC EDUCATION AND INCREASED HAZARD AWARENESS

by

Joyce B. Bagwell
Earthquake Education Center of Baptist College at Charleston
Charleston, South Carolina

INTRODUCTION

An effective public education program begins with individuals addressing a need.

"Listen to the earth for it will teach you."

Seismologists are listening to the Earth, studying earthquakes, and conducting reasearch which reveals that earthquakes occur in Puerto Rico and Eastern United States, as well as in California and other earthquake-prone areas. It is the responsibility of a public education program to teach the populace to listen and be motivated to undertake preparedness actions. How can this be done effectively? Begin with a well-planned program supported by agencies on the Federal, State, or local level. This is easier said than done, one might say, but **IT CAN BE DONE.**

DEFINE THE PROBLEM

People living in 39 of our United States, Puerto Rico, and the Virgin Islands are potentially vulnerable to earthquakes and are subject to moderate or major seismic risk. The difficulty of recognizing that a problem exists in many locations lies in the fact that the large damaging earthquakes occurred 100 years or more ago. South Carolinians, for example, generally having forgotten the 1886 event, have been reminded to a degree that South Carolina is an earthquake-prone area by the small felt events that have occurred over the past years. Interestingly enough the phenomena of atmospheric disturbances (better known as sonic booms) played an important role in making the residents of South Carolina concerned or rather aware of the possibilities of earthquakes. There was confusion as to whether people were experiencing shaking from sonic booms or earthquakes.

Until the 1970's the 432 earthquakes that had occurred in South Carolina had not been recorded on seismic equipment. In 1976, the U.S. Geological Survey had expanded its South Carolina seismic network to include a mininetwork at the Baptist College at Charleston. (A libral arts college located about 2 km from one of the two 1886 earthquake epicentrum.) The purpose of the network was to study the mechanism of the 1886 Charleston earthquake (epicentral intensity of X). From 1976-1984 people had been experiencing shaking of their homes, reported their experiences to the media, who in turn received information from the seismic network set-up at Baptist College. In 1977 there were four felt earthquakes, ranging in magnitude from 2.0-3.0, and numerous sonic booms. Isoseismal intensity maps were drawn from reports of the events. Public awareness grew. The public gained information from the Baptist College network about what they were experiencing--earthquakes or sonic booms. The community was involved.

The work of Marjorie Greene and Paula Gori in Open-file Report 82-233, "Earthquake Hazards Information Dissemination: A Study of Charleston, South Carolina" was a step for helping define the problem in South Carolina. The level of awareness had been raised because of the earlier mentioned events, but the area was not well prepared for a damaging future earthquake. In 1981 the U.S. Geological Survey and the Federal Emergency Management Agency convened a workshop in Knoxville, Tennessee, similar to the one you are attending here in San Juan. At the Knoxville, Tennessee, workshop, the components of an earthquake preparedness program were identified. Public education was seen as one need to be addressed. An Ad Hoc Southeastern SEismic Safety Committee was formed. Grass-root individuals volunteered their time and efforts in initiating a program to organize a seismic safety consortium. Additional workshops were held to determine the risk of earthquakes in the southeast and to learn the lessons from similar organizations of California and Utah. The difference in the West Coast and East Coast earthquakes was recognized. Earthquakes of small magnitude in the South produce greater amplification over a larger area due to the difference in the geological structure of the Earth.

PRTOTYPE EARTHQUAKE EDUCATION CENTER

One involvement led to another and in August 1983 a prototype Earthquake Education Center was established at Baptist College at Charleston. The important elements of the center are described below.

An effective earthquake education program begins with persons concerned about earthquakes reaching out to others on a one-on-one basis. When concerned individuals begin asking what does one do before, during, and after an earthquake, the demands of these citizens motivates the public official, educator, or scientist to respond.

Motivating a community to move from a state-of-unpreparedness to a state-of-preparedness requires interested individuals who recognize the dilemma to begin a program of education. An effective public education and hazard awareness program results from developing a well-laid innovative plan to meet the needs of a community. The common sense insurance policy of preparedness for an earthquake will provide a carryover effect for any disaster response. A guideline for establishing an earthquake education center could follow the format of the prototype Earthquake Education Center that will be at the end of the paper. The key factor is tailoring the educational products to a local situation. The goals, objectives, target audiences, and planning approach shown have been used in South Carolina. The main target audience in the first year has been the school population and general public. Setting priorties becomes an important task. The school population is one of the most vulnerable in a natural disaster. Therefore, in tailoring the material for the school audience, the idea of using an unorthodox ostrich for a mascot evolved. "HAPET" is the name of our mascot. Her name stands for Hazard Awareness Preparedness Earthquake Teacher. HAPET teaches students everything from drop and cover drills to dispelling myths about earthquakes.

Let creativity and imagination be used to create and call attention to an action plan for educating the community on history, cause, effects, and preparedness of an earthquake. The services of volunteers from community organizations can do more for promoting an education program than any other factor. The volunteers need to be trained. This will be one important task of an Earthquake Education Center. Providing the volunteers with training would be the ingredient necessary for an outreach program. Establishing a network of community outreach volunteers has been one of our primary objectives. Their enthusiasm gives impetus to the program.

CONCLUSIONS

In conclusion, the following outline provides an overview of an effective program of public education and increased hazard awareness that can be accomplished through an earthquake education center.

Prototype Earthquake Education Center

Goals:

To increase community access to information about earthquake hazards, risk, and safety measures.

To improve individual and community capability to effect life protecting actions before, during, and following an earthquake.

Objectives:

1. To make widely known and available quality products addressing earthquake hazards, earthquake risk, and special information and education needs of target audiences identified below.
2. To provide information through two-way communication channels.
3. To provide opportunities for community participation in project development and implementation.
4. To provide a foundation for short- and long-term project evaluation.

Target Audiences:

Individuals, families, neighborhoods, youth groups, schools, civic organizations.

Planning Approach:

1. Establish an advisory board composed of community representatives and region, State, and local emergency services officials.
2. Establish a network of community outreach volunteers.
3. Enhance volunteer knowledge and capability to educated audiences by providing workshops and educational tools.

4. Modify existing products and develop new items to address the seismic risk of the study area and to reflect user language/style and levels of knowledge.

5. Develop and employ mechanisms for product dissemination and evaluating the effectiveness or products and community services.

HOW CAN BETTER EARTHQUAKE-RESISTANT DESIGN OF STRUCTURES AND LIFELINES REDUCE LOSSES FROM DAMAGING EARTHQUAKES

by

Leandro Rodriguez
University of Puerto Rico
Mayaguez, Puerto Rico

INTRODUCTION

In Puerto Rico we have been very lucky since no major earthquake has impacted the island in recent years. Yet, we should not get overconfident by this fact since the probability of a major event affecting the island increases each day. For this reason we should take steps to be prepared.

Better design of earthquake-resistant structures and lifelines can reduce losses in the event of a strong earthquake. Unfortunately, certain circumstances exist in Puerto Rico that hinder the design and construction of earthquake-resistant structures. In some cases inadequate earthquake design considerations are the rule rather than the exception.

In the following section, I will try to identify some of the factors which I consider to be very important if we are going to design and construct earthquake-resistant structures in Puerto Rico.

CONSIDERATIONS IN EARTHQUAKE-RESISTANT DESIGN

First, I would like to point out the fact that <u>we are badly in need of a new building code</u>. One has been recommended already by a committee created by the Colegio de Ingenieros y Agrimensores de Puerto Rico, but it has yet to be approved and implemented by the pertinent agencies. The need for this new code is easily understood if we consider that the one presently in use dates back to 1968 and does not consider ductility even though the loads it specifies presume a ductile behavior. Also the load magnitudes recommended are too small for our location in a high risk area. Many other factors are not considered in our present code. Among these the most important are:

1) It doesn't address soil-structure interaction.

2) It doesn't consider the importance of the structure (for example, the same design criteria are used for a hospital and a one-family house).

3) It doesn't recommend earthquake-resistant design for underground lifeline structures.

In addition to the difficulties presented by the lack of an appropriate building code we need to make integrated designs. Many times we forget how important it is for the architect, soils engineer, structural engineer, geologist, and contractor to work together to attain a correct and efficient design. All nonstructural details such as concrete block walls and prefabricated elements should be taken into consideration in the design. Efficient supervision and inspection during construction are also needed since many problems result from inadequate supervision and inspection practices.

Another factor which should be considered is the development of effective research on subjects which are particular to Puerto Rico. This research is needed if we are to find solutions to Puerto Rican problems, some of which are not found (and therefore not studied) elsewhere. But once more we find difficulties in doing research. Due to the fact that some of the problems that need to be studied don't apply to other areas, it is very difficult to get Federal funding. State funds are equally as difficult, if not more difficult to obtain. Some examples of problems that need to be studied are: infill frames, rehabilitation of infills, increase of resistance due to infill, and the change of center or rigidity due to infill. Another example, although not related to earthquakes, is the problem of concrete roof leakage.

Last, but not least in importance, is the fact that government agencies (municipal, State, and Federal) continue funding construction projects that are not properly designed to resist earthquakes. Among the many examples of this practice we find municipal and HUD-financed projects such as poorly designed wooden houses and asbestos-cement houses and schools. Some prefabricated houses that have been built, although not all, are also not properly designed to resist earthquakes that are expected to occur in their lifetime on Puerto Rico.

CONCLUSION

The purpose of my presentation was to increase awareness of some of the existing problems. In this way each of us can contribute, in proportion to our means, to the solution of these problems.

EARTHQUAKE HAZARD MITIGATION THROUGH IMPROVED SEISMIC DESIGN

by

Charles G. Culver
National Bureau of Standards
Washington, D.C.

INTRODUCTION

Buildings and other structures represent a substantial portion of a nation's wealth. For example, the total construction value of buildings and other structures in the United States are estimated at $2.3 trillion in 1980. These facilities support a variety of activities ranging from providing basic shelter to facilities housing commercial and industrial functions. Safety and economy are two important factors that must be considered in the design and construction of buildings.

Most deaths and injuries during earthquakes result from the failure of man-made structures. Building collapse, falling debris within and around buildings, and the loss of life support systems represent significant hazards. Immediate and long-term economic losses are a direct consequence. Losses include:

1) Life loss, injury and property loss during the event,

   a) Economic dislocations, opportunities lost, and marginal enterprises not restarted after the destructive event.
   b) Tax revenues allocated to reconstruction and redevelopment that could be used for other compelling public and private benefit.

An example of an extreme earthquake disaster is the one that shattered the city of Tangshan, China, on July 28, 1976. This industrialized city of approximately one million people is located 100 km (60 miles) east of Beijing. The 7.8 magnitude earthquake caused collapse or severe damage to 85 percent of the city's buildings. Several hundred thousand people lost their lives. By 1982, 6 years after the earthquake, only one-half of the city had been rebuilt.

HAZARD MITIGATION

A number of actions may be taken to mitigate the threat posed by earthquakes, including:

1) Development of an earthquake prediction capability
2) Strengthening existing and new construction
3) Restricting land use to avoid both the direct hazards of the site (such as faulting and soil failure) and indirect hazards that could occur if an earthquake damages other facilities (such as flood waves from a ruptured dam)
4) Insurance or other financial arrangements to cushion the impact of losses
5) Maintenance of emergency plans, materials, and personnel to respond to the emergency.

History shows that properly designed and constructed facilities can withstand earthquakes. In the long run, the best way to reduce the loss of life and destruction of property from earthquakes is to control the use of land in high risk areas and to impose appropriate structural engineering and material standards for both new and existing buildings. New construction can be made more resistant to seismic effects at minor to moderate increases in cost by the use of modern techniques. Economic issues and the consequences of disrupting current activities must be addressed when considering strengthening or replacement of existing buildings.

Studies have been conducted to estimate the loss reductions possible by replacing existing buildings and upgrading new construction. Wiggins (1), for example, projects an 8 to 10 percent reduction in the annual losses to the U.S. building inventory due to earthquakes if the nation were to replace existing structures at a rate 10 percent faster than it is currently doing, and require that all new construction adhere to the 1973 edition of the seismic design code used in the Western United States.

IMPROVED SEISMIC DESIGN

Building codes contain earthquake-resistant design criteria. These codes are designed to: a) establish minimum safeguards in the construction of buildings, b) to protect occupants from fire hazards or the collapse of the structure, and c) prohibit unhealthy or unsanitary conditions. Current seismic design requirements in the model codes in the United States are patterned after recommendations developed on a voluntary basis by concerned professionals in the Structural Engineers Association of California (SEAOC). Many countries throughout the world use the United States seismic design requirements as a basis for developing their building regulations.

It is important that seismic-design requirements be reviewed periodically and updated to incorporate the results of research and knowledge gained from the performance of buildings in earthquakes. A continuing program in this area is underway in the United States. The Seismology Committee of SEAOC (2) developed the following broad list of items to be considered in improving seismic design provisions:

1) The attainable goals of a seismic code should be clearly defined in the areas of:

    a) Structural damage
    b) Nonstructural damage
    c) Postearthquake functions
    d) Human risk

    Current commentaries on seismic codes do not specifically outline the various damage levels that may occur by application of the provisions even though the basic design philosophy has been expressed.

2) Basic provisions of a seismic code should contain:

    a) Equivalent static forces for most structures
    b) Dynamic and inelastic analyses for others which would be

o required in certain cases

o optional for all structures

c) Simple factors for low buildings

The first and third items are the design approaches currently used in seismic codes. Experience to date indicates that when designing applicable structures, the concepts need not change. The second item should be required only on structures for which a minimum probability of failure is desired. Emergency communication centers and hospitals might be included.

3) Seismic codes should include provisions for determining:

a) Basic realistic levels of ground motion to represent a design earthquake at a site of average exposure having no unusual soil conditions.

b) Necessary levels of structural systems damping, ductility, and stability to survive this ground motion.

4) Tolerable levels of cracking for brittle materials should be established.

5) Factors for determination of equivalent static force design should be established.

6) Realistic deterministic ultimate design stresses and load and resistance factors should be established for all materials. Uniformly consistent load factors should be established for various loading conditions which are common for all materials. Variability factors should be established for different materials, combinations of materials and types of construction. Arbitrary limits and details necessary to accomplish these factors also should be established.

7) Conventional one-story light-frame requirements should be redrafted consistent with requirements for designed structures. The design criteria for conventional one-story light-frame construction has been

specified by standard minimum details rather than by stress design. This method should be retained but a review of the commonly used arbitrary construction details should be made to insure that provisions are consistent with the level of safty chosen for other construction.

8) The classes of structures requiring dynamic analyses should be established. The choice of those structures to be named in the code to have a specified kind of dynamic analysis should be carefully considered so that the cost of analysis will not be out of line with the risks involved.

9) Drift limitations should be established consistent with the realistic response to strong earthquakes. Compatibility with architectural, mechanical, and electrical systems should be considered for establishing limits.

10) Where required, criteria should be established to cover the vertical acceleration problem. Existing data on the concurrent behavior of vertical and lateral motions should be reviewed. Provisions should be incorporated in the design code to account for this behavior. This can be done by appropriately modified load factors. Basic study should continue on this subject.

11) Shear wall-frame interaction provisions should be established. Special shear wall-frame interaction provisions are required so that the difference in ductility between the two systems may be accounted for in elastic analyses.

12) Criteria should be established for the repair of earthquake-damaged buildings.

13) Criteria should be established for rehabilitation and upgrading of existing buildings.

14) Seismic design requirements for mechanical and electrical equipment should be established.

15) Minimum requirements for quality control should be established. The varying abilities of communities to perform the checks of the contractor's quality control should be a factor in the level of design just as the ability of a community to combat fires is considered in insurance rates.

16) A commentary should be written and it should be complete and instructive for those not experienced in seismic design. The use of a building code is dependent on a common understanding of the intent of the code provisions. A detailed commentary explaining the intent of the various provisions is necessary.

This list should be useful to engineers in other countries as they consider improvements to their seismic design requirements.

SUMMARY

Improved earthquake-resistant design of new structures and strengthening or replacement of hazardous existing structures represent effective means for mitigating earthquake damage. A number of factors that should be taken into account in developing improved seismic design requirements have been identified.

REFERENCES

Building Losses from Natural Hazards: Yesterday, Today and Tomorrow, J. H. Wiggins Co., Redondo Beach, California.

Pinkham, C. W., 1973, Procedures and Criteria for Earthquake-Resistant Design, Building Science Series 46, National Bureau of Standards, Washington, D.C.

DEVELOPING A COMMUNITY PROGRAM TO PREPARE FOR AND RESPOND TO A MAJOR EARTHQUAKE

by

Claire B. Rubin
Natural Disaster Research Center
George Washington University
Washington, D.C.

INTRODUCTION

I would like to speak to the WHY of community preparedness for a major earthquake rather than how to do it. While I do not want to suggest that HOW to go about emergency preparedness is not important, most people can determine out HOW to do it once they have made up their minds it is necessary to prepare for an emergency or disaster.

For those of you already at the "how to do it" stage, I have prepared a list of "Selected Sources on Earthquake Preparedness Planning," which cites about 30 useful publications on various aspects of earthquake planning and preparedness. Also, FEMA provides guidance documents, such as those on the Integrated Emergency Management System.

WHY?

Why take preparedness measures? Because in all localities that have had a major disaster, local officials say they wished they had been better prepared. I'm reporting first-hand on this general admission of inadequate local preparedness. For the past four years, I have been engaged in research on local recovery from a major natural disaster, which entails doing field visits to communities impacted by a major natural disaster. The research has been supported by grants from the National Science Foundation. Since 1980, we have visited 14 communities at least once to observe and document the disaster recovery process. Thus far, we've observed that most localities have learned via first-hand experience about disaster preparedness, response, and recovery. Learning from experience is both the hard way and the expensive way. We, as researchers, have been working to provide information and to design training programs for not-yet-impacted communities to spare them the deaths, injuries, damage, and general anguish that go with most major natural disasters.

LESSONS

In an article subtitled "Lessons Learned the Hard Way," (1) I summarized some of our findings about recovery from a major natural disaster. They are:

1) Federal resources are essential.

2) Intergovernmental relations (offices & processes) are very important.

3) Know State and Federal programs and benefits before a disaster occurs.

4) Decide what to do, with whom, and when.

5) Urban renewal approach is better than a "snap back" recovery; it encourages integrating reconstruction into community plans.

Let me use the recent example of Coalinga, California, a community of about 7,200 population, to dramatize a few aspects of the postearthquake conditions in one small city. On Monday, May 2, 1983, an earthquake of magnitude 6.7 struck Coalinga at 4:42 p.m. on a Monday. While the local officials knew the community was about 20 miles east of the San Andreas fault, neither they nor anyone else (including the local geologists) were aware of the deep fault about 15 miles northwest of their small city where the earthquake occurred that fateful day. In a matter of seconds, about 200 businesses were seriously damaged or wrecked (just about the entire central business district) and almost 2,000 homes were damaged. In fact, virtually every structure in the city sustained some damage. Coalinga is relatively isolated--the nearest neighboring community is 17 miles away. Fortunately, neither the adjacent cities nor the county were seriously impacted. Consequently, all aid and resources could be focused on Coalinga.

The structures sustaining the most damage were the older ones, mainly those of unreinforced masonry construction. The more recently constructed, reinforced buildings fared far better. The total estimate of damages was $31 million, of which about $6 million was to local public facilities. Only a few homes or business owners had earthquake insurance. Most of the damaged structures, public and private, were not insured. Miraculously, no one was killed, although 47 persons were injured.

Coalinga was not prepared for a major earthquake event. Let me cite some of the problems this unprepared city had during the response phase. According to a report prepared for the California Seismic Safety Commission, several major problems occurred in the aftermath of the earthquake. They are:

MAJOR PROBLEMS ENCOURNTERED IN COALINGA

1) Although Coalinga had an emergency plan, the plan was considered impractical and not followed. Lack of a practical emergency plan, and no prior exercise of that plan precluded optimum emergency response.

2) A second, extremely serious problem was the lack of adequate communications. Telephones generally were inoperative and the city repeater on a nearby hill stopped functioning. City radio communications became limited to vehicle-to-vehicle, although some use was made of CB radios. Fire units could talk to other fire units on a limited basis and law enforcement could talk to law enforcement on a limited basis, but there was absolutely no communications system Direction and Control, uses to effectively coordinate the use of the available resources.

3) There were no previously designated alternate Emergency Operating Center (EOC) sites. After the decision was made that neither the fire station nor the police station could be used as an EOC, considerable confusion existed as to what to do. Approximately 2 hours after the initial shock, the California Highway Patrol office was selected to be the EOC and Command Post.

4) The news media had an extremely disruptive influence. They frequently hindered response actions in their efforts to obtain camera coverage or to interview rescue workers, city officials, or other response officials.

5) Once the decision was made to turn off the natural gas system, the people designated to take the action could not identify which values to turn to complete the shut-off. When the gas was finally turned off, all electrical power generated through natural gas was lost.

6) A major problem was the influx of people into Coalinga (primarily news media, well-intentioned information seekers, and curious sightseers). This took considerable effort to control and actually impeded recovery efforts.

7) Since the majority of buildings in the downtown area were considered unsafe, it became a serious problem to keep the businessmen from entering the area while reassuring them that their property was under 24-hour security and that they would be allowed entry at a later time (2).

Regarding the recovery in Coalinga, it was problematic at first. Initially, officials at all levels of government questioned whether the city could and should rebuild. This is the first time we studied a community where there was a major question about whether recovery could and should take place. We later learned that Coalinga was not so much in danger of becoming a ghost town as it was of losing its central business district to another location, outside of the downtown area. In addition to the main shock, which caused most of the structural damage, many aftershocks (some as sizable as magnitude 5.6) went on for months. Geologists advised the residents that there could be aftershocks for as long as 7 years.

When I visited in March 1984, (about 10 months after the main earthquake), the central business district remained leveled. Empty lots and an occasional gaping hole are what you see in the center of the city. Some businesses are operating in trailers; others are in houses and garages until new commercial structures are completed. While the city obtained about $900,000 in grants from the Economic Development Administration (Department of Commerce), the two EDA-subsidized commercial buildings are not yet under construction. At the present time it appears that most businesses will be displaced a minimum of 1 1/2 years.

APPROACHING THE PROBLEM

I've used this recent example to dramatize the destruction and hardships that can result from an unexpected and unplanned event. You may not guess the exact date, location, or origin of your next major disaster, but you can develop a strategy or approach to emergency preparedness and emergency management--if you are convinced that the threat exists and that planning can and will reduce deaths, injuries, damage, and hardships.

A positive example of preparedness is Marin County, California, one of the many counties that the San Andreas fault runs through. The County has engaged in emergency preparation and training for the time that a major earthquake would hit since about 1970. For about 12 years, the annual emergency drills were just practice. But in 1982, when the county was hit by a rash of landslides and mudflows, attendant with heavy rains and flooding, the county officials were ready and able to deal effectively with this disaster--even though it was quite different from the one they thought would hit them. The dozen years of diligent readiness and exercises during quiet times is highly unusual; but with the threat of an earthquake ever present, the county had maintained a high state of readiness. When disaster struck, their preparations paid off.

What do I mean by a strategy for emergency management? To develop an effective strategy, you must have an overall concept of what your community is and what it should and could be in the future. You want to protect the lives and property there now. But, that is not enough. Should major systems and numerous structures be destroyed, you wil have to adjust your sights and your actions. Knowing what you want your community to be in the future is essential. ("If you don't know where you are going, any road will do.")

One of the lessons learned in doing recovery research was "Those local public officials who were clear about who they wanted to recover, knew who they wanted to help plan and implement the recovery, and made a firm public commitment to mitigation measures during the recovery fared best."

Assuming you are clear on your goals and your strategy for managing a major disaster in your community, let's get down to the specifics of an emergency management plan. To be effective, emergency plans must reflect the special characteristics and expected consequences of a likely earthquake in a particular region. Emergency plans should not be checklists of generalized conditions that must be dealt with; rather, they should be systematically derived guidance for likely actions that take into consideration the special characteristics and circumstances of the area for which they are designed. Plans for various terrains will necessarily be distinctive and not be interchangable. Islands, for example, have many special characteristics that must be factored into emergency planning and management efforts. Most obvious is the lack of adjacent communities from which aid and assistance can be expected. Other considerations include the financial and material resources likely to be needed after a highly destructive disaster. If you know you don't have them at local or even at State (territory) level, think about where you can get them.

Special local characteristics are essential to consider. Even within California, earthquake planning for Los Angeles and San Francisco are quite different. Let's think for a moment about San Francisco, a large densely populated city at serious risk from earthquakes. In a recently prepared earthquake scenario prepared for northern California, (3) the State agency noted that the expected consequences of an earthquake in San Francisco area will overwhelm existing capabilities, most notably in coping with significant interruption of ground transportatin, communications, water supply, sewage treatment, electricity, and pipeline distribution of natural gas and petroleum. Existing emergency-response capabilities will be taxed beyond their limits by the combined effect of regional damage to all the important lifelines upon which the metropolitan areas depend. These circumstances will compound the problem of providing medical aid and search and rescue services to the stricken areas.

Imagine yourself in similar circumstances. Have you ever thought about disruptions to virtually all systems in a major urban area? Think also about the prospect of aftershocks, which will further impair your ability to rebuild quickly. Also, will tourists want to vacation in a place that has recently had a disaster and is still having aftershocks? Probably not. Plus, local public officials can expect a sharp increase in demand for services while at the same time revenues probably will drop due to the loss of property and sales tax income. In short, the impact of an earthquake on local economies also could be catastrophic.

The catastrophic circumstances after a major earthquake will overwhelm the institutional and personal capacities to cope. To counter that, you will have to take steps to see that public awareness is high; that significant emergency preparedness, response, and recovery actions have been taken; and that you make it your business to develop an effective emergency management strategy in advance of the disaster.

The information being provided at this workshop is intended to be a basis for building the capability and developing the plans to cope with a major earthquake and its aftermath.

REFERENCES (Numbers are cited in the text)

1. Forthcoming, Spring 1984 issues of Emergency Management Review (published by the National Coordinating Council of Emergency Managers, Columbia, South Carolina), In Press.

2. California Seismic Safety Commission, "Preliminary reports submitted to the Seismic Safety Commission on the May 2, 1983 Coalinga Earthquake;" Sacramento, California: June 9, 1983.

3. California Division of Mines and Geology (Department of Conservation) "Earthquake Planning Scenario for a M 8.3 Earthquake on the San Andreas Fault in the San Francisco Bay Area," Special Publication #61, 1982.

PUBLIC AWARENESS PROGRAMS OF THE PUERTO RICO DEPARTMENT OF NATURAL RESOURCES

by

Julia Ivette Malave
Department of Natural Resources
San Juan, Puerto Rico

INTRODUCTION

In her remarks at the opening session of this conference, the Secretary of Natural Resources, the Honorable Hilda Diaz-Soltero, touched upon some of the Department's activities related to flood hazard mitigation. This is one of the responsibilities that we take very seriously. It takes a lot of time and effort, but in the long run making people aware that a risk exists and advising them how to reduce their exposure to the effects of a natural hazard produces great benefits. These nonstructural mitigation efforts help to cut the public costs associated with catastrophic events, and they save lives.

As my colleagues on this morning's panel indicated, it is difficult to change public attitudes if people have not been exposed to a specific kind of natural disaster event. Our flood hazard mitigation efforts have met with a great public acceptance because we were dealing with people who had just been through a flood disaster. They had personal knowledge of the tremendous damage caused by water that is out of control. Their children had been exposed to danger and their lives had been disrupted. They did not have to be convinced that their homes were in danger, and that something had to be done to prevent a recurrence of such an event. They were aware of and eager to participate in individual and community mitigation efforts, not only to protect their property, in which a major portion of their life's savings were invested, but also to preserve their lives.

PROBLEMS TO OVERCOME

The problems we encountered in obtaining funds for hazard mitigation are a result of the reluctance of public officials to acknowledge that a mistake was made in permitting people to settle in an area exposed to great risk in the first place, the tremendous cost of getting them out of the area, and the concern of municipal officials over the "transplanting" of large groups of people from one community to another, with resulting burdens on schools and other services, plus some political overtones that are always present in any public decision. Luckily, the situation in Puerto Rico is such that the Department does not have to deal with a multiplicity of special districts and local governments, such as would be the case in the United States. In Puerto Rico, all public services and programs are centralized either in executive agencies or in public corporations. The mitigation planning effort included representatives of the major agencies involved. Once a decision was reached, and the funding made available, each of the agencies was able to initiate its activities under the general coordination of the Department's Assistant Secretary for Flood Control.

The challenge we face is to persuade people who have not had direct experiences in which their property, their jobs or their lives are exposed to danger that such hazards do exist and that they can and should take steps to protect themselves, either on their own or in cooperation with others.

CURRENT EFFORTS

My unit in the Department (the Office of Education and Publication) initially functioned as a clearinghouse for information about resources and the laws and regulations that affect how people can use them. My area of responsibility is gradually expanding, as the Department gains a better understanding of the relationships among people and resources. We are just completing a first cycle of training for staff, representing the Department's various areas of concern, on how to deal with the public, both to impart the Department's point of view about specific issues and to obtain feedback about issues that concern people. The Secretary believes that it is most important to maintain a dialogue--a two-way exchange of communications--at all levels. It is not enough for our technicians and specialists to be aware of the problems of flora and fauna and to implement management programs. The basic values and ideas behind their work must be shared with the public if we are to win support for our programs.

As the Secretary noted yesterday, an interagency task force, organized to deal with problems of flooding after Hurricane David, has been retained and expanded to include specialists in geology, meteorology, and other fields so as to be able to provide guidance for the earthquake and hurricane studies. A basic element of the preparedness planning related to those studies is the raising of the public level of awareness of those hazards and what can be done to ward off the dangers to persons and property. We expect to follow the same general program of activities that was found useful for floods, consisting of the following activities:

1) A general educational program to bring the problem to public attention;

2) A program to make public officials aware of the hazards involving their particular community or agency, so that they can begin to develop their own preparedness plans;

3) Special units to be included in the curriculum of social science and/or natural science in the schools and universities;

4) Cooperation with the State Office of Civil Defense, where necessary, to raise the awareness of specific communities and to help them develop preparedness plans.

In addition, because of the different effects that may be expected from geologic hazards discussed at this conference, we must become involved in some other activities:

5) Stimulating voluntary and service organizations to become partners in the public awareness programs;

6) Generating interest and involvement among business and industry;

7) Developing special programs for schools, hospitals, and institutions;

8) Promoting special exercises or drills to assure that people at all levels are aware of the problems and of their responsibilities in coping with them when they occur.

What kinds of things are we doing? Our accomplishments include the following:

1) We have designed and printed a variety of posters related to flood insurance, storm surges, and flood-related preparedness, which have been distributed to schools and other groups, posted at every town hall, and made available upon request to other interested parties. A set of the posters is on display at the conference.

2) We have prepared and recorded spot announcements on radio and TV, especially related to the hurricane season, urging people to prepare themselves and their families for the possibility of hurricane activity, plus the need to obtain flood insurance to protect their property.

3) We have participated in training sessions for municipal civil defense personnel, at the Commonwealth's civil defense training center in Gurabo, giving talks on the various kinds of natural disaster that may be expected in Puerto Rico, ways of effecting mitigation programs, and the need to promote flood insurance.

4) We have participated in special programs for the bankers and mortgage bankers, to make them aware of the requirements of the National Flood Insurance Program and the need for them to assure that their loans are covered by flood insurance, where appropriate.

5) We have sponsored talk shows on television and articles in newspapers, at which the basic concepts of preparedness planning against flood hazards were set forth.

6) We are designing and will publish in time for the 1984 hurricane season a special newspaper supplement advising people about specific activities and steps to be taken to prepare against hurricane damage. That will be the first such document in Spanish and English.

7) We still have high hopes of obtaining funds with which to produce a television documentary on hurricanes in Puerto Rico, and perhaps another on geologic hazards, for periodic screening as a public service by the local television stations, and to be circulated to schools.

Where do we find the resources with which to accomplish these tasks?

1) We have depended almost entirely on funding provided by the Coastal Zone Management Program and the Federal Emergency Management Agency for specific tasks that can be related to their interests. Under the tight-fisted approach of the current administration, those funds are diminishing.

2) We obtain a small amount each year from the appropriations from the Commonwealth's General Fund for the Department of Natural Resources. This has not been sufficient to meet all of the identified needs.

What can we do to support the public awareness programs?

1) We must promote the interest of the Administration and the Congress in supporting these nonstructural efforts. They are much less expensive than remedying the problems after-the-fact, and more effective.

2) We must urge the Federal agencies to publish materials in Spanish, for dissemination in Puerto Rico and other areas where Spanish is used by large segments of the population. We have had an arrangement with FEMA under which we do the translation and they pay for the reproduction of pamphlets related to the National Flood Insurance Porgram. A similar program should be pursued with USGS.

3) We must push for larger local appropriations for hazard mitigation, with a portion of the annual sums dedicated to public awareness activities.

4) We must identify additional sources of funding, possibly from business, industry, or foundations, with which to carry out special projects such as the television documentaries and the special hurricane bulletins.

5) We are always open to suggestions and support. If anyone has ideas to share, especially about improving the effectiveness of our outreach, we will be very happy to discuss them.

APPENDIX A
PARTICIPANTS AT WORKSHOP ON "GEOLOGIC HAZARDS IN PUERTO RICO"

Juan A. Deliz
U.S. Geological Survey
Division of Water Resources
G.P.O. Box 4424
San Juan, Puerto Rico 00936

Virgilio J. Acevedo
Study and Design Division
G.P.O. Box 2829
San Juan, Puerto Rico 00936

Felix Aponte
Departamento De Recursos Natural
Apartado 5887
Puerta De Tierra Station
San Juan, Puerto Rico 00906

Joyce Bagwell
Baptist College at Charleston
Charleston, South Carolina 29411

Luis E. Biaggi
Puerto Rico Planning Board
Box 41119, Minillas Station
Santurce, Puerto Rico 00619

Juan A. Bonnet
Center for Engergy & Environmental Research
University of Puerto Rico
Caparra Heights Station
San Juan, Puerto Rico 00935

Earl Brabb
U.S. Geological Survey
345 Middlefield Road, MS 21
Menlo Park, California 94025

Jane Bullock
Federal Emergency Management Agency
500 C Street, S.W.
Washington, D.C. 20472

Carmen L. Burges
Department of Social Services
San Juan, Puerto Rico 00936

Cesar S. Canals
Cesar S. Canals Associates
1202 Banco De Ponce Building
Hato Rey, Puerto Rico 00918

Jose M. Canan
Puero Rico Electic & Power Authority
G.P.O. Box 4267
San Juan, Puerto Rico 00936

Heriberto Capella Acevedo
Civil Defense Program
Department of Education of Puerto Rico
Orense 309, Urb. Valencia
Hato Rey, Puerto Rico 00923

Andres Castillo Oritz
United Retailers Center
P.O. Box 127
Hato Rey, Puerto Rico 00919

Walter Cedeno Rivera
Center for Environmental Energy Research
GPO Box 3682
San Juan, Puerto Rico 00936

Jose A. Colon
Meterologist in Charge
National Weather Service Forecast Office
Isla Verde International Airport
San Juan, Puerto Rico 00913

Jacobo Colon Gutierrez
Jeffe de Operaciones
P.O. Box 70179
Hato Rey, Puerto Rico 00936

Orlando Cordero
University of Puerto Rico
Mayaguez, Pueto Rico 00708

Benicio Correa Matos
Oficial Amd. Y Adiestramientos
G.P.O. Box 1588
Civil Defense of Bayamon
Baymon, Puerto Rico 00619

Charles Culver
National Center for Building Technology
National Bureau of Standards
Washington, D.C. 20234

Jose Dalmau
Puerto Rico Maritime Shipping Authority
Hato Rey, Puerto Rico 00919

Anselmo De Portu
Department of Natural Resources
P.O. Box 5887, Puerta de Tierra Station
San Juan, Puerto Rico 00906

Bernardo Deschapelles-Duque
Hernandez & Hernandez Consulting Engineers
204 F. D. Roosevelt Avenue, Hato Rey
GPO Box 4167
San Juan, Puerto Rico 00936

Luz Delia Diaz Rosado
State Civil Defense Agency
San Juan, Puerto Rico 00936

Hilda Diaz Soltero
Department of Natural Resources
P.O. Box 5887, Puerta de Tierra
San Juan, Puerto Rico 00906

Samuel Diaz Santiago
Engineering Consultant
1634 Calle Santa Angela
Urb. Sagrado Corazon
Trujillo Alto, Puerto Rico 00760

Rafael Esteva
Puerto Rico Plannig Board
P.O. Box 41179 Minillas Station
Santurce, Puerto Rico 00940

Ellis Febres Silva
Puerto Rico Civil Defense
State Civil Defense Agency
P.O. Box 5127
San Juan, Puerto Rico

Luis E. Feliciano Ramos
Puerto Rico Electric & Power Authority
G.P.O. Box 4267
San Juan, Puerto Rico 00936

A. Rosa Fernandez
P.O. Box 2322
Hato Rey, Puerto Rico 00919

Ralph M. Field
Ralph M. Field Associates, Inc.
68 Church Lane
Westport, Connecticut 06880

Angel M. Figueroa Torres
Policia de Puerto Rico
Cuartel General
Oficina Planes y Estudios
Hato Rey, Puerto Rico 00936

Edgar Figueroa
Puerto Rico Port Authority
San Juan, Puerto Rico 00936

Jaime M. Fonseca-Miranda
Underwriter
450 Ferrol Street
URB San Jose
Rio Piedras, Puerto Rico 00923

Esteban L. Fuertes
Citibank, NA
GPO Box 4106
San Jose, Puerto Rico 00936

J. M. Galib Jussef
Puerto Rico Chamber of Commerce
San Juan, Puerto Rico 00936

Manuel Garcia-Morin
Special Assistant to the President
Inter American University of Puerto Rico
G.P.O. Box 3255
San Juan, Puerto Rico 00936

Hildelisa Gonzalez
Hazard Mitigation Unit
Puerto Rico Department of Natural
Resources
P.O. Box 5887, Puerta de Tierra
San Juan, Puerto Rico 00906

Paula Gori
U.S. Geological Survey
905 National Center
Reston, Virginia 22092

Charles B. Gover
Soils Engineering Office
1311 Dember Street, Puerto Nuevo
San Juan, Puerto Rico 00918

Walter Hays
U.S. Geological Survey
905 National Center
Reston, Virginia 22092

Jose E. Hernandez Betaucourt
Center for Energy and Environment Research
San Juan, Puerto Rico 00936

Olga Hernandez
Department of Engineering
University of Puerto Rico
Mayaguz, Puerto Rico 00708

Jorge Hidalgo
Hidalgo & Associates
P.O. Box 11506
San Juan, Puerto Rico 00922

Luis Humberto Vega
Office of the Commissioner of Insurance
Box 8330, Fernandez Juncos Station
Santurce, Puerto Rico 00910

Modesto Iriarte
Center for Energy and Environment
Research, UPR
GPO Box 3682
San Juan, Puerto Rico 00936

Gilberto Isasc Valdes
Civil Engineer
P.O. Box 6447
Caguas, Puerto Rico 00626

Rafael Jimenez
University of Puerto Rico
Mayaguez, Puerto Rico 00708

Rafeal Jimenez Perez
University of Puerto Rico
Mayaguez, Pueto Rico 00708

William Kockleman
U.S. Geological Survey, MS 77
345 Middlefield Road
Menlo Park, California 94025

Juan Luis Trias
Oceanographer (Marine Geology)
U.S. Geological Survey
Box 5917, Puerto De Tierra Station
San Juan, Puerto Rico 00906

Julia Malave
Office of Education and Publications
Department of Natural Resources
P.O. Box 5887, Puerta de Tierra Station
San Juan, Puerto Rico 00906

Rafael Marinez-Alfonso
P.O. Box 1549
Hato Rey, Puerto Rico 00919

Victor M. Marquez
Rio Hondo I
Bayamon, Puerto Rico 00619

Carmen Martin
J-1 Dorado del Mar
Dorado, Puerto Rico 00646

Alba I. Martin
Hazard Mitigation Unit
Department of Natural Resources
P.O. Box 5887, Puerta de Tierra
San Juan, Puerto Rico 00906

Jose Antonio Martinez Cruzado
Civil Engineering Department
University of Puerto Rico
Mayaguez Campus
G.P.O. Box 1381
Mayaguez, Puerto Rico 00709

William McCann
Lamont-Doherty Geological Observatory
of Columbia University
Palisades, New York 10964

Philip McIntire
Natural & Technology Hazards Division
Federal Emergency Management Agency
Region II
26 Federal Plaza
New York, New York 10278

Stan McIntosh
Emergency Management Specialist
Federal Emergency Management Agency, II
26 Federal Plaza
New York, New York 10278

Wilfredo Melendez
Disaster Preparedness Area
State Civil Defense
P.O. Box 5127
Puerta de Tierra Station
San Juan, Puerto Rico 00906

Jose Molinelli
Department of Geography
University of Puerto Rico
Rio Piedras, Puerto Rico 00921

Lizette Montaluo
Department of Natural Resources
P.O. Box 5887, Puerta de Tierra
San Juan, Puerto Rico 00906

Antonio Munera
Puerto Rico Civil Defense
State Civil Defense Agency
P.O. Box 5127
San Juan, Puerto Rico

Pedro F. Negron
Voaro de Puerto Rico
P.O. Box 3831, Old San Juan Station
San Juan, Puerto Rico 00904

Hermenegildo Oritz Quinones
Graduate School of Planning
University of Puerto Rico
Rio Piedras, Puerto Rico 00928

Boris Oxman
Department of Natural Resources
P.O. Box 5887, Puerta de Tierra
San Juan, Puerto Rico 00906

Edgardo Pagan Anes
Soil Engineer Office, Highway Authority
155 Barbosa Avenue, Hato Rey
Santurce, Puerto Rico 00918

Miguel Pagan-Mir
Population Protection Planner
State Civil Defense
San Juan, Puerto Rico 00902

Andres Paiva Liendo
155 Barbosa Ave., Hato Rey
Santurce, Puerto Rico 00918

Risa Palm
Natural Hazards Research and
Applications Information Center
University of Colorado
Boulder, Colorado 80309

Milton R. Palmer
Engineer
Building and Grounds Divison, DEH
Fort Buchanan, Puerto Rico 00934

Francisco Pantoja
Soils Engineering Office
2615 Aguila St. Levittown
Catano, Puerto Rico 00632

Jesus Parrilla Cadedron
University of Puerto Rico
Professor of Physics
Department of Mathematics and Physics
Cayey, Puerto Rico 00633

Fernando L. Perez
Environment & Energy Studies Department
Puerto Rico Electric Power Authority
G.P.O. Box 4267
San Juan, Puerto Rico 00936

Guillermo Pescador
Divison of Technical Advice and
Systems on State Administration
Department of the Treasury
P.O. Box S-4515
San Juan, Puerto Rico 00905

Robert D. Prince
Atlantic Division
Naval Facilities Engineering Command
Naval Station
Norfolk, Virginia 23511

Miguel Puig
Puerto Rico Telephone Company
1500 Roosevelt Avenue
Rio Piedras, Puerto Rico 00936

Cesar E. Pujols
Soil Engineering Office, Highway Authority
155 Barbosa Ave. Hato Rey
Santurce, Puerto Rico 00918

Nestor R. Ramirez
Public Building Authority
Minellos Gubernamental Center
Santurce, Puerto Rico 00940

Juan Rivera Rivera
Executive Director-Puerto Rico Hospital
Association
Villa Nevarez Professional Center
Rio Piedras, Puerto Rico 00927

Loudes Rivera
Resident V.P. Citibank
GPO Box 4106
San Juan, Puerto Rico 00913

Carlos J. Rodriguez
President
Association Insurance Company
P.O. Box S-2709
San Juan, Puerto Rico 00903

Emilio Rodriguez Esteban
Engineer, Puerto Rico Department of Commerce
Box 468
Ponce, Puerto Rico 00733

Leandro Rodriguez
College of Engineering
University of Puerto Rico
Mayaguez, Puerto Rico 00708

Jesus Rodriquez
Geological Specialist
Water Planning Division
Department of Natural Resources
P.O. Box 5887
Puerta de Tierra
San Juan, Puerto Rico 00906

Ismael Roque
President, Continental Claims Service, Inc.
P.O. Box 1923
Hato Rey, Puerto Rico 0919-1923

Claire Rubin
The George Washington University
Program of Policy Studies in Science & Technology
Library 714
Washington, D.C. 20052

Pedro Salicrup Rivera
Civil Engineer
10 I 10 Vista Bella
Bayamon, Puerto Rico 00620

Pedro Salicrup Rivera
Soil Engineering Office
Highway Authority
155 Barbosa Avenue
Hato Rey
Santurce, Puerto Rico 00918

Donald Sanchez
Vice President, Underwriting Property
Ochao Building
Box 5-112
San Juan, Puerto Rico 00902

Ramon Santiago
Civil Engineer
U.S. Soil Conservation Service
Federal Building, Room 633
Calie Chardon
Hato Rey, Puerto Rico 00913

Graciela Seijo
Puerto Rico Chapter
American Red Cross
P.O. Box 1067
San Juan, Puerto Rico 00902

Dan Shelley
Banco Popular Center
Hato Rey, Puerto Rico 00918

Robert A. Shuman
Robert A. Shuman & Associates, Inc.
P.O. Box 1393
Hato Rey, Puerto Rico 00919

Alejandro Soto
University of Puerto Rico
Mayaguez, Puerto Rico 00708

Sam Speck
State & Local Programs and Support
Federal Emergency Management Agency
500 C Street, S.W.
Washington, D.C. 20472

Rodolfo Tardy Garcia
Engineer
University of Puerto Rico
Mayaguez, Pueto Rico 00708

Thomas Thornton
Geological Section
U.S.A. Army Corps of Engineers
P.O. Box 4970
Jacksonville, Florida 00732

Heriberto Torres-Sierra
Division of Water Resources
U.S. Geological Survey
G.P.O. Box 4424
San Juan, Puerto Rico 00936

Luis Urbina
FUNVISIS
P.O. Box 1892
Caracas 101, Venezuela

Esmael Valazquez
Land & Building/Engineering Department
Director/P.R.T.C
G.P.O Box 998
San Juan, Puerto Rico 00936

Mariano Vargas
Specialist II
Hazard Mitigation Unit
Departent of Natural resources
P.O. Box 5887
Puerta de Tierra
San Juan, Puerto Rico 00906

Manuel Vazquez
Advisor in Operations Matters-Power Plants
G.P.O. Box 4267
San Juan, Puerto Rico 00936

William Vazquez
Reo Manager-Internation Charter
Mortgage Corp.
G.P.O. Box 4628
San Jaun, Puerto Rico 00936

Antonio Zaragora Rodriguez
Graduate Student of Civil Engineering
University of Puerto Rico, Mayaguez Campus
Calle 1 H 12 A
Mayaguez Terrace
Mayaguez, Puerto Rico 00708

Nora Zenoni
Planner
State Civil Defense Agency
San Juan, Puerto Rico 00936

APPENDIX B

GLOSSARY OF TERMS FOR PROBABILISTIC SEISMIC-RISK AND HAZARD ANALYSIS

This glossary of technical terms is provided to facilitate their use in a standard manner. These terms are encountered frequently in the literature and in discussion of earthquake hazards and risk.

ACCEPTABLE RISK - a probability of social or economic consequences due to earthquakes that is low enough (for example in comparison with other natural or manmade risks) to be judged by appropriate authorities to represent a realistic basis for determining design requirements for engineered structures, or for taking certain social or economic actions.

ACTIVE FAULT - a fault that on the basis of historical, seismological, or geological evidence has a high probability of producing an earthquake. (Alternate: a fault that may produce an earthquake within a specified exposure time, given the assumptions adopted for a specific seismic-risk analysis.)

ATTENUATION LAW - a description of the behavior of a characteristic of earthquake ground motion as a function of the distance from the source of energy.

B-VALUE - a parameter indicating the relative frequency of occurrence of earthquakes of different sizes. It is the slope of a straight line indicating absolute or relative frequency (plotted logarithmically) versus earthquake magnitude or meizoseismal Modified Mercalli intensity. (The B-value indicates the slope of the Gutenberg-Richter recurrence relationship.)

COEFFICIENT OF VARIATION -- the ratio of standard deviation to the mean.

DAMAGE - any economic loss or destruction caused by earthquakes.

DESIGN ACCELERATION - a specification of the ground acceleration at a site, terms of a single value such as the peak or rms; used for the earthquake-resistant design of a structure (or as a base for deriving a design spectrum). See "Design Time History."

DESIGN EARTHQUAKE - a specification of the seismic ground motion at a site; used for the earthquake-resistant design of a structure.

DESIGN EVENT, DESIGN SEISMIC EVENT - a specification of one or more earthquake source parameters, and of the location of energy release with respect to the site of interest; used for the earthquake-resistant design of a structure.

DESIGN SPECTRUM - a set of curves for design purposes that gives acceleration velocity, or displacement (usually absolute acceleration, relative velocity, and relative displacement of the vibrating mass) as a function of period of vibration and damping.

DESIGN TIME HISTORY - the variation with time of ground motion (e.g., ground acceleration or velocity or displacement) at a site; used for the earthquake-resistant design of a structure. See "Design Acceleration."

DURATION - a qualitative or quantitative description of the length of time during which ground motion at a site shows certain characteristics (perceptibility, violent shaking, etc.).

EARTHQUAKE - a sudden motion or vibration in the earth caused by the abrupt release of energy in the earth's lithosphere. The wave motion may range from violent at some locations to imperecptible at others.

ELEMENTS AT RISK - population, properties, economic activities, including public services etc., at risk in a given area.

EXCEEDENCE PROBABILITY - the probability that a specified level of ground motion or specified social or economic consequences of earthquakes, will be exceeded at the site or in a region during a specified exposure time.

EXPECTED - mean, average.

EXPECTED GROUND MOTION - the mean value of one or more characteristics of ground motion at a site for a single earthquake. (Mean ground motion.)

EXPOSURE - the potential economic loss to all or certain subset of structures as a result of one or more earthquakes in an area. This term usually refers to the insured value of structures carried by one or more insurers. See "Value at Risk."

EXPOSURE TIME - the time period of interest for seismic-risk calculations, seismic-hazard calculations, or design of structures. For structures, the exposure time is often chosen to be equal to the design lifetime of the structure.

GEOLOGIC HAZARD - a geologic process (e.g., landsliding, lequefaction soils, active faulting) that during an earthquake or other natural event may produce adverse effects in structures.

INTENSITY - a qualitative or quantitative measure of the severity of seismic ground motion at a specific site (e.g., Modified Mercalli intensity, Rossi-Forel intensity, Housner Spectral intensity, Arias intensity, peak acceleration, etc.).

LOSS - any adverse economic or social consequence caused by one or more earthquakes.

MAXIMUM - the largest value attained by a variable during a specified exposure time. See "Peak Value."

MAXIMUM CREDIBLE
MAXIMUM EXPECTABLE
MAXIMUM EXPECTED
MAXIMUM PROBABLE

These terms are used to specify the largest value of a variable, for example, the magnitude of an earthquake, that might reasonably be expected to occur. In the Committee's view, these are misleading terms and their use is discourage. (The U.S. Geological Survey and some individuals and companies define the maximum credible earthquake as "the largest earthquake that can be reasonably expected to occur." The Bureau of Reclamation, the First Interagency Working Group (Sept. 1978) defined the maximum credible earthquake as "the earthquake that would cause the most severe vibratory ground motion capable of being produced at the site under the current known tectonic framework." It is an event that can be supported by all known geologic and seismologic data. The maximum expectable or expected earthquake is defined by USGS as "the largest earthquake that can be reasonably expected to occur." The maximum probable earthquake is sometimes defined as the worst historic earthquake. Alternatively, it is defined as the 100-year-return-period earthquake, or an earthquake that probabilistic determination of recurrence will take place during the life of the structure.)

MAXIMUM POSSIBLE - the largest value possible for a variable. This follows from an explicit assumption that larger values are not possible, or implicitly from assumptions that related variables or functions are limited in range. The maximum possible value may be expressed deterministically or probabilistically.

MEAN RECURRENCE INTERVAL, AVERAGE RECURRENCE INTERVAL - the average time between earthquakes or faulting events with specific characteristics (e.g., magnitude $\geq$ 6) in a specified region or in a specified fault zone.

MEAN RETURN PERIOD - the average time between occurrences of ground motion with specific characteristics (e.g., peak horizontal acceleration $\geq$ 0.1 g) at a site. (Equal to the inverse of the annual probability of exceedance.)

MEAN SQUARE - expected value of the square of the random variable. (Mean square minus square of the mean gives the variance of random variable.)

PEAK VALUE - the largest value of a time-dependent variable during an earthquake.

RESPONSE SPECTRUM - a set of curves calculated from an earthquake accelerogram that gives values of peak response of a damped linear oscillator, as a function of its period of vibration and damping.

ROOT MEAN SQUARE (rms) - square root of the mean square value of a random variable.

SEISMIC-ACTIVITY RATE - the mean number per unit time of earthquakes with specific characteristics (e.g., magnitude $\geq$ 6) originating on a selected fault or in a selected area.

SEISMIC-DESIGN-LOAD EFFECTS - the actions (axial forces, shears, or bending moments) and deformations induced in a structural system due to a specified representation (time history, response spectrum, or base shear) of seismic design ground motion.

SEISMIIC-DESIGN LOADING - the prescribed representation (time history, response spectrum, or equivalent static base shear) of seismic ground motion to be used for the design of a structure.

SEISMIC-DESIGN ZONE - seismic zone.

SEISMIC EVENT - the abrupt release of energy in the earth's lithosphere, causing an earthquake.

SEISMIC HAZARD - any physical phenomenon (e.g., ground shaking, ground failure) associated with an earthquake that may produce adverse effects on human activities.

SEISMIC RISK - the probability that social or economic consequences of earthquakes will equal or exceed specified values at a site, at several sites, or in an area, during a specified exposure time.

SEISMIC-RISK ZONE - an obsolete term. See "Seismic Zone."

SEISMIC-SOURCE ZONE - an obsolete term. See "Seismogenic Zone" and "Seismotectonic Zone."

SEISMIC ZONE - a generally large area within which seismic-design requirements for structures are constant.

SEISMIC ZONING, SEISMIC ZONATION - the process of determining seismic hazard at many sites for the purpose of delineating seismic zones.

SEISMIC MICROZONE - a generally small area within which seismic-design requirements for structures are uniform. Seismic microzones may show relative ground motion amplification due to local soil conditions without specifying the absolute levels of motion or seismic hazard.

SEISMIC MICROZONING, SEISMIC MICROZONATION - the process of determining absolute or relative seismic hazard at many sites, accounting for the effects of geologic and topographic amplification of motion and of seismic microzones. Alternatively, microzonation is a process for identifying detailed geological, seismological, hydrological, and geotechnical site characteristics in a specific region and incorporating them into land-use planning and the design of safe structures in order to reduce damage to human life and property resulting from earthquakes.

SEISMOGENIC ZONE, SEISMOGENIC PROVINCE - a planar representation of a three-dimensional domain in the earth's lithosphere in which earthquakes are inferred to be of a similar tectonic origin. A seismogenic zone may represent a fault in the earth's lithosphere. See "Seismotectonic Zone."

SEISMOGENIC ZONING - the process of delineating regions having nearly homogeneous tectonic and geologic character, for the purpose of drawing seismogenic zones. The specific procedures used depend on the assumptions and mathematical models used in the seismic-risk analysis or seismic-hazard analysis.

SEISMOTECTONIC ZONE, SEISMOTECTONIC PROVINCE - a seismogenic zone in which the tectonic processes causing earthquakes have been identified. These zones are usually fault zones.

SOURCE VARIABLE - a variable that describes a physical characteristic (e.g., magnitude, stress drop, seismic moment, displacement) of the source of energy release causing an earthquake.

STANDARD DEVIATION - the square root of the variance of a random variable.

UPPER BOUND - see "Maximum Possible."

VALUE AT RISK - the potential economic loss (whether insured or not) to all or certain subset of structures as a result of one or more earthquakes in an area. See "Exposure."

VARIANCE - the mean squared deviation of a random variable from its average value.

VULNERABILITY - the degree of loss to a given element at risk, or set of such elements, resulting from an earthquake of a given magnitude or intensity, which is usually expressed on a scale from 0 (no damage) to 10 (total loss).