UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A WORKSHOP ON "EARTHQUAKE HAZARDS IN THE VIRGIN ISLANDS REGION"

APRIL 9-10, 1984
ST. THOMAS, VIRGIN ISLANDS

OPEN-FILE REPORT 84-762

Reston, Virginia
1984

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

A WORKSHOP ON "EARTHQUAKE HAZARDS IN THE VIRGIN ISLANDS REGION"

APRIL 9-10, 1984
ST. THOMAS, VIRGIN ISLANDS

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 84-762

Compiled by
Lynne N. Downer and Carla J. Kitzmiller

Reston, Virginia
1984

TABLE OF CONTENTS

BACKGROUND INFORMATION AND SUMMARY OF THE WORKSHOP

Background and Summary of the Workshop on "Earthquake Hazards in the Virgin Islands Region"
Walter Hays and Paula Gori 1

EVALUATION OF THE WORKSHOP

Evaluation of the Workshop on Earthquake Hazards in the Virgin Islands Region
Ann FitzSimmons 18

NATURE AND EXTENT OF EARTHQUAKE HAZARDS IN THE VIRGIN ISLANDS REGION

On the Earthquakes Hazards of Puerto Rico and the Virgin Islands
William McCann 23

Evaluation of the Earthquake Ground-Shaking Hazard for Earthquake Resistant Design
Walter Hays 43

Earthquake Vulnerability of Critical Facilities: St. Croix - St. John - - St. Thomas, Virgin Islands
Joseph Fischer 55

INCREASING HAZARD AWARENESS, PERSONAL PREPAREDNESS, AND RESPONSE CAPABILITY

Increasing Hazard Awareness and Personal Preparedness
Risa Palm 64

Disaster Planning in the Virgin Islands
Pamela Johnston 70

Types of Federal Assistance Following an Earthquake in the Virgin Islands
Philip McIntire 75

LAND USE, BUILDING CODES, AND EARTHQUAKE-RESISTANT DESIGN

Virgin Islands' Philosophy Concerning Land Use Planning and Historic Building Rehabilitation
Roy Adams 78

Geology of the U.S. Virgin Islands, A Progress Report
Douglas Rankin 83

Landslide Potential on St. Thomas, Virgin Islands
Earl Brabb 97

Earthquake Resistant Design Criteria
Charles Culver 103

APPENDIX A--SELECTED PAPERS ON WORKSHOP TOPICAL THEMES

Suggestions for Planning an Effective Program of Public Education to Increase Earthquake Hazard Awareness
Joyce Bagwell.. A-1

Examples of Earthquake Hazards Mitigation Techniques Available to Planners and Decisionmakers
William Kockelman.. A-6

APPENDIX B--GLOSSARY OF TERMS USED IN EARTHQUAKE ENGINEERING............... B-1

APPENDIX C--LIST OF PARTICIPANTS.. C-1

BACKGROUND AND SUMMARY OF THE WORKSHOP ON "EARTHQUAKE HAZARDS IN THE VIRGIN ISLANDS REGION"

by

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

BACKGROUND

The workshop, "Earthquake Hazards in the Virgin Islands Region," was held in St. Thomas, Virgin Islands, on April 9-10, 1984. The U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the National Bureau of Standards (NBS), and the Civil Defense and Emergency Services Office of the Virgin Islands sponsored the workshop, the twenty-fifth in a series of workshops and conferences that was devised in 1977 under the auspices of the Earthquake Hazards Reduction Act. This 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 this workshop was to strengthen the capability of the public officials and the scientific-technical community of the Virgin Islands to undertake an effort having short- and long-term goals of reducing losses from geologic hazards. The strategies employed in the workshop were designed: 1) to improve understanding of geologic hazards in the Virgin Islands and 2) to foster a process that links knowledge producers and users (sometimes referred to as a network) and enhances the use of the existing network to increase hazard awareness and to devise loss-reduction measures.

The papers contained in this publication were presented at the workshop. Two additional papers on earthquake hazard awareness and personal preparedness are included in Appendix A. A glossary of terms used in earthquake engineering are contained in Appendix B to facilitate understanding of the technical terminology.

A planning meeting to organize this workshop was held in St. Thomas on April 4-8, 1983. A summary of this meeting is enclosed as Attachment 1 of this report.

This workshop brought together 105 participants having varied backgrounds in earth science, social science, planning, architecture, engineering, and emergency management. The participants (see Appendix C for a list) represented industry, volunteer agencies, and academic institutions of the Virgin Islands, as well as representives of the government of the Virgin Islands, Federal Government, other States, and the private sector. Representatives from the British Virgin Islands also attended. Collectively the participants represented a major part of the resources of the Virgin Islands needed to prepare for and to respond to the geologic hazards of earthquake ground shaking, earthquake-induced ground failures, surface faulting, tectonic deformation, tsunamis, landslides, and rock falls.

HISTORICAL SEISMICITY IN THE THE VIRGIN ISLANDS REGION

The Virgin Islands, a part of the Greater and Lesser Antilles, are 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 major 50 to 60 mile thick rigid plates or segments of the Earth's crust and upper mantle that move slowly and continously over the interior of the Earth, is marked by a high rate of seismicity (Figure 2). During the past 450 years damage has occurred from historical earthquakes in the Virgin Islands region. Because many of the causative faults are offshore or deeply buried, the hypocentral 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.

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)

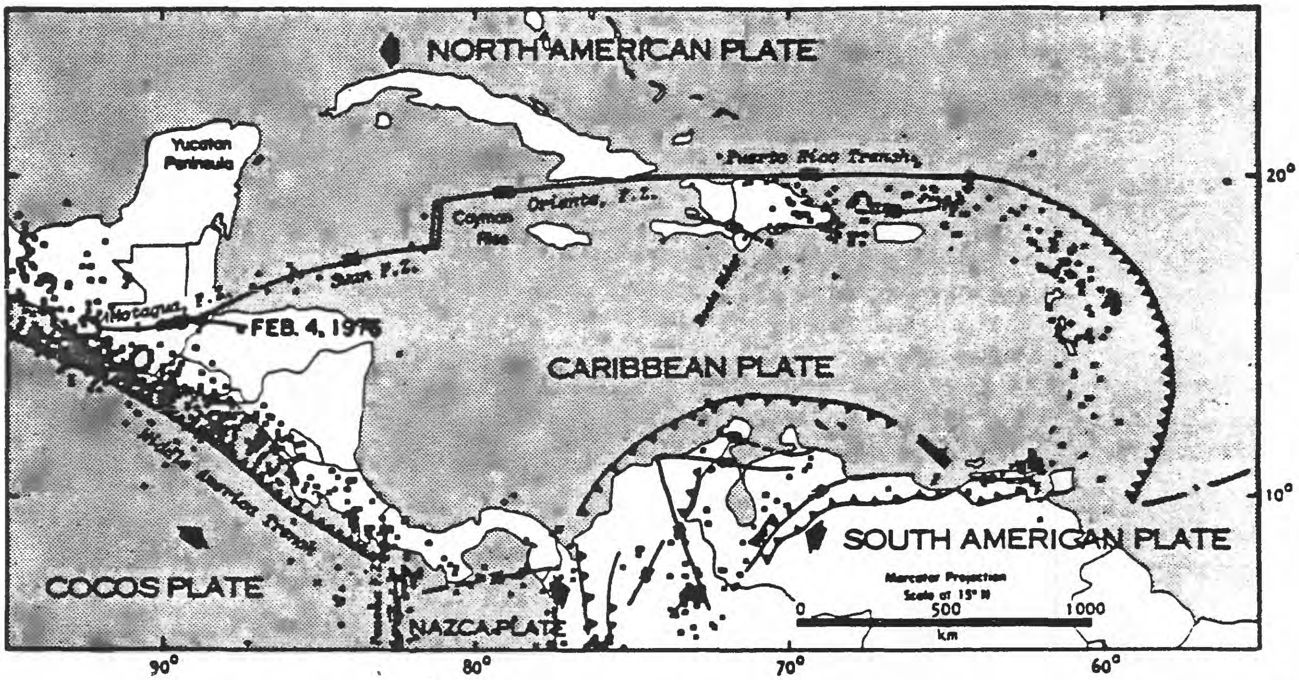


Figure 1.--Diagram showing the relation of the Caribbean plate to the North and South American plates. The North American plate is moving westward at a rate of approximately 0.8 inches per year relative to the nearly stationary Caribbean plate.

DATE (GMT)	LOCATION	MAXIMUM MM INTENSITY
Apr 20, 1824	St. Thomas, Virgin Islands	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)

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 Virgin Islands region; however, the potential losses would be significantly greater now as a consequence of the increased building wealth.

OBJECTIVES OF THE WORKSHOP

This workshop was designed to address the potential effects of earthquakes and other geologic hazards in the Virgin Islands. The workshop was the seventh in a subseries specifically designed to define the threat from earthquakes in the

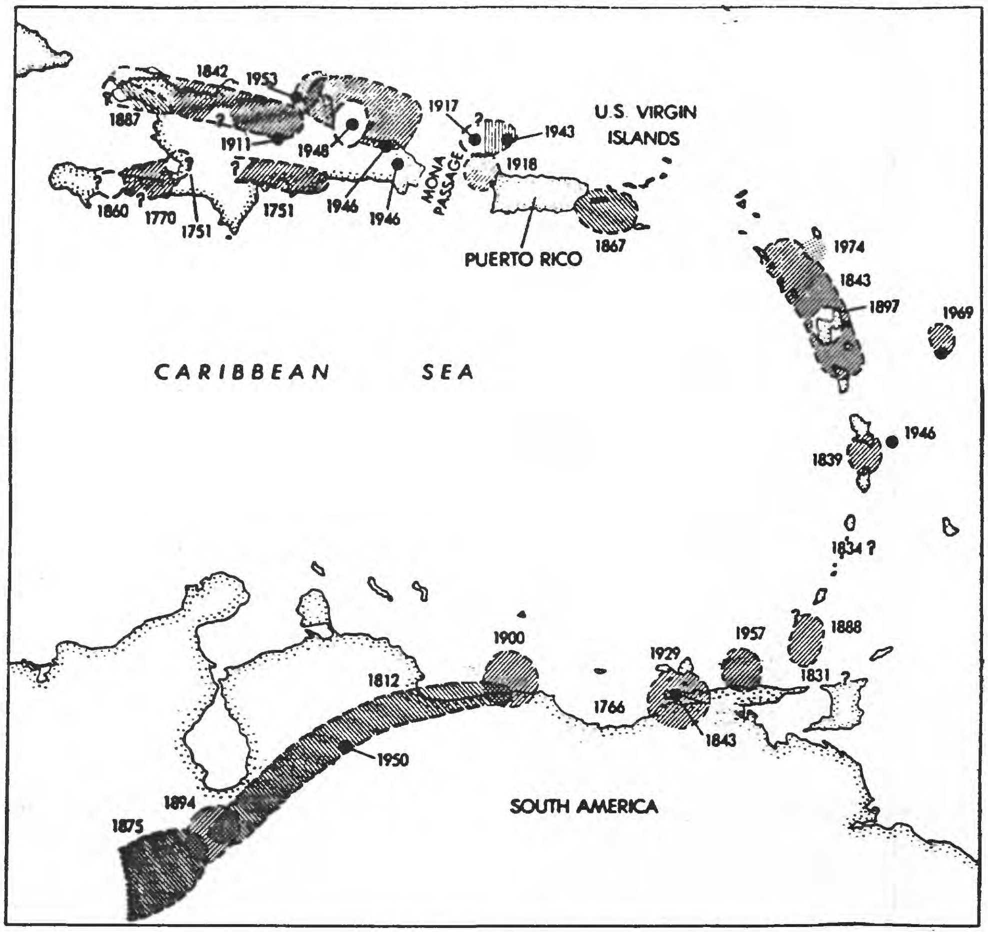


Figure 2.--Map showing location of the Virgin Islands and rupture zones of Caribbean earthquakes since 1800. Areas having the highest potential for earthquakes of magnitude equal to or greater than 7 are shaded. The possibility of great earthquakes (magnitudes of 8 or greater) cannot be ruled out.

Eastern United States and to improve earthquake preparedness. The six prior workshops on earthquake preparedness were sponsored by USGS and FEMA and brought together producers and users of geologic hazards information with the goal of fostering local-state-Federal partnerships and more 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/engineers 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, providing 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.

The sixth workshop, held in San Juan, Puerto Rico, on April 4-6, 1984, was designed to strengthen the short- and long-term activities of the Department of Natural Resources of Puerto Rico to reduce losses from earthquakes and other geologic hazards. The results of this workshop (described in USGS Open-File Report 84-761) pointed out that Puerto Rico is potentially vulnerable to landslides, large earthquakes, and tsunamis.

DECISIONMAKING AND GEOLOGIC HAZARDS

This workshop in the Virgin Islands emphasized the well known fact that understanding geologic hazards is the most important step in devising practical methodologies for reducing future economic losses and social impacts. The potential losses in the Virgin Islands are increasing annually as a consequence of factors such as: 1) increased population density and 2) increased building wealth exposed to potential geologic hazards as urban centers grow through constructions of homes, schools, hospitals, high rise buidings, factories, utility systems, oil refineries, and other facilities.

The choices facing decisionmakers are difficult for three reasons: 1) future geologic hazards occur at uncertain times and locations and have great variation in magnitude and probability of occurrence, 2) reduction of losses requires integration of technical information in the planning process, and 3) loss reduction measures cost money and require local-Federal partnerships having short- and long-term objectives in order to be cost effective. The variety of options for reducing losses from geologic hazards includes:

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

2) Avoidance--if maps and other technical information are available to answer the questions WHERE? and HOW OFTEN?, avoid the hazards by selecting the least hazardous area for construction.

3) Land-use planning and regulation--reduce losses to certain types of structures susceptible to a particular geologic hazard either by reducing their density or by prohibiting 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 engineering design and construction that is appropriate in terms of the frequency of occurrence and the severity of the hazard.

5) Distribution of losses--use insurance and other financial methods to distribute the potential losses in an area susceptible to geologicl hazards.

6) Response and recovery--plan response and recovery measures that are appropriate in terms of a realistic disaster scenario based on past hazardous events.

Decisonmakers have different perspectives about geologic hazards than scientists and engineers. These differences have been summarized by Szanton (1981) 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.

3) The focus of 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 differences in perspectives emerge in discussions of the basic questions forming the basis for an earthquake hazards reduction program:

1) WHERE are the earthquake hazards of ground shaking, earthquake-induced ground failure, surface fault rupture, tectonic deformation, and tsunamis occurring? Where did they occur in the past?

2) WHY are these hazards occurring?

3) HOW OFTEN do they occur?

4) WHAT physical effects are expected to occur in a given period of time (for example, 50 years, the useful life of an ordinary building)?

5) WHAT are the viable options for reducing losses from these physical effects?

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

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: Pamplets and brochures describing basic information as well as effective loss reduction measures that can be incorporated in personal preparedness planning were distributed to all the participants. These included:

- "Family Disaster Plan and Personal Survival Guide" (American Red Cross)
- "Safety and Survival in an Earthquake" (American Red Cross)
- "27 Things to Help You Survive an Earthquake" (American Red Cross)
- "A Blueprint for Earthquake Survial" (American Red Cross)
- "Family Earthquake Drill" (Federal Emergency Management Agency and the American Red Cross)
- "Earthquake Safety Checklist" (Federal Emergency Management Agency and the American Red Cross)
- "Home Hazard Hunt" (Federal Emergency Management Agency)
- "Coping with Children's Reactions to Earthquakes and other Disasters" (Federal Emergency Management Agency)
- "Safety Tips for Earthquakes" (Federal Emergency Management)
- "The Severity of an Earthquake" (U.S. Geological Survey)
- "Earthquakes" (U.S. Geological Survey)
- "Facing Geologic and Hydrologic Hazards: Earth Science Considerations" (U.S. Geological Survey)

PROCEDURE 2: 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 3: Scientists, social scientists, engineers, and emergency management specialists gave oral presentations in three 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 the Virgin Islands 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 4: The participants were encouraged to respond to the presentations of the speakers. One discussion session involving all of the participants was held at the end of the workshop.

PROCEDURE 5: The opinions of the participants on a variety of issues on earthquake and geologic hazards were solicited through a series of questions having "yes" or "no" answers. A written balloting process was used to obtain the concensus of the group prior a presentation on the same subject.

PROCEDURE 6: Ad hoc discussions on topics not addressed during the plenary and discussion group sessions were encouraged to add a spontaneous dimension.

PLENARY SESSIONS

Following the welcome and introductions, the overall theme of the workshop was developed in three plenary sessions which stressed three ways of reducing potential losses from earthquakes and other geologic hazards in the Virgin Islands. The loss reduction that were emphasized are: 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, obtaining, and organizing all available resources (governmental as well as private) 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 the Virgin Islands with other parts of the United States.

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

WELCOME, BACKGROUND, OBJECTIVES, AND GOALS OF THE WORKSHOP.

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

SPEAKERS: The Honorable Julio Brady, Lt. Governor of the Virgin Islands
Philip McIntire
Walter Hays

SESSION I: THE NATURE AND EXTENT OF EARTHQUAKE HAZARDS IN THE VIRGIN ISLANDS.

OBJECTIVE: Presentations giving the geologic setting of the Virgin Islands in the context of the Caribbean plate. Topics included: a) historical earthquakes in the Virgin Islands region, their frequency of occurrence and potential impacts, ground motions expected for various planning scenarios, and potential tsunami impacts, b) the 1867 earthquake, and c) the potential vulnerability of specific facilities in the Virgin Islands.

SPEAKERS: William McCann
Walter Hays
Isidore Paiewonsky
Joseph Fischer

SESSION II: INCREASING HAZARD AWARENESS, PERSONAL PREAPAREDNESS, AND RESPONSE CAPABILITY

OBJECTIVE: Presentations giving: a) suggestions for increaseing hazard awareness and personal preparedness, b) status of the Virgin Islands' disaster plans and its resources for disaster response, and c) types of assistance available from the Federal government before and after an earthquake.

SPEAKERS: Risa Palm
Pamela Johnston
Philip McIntire

SESSION III: WAYS TO MITIGATE THE EFFECTS OF AN EARTHQUAKE AND OTHER GEOLOGIC HAZARDS THROUGH LAND USE, BUILDING CODES, DESIGN, AND CONSTRUCTION.

OBJECTIVE: Presentations giving information on: a the philosophy of the Virgin Islands concerning land-use planning and historic building rehabilitation, b) knowledge of the geology of the Virgin Islands and its incorporation in land-use planning, c) legal liability of government officials, d) recent progress in earthquake-resistant design of Virgin Islands' type structures, e) status of proposed earthquake design revisions to the Virgin Islands' building code, and f) legal liability of government officials.

SPEAKERS: Roy Adams
Douglas Rankin
Earl Brabb
Charles Culver
Justus Villa
Arthur Finch

DISCUSSION GROUP

One discussion session was held at the end of the workshop. The goal was to stimulate interactive discussion of the problems that had been identified in the plenary session and their solutions. The following subjects were discussed:

1) Uniqueness of the Virgin Islands with respect to the reduction of earthquake hazards.

2) Transfer of technology from other parts of the United States to the Virgin Islands to enhance preparedness for earthquake hazards.

3) Immediate and long range actions to reduce potential losses from earthquakes in the Virgin Islands region.

4) Research needs.

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

VIEWS OF THE PARTICIPANTS

Written ballots were taken informally during the workshop to define the areas of agreement and disagreement of the participants and to sharpen the focus of the presentations and subsequent discussions. The results are summarized below:

Question 1: If the following social and economic problems (unranked) of concern to the populace of the Virgin Islands are on the agenda of decisionmakers in the Virgin Islands:

Quality of public schools
Economic development
Hurricanes
Traffic
Supply of electrical power
Drought
Unemployment
Crime
Drug and alcohol abuse

do earthquake hazards fall a) in the upper one-third? b) middle one-third? c) lower one-third?

Answer:
a) 10% of the participants answered that earthquake hazards would fall in the upper one-third
b) 31% answered middle one-third
c) 51% answered lower one-third

Question 2: Are you confident that: a) you and your home will survive earthquake ground shaking of Modified Mercalli intensity VIII? b) you and your office will survive earthquake ground shaking of Modified Mercalli intensity VIII? c) your children and their school will survive earthquake ground shaking of Modified Mercalli Intensity VIII?

Answer:
a) 21% answered yes to question 2a
b) 25% answered yes to question 2b
c) 21% answered yes to question 2c

Question 3: If you received a brochure in the mail from a credible source telling you that earthquake hazards in the Virgin Islands region are a significant threat to your safety, would you a) purchase earthquake insurance, b) undertake appropriate personal preparedness measures such as providing adequate water supply, straping down the water heater, bolting bookcases to the wall, reinforcing weak sections of your house, preparing a family response plan, etc.?

Answer: a) 70% said they would purchase earthquake insurance.
b) 78% said they would undertake personal preparedness measures.

Question 4: Assuming that a major (Modified Mercalli intensity VIII-IX) earthquake will occur in the next 5 years in the Virgin Islands region, do you think that the Virgin Islands will be prepared to manage the required disaster response and recovery operations?

Answer: 24% percent said that the Virgin Islands will be prepared.

Question 5: Do you or some of your friends live near a ghut? Is the ghut dry most of the year, but full of boulders? Do you consider this a hazard?

Answer: 56% said yes to this question.

Question 6: Assuming that the next damaging (Modified Mercalli intensity VIII-IX) earthquake in the Virgin Islands region will occur 50 years from now, do you think realistic long-term mitigation measures, such as building codes, realistic seismic design provisions, and land-use planning and regulation, will be in effect in the Virgin Islands?

Answer: 54% said realistic long-term measures will be in effect.

CONCLUSIONS AND RECOMMENDATIONS

The following actions were proposed by participants in the workshop:

1) The Virgin Islands has areas susceptible to landslides, washouts (ghuts), and rock falls in addition to areas susceptible to the earthquake hazards of ground shaking, earthquake-induced ground failures, tectonic deformation, and tsunamis. These hazardous areas should be mapped using the resources of U.S. Geological Survey (USGS), participants in the USGS's external program, and the technical community of the Virgin Islands. Some activities can be conducted in conjunction with similar work being performed in Puerto Rico.

2) Geologic hazards should be incorporated in the subdivision regulations. The Virgin Islands Department of Planning has responsibility for these kinds of activities.

3) The Virgin Islands should continue planning for a damaging earthquake. The vulnerability study currently being conducted by Geosciences Inc., under the sponsorship of the Federal Emergency Management Agency (FEMA) should be completed and the results incorporated in response plans and mitigation activities. The Office of Civil Defense, Office of Emergency Preparedness of the Virgin Islands has responsibility for these activities.

4) The technical community of the Virgin Islands is encouraged to take advantage of training opportunities. Examples include: a) regional seminars on earthquake engineering conducted by the Earthquake

Engineering Research Institute (Note: a seminar is tentatively planned for April 15-16, 1985, in Puerto Rico), b) short courses on seismology and geology conducted by USGS scientists in conjuction with field in the Virgin Islands, c) sponsorship of local engineers by the National Bureau of Standards in their "visiting scientists" program, and d) the Summer Institute on Multihazards Protection, conducted annually in July at the Emmitsburg, Maryland, training facility of FEMA.

5) The American and British Virgin Islands should seek ways to cooperate in the developement of strategies for reduction of losses from earthquake and other natural hazards.

ACKNOWLEDGMENTS

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

1) The Steering Committee of Pamela Johnston, Roy Adams, Phil McIntire, Jane Bullock, Douglas Rankin, Risa Palm, Luther Edwards, Marco Lugo, Charles Culver, and Earl Brabb assisted in the planning and organization of the workshop.

2) The support of Dr. Norwell Harrigan, Caribbean Research Institute, who encouraged representatives of the British Virgin Islands to participate in 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) The state of earthquake and other natural hazard preparedness in the Virgin Islands has been directly influenced by Pamela Johnston. Pamela Johnston and her staff provided valuable logistical support which made this workshop possible.

4) Carla Kitzmiller, Joyce Costello, Cheryl Miles, Susan Kibler, and Lynne Downer 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.

ATTACHMENT 1

RECOMMENDATIONS OF PLANNING MEETING TO ORGANIZE WORKSHOPS ON GEOLOGIC HAZARDS

INTRODUCTION

A planning meeting involving 20 people, identified below, was held in St. Thomas, U.S. Virgin Islands, April 4-8, 1983. The outcome of the meeting was the identification of a wide range of needs for information on gelogic hazards in the U.S. Virgin Islands. Preliminary plans were made to hold several workshops on the scientific, engineering, societal, and preparedness aspects of geologic hazards, focussing on the specific needs identified by public officials and representatives of business, industry, and universities in the Virgin Islands.

Name	Organization
Roy Adams	Planning Office, U.S. Virgin Islands
Bob Brandes	National Park Service, U.S. Virgin Islands
Luther Edwards	Hess Oil Virgin Islands Corp.
Arnold M. Golden	Department of Public Works, U.S. Virgin Islands
Dr. Norwell Harrigan	Caribbean Research Institute
Dr. Walter W. Hays	U.S. Geological Survey
Barry Hurst	St. Thomas Hospital
Captain John James	Department of Public Safety, U.S. Virgin Islands
Ms. Pamela Johnston	Office of Civil Defense, U.S. Virgin Islands
Francine Lang	Department of Conservation and Cultural Affairs, U.S. Virgin Islands
Marco Lugo	Martin Marietta Alumina
Robert Mathes	Department of Public Works, U.S. Virgin Islands
Bill McCann	Lamont-Doherty Geological Observatory
Stan McIntosh	Federal Emergency Management Agency, Region II
William McLean	College of the Virgin Islands
Ugo Morelli	Federal Emergency Management Agency
Dr. Risa Palm	University of Colorado
Claire B. Rubin	George Washington University
Barry Sans	Hess Oil Virgin Islands Corp.
Brian Turnbull	Planning Office, U.S. Virgin Islands

Walter Hays served as moderator of the planning meeting. With assistance from the three U.S. Geological Survey consultants: Dr. Risa Palm, Claire Rubin, and Dr. William McCann; and from Ugo Morelli, and Stan McIntosh, general information on the geologic hazards of earthquakes, ground failures, and volcanoes was presented to the attendees, along with data about societal impacts, response and recovery, and preparedness planning.

To set the stage, the likely impacts from a repeat of the major earthquake of November 1867, which affected the Virgin Islands, were described. This earthquake today would cause considerable physical damage and extensive societal impacts from ground shaking, tsunami waves, ground failures, and regional tectonic deformation. The response and recovery period would be complicated by the high probability that the Virgin Islands might be totally isolated for up to several days.

RECOMMENDATIONS

The participants of the meeting recognized the need for increasing knowledge of geologic hazards and various mitigation measures as well as improving earthquake preparedness planning. Because no one who experienced the 1867 earthquake is still alive and very few have experienced a damaging earthquake, a great deal of information must be transferred to bring knowledge of earthquakes (and other geologic hazards) up to that of hurricanes.

Listed below are the needs identified at the workshop planning meeting and a suggested program for a planned workshop to address these needs.

NEEDS IDENTIFIED BY PARTICIPANTS AT HAZARDS WORKSHOP PLANNING MEETING

- Identification of geologic hazards research problems that should be undertaken by Virgin Islands.
- Geologic data base for making decisions about the threat of geologic hazards and extrapolating to particular applications.
- Comprehensive plans to help the people help themselves pre- and postdisaster; land-use plans to guide financial community; legal mechanisms and memoranda of understanding to speed recovery.
- Increased public awareness of geologic hazards; relation of geologic hazards to hurricane hazards.
- A building code that reflects earthquake threat to Virgin Islands relative to other parts of U.S.
- Assessment of vulnerability, especially to water supply.
- Communications to the people to advise them what to do in each stage of disaster recovery.
- Education of the public (for example, identification of edible vegetation in times of disaster).
- Identification of areas where wave problems exist, especially from tsunamis.
- Use of geologic information in public works, public health, and public safety activities to mitigate geologic hazards.
- Studies of ways to use nature (reefs, vegetation, etc.) to mitigate hazards of ground shaking, tsunamis, and landslides.
- Guidelines for retrofitting and strengthening existing buildings.
- Guidelines for design, construction, and inspection of new buildings in seismic zone 3.
- Identification of alternate locations for certain classes of construction.

EVALUATION OF THE WORKSHOP ON "EARTHQUAKE HAZARDS IN THE VIRGIN ISLANDS REGION"

by

Ann FitzSimmons
University of Colorado
Boulder, Colorado 80309

At the conclusion of the two-day gathering, participants were asked to evaluate the success of the workshop in reaching its goals, to rate various activities, and to estimate possible changes in awareness and concern as a result of having taken part. The workshop was designed to define the earthquake threat in the Virgin Islands, describe current capabilities for responding to an earthquake in the Virgin Islands, develop strategies to increase awareness and concern and describe earthquake mitigation methods.

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 Figure 1). Since not all respondents answered all the questions, percentages are based only on those who submitted evaluations (see Figure 2).

Evaluations returned by 50 participants indicate that the workshop was successful in meeting its goals. Ninety-six percent of the evaluators thought the workshop did a good job of defining the earthquake threat in the Virgin Islands. The workshop's role in developing strategies to increase awareness and preparedness was also well received with 70% of the respondents rating this segment as highly effective. Response was less enthusiastic when evaluating the success of the workshop in describing methods to mitigate the earthquake threat and in providing information dealing with current response capabilities. One-half found the workshop successful in its description of earthquake response capabilities, 26% thought it moderately helpful and 20% 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 the seismic problem in the Virgin Islands. Over 75% of the respondents gave the workshop high marks for providing new sources of information or expertise, and another 16% 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. Sixty-eight percent said that the workshop was very successful in providing a better understanding of problems faced by decisionmakers, and 24% 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, discussions following the formal presentations, informal discussions, and materials such as notebooks and abstracts. Formal presentations received the most enthusiastic evaluation; 90% of the respondents judged them to be highly useful. Discussions following the formal presentations were judged highly successful by over 70% of the respondents. Informal discussions were less useful as only 48% of the respondents gave them high marks. The workshop materials were seen to be a valuable part of the meeting with only one participant finding them to be of little use.

The importance attached to this workshop is shown in the response of 92% 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 of heightening levels of awareness and concern. Significant numbers of participants (42%) reported their levels of awareness prior to the workshop would have been described as low. Twenty-six percent rated their levels of awareness as moderate, and 32% rated them as high before the workshop. Following the workshop, however, no participant felt his or her awareness was low; only 6% considered their awareness moderate, while 94% 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 nearly one-half of the respondents, with 20% registering moderate concern and 30% high concern. After the workshop, participants revised their perceptions of concern significantly; only 4% defined their levels of concern as low, 10% said they were moderate, and 86% said they were highly concerned about the state of earthquake preparedness in the Virgin Islands.

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 on the evaluation sheet asked respondents to consider actions they might take to improve the awareness and concern of others or to implement mitigation activities in the Virgin Islands. Response from 19 participants to this question was varied.

The majority of these participants indicated plans to get earthquake information out to the public through a variety of means. Most were going to discuss what they learned with friends, colleagues and local community groups in order to awaken hazard awareness and get people interested in mitigation. Public awareness through education programs was also envisioned, with the schools and media as information disseminators.

Other particiapnts had more specific steps in mind such as incorporating earthquake concerns into documents produced by the Virgin Islands planning office, obtaining California's seismic design criteria for architects, and continuation of efforts toward the adoption in the Virgin Islands of the Uniform Building Code. It is evident from these responses that the workshop provided enough new information to cause participants to begin thinking of ways in which to pass on newly acquired knowledge of the earthquake threat in the Virgin Islands.

Figure 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 the Virgin Islands Region?	1	1	48
b. Describing methods of mitigating the effects of an earthquake through land-use, building codes, earthquake-resistant design, and individual preparedness?	3	16	29
c. Increasing hazard awareness and preparedness in the Virgin Islands Region?	1	12	35
d. Describing the current capabilities of responding to an earthquake in the Virgin Islands Region?	10	13	25
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?	3	8	39
b. Establish better understanding of the problems faced by researchers and decisionmakers?	1	12	34
3. Did you find the following activities useful:			
a. Formal presentations?	1	3	45
b. Discussions following the formal presentations?	5	5	36
c. Notebook and abstracts?	1	11	33
d. Informal discussions during coffee breaks and after hours?	9	13	24
4. If the clock were turned back and the decision to attend the workshops were given you again, would you want to attend?	--	4	46
5. Should future workshops be planned to continue the work initiated at this meeting?	--	3	47
6. Prior to attending this workshop, I would rate my awareness of the earthquake threat in the Virgin Islands as	21	13	16
7. Prior to attending this workshop, I would rate my concern about the state-of-earthquake preparedness in the Virgin Islands Region	25	10	15
8. I now rate my awareness as	--	3	47
9. I now rate my concern	2	5	43

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.

Figure 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 the Virgin Islands Region?	2%	2%	96%
b. Describing methods of mitigating the effects of an earthquake through land-use, building codes, earthquake-resistant design, and individual preparedness?	6%	32%	58%
c. Increasing hazard awareness and preparedness in the Virgin Islands Region?	2%	24%	70%
d. Describing the current capabilities of responding to an earthquake in the Virgin Islands Region?	20%	26%	50%
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?	6%	16%	78%
b. Establish better understanding of the problems faced by researchers and decisionmakers?	2%	24%	68%
3. Did you find the following activities useful:			
a. Formal presentations?	2%	6%	90%
b. Discussions following the formal presentations?	10%	10%	72%
c. Notebook and abstracts?	2%	22%	66%
d. Informal discussions during coffee breaks and after hours?	18%	26%	48%
4. If the clock were turned back and the decision to attend the workshops were given you again, would you want to attend?	--	8%	92%
5. Should future workshops be planned to continue the work initiated at this meeting?	--	6%	94%
6. Prior to attending this workshop, I would rate my awareness of the earthquake threat in the Virgin Islands as	42%	26%	32%
7. Prior to attending this workshop, I would rate my concern about the state-of-earthquake preparedness in the Virgin Islands Region	50%	20%	30%
8. I now rate my awareness as	--	6%	94%
9. I now rate my concern	4%	10%	86%

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 10964

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

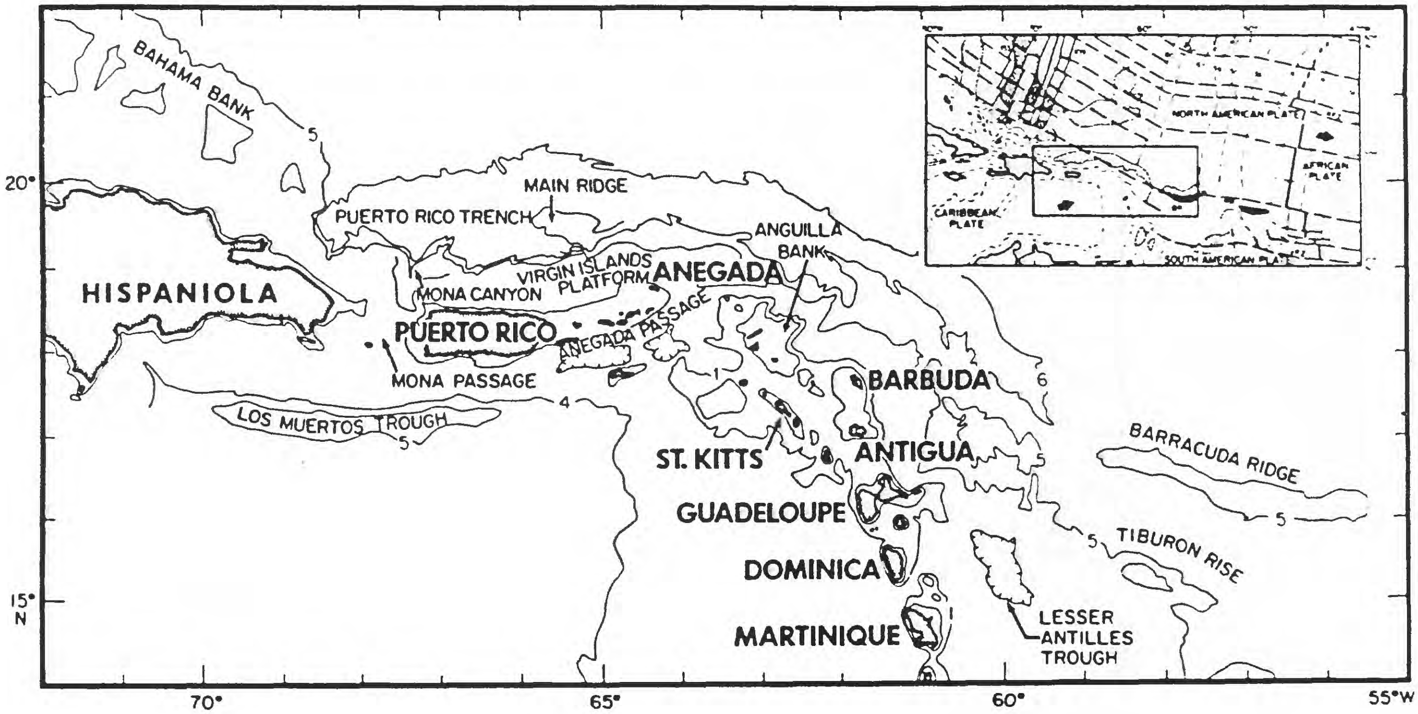


Figure 1. Place names and general bathymetry of northeastern Caribbean. Contours are in kilometers (after Case and Holcombe, 1980). Inset shows tectonic framework fo the eastern Caribbean and Central Atlantic Ocean. Arrows are directions of relative motion of African and Caribbean plates with respect 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).

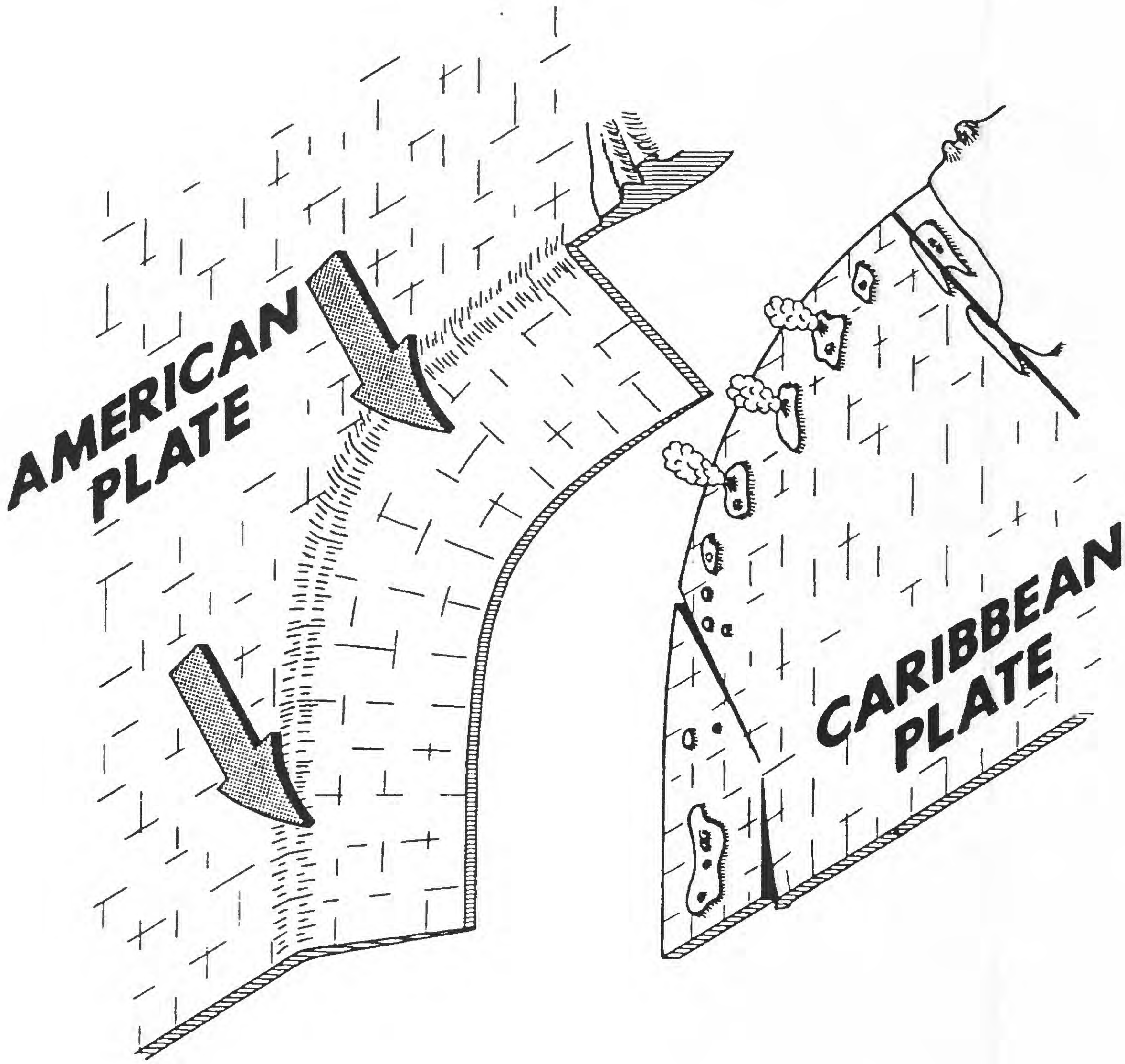


Figure 2. Plate tectonic sketch of eastern Caribbean. North American Plate moves WSW relative to the Caribbean plate. In the view shown here the plates are separated to allow viewing of downgoing section of North American plate. Puerto Rico and the Virgin Islands lie on a block that appears not to be 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.

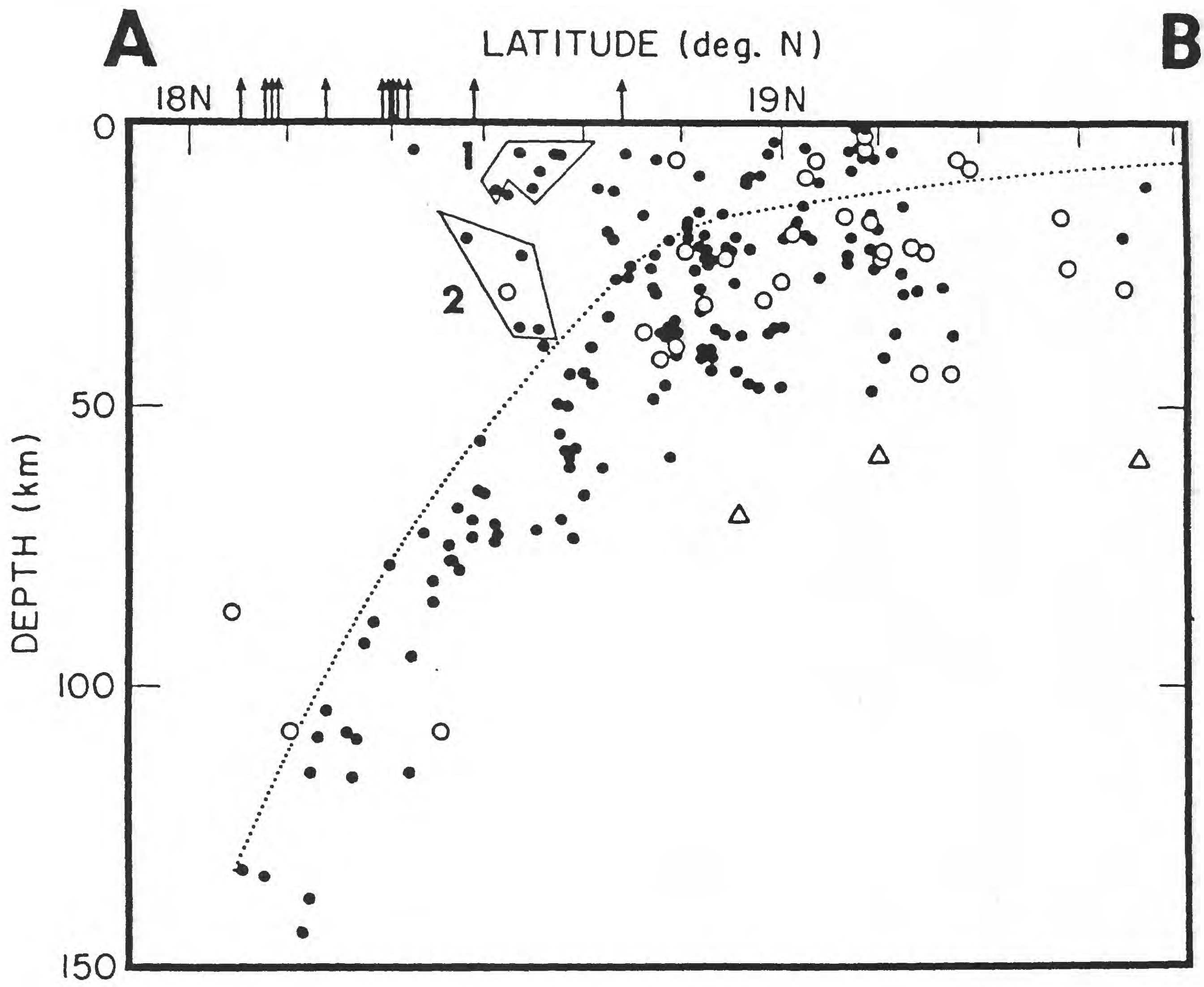


Figure 3. Vertical cross-section of 227 relocated hypocenters, obtained by projecting them onto a vertical plane striking N-S along 64 degrees 40' W in a direction perpendicular to Puerto Rico (only events within 100 km of this line are shown). Open symbols indicate events with residuals $\geq$0.3 sec; solid symbols show events with residuals $\leq$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.

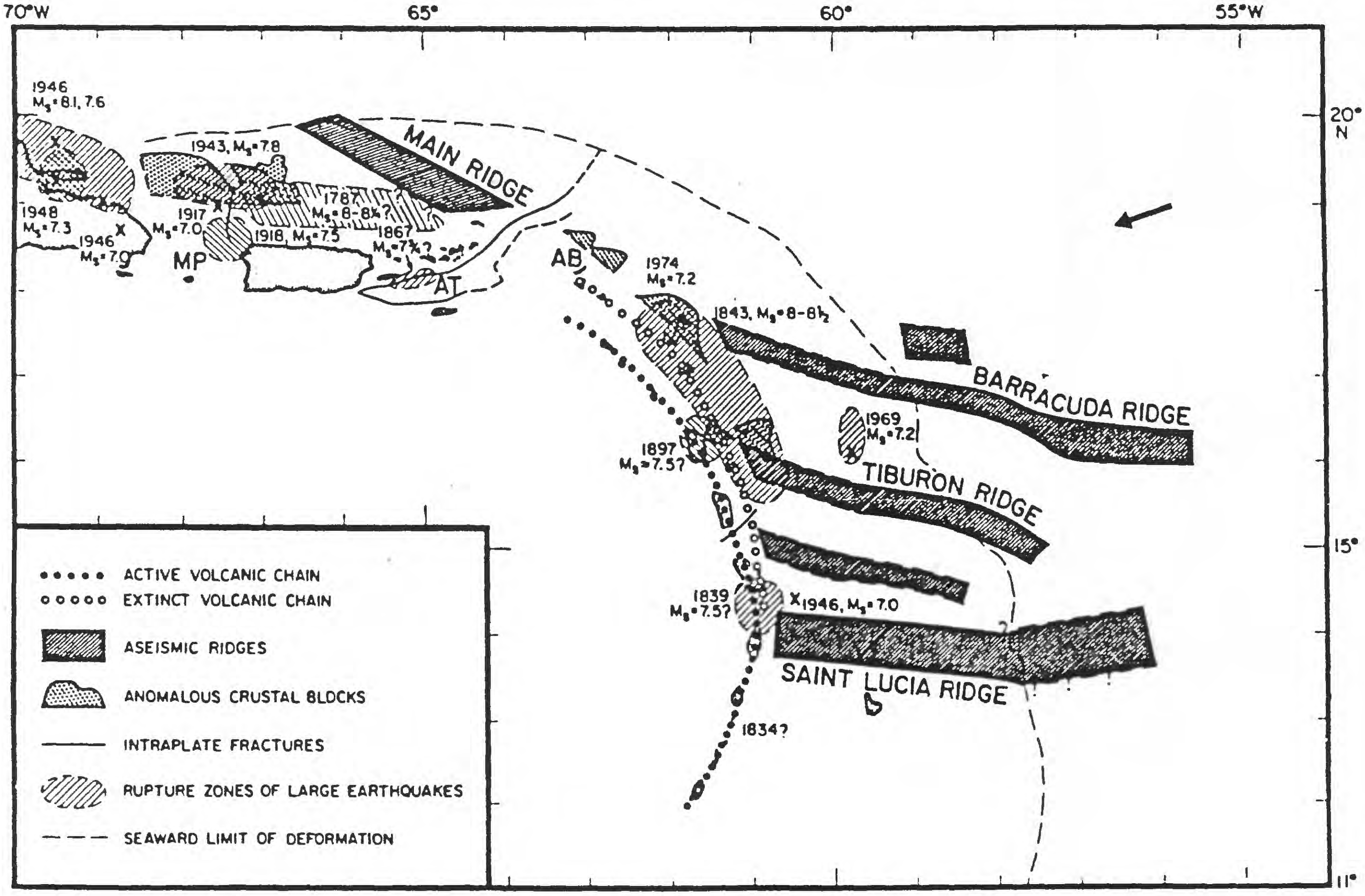


Figure 4. Rupture zones of large earthquakes ($M \geq 7$) in the eastern Caribbean and their relationship to features that bound end of rupture. Several bathymetric highs intersect the plate boundary dividing it into tectonic segments. Rupture during the 1787 event may have been limited by the Main Ridge 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).

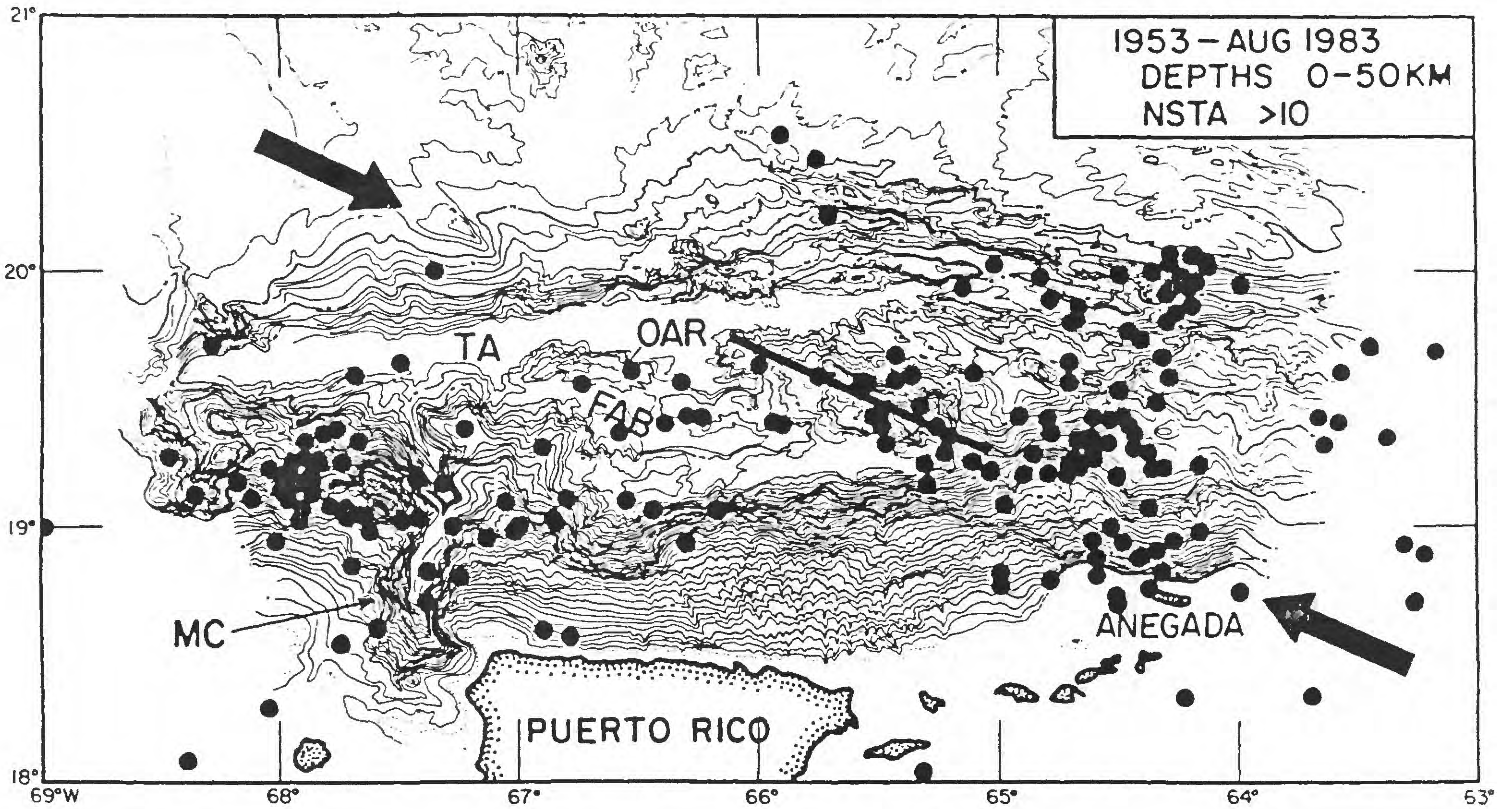


Figure 5. Detailed bathymetry of the Puerto Rico Trench north of Puerto Rico and the Virgin Islands (A. Leonardi, unpublished data). Contours are in hundreds of fathoms (1 fathom = 1.829 meters). Circles are epicenters are moderate-sized shocks from 1953 to 1983 with depths less than 50 kilometers. Only 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 ($M \geq 7.75$) 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.

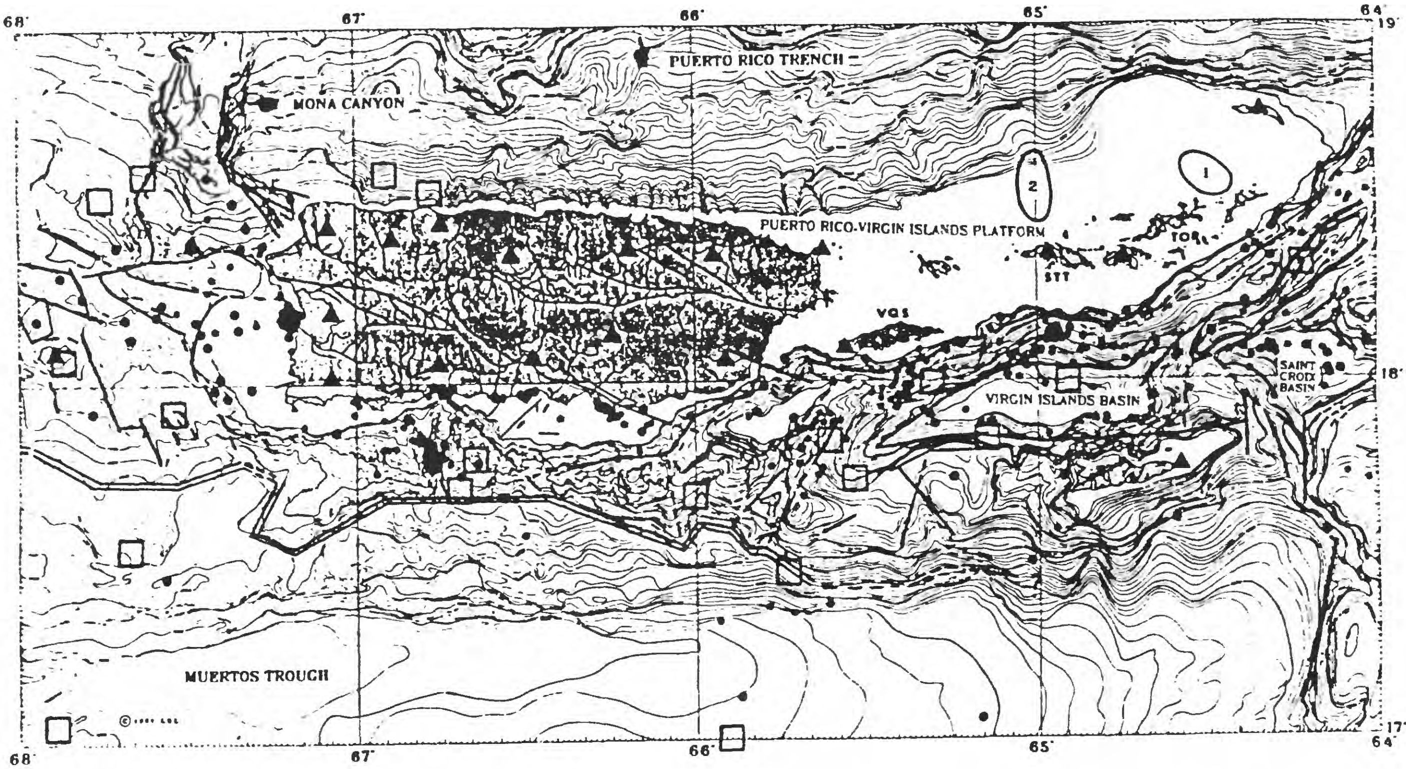


Figure 6. Major, recent tectonic features near Puerto Rico and the Virgin Islands. Contours, showing depth to seafloor in meters, delineate major morphologic features in the offshore region (from Trumbull, 1981). Puerto Rico and the Virgin Islands lie on a long, shallow platform. Saint Croix lies on 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 ($M \simeq 7$-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

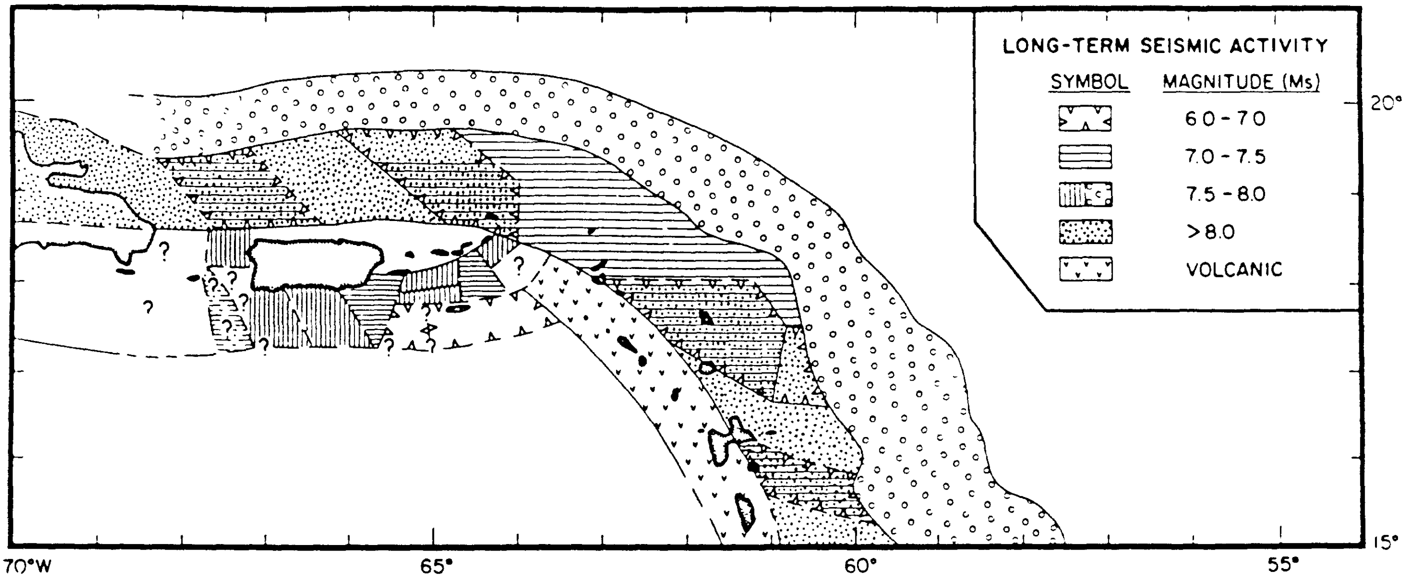


Figure 7. Estimate of long-term seismic activity of shallow focus along the Caribbean - North American plate boundary. Moderate-sized events ($M \simeq 6$-7) are expected to be more frequent along those portions of the seismic zone where bathymetric highs have entered the trench. Large shocks ($M \simeq 7.5$-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.

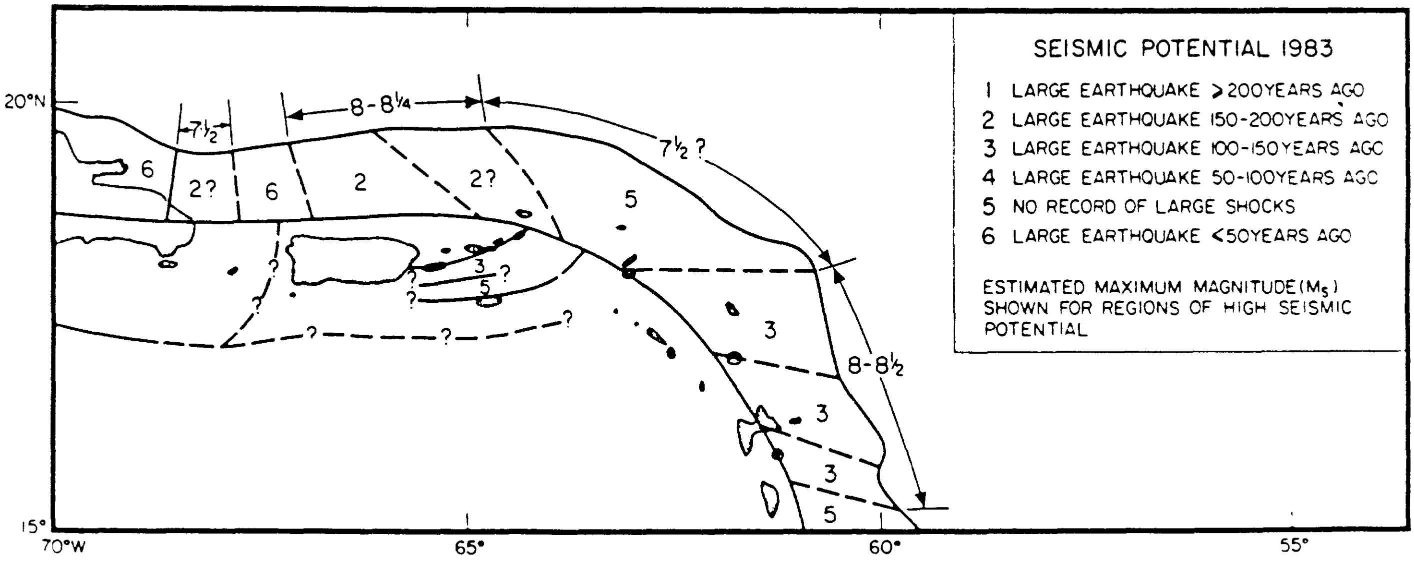


Figure 8. Estimate of seismic potential for the northeastern Caribbean. Potential for large or great shock to occur is estimated by the time elapsed since the last large earthquake. This method assumes repeat times throughout the region are about the same. Magnitudes of future shocks are estimated for 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, Bulietin 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 FOR EARTHQUAKE-RESISTANT DESIGN

by

Walter W. Hays
U.S. Geological Survey
Reston, Virginia 22092

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

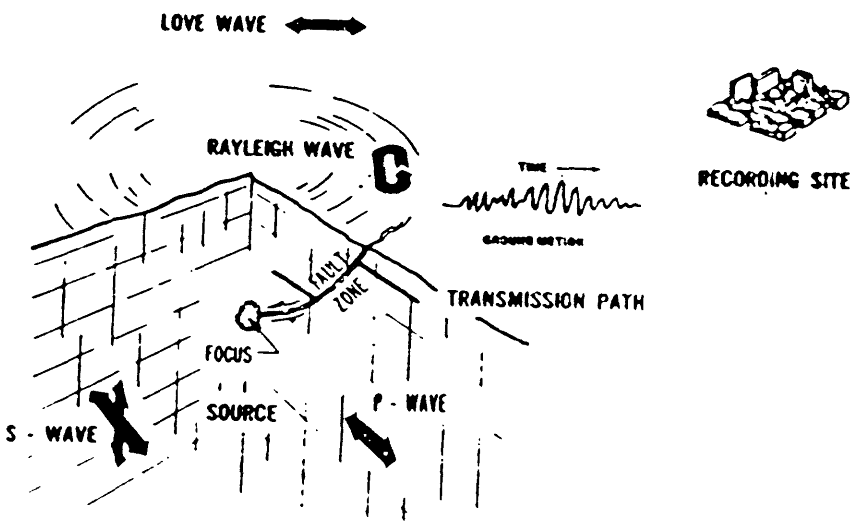


Figure 1.--Schematic illustration of the directions of vibration caused by body and surface seismic waves generated during an earthquake. When a fault ruptures, seismic waves are propagated in all directions, causing the ground to vibrate at frequency ranging from 0.1 to 30 Hertz. Buildings vibrate as 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 <u>minimum</u> 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

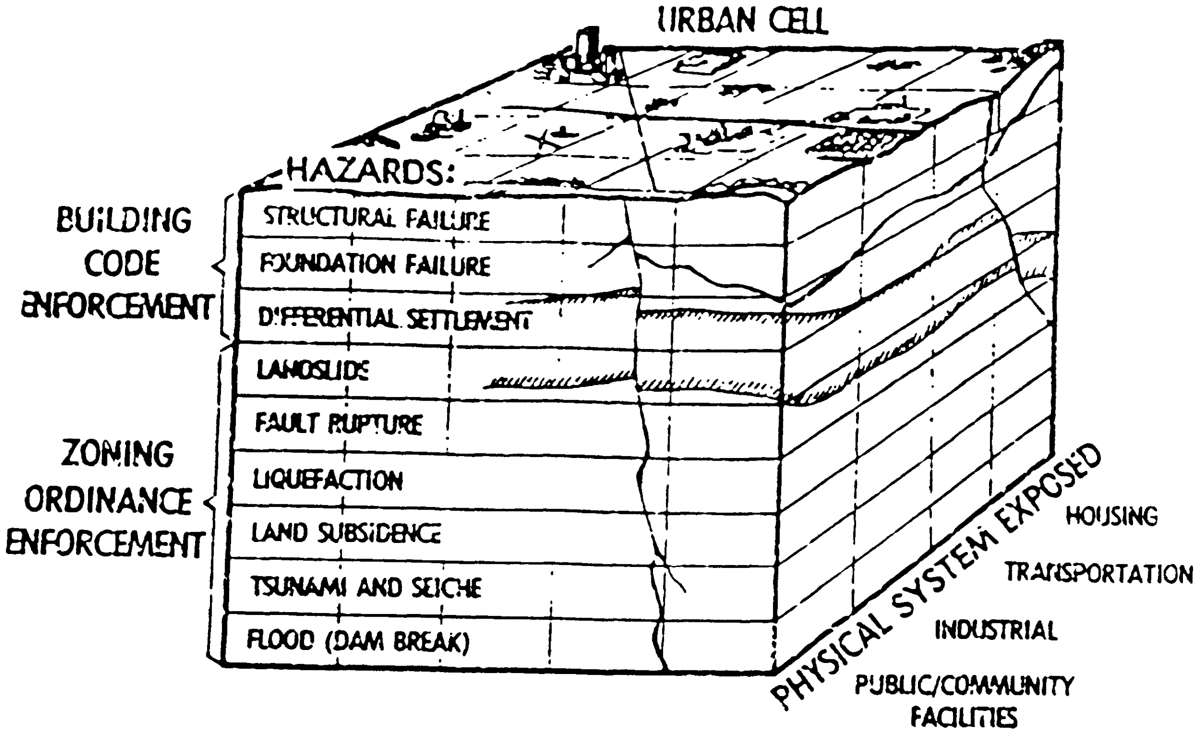


Figure 2.--Schematic illustration of a typical community having physical systems (public/community facilities, industrial, transportation, and housing) exposed to earthquake hazards. Evaluation of the earthquake hazards provides policymakers with a sound physical basis for choosing mitigation strategies 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

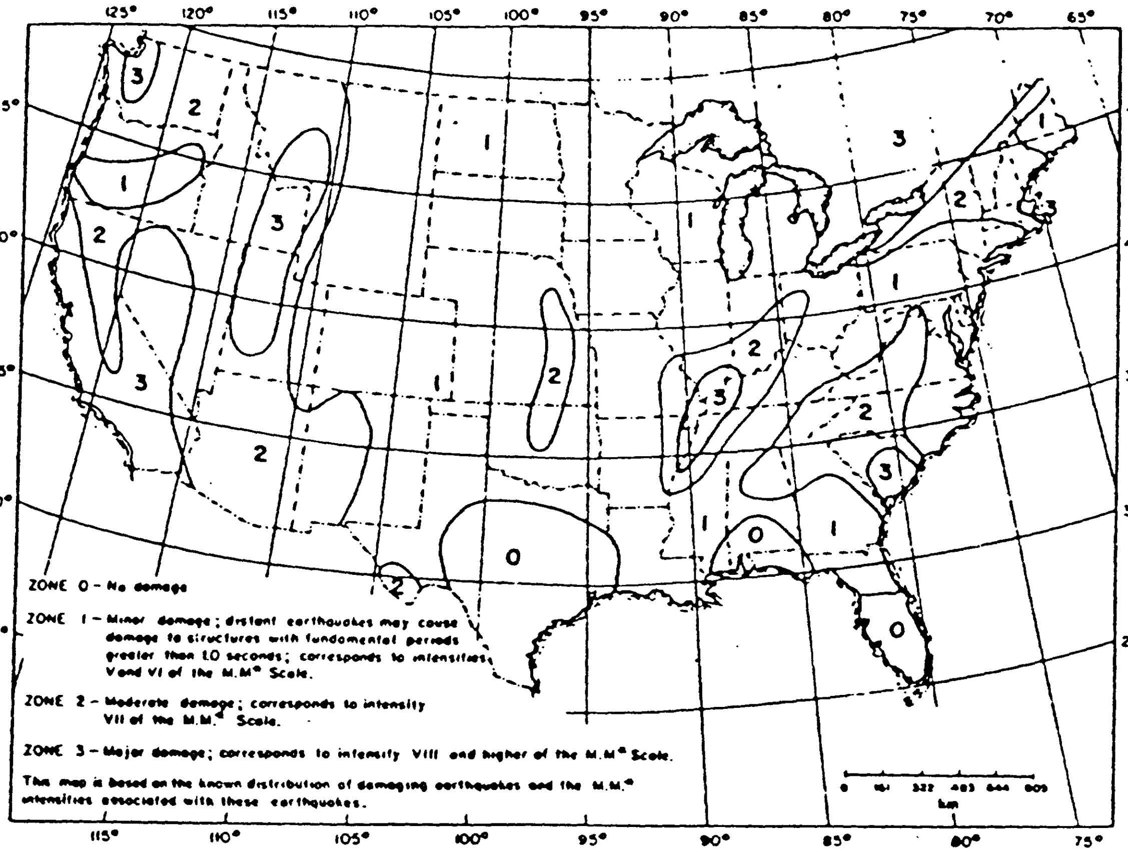


Figure 3.--Seismic hazard zones based on historical Modified Mercalli intensity data and the distribution of damaging earthquakes (Algermissen, 1969). This map was adopted in the 1970 edition of the Uniform Building Code and incorporated, with some modifications, in later editions. Zone 3 depicts the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

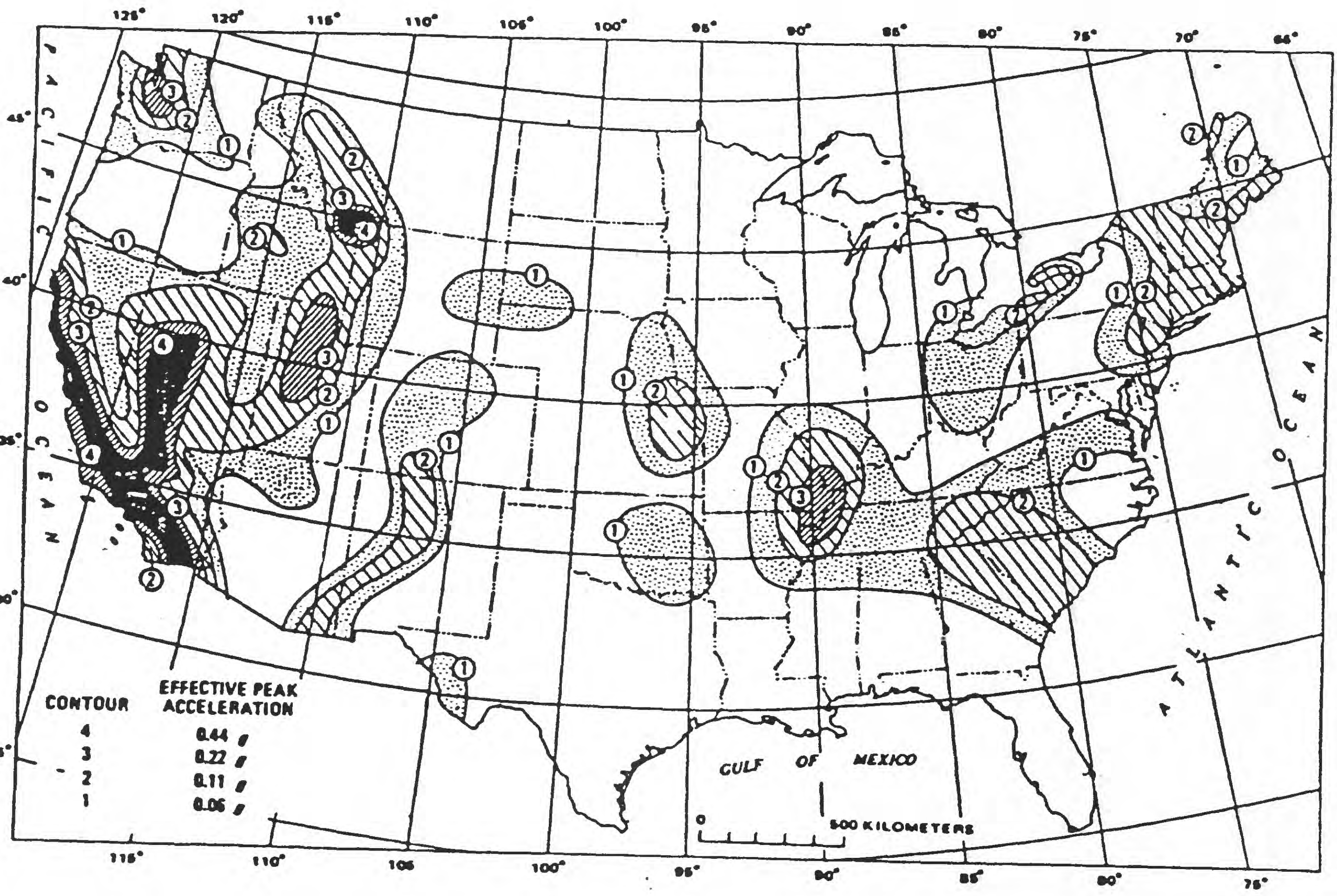


Figure 4.--Map showing preliminary design regionalization zones for the contiguous United States proposed by the Applied Technology Council in 1978 for its model building code. Contours connect areas underlain by rock having equal values of effective peak acceleration. Mapped values have a 90 percent 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).

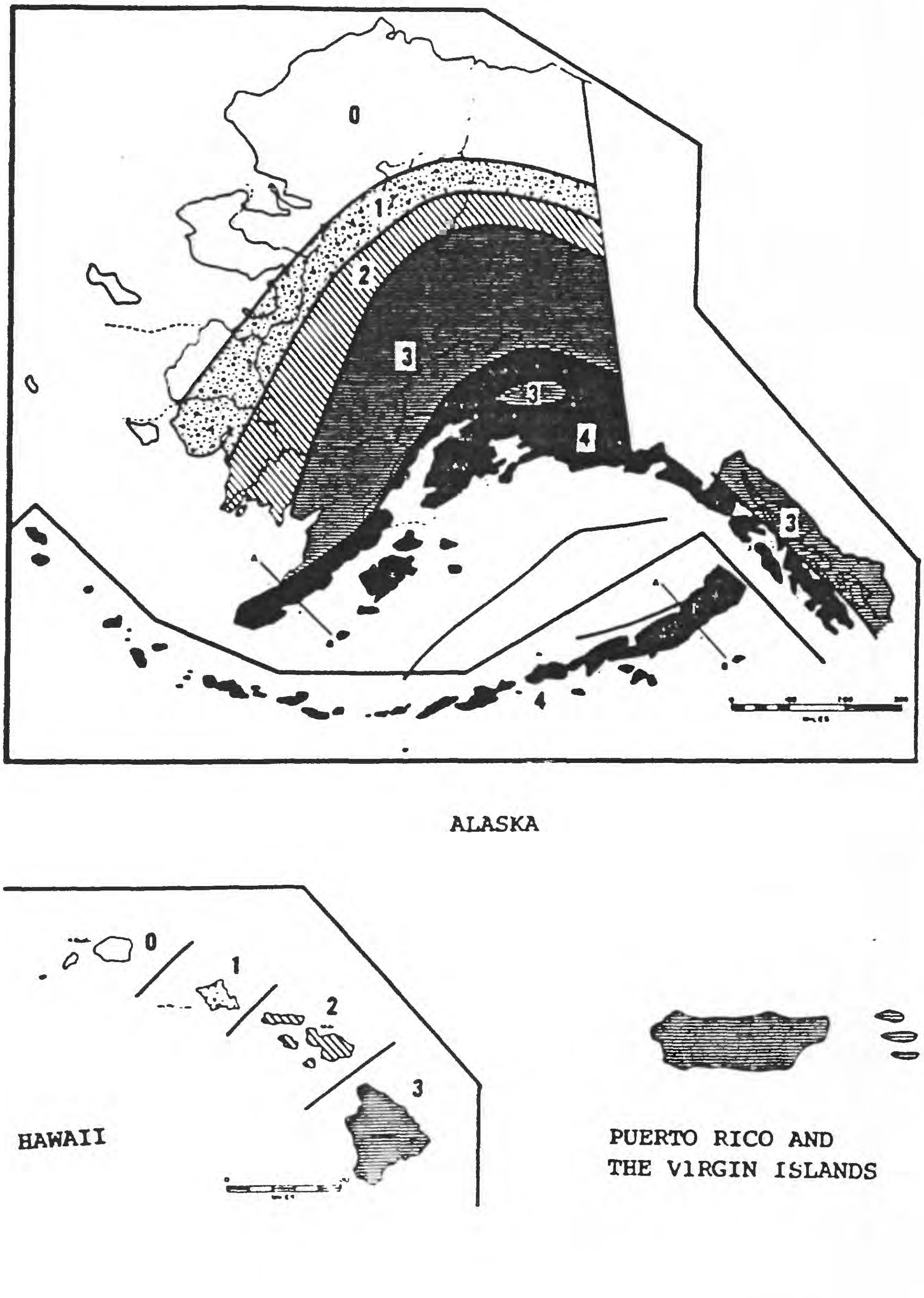


Figure 5.--Map showing preliminary zones of the ground-shaking hazard in Alaska, Hawaii, Puerto Rico, and the Virgin Islands. Puerto Rico and the Virgin Islands lie in zone 3; indicating the requirement for a peak acceleration of about 0.20 g. These maps can be improved with additional research.

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?

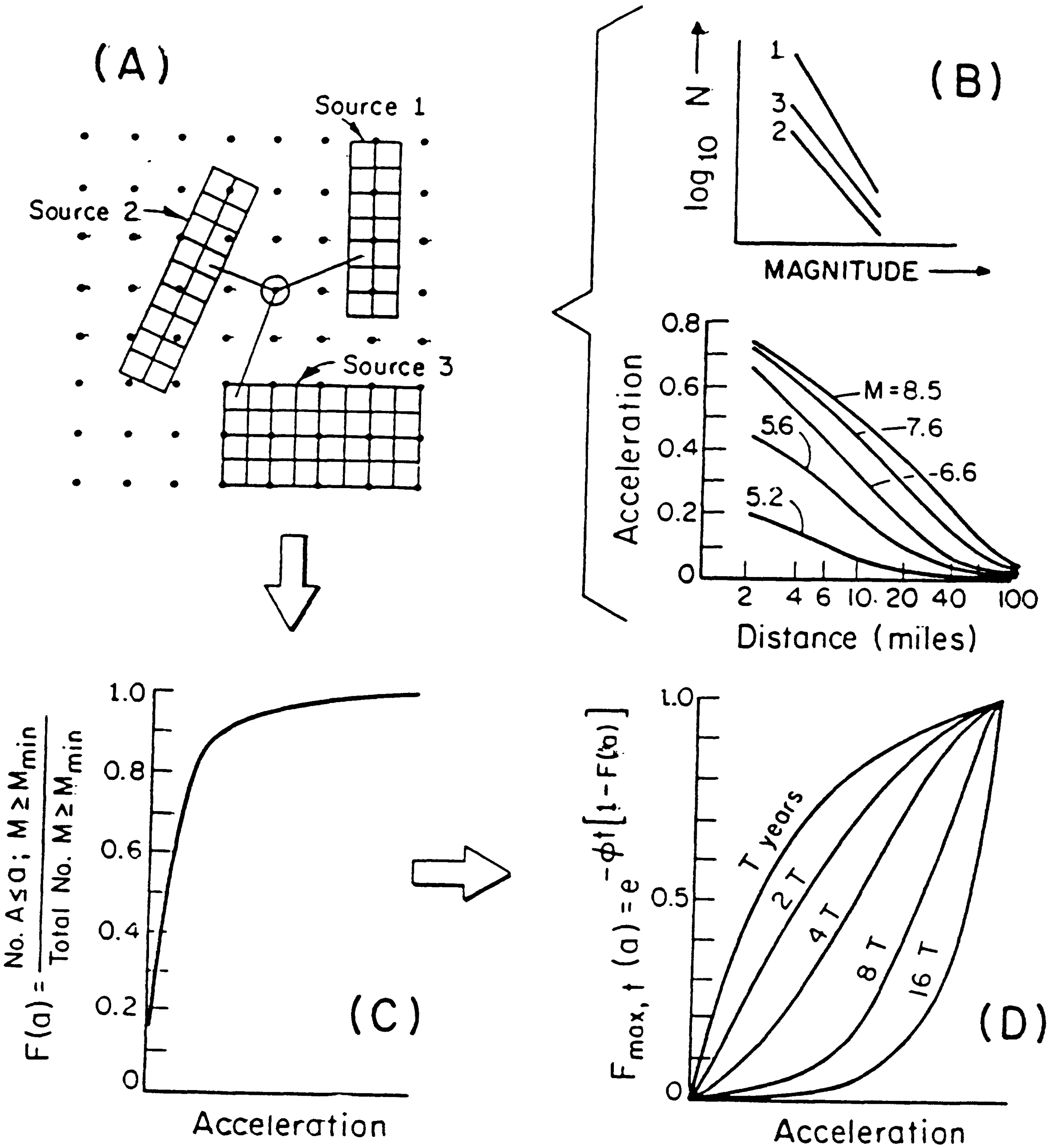


Figure 6.--Schematic illustration of the procedure for constructing a probabilistic ground-shaking hazard map. Inset A shows 3 typical seismic source zones and the grid of points at which the ground-shaking hazard is calculated. Inset B shows typical statistical distributions of historical seismicity 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

EARTHQUAKE RESISTANT DESIGN CRITERIA

by

Charles G. Culver
National Bureau of Standards
Washington, D.C. 20234

INTRODUCTION

History shows that properly designed and constructed facilities can withstand earthquakes. The design and construction of ordinary buildings are governed by building codes, which are legal documents that specify minimum standards of construction and are adopted by government agencies. A summary of design requirements for earthquake resistant construction included in the building regulations of various countries throughout the world is available.[1] It is important that such design requirements be reviewed periodically and updated to incorporate the results of research and knowledge gained from the performance of buildings in earthquakes.

Substantial efforts have been underway in the United States over the last ten years to update seismic design provisions. This work resulted in publication of "Tentative Provisions for the Development of Seismic Regulations for Buildings"[2] by the Applied Technology Council (ATC), a group representing the Structural Engineers Association of California (SEAOC) and the National Bureau of Standards. These provisions include a number of new concepts recommended by the SEAOC Seismology Committee to improve seismic design. The purpose of this paper is to briefly summarize a few of these concepts. A detailed commentary providing the rationale used to establish the provisions is available.[2]

ATC PROVISIONS

The ATC provisions are comprehensive in nature and deal with earthquake resistant design of the structural system, architectural and nonstructural elements, and mechanical-electrical systems in buildings. Both new and

-xisting buildings are included. New concepts in these provisions will be reviewed in the following categories: (1) seismic performance, (2) analysis procedures, (3) design and detailing requirements and (4) nonstructural components.

(1) Seismic Performance - Seismic performance is a measure of the degree of protection provided for the public and building occupants against the potential hazards resulting from the effects of earthquake motions on buildings. The level of performance inherent in a design is a function of the force levels used in the design, detailing requi-e-ents and the quality assurance procedures followed in executing the construction. Two factors are utilized in the ATC provisions to insure this performance: (a) the level of anticipated ground shaking which is a function of the geographic location of the building and (b) the type of occupancy or use of the building. Four categories, expressed in terms of a seismicity index, are used for the levels of ground shaking encountered in the United States. Three categories or seismic hazard exposure groups are used for occupancy and use classification. Although the provisions do not explicitly use an importance factor, one hazard exposure group includes essential facilities necessary for post-earthquake recovery. Low occupancy buildings of a noncritical nature that may only be subjected to low levels of ground shaking do not need comprehensive seismic analysis. Detailing requirements, however, must be met to insure the integrity of the buildings when subject to shaking. For critical facilities in areas of high ground motion, analysis procedures and framing requirements are specified.

(2) Analysis Procedures - Two basic analysis procedures are provided for structures where the level of ground shaking and the type of occupancy warrant: equivalent lateral force and modal analysis. The design of the structure (sizing of individual members, connections and supports) is based on internal forces resulting from a linear elastic analysis and assumes that the structure, as a whole, under the prescribed design forces should not deform beyond a point of significant yield. Significant yield is not the point where first yield occurs in any member but is the level causing complete plastification of at least the most critical region of the structure. This

procedure differs from existing codes where the prescribed loads and determination of structural member sizes are at service or working stress levels.

The equivalent lateral force procedure is similar to that used in existing codes. Computation of the lateral seismic force includes consideration of the ground motion, the periods of the building, soil effects for the site, and the type of lateral load resisting structural system. Modal analysis is required for buildings with irregularities in the vertical framing system (varying story heights, significant changes in stiffness or mass between stories, etc.). A lumped-mass model may be used in this case to calculate the required periods, mode shapes and lateral force distribution over the height of the structure.

(3) Design and Detailing Requirements - The provisions contain requirements for tying together the parts of buildings, concrete or masonry wall anchorage, collector elements, diaphragms, bearing walls, inverted pendulum-type structures, vertical seismic motions, and deflection and drift limits. Some of the requirements cited are spelled out in considerably more detail, and in most cases are more stringent than existing provisions. These requirements were necessary since the overall inelastic response of a structure is very sensitive to the inelastic behavior of its critical regions, and this behavior is influenced, in turn, by the detailing of these regions. The detailing requirements also provide for the large energy dissipation or ductility necessary for structures to resist strong ground motions. This approach was felt to be better than simply increasing the level of design forces.

(4) Nonstructural Components - The provisions establish minimum design levels for architectural, mechanical, and electrical systems and components. The design levels are based on occupancy use, the number of occupants, need for operation continuity, and the interrelationship of structural and architectural, mechanical and electrical systems. The following aspects of seismic safety were considered in establishing the requirements: general life safety, property damage affecting life safety, functional impairment of critical facilities affecting post-disaster recovery, and safety of emergency personnel such as fire and rescue teams. The requirements are expressed in

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.

EARTHQUAKE VULNERABILITY OF CRITICAL FACILITIES: ST. CROIX - ST. JOHN - ST. THOMAS, VIRGIN ISLANDS

by

Joseph A. Fischer
Geoscience Associates, Inc.
Milington, New Jersey 07946

INTRODUCTION

This paper gives a report on the status of an ongoing study of earthquake hazards in the Virgin Island and the potential vulnerability of critical facilities on St. Croix, St. John, and St. Thomas. (Refer to Appendix B for the meaning of terms that are used in this paper.) The results of this vulnerability study will be utilized in the hazards mitigation planning and response activities of the Virgin Islands Disaster Program Office (DPO) and the Federal Emergency Management Agency (FEMA). (Refer to papers by Pamela Johnston and Philip McIntire in this proceeding for specific information.)

Definition of Vulnerability- Prior to any discussion of the "vulnerability" of a specific Virgin Island structure, piece of equipment, roadway or process, it is useful to define the term vulnerability and to explain the purpose of the "Vulnerability Study" in the Virgin Islands. Vulnerability, as used herein, is the susceptibility of any facility to damage or disruption of use at some specified level of earthquake hazard (usually the ground shaking hazard).

Philisophy of a Planning Scenario- From the definition of vulnerabilty it is obvious that the vulnerability of a specific facility depends upon the magnitude or epicentral intensity of the earthquake selected for the scenario (this earthquake is also called a design basis earthquake in some engineering applications). These parameters affect the level of ground shaking and are the key physical parameters needed to define the level of hazard in the scenario. An example of the selection of a hazard level that would be an absurdity in the case of the Virgin Islands would be to postulate an earthquake having an epicentral intensity (given in terms of the Modified

Mercalli Intensity (MMI) scale) of XII as the scenario or design event. The MMI XII corresponds to complete destruction. Thus, there is no planning or recovery scenario that could function satisfactorily if post-earthquake use of critical facilities in the Virgin Islands was a requirement. A Virgin Islands planning scenario using the occurrence of a great earthquake (magnitude of 8 or greater) centered near Guadeloupe would be at the other end of the philisophical spectrum if one were evaluating the vulnerability of critical facilities in the Virgin Islands. While the use of a large magnitude event may sound conservative, the hazard level of such a shock in the Virgin Islands would be no more than about MMI V (i.e. no damage). A rough analogy is planning for a plane crash at the airport. Plans derived for responding to a plane crash at the airport work because the infrastructure is still intact. We can see, therefore, that the selection of the size of the scenario event requires not only technical judgement, but also an appreciation of local needs and economics.

A Natural Hazards Planning Council, composed of representatives of the private and government sector of the Virgin Islands was formed to provide realistic technical input for this vulnerability study. The work of the council is complex because, once the scenario event is selected, the nature of the threat to each crtical facility must be evaluated. An earthquake not only damages a structure as a result of vibratory ground motion (the most destructive hazard), but a major earthquake can also cause fault rupture, tsunami, liquefaction, and landslides. Both the physical properties and dimensions of the subsurface materials underlying a facility will influence the damage pattern. Once the scenario event and the hazard level is established, the next step is to understand and quantify all the potential earthquake effects at all the sites of interest.

The final requirement in evaluating the vulnerability of a facility is to estimate, measure, or calculate the capability of the facility to withstand the postulated severity of the seismic induced forces which are expected to occur in the event selected for the planning scenario.

The following sections will discuss the tectonics, seismicity, geology, and construction practices in the Virgin Islands, the physical basis for defining the hazard.

LEVEL OF HAZARD

Tectonic Setting and Seismicity- Dr. McCann's paper (contained in this proceedings) describes the tectonic setting of the Virgin Islands and the rationale for considering the area to be susceptible to damaging earthquakes. Studying this type of information led to the definition of five earthquake source zones (see Figure 1). However, any attempt to define the largest possible earthquake, source parameters, depth, and location for each source zone is fraught with difficulty and speculation. It is even more dangerous if one extrapolates the relatively short instrumental record of seismicity with the intention of predicting the time and size of future events. So, what do we do? "...the future is only the past entered through another gate." This homily is useful in seismicity evaluations as well as in literary allusions. We can attempt to establish an understanding of the seismic potential of these source zones by reviewing their earthquake history in light of current knowledge of regional tectonics. As a first step we should estimate, or record, (if instrumental data are available), the largest earthquake experienced in each source zone. Table 1 presents the results of such an evaluation. In addition, Table 1 also gives the largest events postulated by various authors who have studied the area.

The record of seismicity in the Virgin Islands region was examined to aid in developing realistic measures of earthquake frequency versus size of earthquake. These data (shown in Figure 2) were used by the Natural Hazard Planning Council of the Virgin Islands. The examination of earthquake frequency was performed using current knowledge of regional tectonics and the historical seismicity record. MMI was used as a parameter because of the lack of instrumental data to assign reliable values of magnitude.

The history of Caribbean shocks dates back to about 1530. There is a possibility that even an earlier event was noted, but the records are not clear. From a review of the historical record a plot of earthquake intensity data for St. Thomas versus time intervals was made (see Figure 2 and Table 2). These data indicate that a recurrence of the level of motion believed to have been experienced in the 1867 earthquake could be expected about once every 100

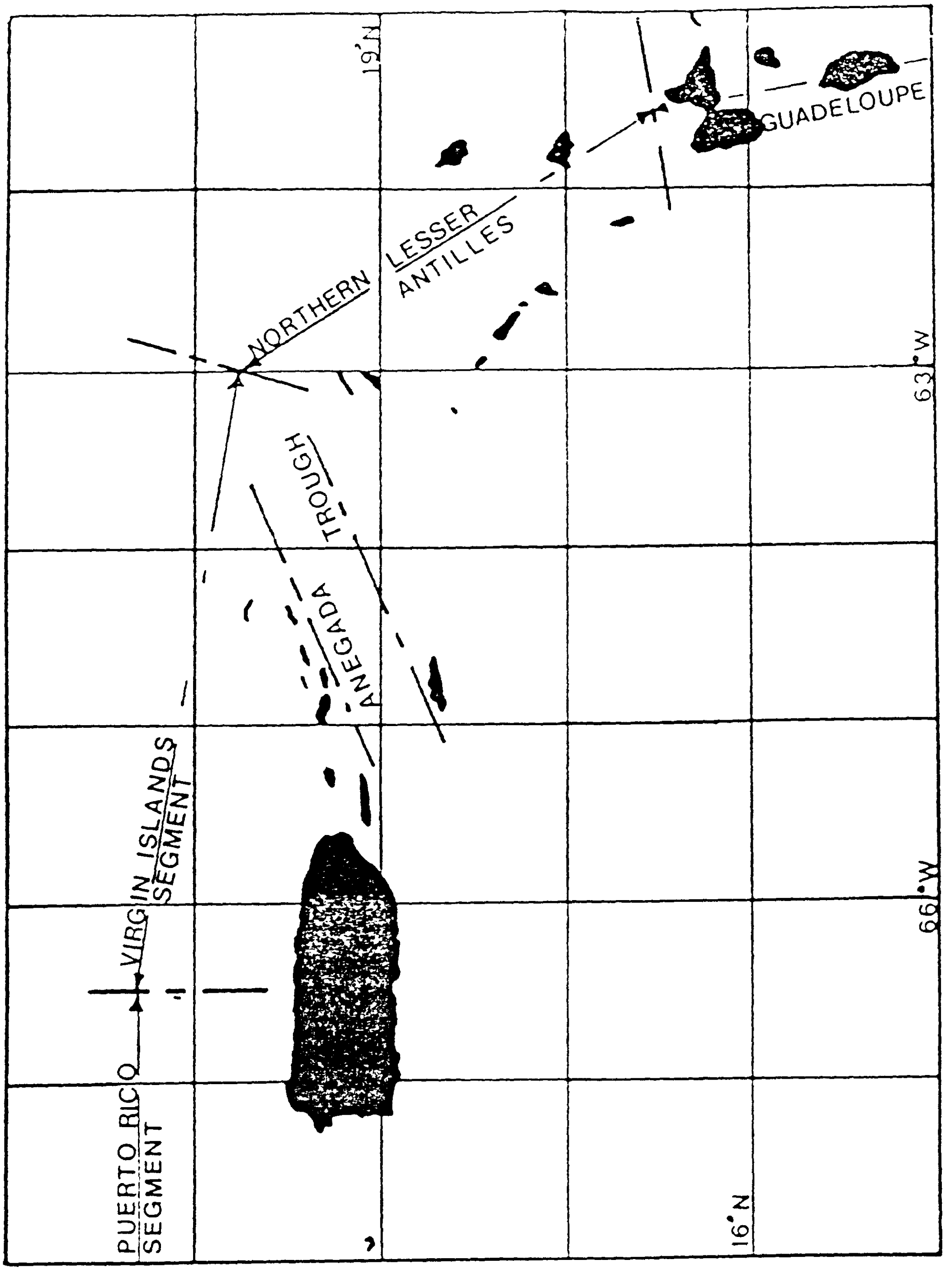


Figure 1. Identification of seismic source zones in the Virgin Islands region.

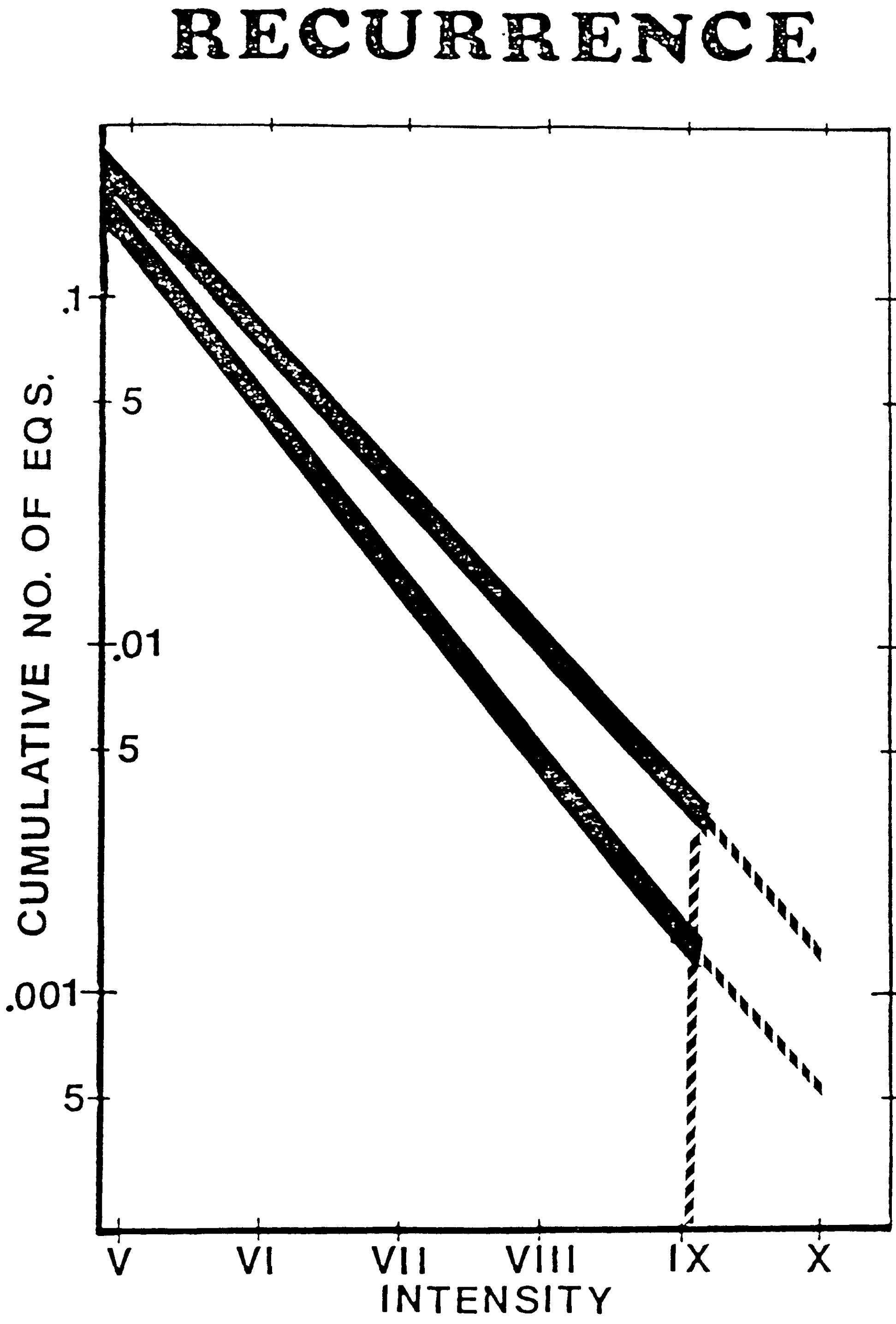


Figure 2. Estimate of recurrence intervals for earthquakes in the vicinity of St. Thomas, Virgin Islands. Recurrence is given in terms of the parameter Modified Mercalli intensity.

TABLE 1

Source Zone	Magnitude (Ms)	Remarks
Puerto Rico Segment	7-3/4	NW of Puerto Rico, 1943
	7-1/2	NW of Puerto Rico, 1918
	>8	McCann & Sykes, 1983
	8	Woodward-Clyde, 1978
Virgin Island Segment	6-1/4	1919
	7 to 7-3/4	MCann & Sykes, 1983
	8	Woodward-Clyde, 1978
Northern Lesser Antilles Segment	7-1/4	1974
	7 to 7-1/2	McCann & Sykes, 1983
Guadeloupe Segment	8 to 8-1/2	1843
	8 to 8-1/2	McCann & Sykes, 1983
	8-1/2	Woodward-Clyde, 1978
Anegada Trough	6-3/4 to 7	1867
	7-1/4 to 8	McCann & Sykes, 1983
	6-3/4	Woodward-Clyde, 1978

TABLE 2
PROBABILITY

Location	MM Intensity	Recurrence (Years)	Estimated probability Of Occurrence (next 20 yrs)	(next 50 yrs)
St. Thomas/	VIII	110-200	50-70%	60-80%
St. John	IX	330-700	15-35%	20-40%
St. Croix	VIII	130-275	40-60%	55-75%

to 200 years, on the average. We believe that the level of hazard on St. John would be about the same as on St. Thomas; whereas, St. Croix would have a somewhat lower level of hazard.

The Natural Hazards Planning Council used these data as a basis for selecting an MMI VIII earthquake as the scenario earthquake for the vulnerability study of the Virgin Islands.

Geology- In using intensity levels to describe the effects of an earthquake one must be aware of many geologic factors. Intensity levels of past earthquakes, as assigned by post-earthquake investigators, are predicated upon "worst" effects experienced in any particular area, greater structural damage or higher levels of motion are experienced on the poor soils in every locale. In attempting to extrapolate past intensity data to current conditions, one must be cognizant of not only the changes in design and construction between today and the past, but also recognize the varying effects of soil or rock properties on earthquake ground motion and slope stability. Thus, the geologic conditions on each island are very important and must be reflected in the vulnerability analysis.

St. Thomas and St. John are primarily upthrust underwater volcanic flows. Some sedimentary deposits, limestones, alluvium and beach deposits, may be found on both islands. Soil cover is generally thin. From a geologic standpoint the two islands are essentially the same land mass, separated by a graben, Pillsbury Sound. The rocks of St. Thomas and St. John have been severely deformed and faulted. In general, the rocks of St. Croix were formed by sedimentary processes, rather than igneous events, as in the islands to the north. However, many of these sedimentary rocks resulted from erosion of materials of volcanic origin. The main rock types are siltstones, sandstones, and minor granitic intrusions. Alluvium and beach deposits are widespread. Although not as severely affected as St. Thomas and St. John, St. Croix is nevertheless criss-crossed with numerous folds and faults.

Physical Effects- For the Virgin Islands the types of physical effects that can be expected in an MMI VIII earthquake are:

1. Vibratory ground motion.
2. Tsunami.
3. Landsliding.
4. Liquefaction.

On the basis of the available scientific data, emergency planners must also consider the likelihood of the occurrence of a number of relatively large aftershocks. These aftershocks, which could impact oveall planning concepts, could have a significant effect on human responses to the emergency as well as causing further weakening of slopes and structures.

VIRGIN ISLANDS CRITICAL FACILITIES

The Natural Hazards Planning Council selected the facilities on the Virgin Islands that they believed were critical to post-earthquake recovery operations. Unlike a number of other natural hazards, little or no warning of the occurrence of a major earthquake is possible at this time. Thus, emergency management is essentially limited to post-earthquake considations (incorporating both primary and secondary effects of the shock) and perhaps the implementation of suitable building codes.

The Vulnerability Study of the Virgin Islands is currently at the stage where preliminary evaluations of a number of critical facilities are being made. The objective is to place these facilities into one of the following categories:

1. Likely little damage.
2. Possible critical damage.
3. Likely major damage, or total destruction.

The facilities that have been inspected can be grouped into five broad types:

1. Health (hospitals, food, water).
2. Shelter (housing, schools, open space).
3. Safety (public housing, schools, jails, fire/police stations).
4. Financial/Administrative (banks, government).
5. Communications/Power/Transportation.

The following facilities are of particular interest:

St. Croix   Public Safety Building - Although of relatively recent design and construction, the building presently shows signs of structural distress.

WAPA - Although in generally good repair, many of the pieces of equipment, switching gear, storage areas, etc. are potentially susceptible to both vibratory ground motion and tsunami wave action.

St. John   Centerline Road - Many segments of the road traverse active or incipient landslide areas. Earthquake ground shaking will trigger numerous slides, making the road impassable to normal traffic.

St. Thomas   Vitelco - An example of a realistic consideration of earthquake forces in the design and construction of buildings and electrical equipment.

Public Housing - Although apparently designed in accord with applicable standards, certain design details, apparent construction procedures, and sidehill or waterfront sites create the potential for significant loss of life and extensive damage to structures.

CONCLUSIONS

The Virgin Islands, as a result of their tectonic setting, local geology, variety and types and ages of construction, and the long period of time that has elapsed since the last major earthquake in the Virgin Islands region, are a challenge for the scientist, engineer and emergency planner or manager. I believe this presentation introduces the workshop participants to the overall scope of that challenge.

INCREASING HAZARD AWARENESS AND PERSONAL PREPAREDNESS

by

Risa I. Palm
University of Colorado
Boulder, Colorado 80309

INTRODUCTION

The title of this session suggests that there is an association between increased hazard awareness and increased personal preparedness. In this paper, the extent to which such a linkage exists will be discussed, as well as the implications of this relationship for public policy - particularly public education campaigns.

At the outset, it is important to determine both the current and the optimum levels of awareness of the earthquake hazard in the Virgin Islands. Although the Virgin Islands have experienced numerous earthquakes, the level of awareness of such earthquake susceptibility by either the resident or visiting population is not known. However, one suspects that resident awareness in the Virgin Islands is less than that observed in a state such as California with a history of major damaging earthquakes and an extremely active program of public and private efforts to increase awareness and mitigation behavior. The adoption of mitigation measures directly related to the Virgin Islands earthquake hazard could also be assumed to be less than the level observed for California - which means that it is highly likely that only a minority of the population have earthquake insurance policies on their homes, and few people have taken preparedness measures related to the earthquake hazard.

COMMUNICATION CHANNELS

What sorts of campaigns should be taken then, both to increase general awareness of the earthquake hazard, and more importantly, to induce personal preparedness?

To answer this question, the communications channels which can be used to inform the public about earthquake hazards should be reviewed. In order to transmit information on natural hazards, the public official may use a number of formal or informal channels. These channels may include (1) formal education in school, (2) education via media such as TV, newspaper reports, radio programs, (3) informal information sources such as club meetings, or (4) formal and official sources such as information contained in telephone books, pamphlets distributed by official sources, or civil defense notices. Which of these channels are most effective? Unfortunately research does not provide any definitive answer to this question with respect to earthquake hazards, but some research may be relevant. For example, in a survey of Hawaii geography students, Sorenson (1983) found that respondents reported that school had been their most important source of learning about appropriate response to earthquakes, followed by media, informal sources, and lastly, formal or official sources. Almost half of the respondents indicated that school had been the significant information source, while only 2 percent cited information in telephone books, and 6 percent cited pamphlets or books produced by formal or official sources. More than one-fifth of the respondents indicated they had never learned about earthquake hazards.

This research suggests that a heavy dependence on such formal and impersonal information channels as instructions in the telephone book, advertisements in the newspaper, or the distribution of flyers - no matter how beautifully designed and written, have but a limited impact on the general population. These formal channels must be supplemented with communication through the public schools, and with other information networks. It is important to note, in evaluating the Sorenson findings, that university students may be more dependent than the general public on school as a source of information. Cultural variation and traditions present in a minority population may also affect the receptivity of any population to information from the public schools or from a distant and formal government source. What this means is that a public information campaign in the Virgin Islands which attemps to reach a population which is diverse in cultural and economic characteristics must be flexible and experimental - there must be opportunities to reach individuals through a variety of channels, and monitor the effectiveness of various communication strategies.

GUIDANCE FOR INTRODUCING NATURAL HAZARDS INFORMATION

If one were to elect to attempt to introduce material about natural hazards in the public school curriculum, it is important to note previous research which provides guidance as to the need for such material and the impacts of curriculum changes involving natural hazards material on awareness of the hazard and the adoption of appropriate responses. Previous research in other areas and on other natural hazards has indicated that generally there is little taught in the public schools about local natural hazards. For example, Vitek and Berta (1982) found that students in the Flint, Michigan public schools had an inadequate education about such natural hazards as tornadoes and flooding which had seriously affected the city. In such studies, residents and officials are often quick to suggest that the most effective government action which can be taken to improve natural hazard awareness is the development of educational programs. Indeed, these authors suggested that such programs could inform "residents of natural hazards in their area and how to respond to emergencies in order to minimize losses." They recommended instruction in natural hazards as a mandatory part of the K-12 curriculum, and a short-term emphasis on adult education programs for post-school age population.

Such recommendations are appealing and intuitively attractive. The question remains whether hazard information such as that which would be imparted in a revision of school curriculum is actually linked with preparedness in coping with hazard events in an adaptive fashion. To begin to answer this question, we will first review why <u>the linkage between the mere transmission of hazards information is NOT equivalent to the preparation of a population to respond in an adaptive fashion to the hazard event</u>, and reiterate the findings of social scientists concerning the optimum design of an information campaign which <u>would</u> induce behavioral change or the adoption of mitigation responses.

HAZARD AWARENESS AND MITIGATION BEHAVIOR

The belief that the provision of information about hazards will eventuate in a change in behavior and the adoption of mitigation strategies rests on a model of the voluntary adoption of mitigation measures by the rational individual. In this model, information is presented to an individual who then changes his/her attitudes towards the environment. Once the attitude of the individual is affected, he/she will be prepared to adopt mitigation measures and will prepare for the hazard.

This model has generated a vast literature exploring the relationship between information, attitude change, and behavior change, some of which is summarized in such reviews as Saarinen (1980) and Baumann (1980). It is fair to say that there is consensus that the mere provision of information is NOT guaranteed to promote a change in attitudes, and that furthermore a change in attitudes is not sufficient to guarantee change in behavior. There are several reasons for the lack of equivalence between the provision of information and the adoption of appropriate responses. First, the learner may not understand that the information being presented is relevant to his or her daily life - that the individual, family, neighborhood, community could actually be adversely affected by the abstract hazard being discussed. Second the individual may feel that even though there may be a present danger, there is nothing that he or she can do to mitigate against its worst effects. Third, the individual may not know the costs or benefits of adopting mitigation measures, and therefore may not be able to assess the rational response to the hazard information. Fourth, the individual may not know exactly what to do to mitigate the hazard. Finally, the salience of the hazard and therefore the importance of "doing something about it" may be diluted by a perception that others are not responding to it, or that it has only a low probability of occurrence in the immediate future and that therefore other, more pressing problems should be attended to first. It is necessary that any successful information campaign overcome these obstacles to behavior change.

To return to the question of the effectiveness of a campaign to revise the school curriculum, one must ask if there is a relationship between formal education and the adoption of truly adaptive strategies? The same students tested by Sorenson for knowledge of natural hazards were presented with a scenario of an impending earthquake and asked what they would do. Their responses were evaluated as "adaptive" or "nonadaptive" based on compatibility with standard civil defense guidelines, or the probability that such a response would increase the person's likelihood of escaping adverse effects. A cross-tabulation of adaptive responses and other characteristics revealed that knowledge of such responses was NOT systematically related to perceptions of high levels of risk, length of residence in the place, type of locus of control orientation, experience with the hazard, or self-judgment that they have received prior education about the hazard. Prior learning was moderately associated with knowledge about adaptive responses to earthquakes, but no single information source seemed to predict knowledge of adaptive responses. Although this study was based on a highly biased sample of the U.S. population, and the response of Hawaii undergraduate students in geography may not at all represent that of the general population of the U.S. as a whole or the Virgin Islands in particular, there seem to be two important lessons in this study for hazard information campaigns: (a) experience with the hazard is neither necessary nor essential to affect adaptive responses; and (b) prior education in itself may not affect adaptive responses.

RECOMMENDATIONS

What positive recommendations would the social scientist make to those who wish to initiate notification campaigns or information campaigns to not only increase awareness of the hazard but also influence adaptive responses?

Based on the research summary of Baumann (1983), there are several elements which characterize successful notification efforts. These include:

1. specificity of information - the hazard should be identified with as great a degree of specificity as possible. If feasible, probability statements concerning the likelihood of damage and its location should be provided.

2. costs of taking particular preparedness measures should be provided, again with as great a level of specificity as possible. Optimal disclosure provides detailed instructions concerning what measures individuals can adopt, and how precisely these can be carried out.

3. source credibility - the information source should be credible for the particular target audience. This will probably mean a

multifaceted campaign using community leaders including clergy, civic leaders, and individuals central to informal communication networks as well as more official channels.

4. social reinforcement - it is important to communicate the idea that "everyone" is responding to the hazard.

5. external incentives - positive reinforcement (tax credits, for example) may encourage preparedness, even in the absence of attitude change.

In summary, while it will be up to local leaders, working in concert with federal agencies, to decide on the goals of a hazard awareness and preparedness campaign, it is important to keep in mind that mere awareness will not be sufficient. There is a large body of research in the social sciences on past successes and failures of public notification campaigns with respect to earthquake and other natural hazards - policy-makers in the Virgin Islands will be well-advised to select from the successful strategies and avoid the unsuccessful ones as they embark on their attempt to both increase hazard awareness and, more importantly, to increase levels of personal preparedness for earthquake hazards.

REFERENCES

Baumann, Duane, 1983. "Floodplain Resident Notification Project: Assessment of Publication Information Programs." Report submitted to Illinois Department of Transportation, Division of Water Resources, March 4, 1983, mimeo.

Saarinen, Thomas R., 1982. Perspectives on Increasing Hazard Awareness. Boulder: University of Colorado, Institute of Behavioral Science, Program on Environment and Behavior, Monograph #35.

Sorensen, John H., 1983. "Knowing How to Behave Under the Threat of Disaster. Can it be Explained." Environment and Behavior, Vol. 15, No. 4, pp. 438-457.

Vitek, John D. and Susan M. Berta, 1981. "Improving Perception of and Response to Natural Hazards: the need for local education." Journal of Geography, Vol. 81:6.

DISASTER PLANNING IN THE VIRGIN ISLANDS

by

Pamela Johnston
Disaster Programs Office
Civil Defense & Emergency Services
St. Thomas, Virgin Islands 00801

INTRODUCTION

Studies have proven that disaster plans are more likely to be effective if, during or following an emergency, personnel are assigned the same or similar function that they perform in their everyday work.

On this premise the disaster plans of the Territory of the U.S. Virgin Islands were first developed in 1976. Today 15 agencies have such plans. They are structured to reflect personnel assignments both before, during and after any emergency or disaster in the Territory. While the plans are not infallible, we have learned that they obviously work best when there is warning of an event. For example, the response on St. Thomas in 1979 to Hurricane David and Tropical Storm Frederic was far better than the response to the sudden floods of April 1983. I don't think this means we are any less prepared but rather that each agency should take a second look at its plan and ask how it can be revised to account for disasters such as earthquakes for which there is no warning.

ARE PLANS NEEDED FOR EVERY TYPE OF EMERGENCY?

Often I am asked two questions: 1) Do the agencies read their emergency plans and 2) Do we need plans for every type of emergency or disaster? To the first question, I answer, some do and some don't but the solution is not necessarily more plans or exercises but rather more experience with actual disasters. To the second question, I say that we do not need specific plans for specific types of disasters but rather plans flexible enough to deal with the consequences of any type of disaster event. If a disaster plan is developed on the premise that it anticipates the variety of possible emergency needs as well as coordinates emergency functions and resources, then it should be transferrable to any disaster.

CRITICAL EVALUATION OF DISASTER PLANS

If there is a weakness in the Territory's disaster plans it is not in the functional assignment of emergency responsibilities, but rather in coordination when effective response often depends upon cutting across normal or established lines of authority in government and the private sector. In short, we have emergency technicians but few emergency managers.

The other area in which we are weak is, of course, resources whether it be people, supplies or equipment. Each agency's emergency plan includes the addresses and telephone numbers of key personnel as well as a listing of the agency's emergency equipment and the resources that the agency might need from another agency or from the private sector to supplement their emergency efforts. As you can well imagine, many agencies duplicated resources, not because they didn't do their homework but because even in normal times resources in the Virgin Islands are almost nonexistent and those which are available are constantly in use.

It is for this reason that we have cautioned the Federal Government and the national offices of such relief agencies as the American Red Cross that following any disaster of even moderate proportions in the Virgin Islands, we will need aid quickly and without red tape. In this regard even California with its extreme vulnerability to earthquakes and vast resources has warned its residents to plan on self-sufficiency for at least 72 hours before organizations can begin to provide even basic services. In the Virgin Islands I would say we should probably plan on a week or more.

PRACTICAL LOSS-REDUCTION MEASURES

Now that I have told you the bad news, let me tell you the good news. There are some things that can be done to lessen the impact of an earthquake in the Virgin Islands other than revising disaster plans. They include:

- First, improve construction through the addition of more effective seismic standards to the Virgin Islands Building Code.

- Second, begin a program on non-structural mitigation measures that can be undertaken in business and government offices as well as by homeowners.

- Third, publicize the availability of earthquake insurance.

- Fourth, educate the public as to what they can do as individuals to protect themselves and their neighbors before, during and following an earthquake.

DISASTER MYTHS

If we take these steps now the impact of future earthquakes can be lessened. And while I expect that we will have serious problems in the recovery stage, there are many things that people assume will happen that rarely do. Often referred to as "disaster myths" are the following:

PANIC - Most people do not panic, rather they tend to take actions to protect themselves and their neighbors. However, the ones who panic do so under three conditions, all of which must be present: 1) individuals are under immediate and severe danger; 2) there are limited or closed escape routes; and 3) there is limited information about what is happening.

CASUALTIES - Although casualties are expected, the percentage of casualties in most disasters is generally low. Earthquakes primarily produce structural damage. Most deaths are caused by collapsed structures. Statistics indicate that seventy percent of the injured in an earthquake don't need hospitalization; also there is historically 1 dead for every 3 or 4 injured.

SHOCK - Although there is always an initial shock as a result of the disaster situation, recovery is rapid and only a small percent show measurable shock reactions. For the majority, the shock reaction only lasts for a short time (minutes to a few hours).

STRESS - Generally this is not a paralyzing emotional reaction. Instead, the reaction is to do something. Also, it has been found that official rescue workers (police, fire, etc.) generally do not abandon their posts to care for their families.

MORALE - Normally morale is quite high following a disaster. The majority of survivors feel that the situation could have been worse and are thankful for being spared.

CRIME - Crime falls drastically during and immediately following a disaster. It dropped 26.6 percent in New Orleans immediately following Hurricane Betsy.

LOOTING - Records show looting to be very low after natural (not civil) disasters. In one disaster only three percent of the citizens reported cases of possible looting. The major problem appears to be fear that looting might occur and, therefore officials have to take precautions to secure certain areas against the possibility.

SUPPLIES - Normally food, clothing, bedding, etc., pour into an area following a disaster and generally they are unneeded--victims have already been provided for by friends and relatives. On the contrary, the problem is what to do with all the excess food and materials.

VOLUNTEERS - A similar problem occurs with volunteers who often converge on an area following a disaster. While useful in rescue and recovery efforts, their effectiveness is often diminished by failure to direct and coordinate their efforts.

INDIVIDUALS VS. ORGANIZATIONS - People as a whole react much better in the emergency periods of a disaster than is normally assumed, although their response is far from perfect. On the contrary, groups and organizations tend to stumble around, at best being effective eventually, although seldom efficient. But the studies that substantiate such behavior also show that both individuals and groups do better if there has been prior planning.

CONCLUSIONS

In summary, while some of the concerns we all read about following a disaster may be overblown and the disaster plans that the Virgin Islands now have may need some modifications to deal with earthquakes, their effectiveness and that of the entire disaster mitigation and recovery process can be improved. Everyone in this room has a stake in the process.

TYPES OF FEDERAL ASSISTANCE
FOLLOWING AN EARTHQUAKE IN THE VIRGIN ISLANDS

by

Philip McIntire
Federal Emergency Management Agency, Region II
New York City, New York 10278

INTRODUCTION

The Federal Emergency Management Agency and its predecessor, the Federal Disaster Assistance Administration, have on several occasions responded to natural disasters in the Virgin Islands. Floods have been the most common type of natural disasters in recent years. The Territory of the Virgin Islands is also vulnerable to earthquakes.

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 the Virgin Islands, the Territorial Government has the obligation of providing relief after disasters. I would like to point out that over the years the Territorial Government has fulfilled this responsibility in an exemplary manner.

If the event is beyond the capabilities of the Territorial Government, the Governor, and only the Governor, may request that the President declare the Virgin Islands 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 Officier (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 Territorial Coordinating Officer (TCO) appointed by the Governor.

Federal disaster assistance is supplemental to Territorial assistance. That is, all relief efforts are closely coordinated with the Territorial Government. A major disaster declaration does not mean that the Federal Government takes over control of the Territory's functions. The FCO's responsibility is to coordinate Federal resources to compliment the relief and recovery effort of the Virgin Islands 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 -- coordination 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, PL93-288 -- the full resources of the Federal Government are potentially available for relief and recovery.

POTENTIAL RESOURCES IN THE EVENT OF AN EARTHQUAKE AFFECTING THE VIRGIN ISLANDS

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

Upon arriving in the Virgin Islands, the FEMA team would immediately make contact with authorities of the Territory and be briefed on the situation. The FEMA team would also contact Federal agencies located in the Caribbean for their assessments. If the earthquake were so destructive that it was immediately evident that the severity and magnitude was beyond the capability of the Territorial 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. The Virgin Islands is fortunate that the Roosevelt Roads Naval Station is nearby. 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.

In a generic sense, 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 committing 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 major earthquake in the Virgin Islands region would be beyond the capability of the Territorial 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 resources for earthquake preparedness in the Virgin Islands. The goals of this program are to minimize the impact of a serious earthquake; prepare the Territory and Federal Governments to respond to the emergency needs of the people of the Virgin Islands and expeditiously recover from the impact of the earthquake while mitigating the effects of future earthquakes.

In summary, both the Territorial Government and the Federal Government are preparing for a serious earthquake in the Virgin Islands. 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.

VIRGIN ISLANDS' PHILOSOPHY CONCERNING LAND USE PLANNING AND HISTORIC BUILDING REHABILITATION

by

Roy E. Adams
Virgin Islands Planning Office
St. Croix, Virgin Islands 00801

INTRODUCTION

The topic for this session is provocative because it speaks to the mitigation of the effects of an earthquake through land use (planning). Realistically speaking, the possibilities of such mitigation are limited. Considering that earthquakes may occur at unpredictable times and locations, it may be facile indeed facetious to say that it is best to encourage non-development as a land use philosophy. However, given our provident climate and beautiful waters, it is clear that the Caribbean region will likely be an attractive location for many years to come for tourists and as a permanent home for increasing numbers of year-round residents. Given also the knowledge that the Caribbean plate has high seismic activity, it is equally clear that there will be conflict between that seismic activity and the desirability of the location.

PHILOSOPHY CONCERNING LAND USE

How do we approach a philosophy of accommodation in this perceived conflict? To quote from the Draft Comprehensive Policy Plan for the Virgin Islands:

> **"Land use planning is the process by which land is designated to be used for certain purposes...protecting areas from encroachment by incompatible uses, protecting the natural environment, and to establish and efficient and safe development pattern. In addition, land use planning allows for orderly growth by designating areas for future use for such things as housing, recreation, transportation and utilities, businesses, and public facilities...Territorial zoning laws have been the basic blueprint for**

determining the geographical distribution of residential, commercial, and other land use activities."

Betsy Peebles, in her monograph entitled Earthquakes: Vulnerability and Mitigation in the U.S. Virgin Islands prepared for the Disaster Preparedness Office in the Office of Civil Defense and Emergency Services, observed that the Virgin Islands Planning Office could contribute to the mitigation effort by zoning and planning efforts that would induce population to move into areas free from landslide and other earthquake related events. The implicit hazards to be protected against include mudslides, land subsidence, and tsunamis caused by earthquakes having their epicenters at sea.

The Flood Plain Regulation for the Virgin Islands specifically identifies all of these natural hazards as phenomena to be protected against, and lodges clear authorities and responsibilities in executive branch regulatory offices to preclude or protect development in those areas where there are clear and present risks of danger to life and/or property.

However, despite all our precautions to the contrary, depending on the location of the epicenter and the magnitude of an earthquake that would adversely affect our territory, it is apparent that the significant physical phenomena accompanying an earthquake could cause even "safe" areas to suffer devastating effects, socially and economically.

Earlier I posed the question, "How can we establish a philosophy of accomodating development that would overcome the potential conflict with our location in a volatile seismic region?" More precisely, the topic assigned for this session requires a statement and rationalization of the Virgin Islands' philosophy concerning land use planning and historic building rehabilitation. If I could state the thesis of that philosophy I would do it this way:

It is the desire of the people of the United States Virgin Islands to develop physically, economically, and socially in such a way as to provide a place for every desirable use of land, consistent with their culture and cognizant of their location.

There are existing statutes and proposed policies that support this thesis. I will refer to the Zoning Law for the Virgin Islands, and to the Draft Comprehensive Policy Plan. As well, I will add to those documents observations on the effectiveness of Federal statute and programs devised to protect and enhance the stock of historic buildings in the Territory.

THE PRESENT PREMISE

After the boom of the 1960's, and the almost unmanaged growth that occurred in the Virgin Islands, our planners felt the need to fashion a zoning law as a means to shape the future growth of the Territory. After two years of writing and testing at public meetings, the Zoning Law was approved and enacted. There are two significant statements that set the tone and intent of that document with respect to land use activities to come, and I quote them here:

> Section 221: Objectives and Intent- The objective of the Zoning Law is to establish standards and policies concerning development of land which may be used in helping to achieve the goals of a General Development Plan for the Virgin Islands. Goals for development of the islands are expressed in many ways through programs and policies on such matters as land use, taxation, capital improvements, urban renewal, public services, and other matters which require public decision.
>
> It is intended that standards and policies established by the Zoning Law reflect and express a sense of community value toward its physical environment including the value, appearance, and congenial arrangement for the conduct of trade, industry, residence, and other uses of the land necessary to the community's well-being, insofar as such values can be related to the broadest goals of the general community development plan.
>
> It is further intended that the zoning districts established by this law shall be implemented in accordance with a comprehensive land use plan and policy whereby the location of each district shall be made with reasonable consideration to the character of the district and its peculiar suitability.

Section 222: Purpose and Scope- The purpose of this law is the promotion of the health, safety, morals, and general welfare of the community by establishing regulations and conditions governing the erection and use of buildings and other structures and the use of land and water for trade, industry, residence and other specified purposes; to lessen congestion in the streets; to secure safety from fire, panic and other dangers; to provide adequate light and air; to prevent overcrowding of land; to avoid undue congestion of population and to facilitate the adequate provision of transportation, water, sewerage, schools, parks and other public requirements of the community;....designating the kind and classes of trade, industry, residences, and other purposes for which buildings and other structures may be permitted to be erected, constructed, reconstructed, altered, repaired or used....; regulating and limiting lot occupancy and population density; providing minimum size yards and other open spaces.

Thus, principles of community development and economic advancement are embodied in our Zoning Law. Specific development provisions set the style of physical development consonant with our culture. Buildings are human-scaled and for the most part "reflect the community's sense of values toward its physical environment" and traditional character - a character that has caused the influx of tourists and an economy that is largely geared to selling historic architecture, amenable temperatures and clean ocean water.

THE FUTURE PROMISE

We recognize the intrinsic cultural and economic value of our historic architectural heritage. In our Draft Comprehensive Policy Plan, we have listed as an objective the preservation and restoration of artifacts, buildings and sites of historical and/or archaeological value to make them available to everyone for education and enjoyment. We have proposed the use of tax incentives and/or grants or other financial arrangements to encourage the rehabilitation of buildings of historic significance. And, finally, we propose that new buildings in historic settings be designed so as to complement historic buildings.

Why the emphasis on rehabilitation? Why the specific provision that new construction be complementary to extant historic architectural fabric? Beyond the cultural considerations, there are practical reasons. Not the least of these are the financial considerations offered by the Economic Recovery Tax Act of 1981, and the Tax Equity and Fiscal Responsibility Act of 1982, both of which afford sizable tax credit incentives for restoring or rehabilitating U.S. Government certified historic structures.

More far-reaching, however, is the knowledge that rehabilitation of such structures is a means of protecting them from damage and loss in the event of a major earthquake. Many of our most valuable and revered architectural specimens date to the eighteenth century Danish regime. They are generally of massive rubble masonry that has no reinforcement, or are wooden and termite infested or a combination of both. Such structures are at greatest risk from earthquakes and deserve and require special attention.

CONCLUSIONS

By taking advantage of the federal tax incentives to repair and upgrade certain prominent buildings, we will be contributing to the revitalization of our central business districts and to that "congenial arrangement of the physical environment necessary to the community's well-being."

GEOLOGY OF THE U.S. VIRGIN ISLANDS, A PROGRESS REPORT

by

Douglas W. Rankin
U.S. Geological Survey
Reston, Virginia 22092

INTRODUCTION

In 1983 the U.S. Geological Survey (USGS) began a program to assist the Government of the U.S. Virgin Islands (USVI) by providing a modern geological data base for the U.S. Virgin Islands. Funding, in part, was provided by the Office of the Assistant Secretary for Territorial and International Affairs, Department of the Interior. The multidisciplinary program includes water resource studies, geologic mapping, a mineral resource appraisal, and a preliminary assessment of geologic hazards. The water resource studies are on-going, a workshop on earthquake hazards has taken place, and field data for the mineral resource appraisal of St. Thomas and St. John have been collected. I report here on some of the results of the geologic mapping program with emphasis on aspects of geologic hazards.

The present most detailed geologic maps of the U.S. Virgin Islands were prepared by Princeton University graduate students as part of their Ph.D. dissertation research. The geologic map of St. Thomas and St. John by Donnelly (1966) is at a scale of 1:63,360 and is based upon field work in 1956 and 1957. The geologic map of St. Croix by Whetten (1966) is at a scale of 1:31,680 and is based upon field work in 1959, 1960 and 1961. One of the objectives of the present program is to prepare geologic maps for all of the USVI at a scale of 1:24,000 on the topographic quadrangle base maps of the U.S. Geological Survey.

GEOLOGIC SETTING

The U.S. and British Virgin Islands comprise the eastern end of the Greater Antilles and are geologically similar to Puerto Rico, recently mapped at a scale of 1:20,000 under a cooperative program between the USGS and the Commonwealth of Puerto Rico. The rocks are an assortment of volcanic (largely island arc affinity), volcaniclastic, carbonate, radiolarian chert, intrusive dike and plutonic rocks of Cretaceous and Tertiary age. According to Case and Holcombe (1980) the Virgin Islands are in two tectonic-geomorphic provinces.

The northern islands, including St. Thomas, St. John and the British Virgin Islands as well as Puerto Rico, are in the Greater Antilles deformed belt in which the major deformation is of late Cretaceous to Eocene age. The belt is probably underlain by oceanic crust. The Puerto Rico-northern Virgin Islands platform was a single subareal landmass during the Pleistocene low stand of sea level. Water depths in the Virgin Passage between St. Thomas and Puerto Rico are less than 100 feet (National Oceanic and Atmospheric Administration Chart 25650, 1983). The stratified bed rock of St. Thomas and St. John is, as far as we now know, of Cretaceous (Albian and pre-Albian) age (Donnelly, 1966). Intrusive rocks may be younger: perhaps Eocene or Oligocene. The Virgin Island batholith, largely on the British Virgin Islands, has been dated by K-Ar methods and is 25 to 40 million years old (Kesler and Sutter, 1979).

St. Croix, to the south, is in the Northern Caribbean deformed belt and is separated from the Puerto Rico-Virgin Island Platform by the Anegada trough with water depths of more than 13,000 feet (Case and Holcombe, 1980 and National Oceanic and Atmospheric Administration Chart 25641, 1983). St. Croix is underlain by strongly folded volcaniclastic rocks of Upper Cretaceous age which have undergone low-grade regional metamorphism, and nonmetamorphosed but gently deformed marine volcanic ash and carbonate of Upper Oligocene and Lower Miocene age respectively, which occupy a graben cutting diagonally through the center of the island (Whetten, 1966). The Cretaceous rocks have been intruded and metamorphosed by a variety of igneous rocks. Rocks of the Northern Caribbean deformed belt, in general, are probably underlain by oceanic crust and have been deformed most recently in the Neogene (Case and Holcombe, 1980); the topographic relief of the Anegada trough presumably dates from this deformation.

The closest volcano in the presently active Quaternary island arc, the Lesser Antilles, is Saba, located 100 miles to the east. For more discussion of the geology and tectonics of the northeastern Caribbean see the paper by McCann contained in these proceedings.

PRELIMINARY RESULTS

The main island of St. Thomas as well as a number of offshore islands and cays have been mapped. This mapping represents the work of one geologist in the field for an aggregate total of four months from July 1983 to June 1984. A preliminary geologic map of St. Thomas at 1:24,000 has been compiled on the USGS topographic quadrangle base maps and a much reduced and simplified version of this new geologic map is presented in figure 1. The present study confirms the stratigraphic succession for layered rocks and the general distribution of major units on St. Thomas as determined by Donnelly (1966). The detailed location and nature of some contacts have been redetermined and changed as shown in figure 1.

SURFICIAL DEPOSITS

A major feature of the geologic quadrangle maps is that they show fairly accurately the distribution determined from field observations of significant deposits of young unconsolidated or surficial material as opposed to older consolidated material or bed rock. Most slopes are covered with loose material (colluvium) and all stream valleys and water courses contain unconsolidated material (alluvium). Colluvium is not portrayed on the geologic map and only valley-fills that can be easily portrayed at 1:24,000 are mapped. An exception to the surficial material being unconsolidated is the modern beach sand where cemented by calcium carbonate (commonly called sandstone locally and known geologically as beachrock). Surficial deposits that are mapped as an undifferentiated unit include artificial (man-made) fill, alluvium (stream deposits), swamp deposits, and beach deposits, consolidated or not. The distribution and nature of the unconsolidated material is important to water resource studies, resolution of environmental concerns, and land-use planning. For example, the ground shaking properties and liquifaction potential during an earthquake differ for different types of unconsolidated material and for bed rock. Many resort facilities and much of

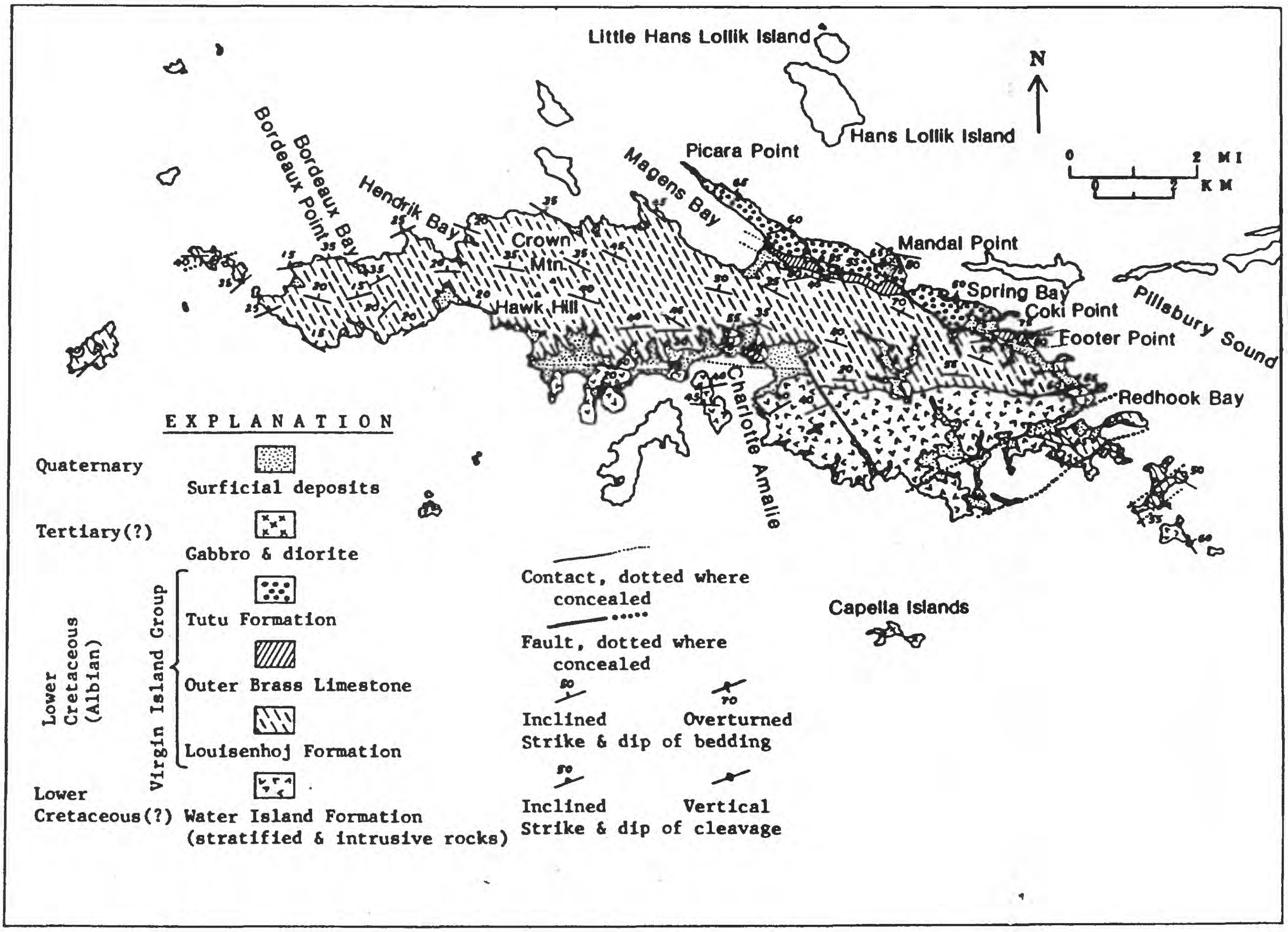


Figure 1. Generalized geologic map of St. Thomas, U.S. Virgin Islands Geology by D. W. Rankin 1983-1984.

Charlotte Amalie, the only city on St. Thomas, are built on unconsolidated material. It should be emphasized that the geologic map portrays only the location of major deposits of unconsolidated material and presents no information as to the engineering properties of these deposits. Site-specific studies would be necessary to address particular questions.

During the course of field work, I observed that most ridge crests and hill tops and many slopes are covered with boulders up to the size of a house. The boulders on the ridge crests and hill tops appear to be more or less in place. That is, the geomorphic expression of the subtropical weathering on St. Thomas leaves residual large blocks on ridge crests. These blocks subsequently break up into smaller blocks (by weathering along joints?). Figure 2 shows one such boulder field in newly cleared land near the crest of the ridge east of Crown Mountain at an elevation of about 1300 feet. Many of the boulders on natural slopes and ridge crests are in dense vegetation and do not appear to have moved significantly in recent times. These boulders may represent a hazard during either a large earthquake or torrential rains.

Landslides on natural inland slopes are not a major hazard on St. Thomas (see paper by Brabb, contained in these proceedings, for more discussion). I have observed some landslide scars and deposits as well as rock falls on steep coastal slopes and cliffs (fig. 3).

Stream valleys and water courses are strewn with boulders, some as large as a house (fig. 4). I was surprised to discover that the stream valleys and water courses are essentially free of undergrowth. This makes them ideal routes of walking for the geologist who wishes access to roadless parts of the islands. Presumably the absence of undergrowth is because flash floods in the water courses are frequent enough to wash out the undergrowth. One wonders about the mobility of the boulders during flash flooding or earthquakes and the safety of houses built close to and in some places in the water courses.

BEDROCK GEOLOGY

The stratified rocks of the main island of St. Thomas consist of the Water Island Formation of pre-Albian (inferred Early Cretaceous) age with the

A

B

Figure 2. Boulders near ridge crest. Recently cleared land near ridge crest east of Crown Mountain at an elevation of about 1300 feet. Photograph taken April 11, 1984.

A. Crest of ridge looking east.

B. Just north of ridge crest looking northeast. Picara Point and Hans Island in background.

Figure 3. Small landslide on natural coastal exposure just east of Bordeaux Point on the north side of western St. Thomas. Photograph taken June 12, 1984. The landslide is on a dip-slope of the Louisenhoj Formation.

A

B

Figure 4. Boulder-filled water courses on St. Thomas. Note absence of undergrowth vegetation.

A. Water course on southwest slope of Hawk Hill. Photograph taken April 11, 1984 from culvert on Highway 30.

B. Stream gorge on west slope of Crown Mountain between Highway 301 and Hendrick Bay. Photograph taken June 8, 1984.

overlying Virgin Island Group of Albian (Early Cretaceous) age (Donnelly, 1966). The Water Island Formation is comprised dominantly of the products of felsic igneous activity - lava flows, breccias, tuffs, and shallow intrusive rocks. Much of it is hydrothermally altered. Commonly it has not been possible in this study to distinguish intrusive from extrusive rocks. Silica contents are in the rhyolite range (70% to 80% SiO_2) and Na/K ratios are high and variable (1.9 to 43.2, commonly 3 to 8) (Rankin, unpublished data). Donnelly (1966) called these rocks keratophyres. The Water Island Formation also contains mafic volcanic rocks and radiolarian cherts. The mafic volcanic rocks include pillow lavas and pillow breccias. They typically have a greenschist mineral assemblage; epidote veinlets and segregations are common. Donnelly (1966) called these rocks spilites. On St. Thomas the Water Island Formation is more than 90% felsic. Donnelly (1966) estimated the thickness of the Water Island as greater than 15,000 feet.

The Virgin Island Group on St. Thomas includes from oldest to youngest the Louisenhoj Formation, the Outer Brass Limestone and the Tutu Formation. A proposed fourth unit, the Hans Lollik Formation mapped by Donnelly (1966) on Hans Lollik, Little Hans Lollik and Tortolla, may actually be the Louisenhoj Formation exposed across a major E-W trending synclinal axis inferred to lie north of St. Thomas.

On St. Thomas the Louisenhoj Formation consits of bedded volcaniclastic deposits of intermediate and lesser amounts of felsic material 3000 to as much as 7000 feet thick. The clasts range in size from silt-size or smaller to boulders more than three feet across. Conglomerate beds are common. Graded bedding and soft sediment deformation features are also common. Lava is rare.

The Outer Brass Limestone forms a narrow belt, largely forming low-lands and interrupted by faulting in northeastern St. Thomas. It consists of thin to medium bedded carbonaceous, argillaceous sandy limestone, calcareous siltstone and sandstone, and some limestone conglomerate. It is as thick as 800 to 900 feet as determined from the thickness of the outcrop belt, but it is cleaved and internally folded. Graded beds occur and fossil hash has been observed by the writer at Magens Bay.

The Tutu Formation consists of interbedded clastic rocks, largely of volcanic detritus with grain size ranging from clay to boulders. It crops out in a band along the north shore of St. Thomas from Picara Point to Coki Point. Graded bedding is common in the finer grained beds; grit and pebble beds are massive. Some rocks have a calcareous matrix. In some areas rip-up slabs of underlying shale and silt beds are present in the coarser beds. Limestone clasts, some fossiliferous, are locally common. In some areas, such as on the east side of Spring Bay where these clasts are as big as 30 x 20 feet, they appear to be derived from the break-up of a limestone bed within the Tutu Formation.

Stratified rocks of St. Thomas are intruded by a great variety of dike and plutonic rocks. Most of the dike rocks except those in the Water Island Formation are mafic to intermediate in composition. Included are some with abundant large hornblende phenocrysts that Donnelly (1966) classed as lamprophyres. The mafic to intermediate dikes including the lamprophyres cut rocks as young as the Tutu. Diorite and gabbro have also been observed in bodies large enough to be mapped at 1:24,000 intruding rocks as young as the Tutu Formation. These are thought to be comagmatic with the Virgin Island batholith. Finally, distinctive felsic dikes up to 30 ft. or more across which contain abundant bipyramidal quartz phenocrysts typically 1 cm across, but as large as 3 cm, are common in the Water Island Formation and have been observed near Redhook at the base of the Louisenhoj Formation. I had interpred these quartz porphyries to be related to the Water Island magmatism. However, in June 1984, I observed a similar quartz porphyry cutting diorite/gabbro on the Capella Islands. The Water Island Formation does not crop out on the Capella Islands.

Stratified rocks on St. Thomas form a generally homoclinal sequence dipping north (fig. 5). Bedding planes are planes of weakness and the direction of dip of the rocks, particularly where the slope of the land is in the same direction as the dip of the beds, ie. a dip slope, must be considered in evaluating geologic hazards. The geologic quadrangle maps will portray the attitude of the beds where that has been measured. Note that on the generalized map (fig. 1), the direction and angle of dip are not constant

Figure 5. North dipping beds (dip slope) of the Louisenhoj Formation. Looking east across Bordeaux Bay from Bordeaux Point, western St. Thomas. North of the main topographic backbone of St. Thomas many topographic slopes are in the same direction as the dip of bedding planes of the stratified rocks. Excavations on such slopes may create engineering problems.

across the island. The physical properties of the rocks are complicated further by the presence of many dikes and in northeast St. Thomas of a prominant slaty cleavage. Locally the beds are tightly folded; for example, beds of the Outer Brass Limestone on Footer Point. At Mandal Point, folding has been sufficiently intense so that beds of the Tutu Formation are overturned (fig. 6).

The pervasive slaty cleavage in northeastern St. Thomas indicates that the grossly homoclinal sequence on the island is not simply a tilted fault block, but the south limb of a large syncline whose axis lies north of the main island of St. Thomas. This large structure has been deformed by large cross folds (wave lengths of two to several miles) whose axes strike north (fig. 1). Major faults appear to post-date these cross folds. One set strikes ENE and produces grabens at the east end of St. Thomas. The present mapping modifies somewhat this set from that portrayed by Donnelly (1966). Donnelly did point out the parallelism of trend and nature of the fault set with the Anegada trough.

RECOMMENDATIONS

The mapping of St. Thomas to date has significantly improved our understanding of the geology of the Virgin Islands and contributed to the identification of geologic hazards. The geologic mapping of the remainder of the U.S. Virgin Islands should be completed. Geological problems that have been revealed by geologic mapping on St. Thomas will be pursued as part of the present study. These include determination of the ages of intrusive rocks, determination of the origin of the Water Island Formation through geochemical studies, determination of the source direction for the detritus in the Louisenhoj Formation (was Pillsbury Sound the locus of an andesitic volcano as proposed by Donnelly?), the integration of the geologic map with the geochemical data generated by the mineral resource studies in order to make a mineral resource appraisal, and the determination whether a major synclinal axis lies north of St. Thomas. The last will require visits to the British Virgin Islands and perhaps some cooperative studies. The fault pattern on St. Thomas (and the rest of the islands as that information developes) will be analyzed in terms of what is known of off-shore structures and modern seismicity. A major

A.

B.

Figure 6. Outcrops of thinly bedded siltstone and sandstone of the Tutu Formation on the north shore of St. Thomas at Mandal Point.

A. View west from Mandal Point. The beds strike N60^{o}W and dip 65^{o}S. Graded bedding indicates that the beds young to the north (right). Hence the beds are overturned. Slaty cleavage, not visible in the photograph, strikes N80^{o}W and dips 80^{o}S.

B. Close up of graded beds of the Tutu Formation at Mandal Point. Bedding dips to the left (S). Cleavage refracted by the grain size grading in the beds dips steeply to the right (N) in the sandy bottoms of the beds and steeply to the left (S) in the shaley tops of the beds. Both confirm that the beds are overturned. The coin is a dime.

question to be resolved is whether the Cretaceous island arc, the rocks of which form much of Puerto Rico and the Virgin Islands, originated more or less insitu or whether the island arc originated elsewhere, such as off the west coast of South America as suggested by Krushensky and Elston (1983) and Elston and Krushensky (1983). Additional paleomagnetic studies that could help resolve this question should be undertaken.

Other studies that could be undertaken include location through the mapping of boulder fields of the potential for debris flow hazards at the time of earthquakes or flash floods, inventory of buildings in or close to water courses, and engineering studies of the surficial material underlying much of St. Thomas and some resort facilities.

REFERENCES CITED

Case, J. N., and Holcombe, T. L., 1980, Geologic-tectonic map of the Caribbean region: U.S. Geological Survey Map I-1100, scale 1:2,500,000.

Donnelly, T. W., 1966, Geology of St. Thomas and St. John, U.S. Virgin Islands, in Hess, H. H., editor, Caribbean geological investigations: Geological Society of America Memoir 98, p. 85-176.

Elston, D. P., and Krushensky, R. D., 1983, Puerto Rico: A translated terrane exotic to the Caribbean [abs.]: 10th Caribbean Geological Conference, Program and abstracts of papers, p. 35-36.

Kesler, S. E., and Sutter, J. F., 1979, Compositional evolution of intrusive rocks in the eastern Greater Antilles island arc: Geology, V. 7, p. 197-200.

Krushensky, R. D., and Elston, D. P., 1983, Caribbean plate tectonics: New evidence, new conclusions [abs.]: 10th Caribbean Geological Conference, Program and abstracts of papers, p. 45-46.

Whetten, J. T., 1966, Geology of St. Croix, U.S. Virgin Islands, in Hess, H. H., editor, Caribbean geological investigations: Geological Society of America Memoir 98, p. 177-239.

LANDSLIDE POTENTIAL ON ST. THOMAS, VIRGIN ISLANDS

by

Earl E. Brabb
U.S. Geological Survey
Menlo Park, California 94025

INTRODUCTION

Landslides are a common topic in the St. Thomas Daily News during and after major rainstorms, but very little information about landslides appears in technical journals. During an April 1984 conference at Charlotte Amalie (fig. 1), I had an opportunity to make a reconnaissance survey of the island, to visit several landslide sites mentioned in the newspaper, and to assess the potential for additional landsliding.

LOCATION AND GEOGRAPHIC SETTING

"The Virgin Islands form part of the Antilles island arc. They are located about 1100 miles southeast of Miami, Florida; 600 miles northeast of the north coast of South America; and 1300 miles east of the nearest point in Central America. The islands, therefore, can be considered relatively free of the influences of continental landmasses (fig. 1).

"St. Thomas lies about 50 miles east of Puerto Rico and is the second largest of the more than 50 islands and cays composing the Virgin Islands of the United States, (fig. 1). The island is approximately 14 miles long, 2 to 3 miles wide, and has an area of 32 miles square.

"A central ridge 600 to 1500 feet in altitude runs the length of the island (fig. 2). Slopes commonly exceed 35° and are dissected by numerous dry stream courses. The general appearance is a panorama of steep interstream spurs and rounded peaks. Flat land is confined to the Charlotte Amalie area and to alluvial fans at the mouth of a few valleys. The only variation from these

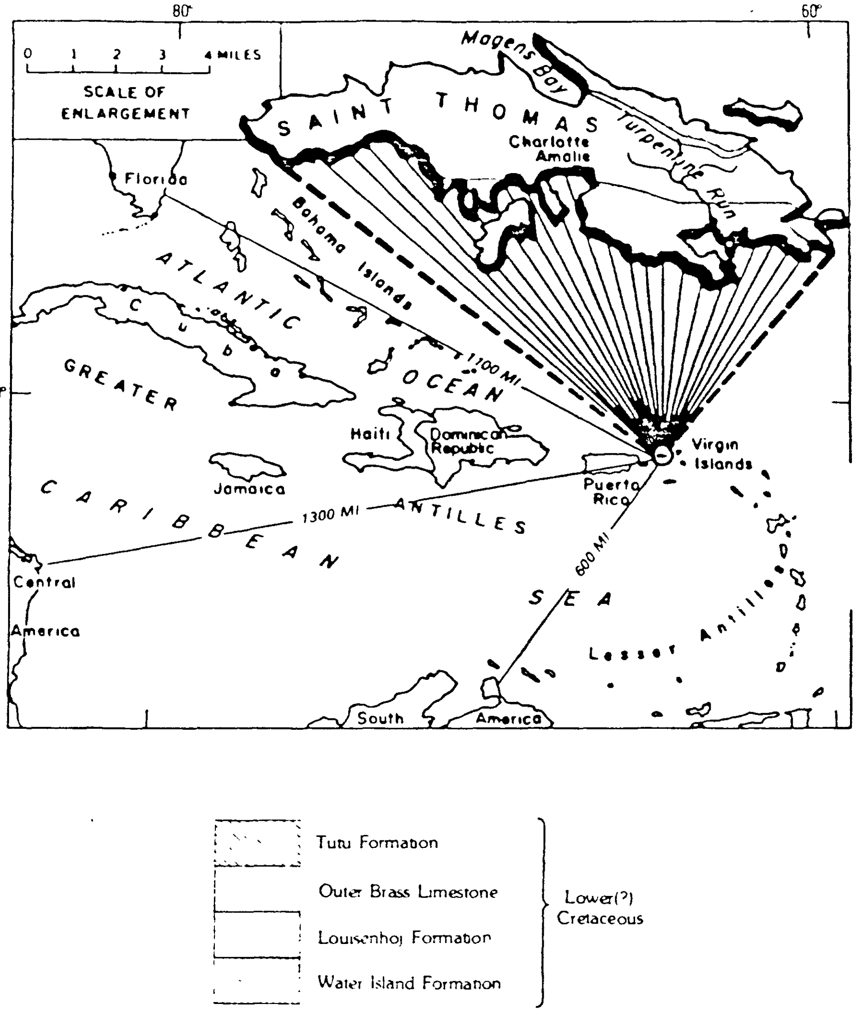


Figure 1.--Location of St. Thomas and general geology (From Jordan and Fisher, 1977; geology and formation names from Donnelly, 1966)

typical surface features is found in the upper valley of Turpentine Run in eastern St. Thomas. The valley has relatively gentle topography consisting of rolling hills in a basin surrounded by steep slopes and sharp ridges.

"At one time almost all the land including the steep slopes was under cultivation, either as pasture or for growing sugarcane and cotton. As of 1966 a few square miles in the eastern part were still used for pasture and about 10 acres were used for truck farming in the north central part of the island. Much of the remainder of the island was in brush and secondary forest." (Verbatim from Jordan and Fisher, 1977, p. 2-5).

CLIMATE

"The climate of the Virgin Islands is maritime tropical, characterized by generally fair weather, steady winds, and slight but regular seasonal and diurnal variations in temperature. The average annual total rainfall at the higher elevations (1500 feet) is between 50 and 60 inches, and approximately 35 inches at the driest sites, with an overall average of 44 inches per year. The temperature ranges between 70° and 90°F, and trade winds blow regularly from an easterly direction at a velocity of 5 to 15 miles per hour" (From U.S. Water Resources Council, 1978, v.4, p.5).

GEOLOGY

Most of St. Thomas is underlain by volcanic rocks of Cretaceous age, according to Donnelly (1966). A generalized geologic map is shown on figure 1. The volcanic rocks consist largely of water-laid and reworked pyroclastic debris and kerotophyre flows, dikes and plugs. Limestone extends across the northeastern part of the island. No terrigeneous material has been found.

STORM OF APRIL 18, 1983

Rainfall of nearly 16 inches fell in 14 hours at Dorothea Bay during April 18, 1983 (U.S. Geological Survey, 1983). The rain caused extensive flooding throughout St. Thomas, closing the airport and isolating parts of some communities.

LANDSLIDES DURING THE STORM

Most of the landslides occurred along oversteepened road cuts in the area between Dorothea Bay and Charlotte Amalie (fig.2). Two were earth flows approximately 100 feet in width and length in extensively weathered colluvium derived from volcanic wacke of the Early (?) Cretaceous Louisehoj Formation of Donnelly (1966). Several were very small debris slides in colluvium at the top of road cuts. Several roads were temporarily blocked by boulders, some of which were transported by creeks in flood and some of which rolled down hill,

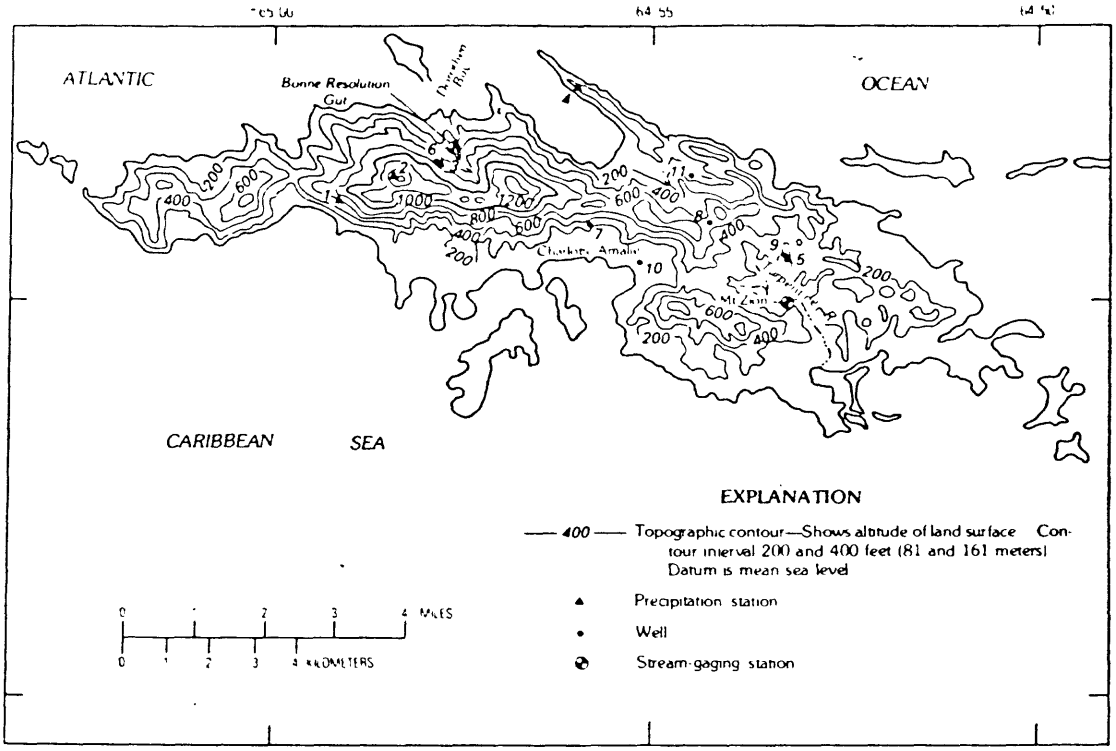


Figure 2. General topography and location of precipation stations, wells, and stream-gaging stations. From Jordan and Fisher (1977).

apparently after their support had been removed by rainwater. One huge boulder 20 feet in maximum dimension moved about 30 feet downhill, stopping next to and above a house.

The very heavy rain could have triggered debris flows but none was reported or could be documented from the photographs taken after the storm. Debris flows have been found in Puerto Rico by Mattson (1968), among others, but none has been recognized yet in the Virgin Islands.

A landslide approximately 1200 feet long and 1200 feet wide mapped prior to 1979 by John W. M'Gonigle (in Peebles, 1979, p. 30) in the area about 1 mile north of Charlotte Amalie is the largest yet discovered. No other information about the landslide has been published.

PAST STORMS

The U.S. Army Corps of Engineers reported (1977) that large floods occurred in the Virgin Islands in 1867, 1916, 1924, 1932, 1960, 1969, 1970, and 1974. Landslides were reported in the 1970 flood; rocks, boulders and other debris were reported in 1969 and 1974.

RECURRENCE OF FLOODS AND LANDSLIDES

The recurrence interval of the five most severe floods from 1867 to 1974 is shown on Table 1. The U.S. Geological Survey (1983) indicates that the 1983 flood was probably a 100-year event. Inasmuch as landslides formed during the 1970 flood, landslides triggered by rainfall can be expected at least every 12 years. The recurrence of landslides triggered by earthquakes and other factors has not been determined.

FUTURE LANDSLIDE PROBLEMS

The most striking landslide hazard observed during my brief reconnaissance of St. Thomas is the abundance and prevalence of boulders on steep slopes and ridge crests throughout the island. Most of the boulders are 1 to 4 feet in maximum dimension but some are as large as 30 feet. The conditions under which these boulders would move, such as the amount of rainfall or earthquake shaking needed, has not been established, but some of the boulders moved

Table 1.
Major floods on St. Thomas Island from 1867 to 1974
(from Haire and Johnson, 1977)

Date	Amount of rain	Period	Rank of Flood	Estimated recurrence interval (years)
11/24/74	6 in.	3-4 hr.	1	60
5/8/60	13.25 in.	48 hr.	2	30
10/9/16	not given	24 hr.	3	20
3/1/69	6.3 in.	24 hr.	4	15
10/7/70	6.7 in.	24 hr.	5	12

during at least 1969, 1974, and 1983 storms. Inasmuch as more and more houses are being built on or close to steep slopes where these boulders could cause damages, injuries, and fatalities, further defintion of the seriousness of the problems and recommendations for mitigation should be done as soon as possible.

ACKNOWLEDGEMENTS

Anibal Morciglio of the Virgin Islands Office of Civil Defense and Aloy Nielson, Director, Virgin Islands Bureau of Public Roads kindly took me to several landslides that formed during heavy rainfall in April 1983. Pamela Johnson, Coordinator, Disaster Programs Office, graciously provided me with an album of photographs taken by Mr. Morciglio after the April storm, plus many other materials related to precipitation and storms in the Virgin Islands.

REFERENCES

Donnelly, T.W., 1966, Geology of St. Thomas, U.S. Virgin Islands: Geological Society of America Memoir 98, p. 85-176.

Haire, W.J., and Johnson, K.G., 1977, Floods of November 12, 1974 in the Charlotte Amalie area, St. Thomas, Virgin Islands: U.S. Geological Survey Open File Water Resources Investigation 91-76.

Jordan, D.G., and Fisher, D.W., 1977, Relation of bulk precipation and evapotranspiration to water quality and water resources, St. Thomas, Virgin Islands: U.S. Geological Survey Water Supply Paper 1663-I, 30 p.

Mattson, P.H., 1968, Geologic map of the Jayuya quadrangle, Puerto Rico: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-520, scale 1:24,000.

Peebles, E.J., 1979, Earthquakes; vulnerability and mitigation in the U.S. Virgin Islands: U.S. Virgin Islands Disaster Program Office report, 73 p.

U.S. Army Corps of Engineers, 1977, Flood hazard information, St. Thomas, U.S. Virgin Islands, Demara (Frenchtown): Jacksonville District, Jacksonville, Florida.

U.S. Geological Survey, 1983, Water Resources in Puerto Rico; a review: U.S. Geological Survey report, v. 2, no. 4.

U.S. Water Resources Council, 1978, The Nation's water resources, 1975-2000: v. 4, Caribbean Region.

EARTHQUAKE RESISTANT DESIGN CRITERIA

by

Charles G. Culver
National Bureau of Standards
Washington, D.C. 20234

INTRODUCTION

History shows that properly designed and constructed facilities can withstand earthquakes. The design and construction of ordinary buildings are governed by building codes, which are legal documents that specify minimum standards of construction and are adopted by government agencies. A summary of design requirements for earthquake resistant construction included in the building regulations of various countries throughout the world is available.[1] It is important that such design requirements be reviewed periodically and updated to incorporate the results of research and knowledge gained from the performance of buildings in earthquakes.

Substantial efforts have been underway in the United States over the last ten years to update seismic design provisions. This work resulted in publication of "Tentative Provisions for the Development of Seismic Regulations for Buildings"[2] by the Applied Technology Council (ATC), a group representing the Structural Engineers Association of California (SEAOC) and the National Bureau of Standards. These provisions include a number of new concepts recommended by the SEAOC Seismology Committee to improve seismic design. The purpose of this paper is to briefly summarize a few of these concepts. A detailed commentary providing the rationale used to establish the provisions is available.[2]

ATC PROVISIONS

The ATC provisions are comprehensive in nature and deal with earthquake resistant design of the structural system, architectural and nonstructural elements, and mechanical-electrical systems in buildings. Both new and existing buildings are included. New concepts in these provisions will be reviewed in the following categories: (1) seismic performance, (2) analysis procedures, (3) design and detailing requirements and (4) nonstructural components.

(1) Seismic Performance - Seismic performance is a measure of the degree of protection provided for the public and building occupants against the potential hazards resulting from the effects of earthquake motions on buildings. The level of performance inherent in a design is a function of the force levels used in the design, detailing requirements and the quality assurance procedures followed in executing the construction. Two factors are utilized in the ATC provisions to insure this performance: (a) the level of anticipated ground shaking which is a function of the geographic location of the building and (b) the type of occupancy or use of the building. Four categories, expressed in terms of a seismicity index, are used for the levels of ground shaking encountered in the United States. Three categories or seismic hazard exposure groups are used for occupancy and use classification. Although the provisions do not explicitly use an importance factor, one hazard exposure group includes essential facilities necessary for post-earthquake recovery. Low occupancy buildings of a noncritical nature that may only be subjected to low levels of ground shaking do not need comprehensive seismic analysis. Detailing requirements, however, must be met to insure the integrity of the buildings when subject to shaking. For critical facilities in areas of high ground motion, analysis procedures and framing requirements are specified.

(2) Analysis Procedures - Two basic analysis procedures are provided for structures where the level of ground shaking and the type of occupancy warrant: equivalent lateral force and modal analysis. The design of the structure (sizing of individual members, connections and supports) is based on internal forces resulting from a linear elastic analysis and assumes that the structure, as a whole, under the prescribed design forces should not deform beyond a point of significant yield. Significant yield is not the point where first yield occurs in any member but is the level causing complete plastification of at least the most critical region of the structure. This

procedure differs from existing codes where the prescribed loads and determination of structural member sizes are at service or working stress levels.

The equivalent lateral force procedure is similar to that used in existing codes. Computation of the lateral seismic force includes consideration of the ground motion, the periods of the building, soil effects for the site, and the type of lateral load resisting structural system. Modal analysis is required for buildings with irregularities in the vertical framing system (varying story heights, significant changes in stiffness or mass between stories, etc.). A lumped-mass model may be used in this case to calculate the required periods, mode shapes and lateral force distribution over the height of the structure.

(3) Design and Detailing Requirements - The provisions contain requirements for tying together the parts of buildings, concrete or masonry wall anchorage, collector elements, diaphragms, bearing walls, inverted pendulum-type structures, vertical seismic motions, and deflection and drift limits. Some of the requirements cited are spelled out in considerably more detail, and in most cases are more stringent than existing provisions. These requirements were necessary since the overall inelastic response of a structure is very sensitive to the inelastic behavior of its critical regions, and this behavior is influenced, in turn, by the detailing of these regions. The detailing requirements also provide for the large energy dissipation or ductility necessary for structures to resist strong ground motions. This approach was felt to be better than simply increasing the level of design forces.

(4) Nonstructural Components - The provisions establish minimum design levels for architectural, mechanical, and electrical systems and components. The design levels are based on occupancy use, the number of occupants, need for operation continuity, and the interrelationship of structural and architectural, mechanical and electrical systems. The following aspects of seismic safety were considered in establishing the requirements: general life safety, property damage affecting life safety, functional impairment of critical facilities affecting post-disaster recovery, and safety of emergency personnel such as fire and rescue teams. The requirements are expressed in

terms of design forces for these components. Force levels are a function of the weight of the component, the design ground motion, the type of system and the desired performance level. Amplification factors are included for taking into account the location of the component in the building recognizing that force levels for these systems vary over the height of the building.

ECONOMIC CONSIDERATIONS

The ATC provisions are intended to be tentative in nature. Prior to adoption in building code requirements, their viability for the full range of applications needs to be established. Trial designs should be made for representative types of buildings from different areas of the country and detailed comparisons made with costs and hazard levels from existing design regulations. This information will be useful in considering adoption of the provisions in building regulations. A detailed plan was developed for this activity[3] and is currently underway.

Trial designs are being conducted for buildings at nine locations throughout the United States. The cities selected for the trial designs are representative of the variations in seismic risk, local practice with regard to seismic safety, and typical construction practices across the U.S. They range from Los Angeles, California with a high risk of strong ground shaking to New York City with a low earthquake hazard risk. Building types include: low, mid and high-rise residential buildings; mid and high-rise office buildings; one-story industrial buildings; and two-story commercial buildings. Forty-seven buildings with the following type of framing are involved: wood, clay brick and concrete block, masonry, reinforced concrete shear wall, precast concrete wall, reinforced concrete frame, steel braced frame, steel moment frame, and steel moment frame with braced frames or shear walls.

Each building is being designed two times, once according to the ATC provisions and once according to the prevailing local code. A report will be prepared for each building describing the criteria used and the calculations made, the final design, and the probable impact on design cost and time of adopting the provisions.

Preliminary results on the economic impact of the provisions indicate that construction costs for the ATC design varied from less than costs associated with current provisions in high risk seismic zones to increases in costs as high as 25-50 percent for low risk seismic areas. Similar results were obtained for structural engineering design costs. The large increases were obtained where existing provisions contain little or no seismic design requirements or where a building layout designed without considerations of seismic effects was redesigned to include seismic effects. Seismic resistance is easier to incorporate if considered at the planning stages. Higher design costs occurred where designers did not have familiarity with seismic design. It is expected that these costs will decrease as local designers become experienced in seismic design and local contractors gain familiarity with seismic design details and how to efficiently fabricate and construct them. This effort is expected to be completed by July 1984 and will provide information useful in considering modifications to the provisions and their adoption in building regulations.

REFERENCES

1. "Earthquake Resistant Regulations - A World List 1973" compiled by International Association for Earthquake Engineering, published and distributed by Gakujutsu Bunken Fukyu-Kai, Oh-Okayama, Meguroku, Tokyo 152.

2. Applied Technology Council, "Tentative Provisions for the Development of Seismic Regulations for Buildings," SP-510, National Bureau of Standards, Washington, D.C. 1978.

3. "Plan for a Trial Design Program to Assist Amended ATC 3-06 Tentative Provisions for the Development of Seismic Regulations for Buildings," NBSIR 82-2589, National Bureau of Standards, Washington, D.C. 1982.

APPENDIX A--SELECTED PAPERS ON WORKSHOP TOPICAL THEMES

SUGGESTIONS FOR PLANNING AN EFFECTIVE PROGRAM OF PUBLIC EDUCATION TO INCREASE EARTHQUAKE HAZARD AWARENESS

by

Joyce B. Bagwell
Earthquake Education Center of Baptist College at Charleston
Charleston, South Carolina 29411

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 remined 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. Individuals at the community level 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.

PROTOTYPE 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.

EXAMPLES OF EARTHQUAKE HAZARDS MITIGATION TECHNIQUES AVAILABLE TO PLANNERS AND DECISIONMAKERS

by

William J. Kockelman
U.S. Geological Survey
Menlo Park, California 94025

INTRODUCTION

Actions to reduce earthquake hazards can be divided into five phases: two before the event, one during the event, and two after the event. These five phasea are: (1) pre-event mitigation techniques which may take 1 to 20 years, (2) Preparedness measures which may take 1 to 20 week, (3) response during the event, (4) recovery operations following the event which may take 1 to 20 weeks, and (5) post-event reconatruction activities which may take 1 to 20 years. Obviously, those times will vary depending upon the magnitude of the earthquake and the resources available to the community and metropolitan area.

Preparedness is just one phase of hazard reduction; personal preparedness is just one aspect of that phase. For example, the Council of State Governments (1976) suggests an outline for a comprehensive state emergency preparedness plan and the Western States Seismic Policy Council (1984, Appendix A) reports on the status of states' earthquake preparedness projects. The Southern California Earthquake Preparedness Project (1983), through "planning partner" arrangements with selected public jurisdiction and private entities, has developed prototypical planning guidelines for responding to, and recovering from, an earthquake. The Federal Emergency Management Agency recently funded the Central United States Earthquake Consortium -- the nation's first effort to develop and coordinate earthquake preparedness activities in a region composed of several states. Corporate, utility, and governmental preparedness (as well as mitigation, response, recovery, and reconstruction) can be very complex; discussion of these is beyond the scope of this paper.

A prerequisite to personal preparedness is familiarity with and concern about all hazard-reduction phases. For example, strengthening the structure of the home, storing water, and showing family members how to shut off the electric-, gas-, and water-supply lines are only a part of one phase -- personal preparedness. Equally important are the other phases which might include picking up children from an evacuated school, securing heavy objects at the work place for the safety of a spouse, and retrofitting the commuter-highway overpasses needed to reunite a family. For purposes of this paper, we will introduce all five hazard-reduction phases.

MITIGATION TECHNIQUES

Many techniques for reducing earthquake hazards before the event are available to planners, engineers, and decisionmakers. Some of these techniques are well known to the planning profession, such as public acquisition of hazardous areas; or to the engineering profession, such as designing and constructing earthquake-resistant structures. Others are obvious, such as warning signs and regulations. Still others have been successfully used in solving landslide, flood, and soil problems, but have not heretofore been applied to earthquake hazards.

These and other techniques are listed in Table 1 under the general headings of discouraging new development, removing or converting existing unsafe development, providing financial incentives or disincentives, regulating new development, protecting existing development, and ensuring the construction of earthquake-resistant structures.

These techniques may be used in a variety of combinations to help reduce both existing and potential earthquake hazards. Most of them are long range, taking from 1 to 20 years or more to prepare, adopt, and execute. Many of the techniques have been discussed and illustrated by William Spangle and Associates, and others (1980), Brown and Kockelman (1983), Kockelman (1983) Blair and Spangle (1979), Nichols and Buchanan-Banks (1974), and Jaffee and others (1981).

Table 1.
Some mitigation techniques for reducing earthquake hazards

<u>Discouraging new development in hazardous areas by:</u>

- Adopting seismic-safety or alternate-land-use plans
- Developing public-facility and utility service-area policies
- Disclosing the hazards to potential buyers
- Enacting Presidential and gubernatorial executive orders
- Informing and educating the public
- Posting warnings of potential hazards

<u>Removing or converting existing unsafe development through:</u>

- Acquiring or exchanging hazardous properties
- Clearing and redeveloping blighted areas before an earthquake
- Discontinuing nonconforming uses
- Reconstructing damaged areas after an earthquake
- Removing unsafe structures

<u>Providing financial incentives or disincentives by:</u>

- Adopting lending policies that reflect risk of loss
- Clarifying the legal liability of real-property owners
- Conditioning Federal and state financial assistance
- Making public capital improvements in safe areas
- Providing tax credits or lower assessments to property owners
- Requiring nonsubsidized insurance related to level of hazard

<u>Regulating new development in hazardous areas by:</u>

- Creating special hazard-reduction zones and regulations
- Enacting subdivision ordinances
- Placing moratoriums on rebuilding
- Regulating building setbacks from known hazardous areas
- Requiring appropriate land-use zoning districts and regulations

<u>Protecting existing development through:</u>

- Creating improvement districts that assess costs to beneficiaries
- Operating monitoring, warning, and evacuating systems
- Securing building contents and nonstructural components
- Stabilizing potential earthquake-triggered landslides
- Strengthening or retrofitting unreinforced masonry buildings

<u>Ensuring the construction of earthquake-resistant structures by:</u>

- Adopting or enforcing modern building codes
- Conducting appropriate engineering, geologic, and seismologic studies
- Investigating and evaluating risk of a proposed site, structure, or use
- Repairing, strengthening, or reconstructing after an earthquake
- Testing and strengthening or replacing critical facilities

PREPAREDNESS MEASURES

Preparedness measures are necessary because long-range mitigation techniques can not completely reduce all damage and all threata to life safety. In addition, preparedness is applicable to home, school, and place of work and enhancea disaster response. Important personal preparedness measures include:

- Storing emergency supplies for survival, sanitation, safety, and cooking.
- Knowing first-aid and water-purification procedures.
- Developing or being familiar with evacuation routes and deciding on a place for the reunion of the family.
- Learning how to shut off gas-, electric-, and water-supply service lines.
- Securing valuable and nonstructural objects to prevent damage or personal injury.
- Keeping portable extinguishers and garden hoses ready for fighting fires.

Preparedness measures can be taken anywhere from 1 to 20 weeks or more before an event. An excellent booklet by Lafferty (undated) on earthquake preparedness includes: suggested topics for family discussions, family-member assignment check list, community-awareness check list, list of food items for a 2-week emergency supply, suggested replacement periods for stored food, and sample menus for the first 72 hours after an earthquake. Another booklet, by the American Red Cross (1982), includes: extensive lists of home-emergency supplies, procedures for purifying water, first-aid instructions, and an earthquake-survival test. These preparedness measures provide not only for increased safety and reduced damage, but have the additional value of giving people confidence in their ability to cope with a disaster.

Many of us are overwhelmed by the broad range of techniques, measures, operations, and activities available for reducing earthquake hazards; this feeling is completely justified. However, we should make an effort to be personally prepared. There are several reasons not to be prepared for an earthquake; those reasons are restated (and refuted) in Figure 1.

Three personal preparedness measures are discussed here: inspecting and strengthening the home; organizing the neighborhood, school, church, or civic group; and securing heavy or valuable objects around the home, school, or workplace.

Inspecting and Strengthening the Home

The 1971 San Fernando earthquake provided lessons in the types of home structures most likely to fail. Potential weaknesses include numerous cracks that penetrate the entire foundations, unbolted sill plates, cripple walls, lack of solid sheeting or shear panels, unreinforced masonry chimneys, poorly attached masonry veneer, lack of diagonal bracing, large window openings, and untied terra cotta or slate roofing tiles.

A special report by Sunset Magazine (1982) on **Getting Ready for a Big Quake** provides general instructions on how to check your home for both structural and nonstructural safety, and how to make it more earthquake resistant. Additional reference material includes **The Home Builders Guide for Earthquake Design** by Shapiro' Okino, Hom, and Associates (1980), **An Earthquake Advisor's Handbook for Wood-Frame Houses** edited by Chusid (1980), and **Peace of Mind in Earthquake Country** by Yanev (1974).

Organizing the Neighborhood

State and Federal assistance takes days to organize and mobilize; see Figure 1, reason nos. 2 and 3. However, immediate help is usually available from your neighbors and friends. According to Popkin, a study by Haas and others (1977, p. xxix) suggests that "families in the United States rely on institutional support for post-disaster assistance, with help from relatives and friends or self-help playing only a small part in their recovery." Neighborhood groups can very often bridge this gap and can influence government decisionmakers in order to expedite recovery operations and reconstruction activities. Sunset Magazine (1982) gives an outline for organizing a neighborhood preparedness group and provides a sample registration form. The Southern California Earthquake Preparedness Project (1983) has developed a neighborhood self-help planning guide which tells how to set up a community program.

Figure 1. -- Seven Reasons Not to Get Ready for an Earthquake

Reason #1 If a bad earthquake hits, we'll all be dead anyway.
Not true. There may be a lot of fatalities, but, many more people will be alive -- and your loved ones may be among those who need your help. This is similar to the "why wear your seat belt" response: defeatist.

Reason #2 If I had food, I'd have to defend it with a gun against all the people who wouldn't have food.
Deciding to store emergency supplies is a personal decision. Some people store much more than they will need, in order to be able to give to others. Other people are organizing their entire block or neighborhood so they aren't the only ones with food. Cooperation is a key to survival. Naturally, you will have to make up your own mind. But ask yourself honestly: how would you react if faced with a life or death situation? Would you steal or kill for your family members? Why not prepare, and spare yourself that predicament.

Reason #3 The rest of the country will come to our aid. Helicopters will be here in no time to drop food and water.
Take a second to think about recent disasters in this country. First of all, none have been on the scale of a good-sized earthquake -- the kind we already know can happen in the Bay Area. Federal or state aid takes days to organize and mobilize; meanwhile, you are on your own. Transportation of emergency supplies will be hampered by destroyed highways, overpasses, train tracks,etc.

Reason #4 I have enough food in my house to last quite a while.
Take another look. In many homes, much of that food is perishable (in your refrigerator or freezer, which may no longer work) or unsuitable (requires cooking or is nutritionally forgettable -- marshmallows, chocolate chips, etc.). Water is even more important. You can live for awhile without food, but it is curtains if you don't have water. If you have a pool in your back yard and a water filter in your emergency kit, you are in A-1 shape. Don't depend on a water heater tank; pipes may rupture and the water may leak out.

Reason #5 I don't have any room to store emergency goods.
Some kits are quite compact and can fit in a linen closet or under a bed. In a small apartment, emergency food and equipment may mean making some changes. But what is more important? 15 pairs of shoes on the closet floor, or food and water that could save your life???

Reason #6 Storing food in your house is useless, because the house will fall down on it. It could be inedible, or impossible to get to.
Possible. If you have a garden shed or a free-standing garage, that might be a safer storage area. But again, wouldn't you rather be trying to figure out how to get to the food after your house falls down, than trying to figure out where to buy, beg, or steal water and food?! If this is a big concern to you, you could have your house inspected to see how likely it is to withstand an earthquake, and what structural changes could improve those chances.

Reason #7 It will never happen to me.
Talk to someone from Coalinga.

Source: Mele Kent (1983) from an interview with Randy Shadoe; reprinted by permission.

Securing Nonstructural Objects

People have been hurt by falling light fixtures, flying glass, overturning shelves, and spilled toxins. The Federal Emergency Management Agency (1981, Table 2) estimates that one-third of the property lost in future earthquakes in California will be attributed to building contents. Such contents are only one part of the nonstructural portion of a building.

Nonstructural damage is caused by object inertia or building distortion. For example, if an office computer or file cabinet is shaken, only friction will restrain it from overturning, falling, or impacting against its user. As the structure bends or distorts, windows, partitions, and other items set in the structure are stressed, causing them to shatter, crack, or spring out of place. Numerous protective countermeasures are available, including:

- Bolting down pedestal bases of sharp or heavy office machines, equipment, and fixtures.
- Tying fragile artwork to the walls.
- Connecting filing cabinets together at the top and tying them to the wall.
- Zigzagging free-standing, movable partitions.
- Using smaller, operable, and wood-frame windows to accommodate structural drift.
- Installing locks on cupboards.
- Boxing classroom carboys that contain hazardous liquids.
- Strapping hot-water heaters to wall studs with plumber's tape.

An excellent book on reducing the risk of nonstructural earthquake damage was prepared for The Southern California Earthquake Preparedness Project (Reitherman, 1983). It describes typical conditions found in office, retail, and government buildings. Measures are suggested for restraining over 20 nonstructural building components, such as office machines, electrical equipment, file cabinets, built-in partitions, suspended ceilings, exterior ornamentation, elevators, piping, stairways, and parapets. Each component is rated for existing and upgraded vulnerability for life-safety hazards, percent of replacement-value damaged, and post-earthquake outages for three levels of shaking intensity (Figure 2)

RESPONSE DURING THE EVENT

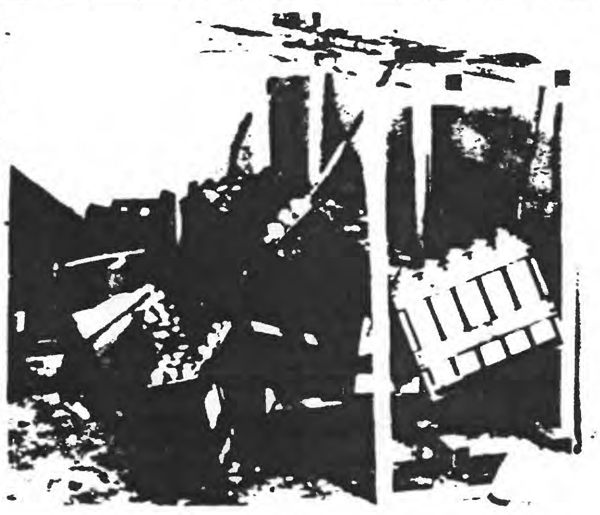
According to Blair and Spangle (1979) "individuals are virtually helpless during the course of an earthquake. They must ride it out wherever they happen to be at the time the earthquake strikes..... Helplessness is confined to those seconds when the ground is shaking; man has the knowledge and ability to avert many of the damaging effects of earthquakes." An enlightened response can occur during and immediately following the event. It includes short-term emergency assistance, and should be geared to reduce secondary damage and speed recovery operations. During and immediately after an earthquake, appropriate responses could include:

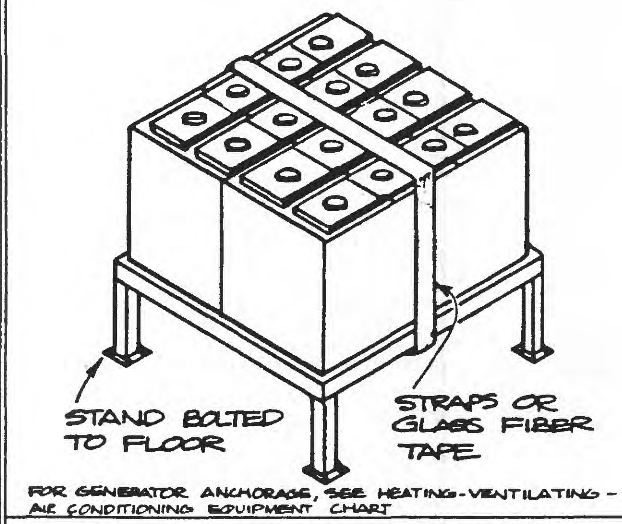
- Ducking under a desk, table, or bed; or standing in a doorway.
- Remaining calm and reassuring children and pets.
- Avoiding window openings, high buildings, power poles, heavy tile roofs, and overhanging structures.
- Fighting fires, escaping, or evacuating.
- Drawing and conserving water.
- Shutting off gas-, water-, and electric-supply lines.
- Checking for injuries.
- Listening to radio and television for emergency bulletins.
- Checking for damage to buildings, sewers, and drains.
- Cleaning up broken glass and spilled toxins.
- Assisting in neighborhood or workplace search-and-rescue operations.

Brochures such as **When an Earthquake Strikes** by the Santa Clara County Girl Scout Council (undated), **Safety Tips for Washington Earthquakes** by the Washington State Department of Emergency Services (undated), and **Earthquakes - How to Protect Your Life and Property** by Gere and Shah (1980) contain excellent advice.

EMERGENCY POWER GENERATORS

DAMAGE EXAMPLE	PROTECTIVE COUNTERMEASURE





earthquake: 1971 San Fernando
credit: John F. Meehan

APPROXIMATE COST: $10 per rack for strapping
$50 for bolting

EXISTING VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	
LIGHT	slight chance of piping connection break	low	0-5%	mod
MODERATE	slight shifting of equipment; batteries slide	low	5-20%	high
SEVERE	lurching of generator off supports; batteries fall	mod	20-50%	high

UPGRADED VULNERABILITY

SHAKING INTENSITY	EFFECTS	✚	$	
LIGHT	no damage	low	0%	low
MODERATE	no damage	low	0%	low
SEVERE	damage to rest of electrical system more likely than generator damage	low	0-5%	low

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED   POST-EARTHQUAKE OUTAGE

Figure 2. Excerpt from Reitherman (1983, p. 39) showing how to reduce a risk from earthquake damage for one type of nonstructural building component.

Lafferty (undated) provides a check list of responses for when an earthquake strikes, safety rules to be followed during an earthquake, and a form for authorizing medical treatment of minors. The American Red Cross (1982) also provides advice on coping with childrens' reactions to earthquakes and instructions for turning off gas-, electric-, and water-supply lines.

RECOVERY OPERATIONS

Recovery operations take from 1 to 20 weeks and may continue until all public facilities, institutions, and utilities return to normal. Repair of critical facilities* usually has first priority in a community or metropolitan area. Personal-recovery activities include:

- Ensuring safe ingress and egress to-and-from the home and its rooms.
- Repairing power and telephone lines.
- Repairing water-, gas-, and sewer-service lines.
- Inspecting structures and posting warning signs if found unsafe for habitation.
- Assisting neighborhood or community work parties that are assigned burial, temporary-shelter, vaccination, and transport tasks.

Personal recovery is difficult to separate from the recovery of the community or metropolitan area. For example, Rubin (1978) has written a helpful booklet on **Natural Disaster Recovery Planning for Local Public Officials** which includes: a discussion of the impact of a disaster on a community, warning signs that indicate insufficient community preparedness, and examples of

---

*The term "critical facilities" is used here to include:

(a) Lifelines such as major communication, utility, and transportation facilities, and their connection to emergency facilities;
(b) Unique or large structures whose failure might be catastrophic, such as dams or buildings where explosive, toxic and radioactive materials are stored or handled;
(c) High-occupancy buildings, such as schools, churches, hotels, offices, auditoriums, and stadiums; and
(d) Emergency facilities such as police and fire stations, hospitals, communications centers, and disaster-response centers.

successful community recovery. The Pan-American Health Organization (1981) has provided easy-to-read comprehensive procedures for emergency relief including: management of mass casualties; disease control; management of relief supplies; and the planning, layout, and management of temporary settlements and refugee camps. Examples of continuing response and recovery activities for a volcanic eruption were given in a series of **Technical Information Network** bulletins released by the Federal Coordinating Office (1980).

RECONSTRUCTION ACTIVITIES

The reconstruction phase usually involves strengthening weakened or damaged structures, razing irreparable or obsolete buildings, or commencing a neighborhood or community redevelopment program. This phase, taking from 1 to 20 years or more, provides a unique opportunity to reduce future damage and loss of life from similar events by:

- Relocating structures to less hazardous areas; for example, out of a fault-rupture zone or landslide area.
- Constructing earthquake-resistant structures, particularly critical facilities.
- Reducing population densities in hazardous areas.
- Realigning infrastructures, such as pipelines power lines, and transportation routes, thereby minimizing the transversing of hazardous areas.
- Introducing redundancy into critical facilities; for example, alternate transportation and pipeline routes across fault-rupture zones.

The post-event reconstruction phase can also be considered a mitigation technique (see Table 1). Other techniques which may be used in conjunction with this one are moratoriums on rebuilding, regulations concerning land-use, location of capital improvements, and financial incentives and disincentives.

William Spangle and Associates, and others (1980) describe reconstruction plans and actions taken after the following earthquake disasters: 1971 San Fernando Valley, California; 1964 Alaska; 1969 Santa Rosa, California; 1963

Skopje, Yugoslavia; and 1972 Managua, Nicaragua. In addition, their discussion of the San Fernando and Alaska earthquakes includes issues, options and opportunities seized or missed. Popkin in **Reconstruction Following A Disaster** (Haas and others, editors, 1979, p. xxix) notes:

> Most policy issues involving reconstruction arise because some element of the community wants to avoid a similar future disaster. This usually happens shortly after the disaster and may cause conflict with the widely-held desire to return to normal as quickly as possible. The strongest pressure of all for prompt return to normalcy comes from the existence of displaced families and businesses. Such pressures do not necessarily make for orderly, well-planned reconstruction processes.

CONCLUSION

Many ways to reduce earthquake hazards are available, including: long-term mitigation techniques, preparedness measures, responses, recovery operations, and reconstruction activities. However, a prerequisite to their effective use is public awareness. Turner and others (1980) make the following recommendations for improving public awareness:

- Carefully prepared and selected advice concerning earthquake preparedness for individuals and households should be given widespread and repeated public distribution through the media as well as other channels.
- This preparedness advice should come from some authoritative government agency and should be endorsed by well-known local government officials and public personages.
- Each recommended preparedness measure should be presented in conjunction with a brief but credible explanation justifying that recommendation and suggesting how it can be implemented.
- Some responsible state agency should develop a program to promote earthquake safety in the household making use of local government, private agencies, and citizen groups. An especially useful program of this type would be one that conducted household safety inspections.

Successful programs promoting public awareness include this conference; SEISMOS '83, a City of Los Angeles simulated seismic event and metropolitan response (Manning, 1983); the 12th Annual Japanese National Earthquake Preparedness Week and Drill (Bernson, 1983); the 1983 National Seismic Policy Conference (Western States Seismic Policy Council, 1984); the South Carolina Seismic Safety Consortium conferences (Bagwell, 1983); and the Governor's Conference on Geologic Hazards (Utah Geological and Mineral Survey, 1983).

ACKNOWLEDGEMENTS

Joyce Bagwell, Baptist College at Charleston, Pamela Johnston, U.S. Virgin Islands Disaster Programs Office, Cheryl Tateishi, The Southern California Earthquake Preparedness Project, and Jane Bullock, Federal Emergency Management Agency, kindly reviewed this paper and provided valuable suggestions. Special thanks are owed Catherine Campbell for editing and Cynthia Ramseyer for word processing.

REFERENCES

American Red Cross, 1982, Safety and survival in an earthquake: Southern California Division, Los Angeles Chapter, American Red Cross, Los Angeles, Calif., 44 p.

Bagwell, J.B., 1983, The current state of earthquake hazard awareness in the Southeastern United States in Hays, W.W. and Gori, P.L., eds., 1983, A workshop on "The 1886 Charleston, South Carolina, earthquake and its implications for today": U.S. Geological Survey Open-file Report 83-843, Reston, Va., p. 315-322.

Bernson, Hal, 1983, Report to the Los Angeles City Council on earthquake preparedness week and drill --Japan 1983: Los Angeles, 8 p. Blaire M.L., and Spangle, W.E., 1979, Seismic safety and land-use planning -- selected examples from California: U.S. Geological Survey Professional Paper 941-B, 82 p.

Brown, R.D., Jr., and Kockelman, W.J., 1983, Geologic principles for prudent land use -- a decisionmaker's guide for the San Francisco Bay region: U.S. Geological Survey Professional Paper 946, 97 p.

Chuaid, J.M., editor, 1982, An earthquake advisor's handbook for wood frame houses: University of California Center for Planning and Development Research, Berkeley, Calif., 90 p.

Council of State Governments, 1976, Comprehensive emergency preparedness planning in state government: The Council of State Governments, Lexington, Ky., 47 p.

Federal Coordinating Office, 1980, Mount St. Helens Technical Information Network: Federal Emergency Management Agency, Vancouver, Wash., series of 33 bulletins.

Federal Emergency Management Agency, 1981, An assessment of the consequences and preparations for a catastrophic California earthquake -- findings and actions taken: Federal Emergency Management Agency, Washington, D.C., 59 p.

Gere, J.M., and Shah, H.C., 1980, Earthquakes -- how to protect your life and property: John A. Blume Earthquake Engineering Center, Stanford University, Calif., 16 p.

Haas, J.E., Kates, R.W., and Bowden, M.J., eds., 1977, Reconstruction following disaster: MIT Press, Cambridge, Mass., 331 p.

International Conference of Building Officials, 1979, Uniform disaster mitigation plan: Whittier, Calif., 26 p.

Jaffe, Martin, Butler, JoAnn, and Thurow, Charles, 1981, Reducing earthquake risks -- a planner's guide: American Planning Association, Planning Advisory Service Report 364, 82 p.

Kent, Mele, 1983, Seven reasons not to get ready for an earthquake: Palo Alto Co-op News, vol. XLIX, no. 22, p. 1.

Kockelman, W.J., 1983, Examples of the use of geologic and seismologic information for earthquake-hazard reduction in Southern California: U.S. Geological Survey Open-file Report 83-82, 58 p.

Lafferty, Libby, undated, Earthquake preparedness -- A guide and handbook for your home, family, and community: Creative Home Economics Services of California, La Canada, Calif., 32 p.

Manning, D.O., 1983, City of Los Angeles, "Seismos '83" -- a simulated seismic event and metropolitan response: City of Los Angeles Fire Department, Los Angeles, Calif., 21 p.

Nichols, D.M. and Buchanan-Banks, J.M., 1974, Seismic hazards and land-use planning: U.S. Geological Survey Circular 690, Reston, Va., 33 p.

Pan American Health Organization, 1981, A guide to emergency health management after natural disaster: Pan American Health Organization Scientific Publication 407, World Health Organization, Washington, D.C., 67 p.

Reitherman, Robert, 1983, Reducing the risks of nonstructural earthquake damage -- a practical guide: California Seismic Safety Commission, Sacramento, Calif., 87 p.

Rubin, C.B., 1979, Natural disaster recovery planning for local public officials: Academy for Contemporary Problems, Columbus, OH., 20 p.

Santa Clara County Girl Scout Council, undated, When an earthquake strikes- be prepared: San Jose, Calif., brochure.

Shapiro, Okino, Hom and Associates, 1980, The home builder's guide for earthquake design -- guideline 6: U.S. Department of Housing and Urban Development, Office of Policy Development and Research, Washington, D.C., 57 p.

Southern California Earthquake Preparedness Project, 1983, Comprehensive earthquake preparedness planning guidelines: Van Nuys, Calif., 9 parts.

Sunset Magazine, 1982, Getting ready for a big quake: Menlo Park, Calif., March 1982, p. 104-113.

Turner, R.H., and others, 1980, Community response to earthquake threat in Southern California: University of California Institute for Social Science Reaearch, Los Angeles, Calif.' 10 parts.

Utah Geological and Mineral Survey, 1983 Governor's conference on geologic hazarda: Utah State Department of Natural Resources Circular 74, 99 p.

Washington State Department of Emergency Services and Federal Emergency Management Agency, undated, Earthquake -- safety tips for Washington earthquakes: Olympia, Wash., brochure.

Western States Seismic Policy Council, 1984, Proceedings of the 1983 National Seismic Policy Conference: Washington State Department of Emergency Services, Olympia, Wash., 158 p., 4 appendices.

William Spangle and Associates, and others, 1980, Land-use planning after earthquakes: William Spangle and Associates, Portola Valley, Calif., 158 p.

Yanev, P.I., 1974, Peace of mind in earthquake country -- how to save your home and life: Chronicle Books, San Francisco, 304 p.

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).