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A WORKSHOP ON "CONTINUING ACTIONS TO REDUCE POTENTIAL LOSSES FROM FUTURE EARTHQUAKES IN NEW YORK AND NEARBY STATES"

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INTRODUCTION

Eighty-five geologists, scientists, engineers, social scientists, emergency planners, and public officials participated in a one and one-half day workshop on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in New York and Nearby States" held in Albany, New York, December 13-14, 1984. The workshop was cosponsored by the U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the New York Geological Survey, and the New York State Divison of Military and Naval Affairs. The workshop was timed to coincide with the formation of a New York Earthquake Advisory Council and the receipt of a $65,000 grant from FEMA to improve earthquake preparedness in New York.

This workshop was the twenty-ninth in a series of workshops and conferences that USGS has sponsored since 1977, usually in cooperation with FEMA and one or more other Federal or State agencies and institutions. Each workshop and conference has a general goal of improving utilization of knowledge on earthquake hazards by bringing together knowledge producers and users. In addition, each workshop has a specific goal of strengthening some current earthquake hazards mitigation activity in the State or region. In this workshop, the specific goal was to enhance the activities of the New York Earthquake Advisory Council (which was created on December 12, 1984) to plan and execute an earthquake vulnerability study.

Two other workshops have been convened by USGS and FEMA to benefit the Northeastern United States. The first workshop was held in Knoxville, Tennessee, in September 1981 and resulted in a draft 5-year plan for the Northeast (see Appendix A). The proceedings of this workshop were published as USGS Open-File Report 82-220. The second workshop was held at Cambridge, Massachusetts, in June 1983. USGS Open-File Report 83-844 contains the recommendations of this workshop, which included the establishment of at least one seismic safety organization in the Northeast.

Appendix B lists the participants in the workshop. The participants included a number of important public officials as well as a diversified group of representatives of the scientific-technical community.

HISTORICAL SEISMICITY IN NEW YORK

New York is a classic example of the problem of earthquake hazards mitigation in the Eastern United States. Other natural hazards (e.g., hurricanes) occur more frequently than earthquakes and are better known by the public. The probability of a major earthquake occurring in either New York or in Canada or a nearby State is quite low, but moderate to severe earthquakes have occurred in the vicinity of New York in the past and will certainly recur in the future. More than in other parts of the United States, the effort to reduce earthquake hazards is compounded by a high population density, many old buildings, and a high degree of modern industrialization. The potential threat to people and property is sufficiently high that it cannot be ignored in spite of the low frequency of occurrence (Figure 1).

A number of historical earthquakes have occurred in the Northeastern United States and have provided evidence of what can happen in New York. Since 1737, New York has experienced 12 earthquakes of Modified Mercalli intensity (MMI) VI (see Appendix C for a glossary of terms used in earthquake engineering), 4 earthquakes of MMI VII, and 3 earthquakes of MMI VIII. Intensities of IV-VI affect the contents of buildings, although they can cause liquefaction of soils. Intensities of VI-VII cause architectural damage (e.g., cracked and leaning chimneys, cracked and fallen plaster, overturned water heaters, etc.); whereas, intensities of VIII or greater cause minor to

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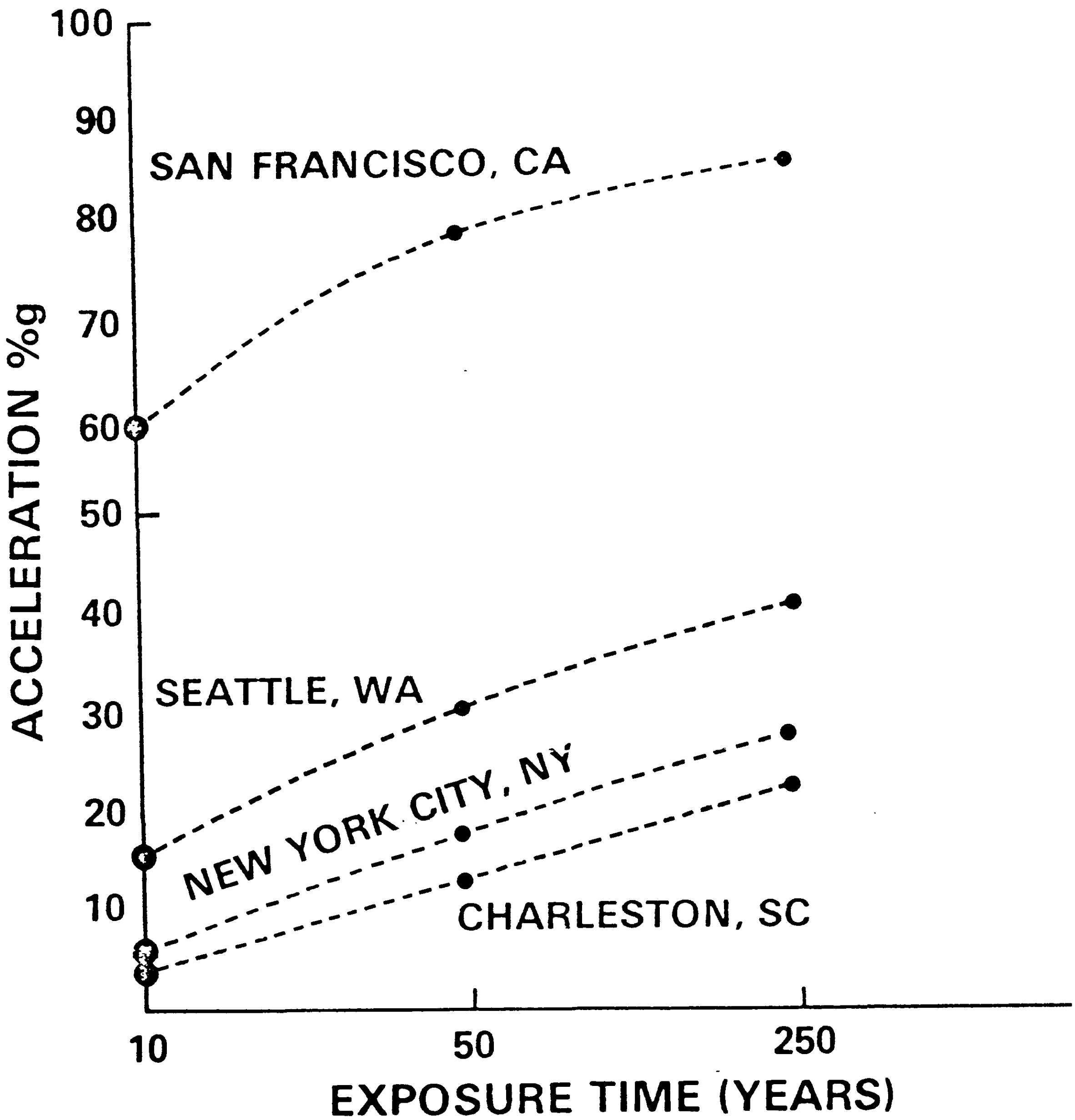

Figure 1.--Comparison of values of peak horizontal bedrock acceleration for the New York City area and other urban areas (from Algermissen et al., 1982). The values have a 90 percent probability of nonexceedance. A 50-year exposure time corresponds to the useful life of ordinary buildings.

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major structural damage (e.g., houses shifted on their foundations, major cracks, partial or total collapse in buildings, foundation failure, etc.).

EARTHQUAKE HAZARDS

An earthquake is caused by the sudden abrupt release of slowly accumulating strain energy along a fault, a surface or zone of fracturing within the Earth's crust. Depending on its size and location, an earthquake causes the physical phenomena of ground shaking, surface fault rupture, earthquake-induced ground failure (landslides, liquefaction, compaction, lurching, and foundation settlement), regional tectonic deformation, and tsunamis (in some coastal locations). Each one of these phenomena (called earthquake hazards) can cause damage to buildings and facilities, economic loss, injuries, loss of life, loss of function, and loss of confidence. Fires and floods can also be triggered by these hazards. In addition, aftershocks may follow the main shock for a period of several months to several years and cause additional damage, loss, and psychological impact.

ASSESSMENT OF POTENTIAL RISK

The assessment of the potential risk (chance of loss) from earthquake hazards in an urban area is a complex task requiring:

1. An earthquake hazards model.
2. An exposure model (inventory).
3. A vulnerability model.

A schematic illustration of the total range of considerations is shown in Figure 2. Each model is described briefly below with additional detail being provided by the papers contained in this report.

EARTHQUAKE HAZARDS MODEL (See papers by Hays, Seeber and Armbruster, Mitronovas and Nottis, Barosh, and Hopper).

Assessments of risk is closely related to the capability to model the earthquake hazards of ground shaking, surface fault rupture, earthquake-

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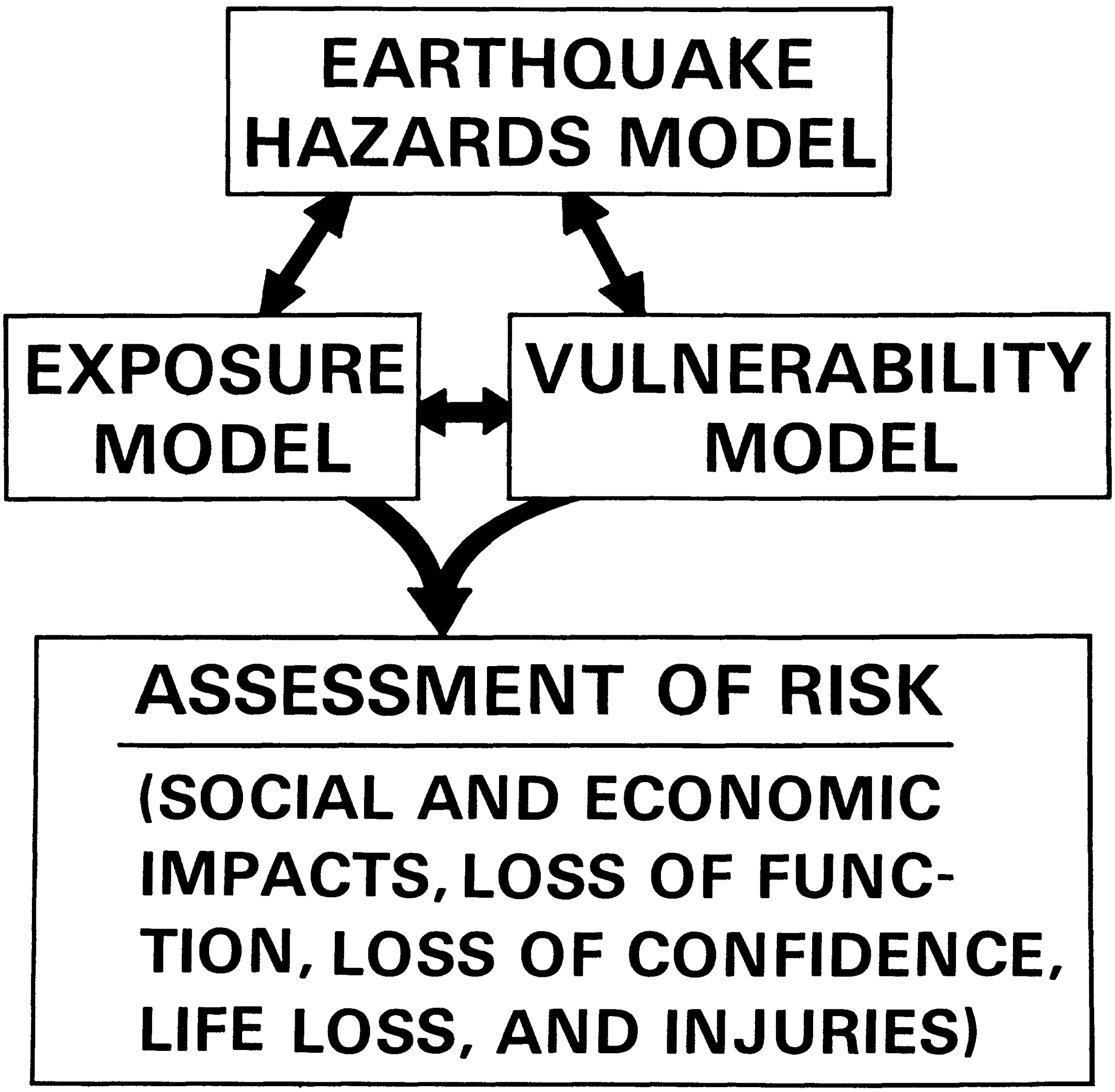

Figure 2.--Diagram showing the wide range of evaluations that are part of the overall process of earthquake hazards reduction and risk assessment. The earthquake hazards, exposure, and vulnerability models are important elements of the process.

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induced ground failure, tectonic deformation, and in some cases, tsunamis. Most of the spectular damage and losses in an earthquake are caused by partial or total collapse of buildings as a consequence of the severity of the horizontal ground shaking. However, ground failures triggered by earthquake ground shaking can also cause substantial damage and losses. For example, during the 1964 Prince William Sound, Alaska, earthquake, ground failures accounted for about 60% of the estimated $500 million total loss with landslides, lateral spread failures, flow failures, and liquefaction causing damage to highways, railway grades, bridges, docks, ports, warehouses, and single family dwellings. Surface faulting, which generally affects a long narrow area, has not occurred in the Eastern United States except possibly in the 1811-1812 New Madrid earthquakes. Surface faulting, which generally occurs in earthquakes of magnitude 5.5 or greater in the Western United States, has damaged lifeline systems and single family dwellings but has not directly caused deaths and injuries. Tsunamis, long period water waves caused by the sudden vertical movement of a large area of the seafloor during an earthquake, occur fairly frequently in Hawaii and have produced great destruction and loss of life. Although occurring much less frequently, destructive tsunamis have also affected Puerto Rico, the Virgin Islands, Alaska, and the west coast of the United States. Historically, they have been absent on the east coast.

The earthquake hazards model must answer the following questions:

1. <u>Where</u> have past earthquakes occurred? <u>Where</u> are they occurring now?
2. <u>Why</u> are they occurring?
3. <u>How often</u> do earthquakes of a certain size (magnitude) occur?
4. <u>How bad</u> (severe) have the physical effects (hazards) been in the past? <u>How bad</u> can they be in the future?
5. <u>How</u> do the physical effects (hazards) vary spatially and temporally?

The answers to these questions are used to define the amplitude, frequency, composition, and duration of horizontal ground shaking--the three parameters that correlate best with damage.

EXPOSURE MODEL (See papers by Hopper and McCann).

The spatial distribution of things and people exposed to earthquake hazards is called inventory. The inventory is one of the most difficult models to characterize. For risk assessment, the term structure is used to refer to any object of value that can be damaged by the earthquake hazards of ground shaking, surface faulting, ground failure, tectonic deformation, and tsunami wave run up. The various categories of structures include:

1. Buildings (residential, agricultural, commercial, institutional, industrial, and special use).

2. Utility and transporation structures (electrical power structures, communications, roads, railroads, bridges, tunnels, air navigational facilities, airfields, and waterfront structures).

3. Hydraulic structures (earth, rock, or concrete dams, reservoirs, lakes, ponds, surge tanks, elevated and surface storage tanks, distribution systems, and petroleum systems).

4. Earth structures (earth and rock slopes, major existing landslides, snow, ice, or avalanche areas, subsidence areas, and natural or altered sites having scientific, historical, or cultural significance).

5. Special structures (conveyor systems, sky lifts, venelation systems, stacks, mobile equipment, tower, poles, signs, frames, antennas, tailing piles, gravel plants, agricultural equipment, and furnishings, appendages, and shelf items in the home).

A structure consists of many elements. To predict losses, the contribution of each individual element to the total response of a structure in response to the dynamic forces induced by ground motion (or another hazard) must be modeled.

Vulnerability Model (See papers by Hopper, McCann, and Fratto).

Vulnerability is a term describing the susceptibility of a structure or a class of structures to damage. The prediction of the actual damage that a structure will experience when subjected to a particular hazard (such as ground shaking) is very difficult as a consequence of:

1. Irregularities in the quality of the design and construction (e.g., some are designed and built according to a building code; some are not).

2. Variability in material properties.

3. Uncertainty in the level of ground shaking induced in the structure as a function of magnitude, epicentral distance, and local site geology.

4. Uncertainty in structural response to earthquake ground shaking, especially in the range where failure occurs.

A fragility curve can be used to represent failure of a specific type of structure (or a structural system) when it is exposed to the dynamic forces induced by ground shaking. For most structures, damage occurs as a function of the amplitude, frequency composition, and duration of ground shaking and manifests itself in varyious states ranging from "no damage" to "collapse." Specification of the damage states of a structure is very difficult because each state is a function of the lateral-force-resisting system of the structure and the severity of the hazard.

OPTIONS FOR RESEARCH AND MITIGATION (See papers by Nigg, Lambright, Gori, Remmer, Connolly, and Barstow and Pomeroy).

In conjunction with an assessment of the potential risk from earthquake hazards, answers are needed for the following questions:

1. What are the viable options for mitigating potential losses from earthquake hazards?

2. What research is needed to provide sound technical and societal bases for devising loss-reduction measures.

The answers to these questions encompass a wide range of possibilities. The options include:

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

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

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

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

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

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

7. A seismic safety organization--devise policy and plans to achieve seismic safety. (Note: such an organization now exists in New York.)

WORKSHOP PROCEDURES

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

PROCEDURE 1: A reception was held the night before the workshop to provide an opportunity for participants to become acquainted and to interact informally.

PROCEDURE 2: Research reports and preliminary technical papers prepared in advance by the participants were distributed at the workshop and used as basic references.

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

PROCEDURE 3: Scientists, social scientists, engineers, emergency management specialists, and public officials gave oral presentations in five plenary sessions.

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

PROCEDURE 4: To stimulate interaction and to reinforce basic facts, a questionnaire was utilized in conjunction with the first three plenary sessions. It is included below.

Questionnaire

Purpose: The purpose of this questionnaire is to determine the range of views and opinions of the participants in the workshop

Question 1: In evaluating the nature and extent of earthquake hazards in New York, the key questions are: WHERE?, WHY?, HOW OFTEN?, and HOW BAD OR HOW SEVERE ARE THE EFFECTS?.

a. On the basis of the available geological, seismological, and engineering data in the New York area, do we have reliable answers to the above four questions for earthquakes of MMI VIII or greater?

b. One of the answers to the question of WHY? is: "the reactivation of old fault systems in response to the current stress environment." Is this the "best" answer from the point of view of emergency preparedness planning?

c. Is the level of ground shaking expected in the New York City area within an exposure time of 50 years (the lifetime of an ordinary building) or greater than that expected in the Charleston, South Carolina, area (the location of a large earthquake in 1886)?

d. Will ground failures (liquefaction, landslides) occur over an extensive area in a New York earthquake of MMI VIII?

e. Are buildings designed to resist wind also able to resist ground shaking from an earthquake of MMI VIII without collapse?

f. Will a vulnerability study provide informatin about the risk in the New York area that can be used for a decade?

Question 2: The range of options in New York for mitigating the effects of earthquake hazards includes preparedness planning, land-use planning, building codes, and other measures.

a. Is preparedness planning for earthquakes more difficult than preparedness planning for other natural hazards?

b. Is land-use planning a viable option in New York?

c. In view of the relatively infrequent occurrence of earthquakes having a maximum MMI of VIII or greater in the Northeast, is the requirement for seismic design provisions in a building code cost effective?

d. Is a substantial increase in earthquake hazards awareness and mitigation activities justified in New York?

e. Can a substantial increase in earthquake hazards awareness and mitigation activities be accomplished in New York in a decade?

f. Is the political climate in New York right for advocating the cause of earthquake hazards reduction?

g. Would the occurrence of a damaging earthquake on the edge of a densly populated urban center in New York improve the political climate and minimize concern about costs of research, mitigation activites, response, and recovery?

PROCEDURE 5: The participants were encouraged to respond to the presentations of the speakers and panelists.

PROCEDURE 6: Three simultaneous discussion groups were convened following the fourth plenary session to discuss the subject of learning from earthquakes in greater detail and to generate recommendations for future research and mitigation activities.

WELCOMING SESSION

After introductory remarks by Frank Petrone, Director of FEMA Region I, the participants were asked to identify whether they were scientists/engineers or decisionmakers. They were reminded of the seven basic perspectives of each group and challenged to work to make these differences in perspectives as small as possible. These characteristics (from Szanton, 1981) are summarized below:

1. The ultimate objective of the decisonmaker is the approval of the electorate; it is the respect of peers for the scientists/engineer.

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

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

4. The mode of thought 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 abtruse and qualified for the scientist/engineer.

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

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

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PLENARY SESSIONS

The overall theme of the workshop was developed in five plenary sessions. A discussion group followed the fourth plenary session. The themes, objectives and speakers for each plenary session are described below:

SESSION I THE NATURE AND EXTENT OF EARTHQUAKE HAZARDS IN NEW YORK

OBJECTIVE: A series of presentations answering to the extent possible the basic questions that policymakers ask scientists and engineers: WHRER?, WHY?, HOW OFTEN?, and WHAT WILL HAPPEN?

SPEAKERS: Walter Hays
Paul Pomeroy
Walter Mitronovas
Gary Nottis
Patrick Barosh

SESSION II: SOCIAL ASPECTS OF EARTHQUAKE HAZARDS IN NEW YORK AND NEARBY STATES

OBJECTIVE: An overview of social aspects of earthquake hazards applicable to New York with emphasis on four key social response issues: 1) hazard awareness, 2) understanding and assessing the earthquake threat, 3) preparedness and hazard mitigation, and 4) response to an earthquake event.

SPEAKERS: Joanne Nigg
David Kelly

SESSION III: POLITICAL ASPECTS OF EARTHQUAKE HAZARDS IN NEW YORK

OBJECTIVE: A panel discussion of the political aspects of earthquake hazards applicable to New York, emphasizing: 1) political constituencies, 2) political advocates, 3) cost of earthquake safety policies, 4) problems of complexity, uncertainty, and frequency of earthquake hazards, and 5) factors influencing seismic safety policies.

PANELISTS: Robert Fakundiny
Henry Lambright
David Kelly
Robert Kutter
Peter Brown

SESSION IV: WHAT FUNDAMENTAL KNOWLEDGE AND INSIGHTS (LESSONS) WILL LOCAL, STATE, FEDERAL OFFICIALS, AND OTHERS LEARN FOLLOWING A HYPOTHETICAL MAJOR EARTHQUAKE ON THE EDGE OF A METROPOLITAN AREA IN NEW YORK?

OBJECTIVE: A presentation raising questions about the possibility of various outcomes in a major earthquake in New York.

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SPEAKER: Paula Gori

SESSION V: ELEMENTS OF A COMPREHENSIVE EARTHQUAKE PLANNING AND PREPAREDNESS PROGRAM FOR NEW YORK

OBJECTIVE: A series of interrelated presentations suggesting specific research, mitigation, and response activities that should be considered as New York continues to improve its earthquake planning and preparedness program.

SPEAKERS: Margaret Hopper
Martin McCann
Ed Fratto
David Axelrod
Stacey Gerard
Gerald Connolly
Norton Remmer
Noel Barstow
Paul Pomeroy

DISCUSSION GROUPS

Following the fourth plenary session, the subject, "WHAT ARE THE IMPORTANT LESSONS THAT MAY BE LEARNED FROM A MAJOR EARTHQUAKE ON THE EDGE OF A METROPOLITA AREA IN NEW YORK" was discussed simultaneously by three discussion groups. The basic guideline for the discussion was:

> **Assume that a major earthquake (epicentral intensity of VIII-IX) happened recently in New York. Because every earthquake provides fundamental knowledge and insight (lessons) which scientists, planners, architects, social scientists, engineers, emergency management managers, and public officials can use to devise measures that will improve research, mitigation, response, and recovery; what did New York learn?**

Using the series of statements given below, the participants of each discussion grup were asked to indicate:

1. Agreement or disagreement with the statement.
2. Two or three factors that could make the postulated lesson "the worst case."
3. Two or three actions that can be taken to minimize "the worst case."

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The postulated lessons were organized in terms of: scientific lessons, building damage, response functions, communication, and intergovermental relations and are given below.

Postulated Scientific Lessons

1. Aftershocks--The earthquake had a long aftershock sequence which caused buildings and structures weakened during the main shock to collapse. They also frightened the populace and disrupted the response and recovery functions.

2. Epicentral Ground Shaking--Although accelerograms of ground shaking in the epicentral area of a major earthquake in New York still did not exist, investigation of the types and characteristics of damage suggest that the level of peak horizonal ground acceleration in the epicentral area was at least 0.25 g.

3. Soil Amplification--Damage data suggest that local soil deposits caused amplification of ground motion in selected frequency bands, causing greater damage to certain classes of structures at some locations (i.e., "hot spots") where the fundamental period of vibration of the structure was the same as the fundamental period of the soil column. Amplification was particularly significant at the edges of sedimentary basins, causing higher levels of acceleration.

4. Surface Fault Rupture--Surface fault rupture did not occur.

5. Ground Failures--Portions of a large area (i.e., about 10,000 square miles) experienced liquefaction and landslides. This area was characterized by ground shaking of MMI greater than or equal to VI.

6. Tsunamis--A tsunami did not occur.

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Postulated Building Damage

1. Seventy-five percent of the buildings not designed in accordance with the seismic design provisions of a modern building code sustained damage. Buildings designed to resist wind also suffered damage, but to a lesser degree.

2. Tall buildings located some distance from the epicentral area experienced damage from ground shaking as a consequence of two factors: a) the low rate of attenuation of low-frequency seismic waves and b) amplification of these waves by thick soil deposits, when present as part of the foundation system.

3. Critical facilities, such as dams and nuclear power plants, which were designed to withstand severe natural and manmade disasters, performed well. However, many facilities needed to operate during the response phase suffered damage and reduced the efficiency of the response. Twenty percent of the hospitals, rescue squads, emergency operation centers, and police and fire departments were disabled for two days or more.

4. Single-family dwellings suffered only minor damage. The most common problems were: shifting on the foundation, overturned water heaters, cracked chimneys, and irrepairable damage to the contents.

5. Fires occurred simultaneously in several areas. The threat of conflagration was more severe than expected, partially due to the severing of waterlines by ground shaking and ground failures.

6. Although highways were not heavily damaged, almost all of the interstate traffic stopped because of damage to the approaches to the bridges.

Postulated Response Function Lessons

1. The resources of State and local emergency response organizations were inadequate, mainly because prior planning had <u>underestimated</u> the impacts.

2. Help from the National Guard supplemented emergency response activities.

3. Individuals responded with unusual speed and initiative during the first 24 hours of the response phase, performing activities which reduced loss of life and injuries.

4. Voluntary agencies, which respond to disasters annually and which have support throughout the Nation, responded efficiently.

Postulated Communication Lessons

1. Rumors and misinformation were the norm. Newspapers and television stations were not operating during the first 48 hours, leaving an information vacuum.

2. Telephone service was very limited for 72 hours.

3. Ham operators performed a valuable service in responding to the need for emergnecy communications.

Postulated Intergovernmental Relations Lessons

1. Relations between local, State, Federal governments, and Canada were ineffective during the first week due to the lack of prior joint exercises, inadequate intergovernmental planning, and disruption of normal communication lines.

CONCLUSIONS AND RECOMMENDATIONS

The timing of the workshop was optimum. By convening just after the formation of the New York Earthquake Advisory Council, the workshop reinforced the commitment of the scientific/technical and public policymaking communities to seek ways to improve research, mitigation, response, and recovery activities to achieve goals of earthquake hazards reduction. In spite of limited resources, the participants concluded that a great deal can be accomplished.

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RESOLUTION

The participants unaminously adopted the following resolution in support of the New York Earthquake Advisory Council:

> **We endorse the formation of the Earthquake Advisory Council and the Technical Advisory Subcommittee (TAS) on Wednesday, December 12, 1984. We urge the council to proceed quickly to accomplish important objectives that include the following:**
>
> 1. **Identification of the range of multidisciplinary (geological, seismological, geotechnical, engineering, and societal) tasks needed to carry out and implement a vulnerability study in New York.**
>
> 2. **Assignment of priorities, specification of technical and societal goals, and identification of appropriate milestones for accomplishing each task.**
>
> 3. **Identification and organization of all resources available to New York, performing the necessary fund raising and creating partnerships to carry out the study.**
>
> 4. **Perform the vulnerability study and implement the results.**

ENHANCED RESEARCH

Several participants, motivated partly by challenging comments from Dr. Robert Fakundiny, State Geologist of New York, recommended an enhanced research program. The state-of-geological-and-seismological-knowledge regarding earthquake hazards in the Northeastern United States and New York, in particular, is incomplete. Better knowledge is required in order to devise and implement effective loss-reduction measures and to prepare for a potentially damaging earthquake. Existing data need to be augmented substantially with new data to resolve technical issues and to close "gaps in

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knowledge" that severely limit current answers to the basic questions: WHERE?, WHY?, HOW OFTEN?, HOW SEVERE?, AND HOW CERTAIN?

Limited detailed knowledge of earthquake hazards was apparent in the discussion groups. Although a major part of the problem was due to inadequate time to discuss the wide range of postulated lessons that may be learned from a major earthquake in New York, the wide range of diverse opinions in each group indicated the need for enhanced research and enhanced hazard awareness programs.

REGIONAL EARTHQUAKE HAZARDS ASSESSMENTS PROGRAM

The USGS encouraged researchers to submit proposals for funding to the external part of its "Regional Earthquake Hazards Assessments" program element, a part of the National Earthquake Hazard Reduction Program.

EASTERN SEISMICITY RESEARCH

USGS recommended continuation of an integrated, multidisciplinary research program on eastern seismicity (see Open-File Report 83-843) that focuses on technical and implementation issues. The U.S. Nuclear Regulatory Commission is also sactively supporting rsearch on eastern seismicity. An example of their support is the report "structural and tectonic studies in New York State."

The technical issues needing resolution include:

1. What is the relationship between the historical earthquake record, pre-exisiting structures, and earthquake potential?

   - What part of the crust is seismogenic?
   - What is its physical character?
   - What are the distinctive physical characteristics of northeastern earthquakes? New York earthquakes?

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2. Is there a relationship between small and large earthquakes in intraplate environments?

- What are their spatial and temporal relationships?
- What are their source parameter relationships?

3. What is the recurrence behavior of intraplate earthquakes?

- Is there evidence of progressive deformation?
- Have any events had a recurrence?

4. What is the association between earthquakes and geologic features?

- At specific locations, is there a systematic relationship between earthquake hypocenters, their focal mechanisms, and geoloigic structures?

5. What is the relationship between the state-of-stress, rate of deformation, and earthquake potential?

- What is the rate of contemporary crustal deformation?
- Does contemporary crustal deformation correlate with the geologic and seismogenic record?

6. What is the distribution of crustal stresses?

- Is the stress field in the New York area similar or different from that of other areas (e.g., Charleston, South Carolina)?
- Does the pattern of crustal stress correlate with crustal structure, geology, and contemporary strain?

7. What is the long-term rate of deformation as indicated in the geologic record?

- How would this affect the maximum magnitude? Recurrence?

8. What is the relationship between strong ground motions recorded in the Western United States and those which may be expected in New York?

   - How do the marked differences in the geology and tectonics of New York and the Western United States affect the amplitude, spectral composition, and duration of ground shaking expected in New York?

The issues associated with implementation are as difficult to resolve as those associated with the technical problems. Successful implementation requires COMMUNICATION OF TRANSLATED SCIENTIFIC INFORMTAION to RESPONSIBLE OFFICIALS AND INTERESTED PARTIES seeking ways to REDUCE LOSSES by use of one or more LOSS-REDUCTION TECHNIQUES. The implementation issues include:

1. What types of earthquake hazards information do policymakers in New York need?

2. If such hazards information were available, what scales should be used for hazards maps? How should the maps be formatted? What should the maps depict? What is the source of the information? What does it cost?

3. What are the current constraints limiting use of earthquake hazards information to devise loss-reduction techniques?

The workshop in New York produced new networks between hazards information producers and users. It also provided specific guidance for conducting a vulnerability study of New York. Every effort should be made to continue the advances that are being made in New York.

ACKNOWLEDGMENTS

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

3. Stanley McIntosh (FEMA) and Randall Davis of New York State Emergency Management Office who provided valuable technical assistance and support.

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EVALUATION OF THE WORKSHOP ON "CONTINUING ACTIONS TO REDUCE POTENTIAL LOSSES FROM FUTURE EARTHQUAKES IN NEW YORK AND NEARBY STATES"

by

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On December 13 and 14, the United States Geological Survey, in an effort to continue the planning process it had begun in five prior workshops, sponsored a workshop for New York and nearby States. The intent of the workshop was "to foster and develop a community of concerned individuals who can take effective short- and long-term actions to reduce losses from earthquakes" in the region.

At the conclusion of the workshop participants were asked to evaluate its success. A questionnaire was provided and participants were to rate: 1) the practical aspect of the information provided; 2) the various session formats; and 3) the level of local earthquake hazard awareness before and after the workshop. Finally, participants were asked to identify possible actions to increase the earthquake hazard awareness and concern of others and to list one or two "positive" and "less than positive" aspects of the workshop.

The workshop was designed to define the nature and extent of the earthquake hazard in New York and nearby states: to inform participants of the options for research, mitigation, response and recovery activities reflecting the hazard; to identify the social and political aspects of the hazard; and finally, to define the elements necessary for a comprehensive earthquake planning and preparedness program.

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. Two questions required a "yes" or "no" response. Not all respondents answered all questions and percentages reflect only those questions completed. Also, percentages discussed in the text are a combined total of a positive response of 3, 4 and 5.

Evaluations returned by 49 participants indicate that the workshop was successful in increasing knowledge about various aspects of the earthquake hazard in the New York area (see Figure 1). Eighty-eight percent of the respondents found the workshop useful for defining the nature and extent of the earthquake hazard. Eighty-three percent felt that the workshop helped to identify options for research, mitigation, response and recovery activities. Similarly, high ratings were assigned regarding the workshop's utility in outlining the social (77%) and political (94%) aspects of earthquake hazards as well as the elements necessary for a comprehensive earthquake planning and preparedness program (83%) in the New York area (see Figure 2).

In other areas, respondents indicated that the workshop was successful in providing new sources of information and expertise for future use (87%) as well as helping to establish a better understanding of the problems faced by researchers and decision makers with respect to earthquake hazard in New York and nearby States (93%).

In evaluating the effectiveness of various session formats, 98% found the formal presentations to be useful with a similarly high rating of 92% for the discussions following them. Rated somewhat lower in effectiveness were small discussion group sessions (65%). Notebook and abstracts (92%) and informal discussions (87%) were also perceived as useful activities for conveying earthquake hazard information. Also, almost all respondents would welcome the opportunity to repeat the workshop experience (96%) and support the planning of similar workshops on the earthquake hazard in the New York area in the future (96%).

Responses related to earthquake hazard awareness before and after the workshop indicate that almost two-thirds of the respondents considered themselves knowledgeable about the earthquake hazard in the New York area. A relatively smaller number, about one-half of the respondents, rated their concern about

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the state-of-earthquake preparedness as high. After the workshop, respondents indicated both increased awareness (98%) and concern (87%).

An important judgement of the success or failure of a workshop can be made by looking to the ways it may affect future behavior. In order to determine whether the workshop might have any long-term effect on the behavior of participants, a final open-ended question was posed. Respondents were asked to identify steps they might take to increase the awareness and concern of others as well as lessen the effects of potential earthquakes in New York and nearby States. They were also asked to indicate "positive" and "less than positive" aspects of the workshop.

Rather surprising was the fact that only about one-fifth of the respondents expressed some plans to increase the earthquake hazard awareness and concern of others. Among these were: promote the Generic Multihazard Response Plan at local planning and/or emergency agencies; investigate building codes; review and improve if necessary, company/agency's emergency plans; organize local community groups to further study the earthquake hazard in the area and promote public awareness through local newspaper reports; and help develop the technical skills necessary for decision makers to assess the earthquake hazard.

Comments regarding "positive" and "less than positive" aspects of the workshop were numerous. Among the latter, and most often noted were; the discussions were often too technically oriented and that audio-visual aids needed improvement. Other "less than positive" impressions were not so widely held among all the respondents but are still worth mentioning in order to improve future workshops. These include: more informal discussions; workshop too structured inhibiting "networking"; agenda disjointed; more emphasis on research being done in the New York area; researchers problems not explicitly addressed; workshop format should not separate local, state and federal officials in the small group discussions and, finally; the participants need more coordination in order to carry out the goals established during the workshop. It should be noted that all of the "less than positive comments addressed the structure of the workshop and not its actual substance.

The "positive" comments which had support among many of the participants included: workshop increased awareness of the earthquake hazard and ongoing research in the New York area; presenters were knowledgeable and represented a wide cross-section of experts; handouts and audio-visuals were informative; workshop provided resources and ideas for future mitigation activities and encouraged participants to attempt to tackle the planning and public education activities necessary to address the earthquake hazard in New York and nearby states.

FIGURE 1

Evaluataions of Workshop by Individual Participants

	LOW 1&2	MED 3	HIGH 4&5
1. Did you find the workshop to be useful for defining:			
a. The nature and extent of earthquake hazards in N.Y.	6	14	29
b. The options for research, mitigation, response and recovery activities in conjunction with New York earthquake hazards in New York	8	23	17*
c. The social aspects of earthquake hazards applicable to New York	11	21	17
d. The political aspects of earthquake hazards applicable to New York	3	14	30
e. The elements necessary for a comprehensive earthquake planning and preparedness program	8	15	23
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	11	30
b. Establishing better understanding of the problems faced by researchers and decisionmakers?	3	13	30
3. Did you find the following activities useful:			
a. Formal presentations?	1	13	35
b. Discussions following the formal presentations?	4	17	27
c. Small discussion group sessions?	16	17	13
d. Notebook and abstracts?	4	16	27
e. Informal discussions during breaks and after hours?	6	16	25

	NO	YES
4. If the clock were turned back and the decision to attend the workshop were given to you again, would you want to attend?	2	46
5. Should future workshops be planned to continue the work initiated at this meeting?	2	43

	LOW	MED	HIGH
6. Prior to attending this workshop, I would rate my awareness of the earthquake threat in N.Y. as	17	12	20
7. Prior to attending this workshop, I would rate my concern about the state-of-earthquake preparedness in N.Y. as	26	15	9
8. I now rate my awareness as	1	6	41
9. I now rate my concern as	6	15	27

*Evaluations were completed by fourty-nine participants. Totals vary as not all respondents completed all questions.

FIGURE 2

Evaluataions of Workshop by Percentages of Participants

	LOW 1&2	MED 3	HIGH 4&5 *
1. Did you find the workshop to be useful for defining:			
a. The nature and extent of earthquake hazards in N.Y.	12	29	59
b. The options for research, mitigation, response and recovery activities in conjunction with New York earthquake hazards in New York	17	48	35
c. The social aspects of earthquake hazards applicable to New York	23	45	32
d. The political aspects of earthquake hazards applicable to New York	6	30	64
e. The elements necessary for a comprehensive earthquake planning and preparedness program	17	33	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?	13	23	64
b. Establishing better understanding of the problems faced by researchers and decisionmakers?	7	28	65
3. Did you find the following activities useful:			
a. Formal presentations?	2	27	71
b. Discussions following the formal presentations?	8	36	56
c. Small discussion group sessions?	35	37	28
d. Notebook and abstracts?	8	34	58
e. Informal discussions during breaks and after hours?	13	34	53

	NO	YES
4. If the clock were turned back and the decision to attend the workshop were given to you again, would you want to attend?	4	96
5. Should future workshops be planned to continue the work initiated at this meeting?	4	96

	LOW	MED	HIGH
6. Prior to attending this workshop, I would rate my awareness of the earthquake threat in N.Y. as	35	24	41
7. Prior to attending this workshop, I would rate my concern about the state-of-earthquake preparedness in N.Y. as	51	31	18
8. I now rate my awareness as	2	12	86
9. I now rate my concern as	13	31	56

GUIDELINES FOR ASSESSING THE NATURE AND EXTENT OF EARTHQUAKE HAZARDS IN THE NEW YORK AREA AND DEVISING OPTIONS FOR RESEARCH AND MITIGATION

by
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EARTHQUAKES AND OTHER NATURAL HAZARDS

Earthquakes are one of the twelve natural hazards affecting all 50 States to some degree. The other natural hazards are: earthquakes, avalanches, coastal erosion, drought, floods, hurricanes, landslides, storm surges, tornados, unstable soil, windstorms, and winter storms. When comparing earthquakes with other natural hazards, it is useful to consider the following characteristics: 1) frequency (how often an event of a given size occurs), 2) duration (the length of time the event lasts), 3) area affected (limited area such as the path of a tornado or a broad area such as with most droughts), 4) impact time (the time between the first precursors of the event and its peak impact), and 5) pattern of occurrence (random time occurrence and difficult to predict, as with earthquakes, or seasonal as with hurricanes, or some other pattern).

Comparison of earthquakes with other natural hazards is beyond the scope of this paper. However, the characteristics of earthquakes will be described below to provide insight for individuals who are concerned with the overall problem of reducing losses from earthquake hazards. A major earthquake has the potential for causing great sudden loss both directly through ground shaking, surface fault rupture, earthquake-induced ground failure, tectonic deformation, and in some cases tusnamis as well as through the triggering of secondary hazards such as fire and flooding. Major earthquakes occur relatively infrequently (about once every 150 years in the Western United States and about once every 700-1000 years in the Eastern United States), have a short duration (a few minutes), cause severe structural damage in an area of several thousand square miles (Modified Mercalli intensity IX-XII), cause structural damage over an area of several tens of thousands of square miles

(Modified Mercalli intensity VIII-IX), and cause architectural damage (such as damaged chimmneys, falling plaster and light fixtures in ceilings, overturned water heaters and bookcases, and other kinds of damage to contents over an area of several hundred thousand square miles (Modified Mercalli intensity VI-VII). Within this large area of impact considerable loss of life, injuries, and social impacts can happen. Although prediction of earthquakes is considered to be viable scientifically, the capability to provide reliable short-term warnings of imminent earthquakes has not yet been achieved; therefore, the impact time of earthquakes is presently on the order of a few minutes and no warning is possible. The pattern of occurrence of earthquakes is more or less random; however, earthquakes tend to recur where they have occurred in the past and long-term forecasts are feasible.

Earthquakes are probably the greatest natural hazard the Nation must face in terms of potential loss of life, property damage, and impact. No region of the country or State is adequately prepared to respond to a major earthquake. Although floods are the most frequent natural hazard and cause annual losses of $3-5 billion, a major earthquake in California, the Central United States, or the Northeastern United States and Canada would cause losses of $50 billion or more as well as thousands of deaths and injuries depending upon the time of day and the season of the year when the earthquake occurred. More than 70 million people in 39 States reside in locations rated as having moderate to high risk from earthquakes (Algermissen and others, 1982).

CHARACTERISTICS OF EARTHQUAKE HAZARDS IN THE EASTERN UNITED STATES

When comparing earthquake hazards in the Eastern and Western United States, scientists/engineers and decisionmakers must be aware of important differences in the hazards of ground shaking, surface faulting, earthquake-induced ground failure, tectonic deformation, and tsunamis. These differences are summarized below.

1) In terms of peak ground acceleration, earthquake ground shaking in the East for a given exposure time such as 50 years (the useful life of an ordinary building) ranges from less than 10% to about 50% of the level expected in California. Although, the level of peak

acceleration in the East can be high, ground motion tends to attenuate slowly away from the epicenter and to be characterized by long duration and low frequencies. These characteristics of the ground shaking create a potential for causing damage to tall buildings (10 stories or greater) located as much as 500 miles away from the epicentral area where no other significant damage from ground shaking is likely to occur.

2) Except for the 1811-1812 New Madrid earthquakes, no historic earthquakes have caused surface faulting in the East. Almost all historic surface faulting has taken place on faults that exhibit geologically young displacements (i.e., displacements within the Holocene--last 10,000 years, or the Quaternary--last 2 million years).

3) The recurrence interval for major earthquakes in California is about once every 150 years; whereas, the corresponding recurrence interval in the New Madrid Seismic Zone and the St. Lawrence River valley is on the order of about once every 700-1000 years.

4) The rate of attenuation of seismic energy in the East is much slower than in the West, causing a much larger area to experience architectural and structural damage in an earthquake.

5) Because of the larger area of strong ground shaking in the East, ground failures which can occur at Modified Mercalli intensities ranging from VI-X are likely to be triggered over a wider area in the East than in the West.

6) Unlike in California, soil and rock columns in the East appear to have physical characteristics that can cause amplification of ground motion in selected frequency bands. Some sites in the East would enchance high frequency ground shaking and other sites would enhance low frequency ground shaking. Low-rise buildings are more susceptible to high frequency ground shaking than tall buildings; whereas, tall buildings are more susceptible to low frequency ground

shaking than low rise buildings. Amplification by soil deposits can increase the Modified Mercalli intensity rating relative to rock by two intensity units (i.e., from V to VII) which can lead to damage in the upper stories of tall buildings.

7) Tectonic deformation, the characteristic feature of earthquakes having magnitudes of 8 or greater, has occurred in both the East and the West. Deformation over a large area occurred in connection with the 1811-1812 New Madrid earthquakes and the 1964 Alaska earthquake.

8) The historical record shows no evidence of tsunamis along the East coast; whereas, tsunamis have occurred historically in Alaska and along the West coast.

9) A Long aftershock sequence, possibly lasting for several years, is typical of major earthquakes in the East. In the West, aftershocks tend to die out after only a few months.

HISTORICAL SEISMICITY IN THE NORTHEASTERN UNITED STATES AND CANADA

A number of major historical earthquakes affecting New York directly or indirectly, have occurred in New England and the St. Lawrence River valley and the Charlevoix Zone in Canada. These earthquakes include:

1) Two earthquakes of MMI IX-X in the St. Lawrence River valley in 1534-1535 and MMI IX on June 11, 1638.

2) Four earthquakes of MMI X, VIII-IX, IX, and IX in the Charlevoix Zone on February 5, 1663, October 17, 1860, October 20, 1870, and March 1, 1925 respectively.

4) An earthquake of MMI VIII near Newbury, Massachusetts, on November 10, 1727.

5) An earthquake of MMI VIII near Cape Ann, Massachusetts, on November 18, 1755.

6) An earthquake of MMI X in the Grand Banks of Newfoundland on November 18, 1929.

Excluding the Canadian earthquakes, the distribution of earthquakes in terms of MMI in the Northeast is as follows: (Algermissen, 1983)

- -- 120 earthquakes of MMI V
- -- 37 earthquakes of MMI VI
- -- 10 earthquakes of MMI VII
- -- 3 earthquakes of MMI VIII

Since 1737 New York has experienced 12 earthquakes of MMI VI, 4 earthquake of MMI VII, and 3 earthquakes of MMI VIII (Stover and others, 1981). The MMI VIII earthquakes occurred on August 12, 1929, September 5, 1944, and October 7, 1983. Figures 1 shows the location of epicenters in New York and other parts of the Eastern United States.

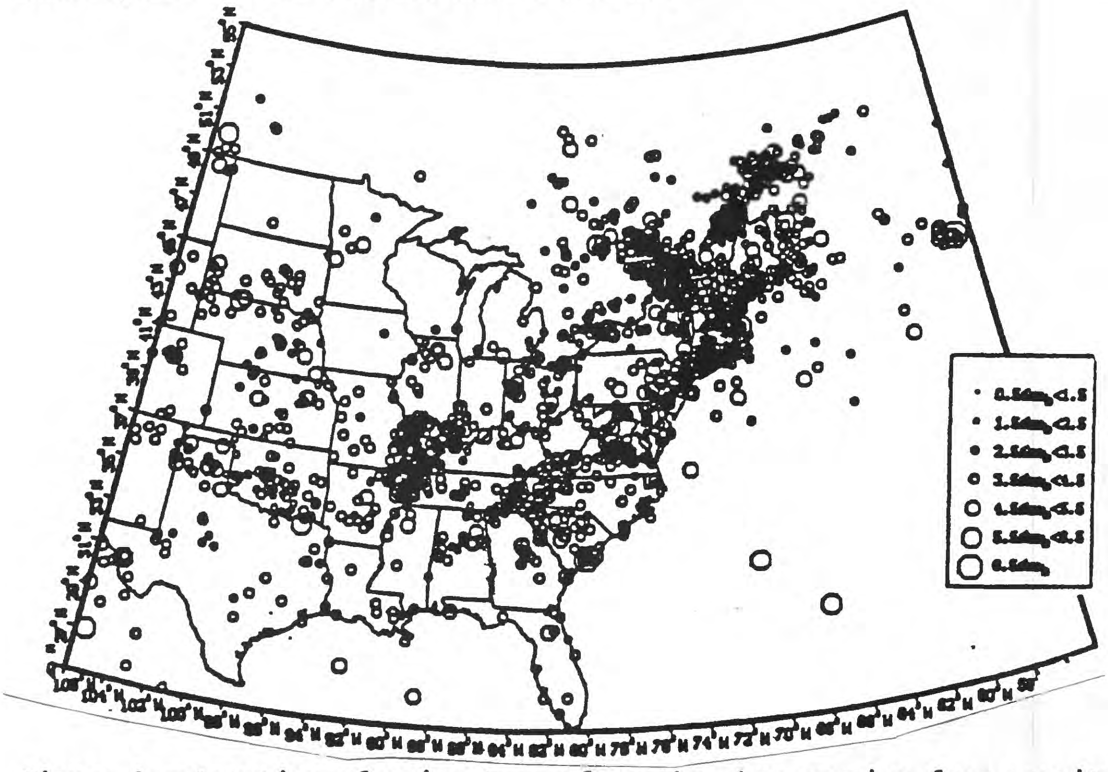

Figure 1.--Location of epicenters of earthquakes ranging from magnitude 0.5 to 6.5 for the time interval 1550-1983. The catalog contains 2,187 events (from Veneziano and Van Dyck, 1984).

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Figures 2 and 3 show the isoseismal maps for the Cornwall Massena earthquake of September 5, 1944, and the Blue Mountain Lake earthquake of October 7, 1983.

The following sections contain information which can be used to assess earthquake hazards and define research and mitigation strategies.

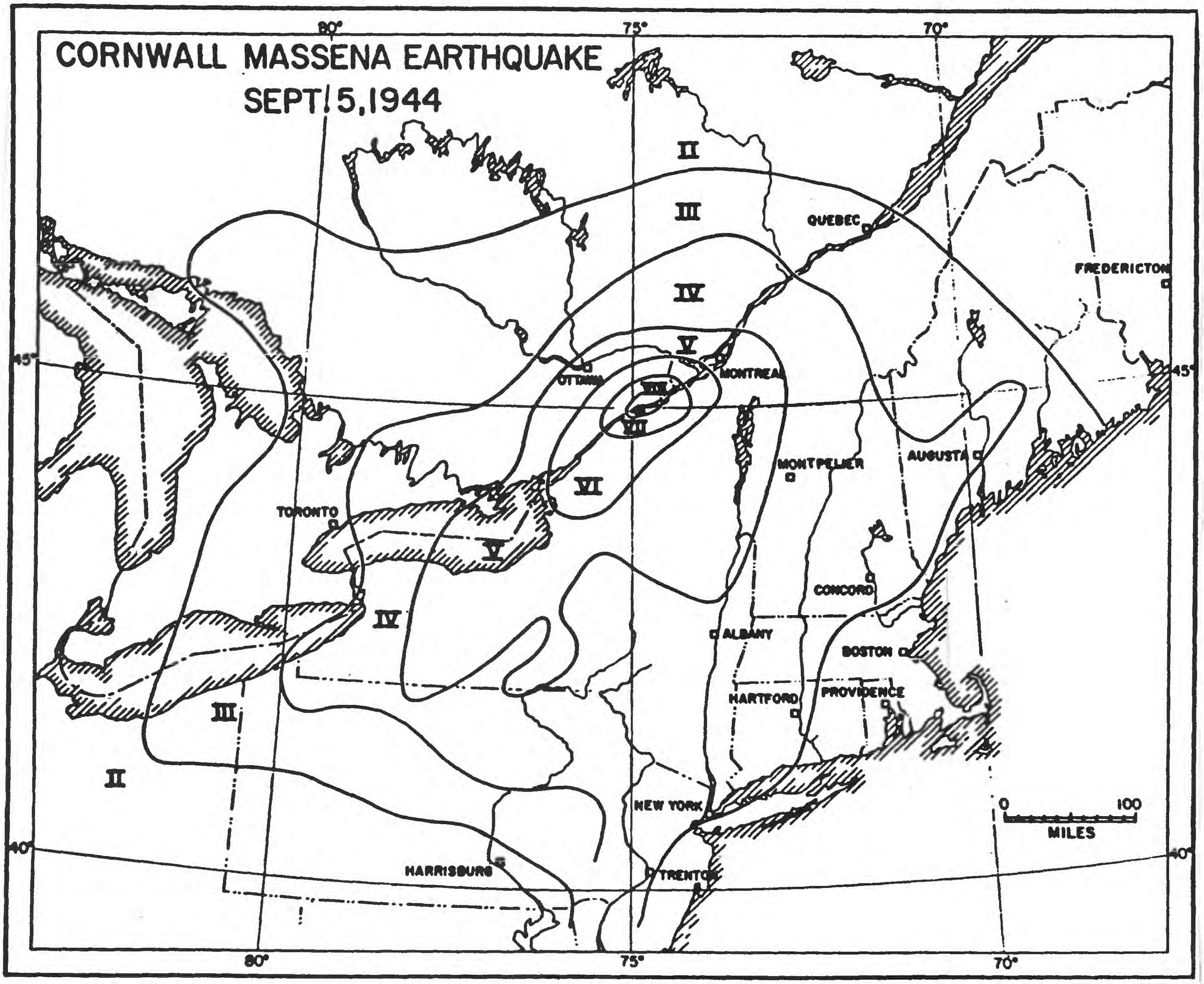

Figure 2.--Isoseismal map for the Cornwall Massena earthquake of September 5, 1944.

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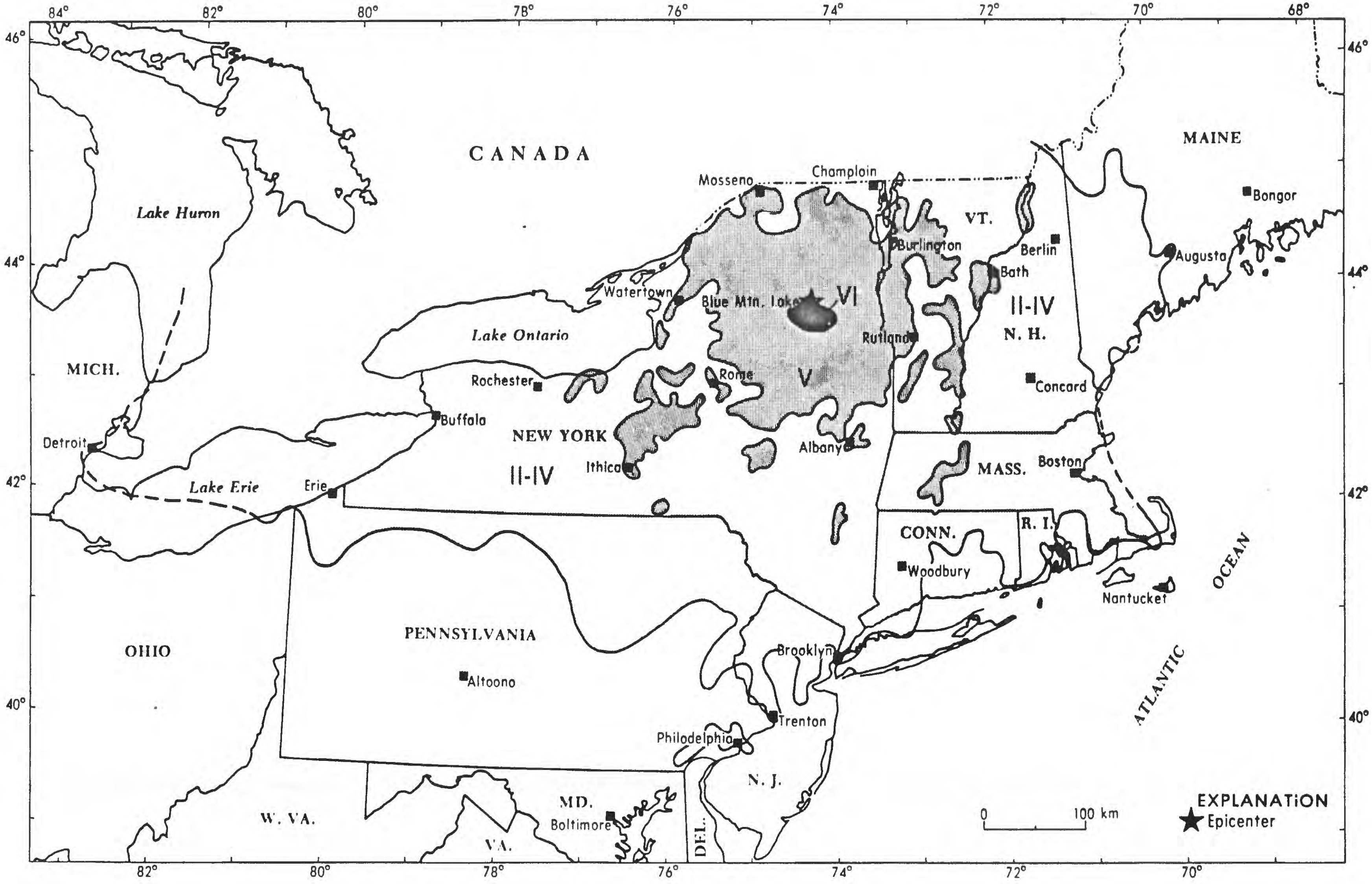

Figure 3.--Isoseismal map for the Blue Mountain Lake earthquake of October 7, 1983.

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DECISIONMAKING TO ENHANCE RESEARCH AND MITIGATION ACTIVITIES

In order to increase the efficiency of research and mitigation activities in connection with earthquake hazards in the New York area, all available fundamental knowledge must be used. The potential losses in New York are increasing annually as a function of factors such as: 1) increased population density, 2) increased building wealth as a result of construction of homes, schools, hospitals, high-rise buildings, factories, utility systems, bridges and highways, and other facilities, 3) increased vulnerability of old existing buildings and lifeline systems that were not designed in accordance with present standards for earthquake resistance, and 4) increased inventory of new buildings and lifeline systems that are not earthquake resistant.

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

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

2) Avoidance--select the least hazardous areas for construction sites.

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

4) Engineering design and buiding codes--require buildings to have a lateral-force-resisting system that is appropriate in terms of the frequency of occurrence and the severity of the ground shaking hazard expected in a given exposure time.

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

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

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

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

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

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

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

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

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

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

Because of these differences, great care must be taken to pose and answer the proper questions when assessing earthquake hazards and devising options for research and mitigation.

QUESTIONS TO BE ADDRESSED WHEN ASSESSING EARTHQUAKE HAZARDS

Figure 4 shows the earthquake hazards model and its relationship to the exposure and vulnerability models. These three models are used when scientists/engineers and decisionmakers assess earthquake hazards and devise options for research, mitigation, response and recovery activities.

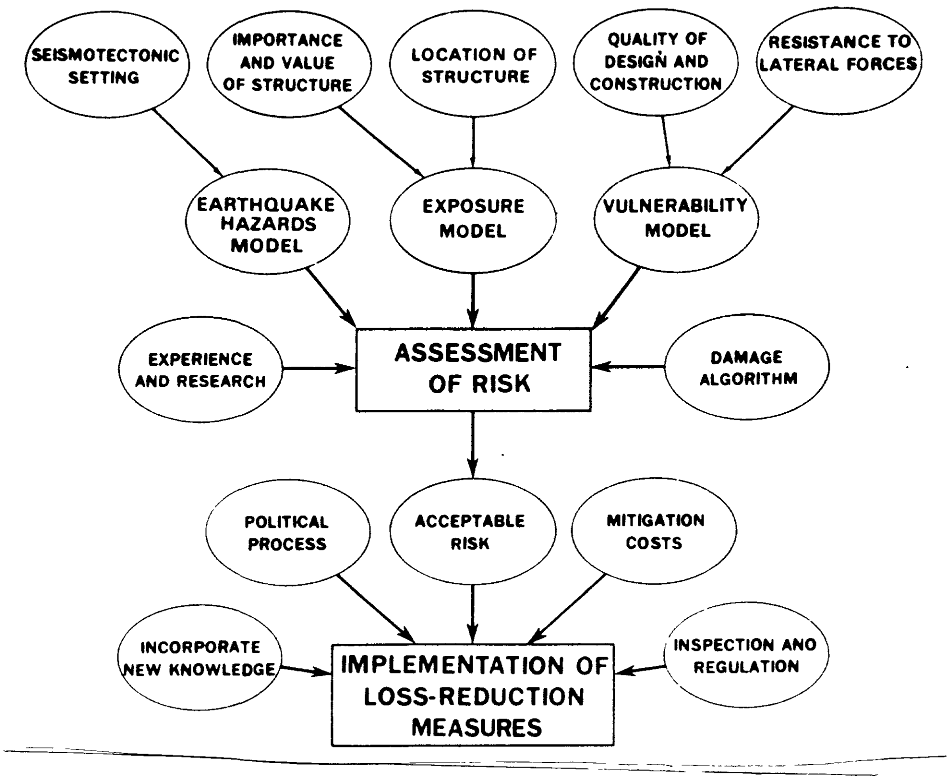

Figure 4.--Schematic illustration of the relationship between the earthquake hazards model, the exposure model, and the vulnerability model and the various factors that must be considered in assessing earthquake hazards and devising loss reduction measures.

To devise an appropriate earthquake hazards model for the New York area requires consideration of the historical seismicity and the tectonic setting. The following technical questions must be addressed:

1) WHERE have the earthquakes hazards of strong ground shaking, surface fault rupture, earthquake-induced ground failures, and tectonic deformation occurred in the past and where are they occurring now?

2) WHY are these hazards occurring?

3) HOW OFTEN do they occur?

4) WHAT are the physical effects and the potential vulnerability of existing buildings, lifelines, communication systems, and industrial and power facilities?

The answer to the question "Why . . ." is complex and is the subject of current research. Some of the causative mechanisms proposed for earthquakes in the East are:

1) Reactivation of preexisting fault structures that are favorably aligned with the present stress field.

2) Reactivation of Triassic or paleo-rift structures, border faults, and other tectonic features.

3) Mafic intrusions which serve as zones of stress concentration.

4) Movement along a decollement surface.

5) Topographic highs and/or lows.

The exposure model requires consideration of the location and variation with time of the structures, lifeline systems, and facilities exposed to the earthquake threat and their importance and value. Inventories are very important in the development of the exposure model. The question which must be addressed is:

5) HOW do the hazards of ground shaking, surface faulting, earthquake-induced ground failure, and tectonic deformation vary spatially and temporally? How do they correlate with the exposure model?

The vulnerability model requires consideration of the quality of design and construction and assessment of the adequacy of the lateral-force-resisting-system of existing buildings, lifeline systems, and facilities. The following question must be answered:

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6) WHAT physical effects are expected at a given location in a given exposure time?

Estimating the physical effects of strong ground shaking at a given location in a given exposure time is a complex research topic. The methodology for estimating the earthquake ground shaking hazard was developed by Algermissen and others (1982). The peak ground acceleration at sites underlain by rock in the New York City area is compared with other parts of the United States in Figure 5. The curves show the level of peak horizontal acceleration expected in exposure times of 10, 50, and 250 years with a 90% probability of not being exceeded.

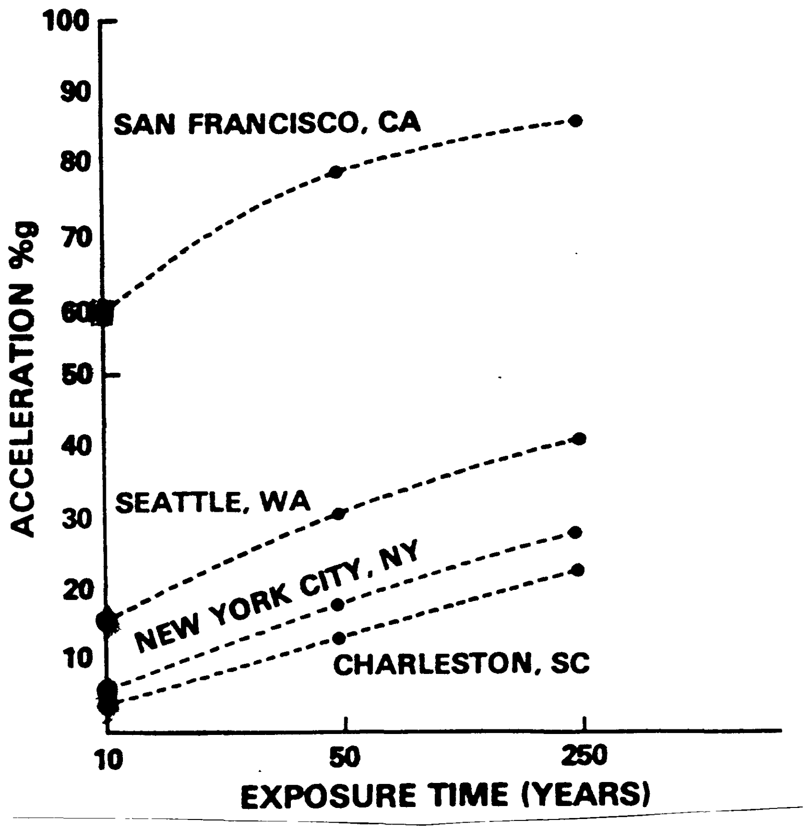

Figure 5.--Comparison of the ground shaking hazard in New York City with other parts of the United States. An exposure time of 50 years is representative of ordinary buildings.

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The earthquake hazards model, the exposure model, and the vulnerability model are combined to produce an assessment of the risk. Estimates of the social and economic impacts, loss of function, loss of confidence, life loss, and injuries are needed in order to devise appropriate loss reduction measures and to identify all of the options for research, mitigation, response, and recovery.

New York, like every other State, must consider the complete range of loss reduction measures and select the ones that are appropriate in terms of the risk that is acceptable to the public, the costs, and the political process. The options include: increasing hazards awareness, increasing personal perparedness, increasing community preparedness, requiring seismic design provisions of a building code (such as the Applied Technology Council's Model Building Code [Applied Technology Council, 1978]), strengthening existing buildings and lifeline systems, and accelerating emergency management planning to accomplish effective response and recovery following a damaging earthquake. Research is needed when the science base is inadequate or significant gaps in knowledge exist in earthquake hazards, exposure, and vulnerability models.

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INTRAPLATE NEOTECTONICS AND EARTHQUAKE HAZARD FROM SEISMIC NETWORK, MACROSEISMIC AND GEOLOGIC DATA IN NEW YORK, NEW JERSEY AND SURROUNDING AREAS

Extended Abstract

by

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It has recently become apparent that reliable estimates of earthquake hazard in eastern North America can only be based on an improved understanding of the mechanism responsible for neotectonic activity in this intraplate environment. In a series of related projects the Lamont-Doherty Geological Observatory (L-DGO) is carrying out research to improve our understanding of neotectonics and of earthquake generating processes in this region. Particular emphasis is given to the New York-New Jersey region where data on recent earthquakes is collected from a seismic network established in the early seventies, data on preinstrumental earthquakes is obtained from systematic searches of archival sources and data on prehistoric earthquakes and recent tectonic deformation is obtained from geologic investigations. The pattern of deformation and seismicity over the long term, much longer than the historic period, will provide the reliable basis for understanding the intraplate neotectonic process and constraining earthquake hazard.

The local seismic network operated by L-DGO covers a wide region with diverse geologic terranes across the Appalachians, from the platform/shield of western and northern New York, through the fold belt and to the crystalline overthrust terrane of southern New York-New Jersey. It also samples prominent Mesozoic rift structures, and the Cretaceous-Cenozoic passive margin. Seismic zones have been recognized in each of these structural provinces. The N.Y.-N.J. seismic network offers the unique opportunity to compare in one data set seismicity from most of the structural environments of the Eastern United States. This opportunity is exploited in a number of detailed studies. They include deciphering active fault kinematics, earthquake source characteristics such as stress-drop and rupture size, space-time seismicity patterns from instrumental and pre-instrumental data, large prehistoric earthquakes from paleoseismic data, and the relationship between preexisting structures and current deformation from detailed studies of seismicity and geology. This approach is inspired by the hypothesis that fundamental characteristics of intraplate neotectonics and seismicity are controlled to a large extent by preexisting structural features.

The strategy adopted in this project is to focus the effort in selected areas for intense studies combining earthquake and structural analysis. The data from the telemetered network is augmented with data from portable seismographs deployed temporarily to obtain high spatial resolution of the seismicity. Archival sources such as newspapers are searched for felt reports on preinstrumental events. The relativley short data base from the reliable instrumental period can be substantially lengthened by systematic studies of felt reports from newspapers particularly along the Atlantic seaboard. Systematic archival searches are carried out to better constrain events of special interest, such as the 1884 New York city earthquake, and to provide uniform long term coverage of the seismicity in areas of particular interest such as Lancaster County, Pennsylvania. Evidence for large prehistoric earthquakes is sought in the geologic record. Large historic events in the East have caused significant secondary deformation, such as landslides and clastic injection features, which have been described from contemporary observations and can be detected geologically. Deformation features of this sort that can be assigned to the same time horizon over a large area could then be expected to indicate the mesoseismal area of a prehistoric earthquake.

SEISMICITY OF NEW YORK: CURRENT STATUS OF SCIENTIFIC KNOWLEDGE AND RESEARCH IN HISTORICAL SEISMICITY

by

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INTRODUCTION

Our knowledge about the true nature of the earthquake activity in the Eastern United States, in general, and in New York State, specifically, can be characterized at present as very limited. Historical record is quite clear that, although rare, damaging earthquakes can occur in the Eastern United States and adjacent Canada. But such important questions as when, where and how large will the next damaging earthquake be cannot be answered at this time. We are not yet at the stage where we understand and agree on the nature, even in general terms, of the forces or the tectonic structures responsible for these earthquakes.

It appears clear from our research effort so far that the true nature of earthquake activity within the Eastern United States is very complex. What is still required in the future is a considerable research effort to study the historical and current seismic activity, to identify and map surface and subsurface geologic structures, to identify the causative forces, and to relate them to the relevant structures. Unfortunately, the present day effort in all these areas is small compared to the immensity of the problem.

Efforts to mitigate potential life and property losses from future large earthquakes in the Northeast will require better evaluation of the ground-shaking hazard. To do this we must have data base that will allow us to address the following three questions: (1) How does ground motion vary as a function of earthquake size, depth, epicentral distance, and local site conditions?; (2) Does the present geographic pattern of seismicity (earthquake activity) agree with the pattern of past (historical) seismicity and to what extent?; and (3) Do the past and present patterns correlate to geological or geophysical structures within the crust? At the present time emphasis is being placed on trying to answer these questions using current seismograph networks and felt-effect surveys for contemporary earthquakes. This approach along, although important, may take too long to produce the required results. More emphasis, we feel, should also be placed on studying the existing historical record. This record, for New York State, extends some 250 to 300 years back into time.

In this paper we present a few examples of our recent research effort in historical and current seismic activity relevant to New York State to illustrate the nature of this work and to point out the significance and limitations of such results.

DATA SOURCES AND QUALITY OF DOCUMENTATION OF HISTORICAL EARTHQUAKES

Prior to 1929 our information of the felt effects of earthquakes in the Northeast comes from the following data sources: (1) published and unpublished earthquake catalogs and listings; (2) diaries and journals; (3) scientific journal articles and unpublished manuscripts; (4) local histories; and (5) contemporary newspaper accounts. For earthquakes that occurred before 1830 the distribution of most of these data sources is population dependent. After about 1850, the distribution of at least the newspapers was fairly uniform throughout the State. Earthquake questionnaire cards, distributed and collected by the U.S. Coast and Geodetic Survey and later by the U.S. Geological Survey, became important only after 1929.

The older earthquake catalogs are, generally, reliable only in that they indicate an approximate date, location and relative size of an event. These catalogs are a mixture of true (tectonic) earthquakes and other non-tectonic events like quarry blasts, mine collapses, meteorite terminations and some weather related phenomena. Such related events are often confused with tectonic earthquake activity. The recent catalog and map of historical and recent tectonic seismicity for northeastern North America published by the New York State Geological Survey (Nottis, 1983), shows that of 81 events listed in the older catalogs for the years 1534-1960 and that have been documented in detail, 40 turned out to be such non-tectonic events. It is not known if this is representative of the rest of the 800 pre-1960 events in this catalog, not yet studied in detail. Information for many of these events is usually based on a single diary entry, letter from an observer, brief journal or newspaper article, or word of mouth. Rarely is more than a single reference used to document an event in the existing catalogs. This, of course, leads to inadequate entries and inaccuracies.

If inadequate catalogs are our primary sources for the pre-1929 events, the earthquake questionnaire cards are our primary data sources for the post-1929 events. However, a single questionnaire card was sent to a community that may have been affected by an earthquake. This single card, usually filled out by the local postmaster, was expected to provide a comprehensive summary of the felt-effects for the whole community. We have found in our documentation of various events that the felt effects as described in newspaper accounts suggest felt intensities on the Modified Mercalli scale (MM) up to 2 units different than those suggested by a questionnaire card. Sowers and Fogle (1979) found similar differences in South Carolina.

Since about 1977 a greater awareness of the need to improve the historical data has existed in the Northeast. Unfortunately, this awareness has not led to substantial effort in this direction so far. For example, only 81 events of the 875 listed in the latest earthquake catalog (Nottis, 1983) have received some serious documentation. About 60 of the 81 events were documented using approximately a third of the available information, while only 20 events were documented using more than 85% of the information accessible in libraries and other places. Table 1 provides a summary of the documentation status of pre-1960 earthquakes for the Northeastern United States obtained from Nottis (1983).

Table 1

DOCUMENTATION STATUS
(EVENTS OF 1534-1960)

Region	No of Events	No. of Events Documented in Detail	No. of Tectonic Events	No. of Non-Tectonic Events
Southeastern New York and Northern New Jersey	65	27	11	16
New York	184	33	11	22
New England, New York, New Jersey and Pennsylvania	875	81	41	40

Table 2

Significant Earthquakes in New York State
1737 - Present

	Location		I_o	M
Date	Latitude (North)	Longitude (West)	Modified Mercalli Intensity	Magnitude
Dec. 19, 1737	40.60	73.80	VI	4.8
Jan. 16, 1840	43.00	75.00	VI	
Mar. 12, 1853	43.70	75.50	VI	
Oct. 23, 1857	43.20	78.60	VI	
Dec. 18, 1867	44.05	75.15	VI	4.8
Dec. 11, 1874	41.00	73.90	VI	
Aug. 10, 1884	40.59	73.84	VI	5.0
May 28, 1897	44.50	73.50	VI	
Feb. 3, 1916	42.80	73.90	VI	
Mar. 18, 1928	44.50	74.30	VI	4.1
Aug. 12, 1929	42.90	78.40	VII	5.2
Apr. 20, 1931	43.50	73.80	VII	4.5
Apr. 15, 1934	44.70	73.80	VI	4.5
Sep. 5, 1944	45.00	74.70	VIII	5.6
Sep. 5, 1944	45.00	74.70	(a)	4.5
Jan. 1, 1966	42.84	78.25	VI	4.6
Jun. 13, 1967	42.84	78.23	VI	4.4
Oct. 7, 1983	43.97	74.25	VI	5.2

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TEMPORAL AND SPATIAL VARIATIONS IN SEISMICITY

Figure 1 shows the distribution in time of all New York State known earthquakes equal to or larger than maximum intensity (I_o) IV in terms of 20 year increments. Although some events are undoubtedly missing before 1960, and even more before 1900, as suggested in the previous section, the data suggest a secular (slow) variation in seismic activity during the past 250 years. Periods of greater activity between 1720 and 1790, 1830 and 1880, and 1910 through present, are separated by periods of lower activity. It is hard to account for such patterns by attributing it to a selective and changing incompleteness in the historical catalog.

The secular or cyclic nature of seismic activity within the State can be represented in a more reliable and convincing way by showing the total seismic energy released as a function of time, rather than by the total number of events (Fig. 1). This is more reliable because the larger earthquakes account for most of the released energy and the list of the larger historical events is more reliable and complete over a longer time span. Direct examination of the geographical distribution of all New York State earthquakes indicates that the total energy curve and the number of events since 1720 is not a random occurrence of a few large events with their associated aftershocks, but rather a slow systematic increase and decrease of seismic activity lasting up to 100 years. In general, seismic activity, both in the form of total released energy and number of reported events, shows considerable syncroneity in every part of the State. Superimposed on the statewide syncroneity are some smaller regional variations in activity, in which a marked increase in seismicity in one region is out of step with increase in activity elsewhere. The overall impression, however, is that secular variations in seismic activity in different parts of the State are not random but reflect some internal or external force (or forces) that may act as a trigger for the seismicity.

The historical data suggest that, in general, the same areas have been active since 1720 as at present. This need not imply that the inactive areas will always stay inactive because the spatial variations may be too slow for the relatively short historical record to indicate. The reality in the secular and spatial variations in seismic activity is well established for such areas

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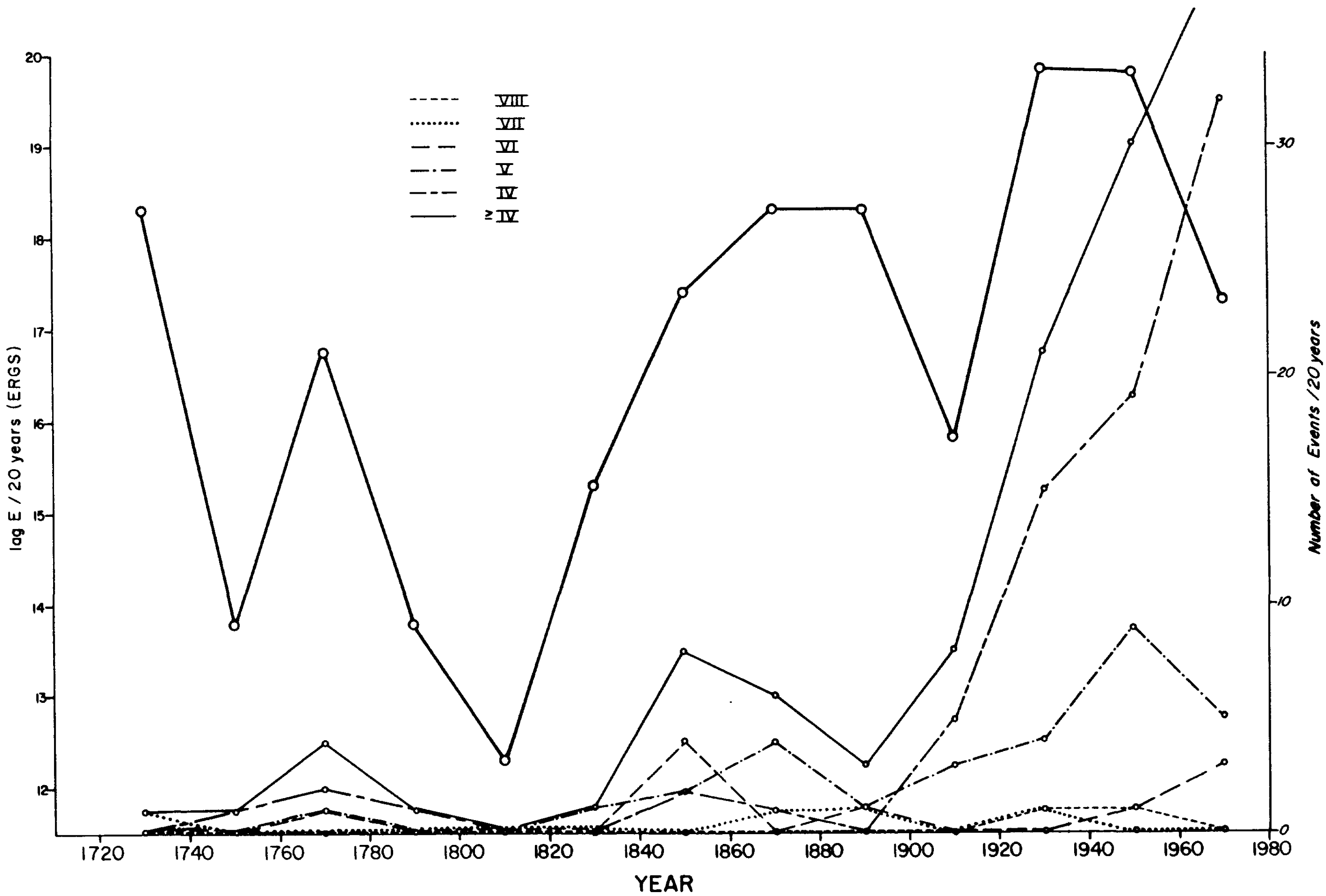

Figure 1. Number of earthquakes and total energy released in New York State as a function of time. Heavy top line - log energy released (ergs) per 20 year intervals. Light solid line - total number of earthquakes of $I_0 \geq$ IV per 20 years. Number of events of different size (IV through VIII - as indicated in figure) per 20 years.

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as China (Allen, 1975; McGuire and Barnhard, 1981) where a relatively long historical record is available. The observed secular, and possible spatial, variations within New York State, therefore should not be too surprising. The cause or causes of such variations are unknown. Additional discussion of this problem is presented in Mitronovas (1981).

EARTHQUAKE HAZARD

To estimate earthquake hazard for the State is to estimate where and how often damaging earthquakes can occur, as well as to determine the maximum possible earthquake. The largest earthquake known to have occurred within New York State during the past 250 years, for which our knowledge of the large events is probably reliable, is I_o=VIII (Table 2). Does this period include the maximum possible earthquake for the State? Based on the most reliable historical and instrumental data for the past 80 years (Mitronovas, 1982), the chance that an event $I_o \geq$ IX should have occurred during the past 250 years somewhere within the State is 68% (Table 3). This evidence is consistent with a possibility that larger events ($I_o \geq$ IX) do occur but are so rare that the available historical record has been too short to include one so far. It is also clear from the historical seismic activity in the rest of eastern North America that larger earthquakes, although rare, do occur. The lack of such large events within New York State cannot at present be attributed with any degree of confidence to any known differences in geology and tectonics between New York and other areas. From the information in Figure 1 it is apparent that secular variations in seismic activity for the State are quite slow, involving hundreds of years. Based on direct observations alone it will probably take considerably longer than 250 years before it becomes clear that the minimum and maximum levels in seismicity really are, what the maximum possible earthquake is, and to what regions such events are confined.

Given this situation, it would be especially useful to have additional evidence bearing on all these questions. Such data could be in a form of the nature of geologic and tectonic structures and the presence or absence of tectonic stress acting on such structures. It is hoped that such information, when available, could be useful in placing limits on the size and location of future earthquakes. There is some evidence that considerable stresses exist

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Table 3

Average Recurrence Times (ART) of Earthquakes
In New York State as a Function of Size

Size		ART (years)	
M	I_o	Calculated	Observed[1]
2.3	IV	0.49	0.59
3.2	V	1.66	2.0
4.0	VI	5.64	8.9
4.8	VII	19.2	42.
5.7	VIII	65.2	125.
6.5	IX	219.8	(0.68)[2]
7.3	X	769.0	(0.28)
8.1	XI	2564.0	(0.09)

1. Observed between 1900-1980 for $I_o \geq$ VI and between 1730-1980 for $I_o >$ VI.

2. Numbers in parentheses: Probability that at least one event ($\geq I_o$) should have occurred during the past 250 years assuming Poisson distribution (only for those I_o not yet observed).

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in the crust near the surface (Sbar and Sykes, 1977; Yang and Aggarwal, 1981). However, it is not at all clear at present whether such stresses as measured at the earth's surface can and will result in very large earthquakes. Also, the currently available geologic and tectonic information and understanding are insufficient to clarify the general relationship between seismicity and the surface tectonic structures, let alone place limits on the maximum possible earthquakes and their locations. There has never been a case of clear surface faulting detected with any of the New York earthquakes, and only in a few cases has it been possible to suggest but not prove a correlation with known faults. Only further research along many aspects of this subject can lead to more realistic estimates of future earthquake hazard in New York State, specifically, and in Eastern United States in general.

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EARTHQUAKE CONTROLS AND ZONATION IN NEW YORK

by

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INTRODUCTION

The recognition that earthquakes pose a hazard, especially to nuclear power plants, in the northeast United States has spurred intensive investigations during the past ten years into their causes and potential effects. This research now indicates a pattern of controlling features that is consistent throughout the region and provides considerable information as to where, why, how large and when earthquakes will occur. This report briefly summarizes this information and provides a map showing earthquake zonation that can be used for hazard preparedness in New York.

Most of the research has been by the New England Seismotectonic Study (sponsored by the U.S. Nuclear Regulatory Commission), the U.S. Geological Survey and Utility Companies. The investigations of the New England Seismotectonic Study in New York, have been mainly conducted by the New York State Geological Survey, whose personnel Yngvar Isachsen, Robert Fakundiny, Gary Nottis and Walter Mitronovas have contributed greatly. Other significant contributors are J.E. Tillman, formerly of Johns Hopkins University, A.S. Hunt, University of Vermont, J.J. Dowling, University of Connecticut, A. M. Thompson, University of Delaware, G. W. Putman, SUNY Albany and others. Reverences will not be cited in the text for easier reading, but can be found in the annual reports of the Seismotectonic Study published by the U.S. Nuclear Regulatory Commission, an earthquake catalog (Nottis, 1983) an early general summary (Barosh 1981) and a fuller one for the entire east coast (Barosh, in press).

BACKGROUND

In order to delineate the distribution of potential damage from earthquakes in a meaningful manner it is necessary to know why earthquakes occur where they do, otherwise it can be argued that they may occur anywhere given enough time. Attempts to circumvent this need by quasi-statistical treatment of earthquake data using assumptions about the geology (probabilistic methods) served as preliminary approximations of the hazard, but have been superseded.

The earthquakes in New York almost certainly arise from sudden movements on faults. Surface fault movement accompanied by an earthquake commonly occurs in the western United States, but none have been verified in the northeast. This has made the cause more difficult to determine. Surface movements may have occurred on faults for the larger earthquakes in the region, but not seen due to water cover in lakes and bays. Many faults, however, are present in the region, although most can be shown to be ancient and not active.

Many reasons have been suggested as to the cause of fault movement responsible for the earthquakes in the eastern United States. Almost all of these suggest causitive features that fail to match the distribution of earthquakes. To determine the cause in the northeastern United States each of the more active areas was investigated. A set of geologic features characterizing the seismically active areas eventually emerged. These features appear consistent with the known development and recent movements within the North Atlantic basin to the east.

DISTRIBUTION AND CAUSE OF EARTHQUAKES

The distribution of earthquakes in the eastern United States is far from uniform. The larger earthquakes are concentrated in particular areas. These particular active areas appear to have generally remained in the same places for the length of our earthquake record and are still active, although the rate of activity within them may vary greatly from time to time. The concentrations with the largest earthquakes in New York are in the vicinities of Attica, Messena, Lake George and Raritan Bay. Each of these areas was active prior to their largest earthquake and each was active recently (1978-1980).

The concentrations of earthquakes lie in zones of general seismic activity. This is well shown by a map showing the number of earthquakes per unit area (Fig. 1). There are two main northeast-trending zones; one extending from Arkansas to the lower St. Lawrence River and one from the southern end of the Appalachian Mountains to the coast of Maine. New York straddles both zones.

A further analysis shows the distribution of earthquakes is related to the altitude of bedrock. The Arkansas-St. Lawrence zone is low, with bedrock along it 200 m. or less in altitude. The zone to the east is divided into an upland belt along the southern and central Appalachian Mountains and a lowland belt from central Virginia to southeastern Maine (Fig. 2). There is also a separate upland area of activity in the Adirondack Mountains and the lowland activity at Charleston, S.C., the site of the largest earthquake on the east coast. Many studies indicate the upland areas are rising and the lowland ones are sinking at present. The cause of earthquakes thus appear related to the vertical movements. To find out what may be responsible for the movements we need to review the geologic history of the region.

A great change occurred in the geologic regime during Triassic time, over 200 million years ago, as the Atlantic basin began to form. Fault movement formed mountains and valleys, such as along the Ramapo fault separating highlands to the northwest from the Newark basin, as northwest Africa began to move away from the eastern United States (Fig. 3). As the Atlantic basin grew between the newly separated continents, the new Atlantic edge of North America

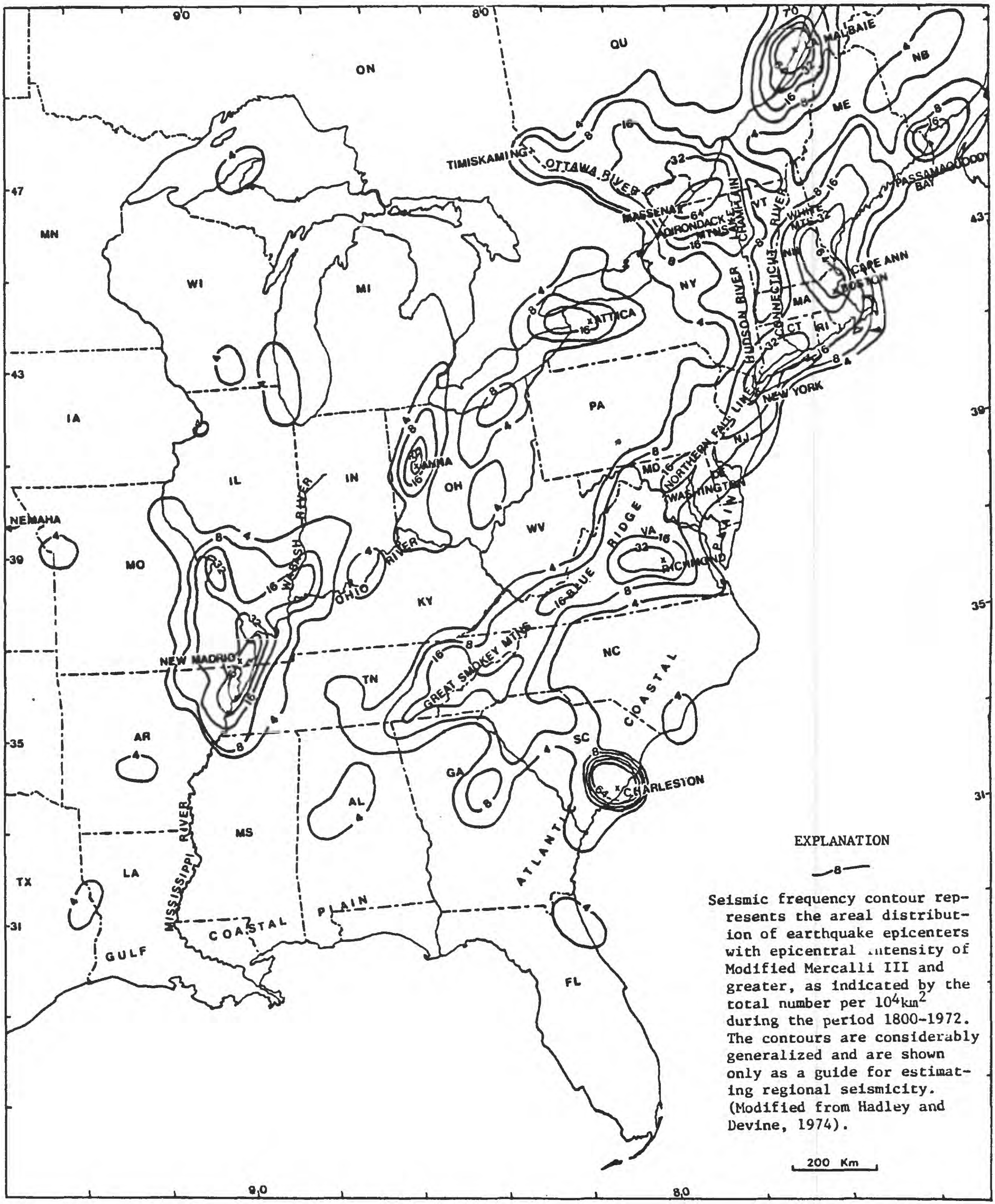

Figure 1. Map showing the seismic frequency in the eastern United States for the period 1800-1972 (from Hadley and Devine, 1974)

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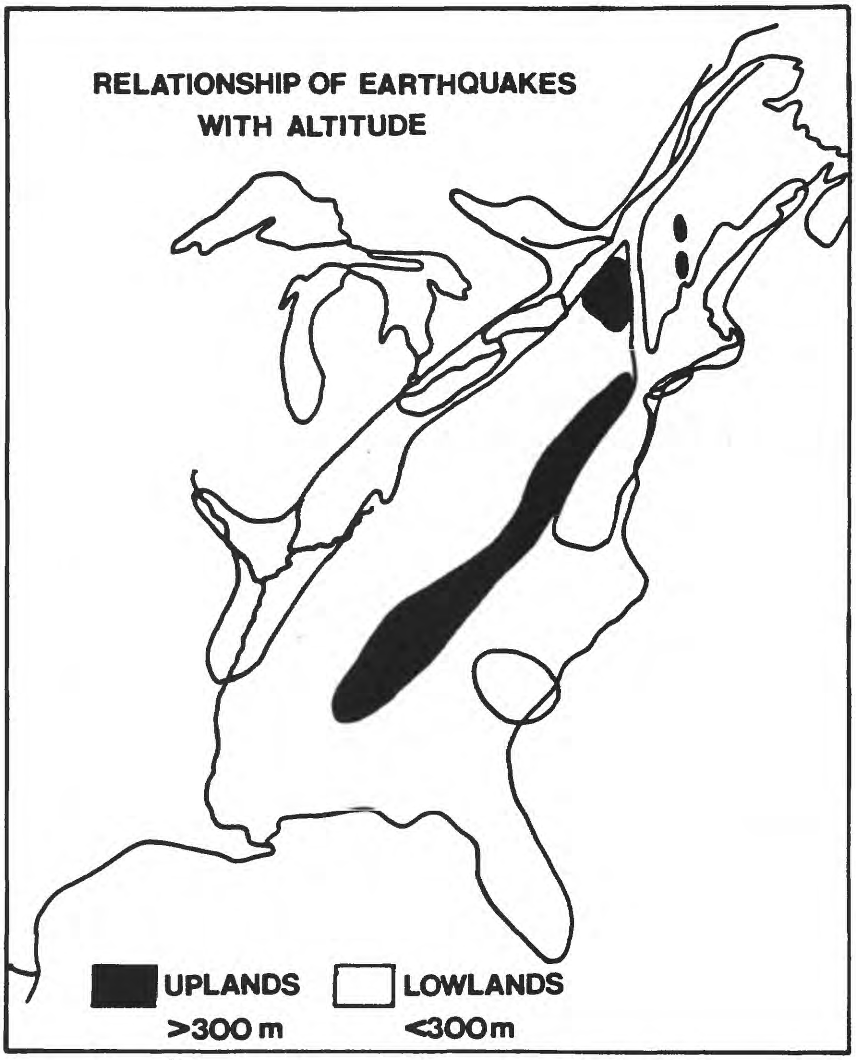

Figure 2. Sketch map of the eastern United States showing general relations of earthquakes with altitude.

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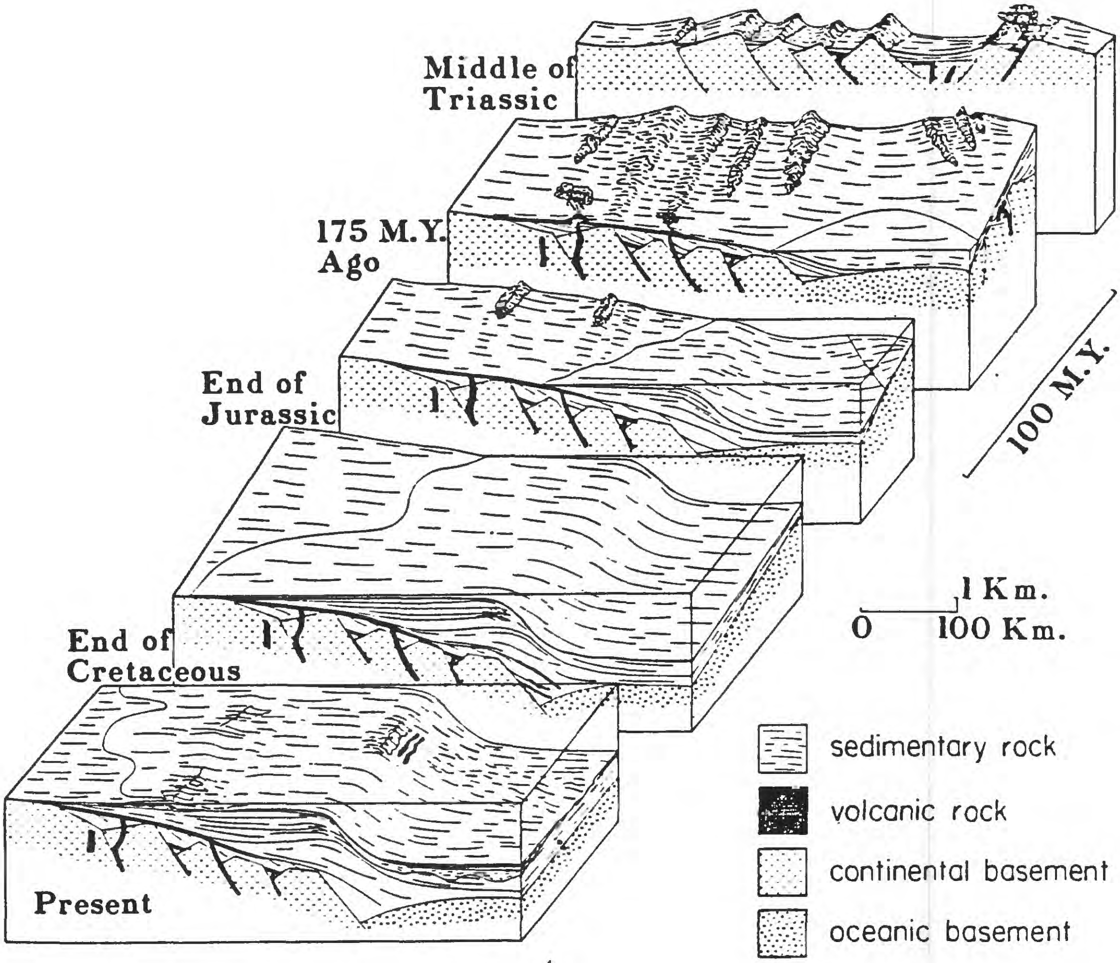

Figure 3. Block diagrams showing a typical development of the continental margin of the east coast of the United States (from Dillon and others, 1983).

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sagged down and the adjacent inland area bowed up (Fig. 3). Erosion from the upland area produced sediment that was deposited on the down side to form the Atlantic coastal plain. These movements appear to be still continuing as the Atlantic basin continues to widen at a rate of 2.5 cm (about one inch) a year. The Arkansas-St. Lawrence lowland parallels the Atlantic coast and appears to be an interior sag also related to movement in the Atlantic basin. Earthquakes in New York are then related to a coastal down warp, adjacent bulges and an interior sag related to the continual opening of the Atlantic basin (Figs. 4 and 5). All large historic earthquakes in the State have been within or at the edge of these zones. Earthquakes, however, are not distributed uniformly in these zones and it is necessary to seek additional controls to explain their locations.

The sediment forming the Atlantic coastal plain does not form a uniform wedge of debris, but a deposit with thicker and thinner areas, whose axes trend northwest (Fig. 6). The areas of thicker sediments are places that subsided to a greater degree in the past and appear to be relatively subsiding at present. Earthquakes are concentrated in these subsiding areas and are apparently related to the sinking. The Raritan Bay area of the northern New Jersey coastal plain, Staten Island and western Long Island is one of these earthquake prone subsiding areas.

The initial fracture zones related to the Atlantic basin opening trend mainly northeast parallel to its axis, but another set of fracture zones formed perpendicular to the axis as the basin developed. This latter set of fracture zones trends northwestward near the east coast of the United States (Fig. 7). The more seismically active areas along the east coast are located where the fracture zones with the larger movements approach the shore. One of these large zones can be followed close to Raritan Bay. It probably continues beneath the bay, weakening the rock there and causing the subsidence. The

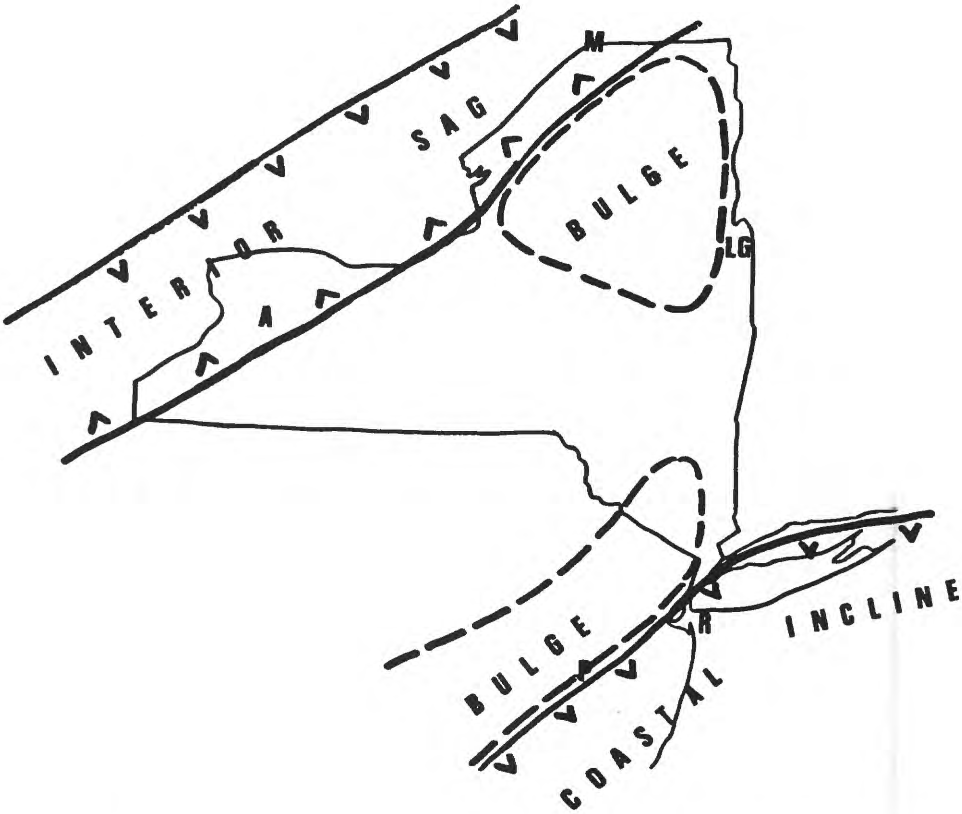

Figure 4. Sketch map of New York showing generalized areas of probable present-day movement. Explanation: M, Massena; L. G., Lake George; A. Attica; and R. Raritan Bay, P. Philadelphia.

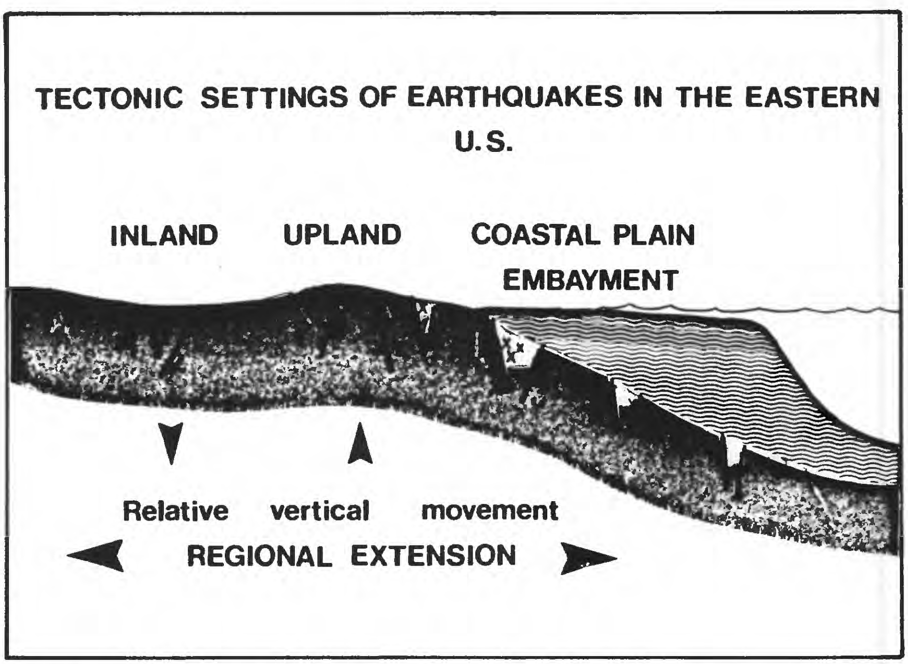

Figure 5. Generalized cross-section showing tectonic settings of earthquakes in the eastern United States and probable present-day movements.

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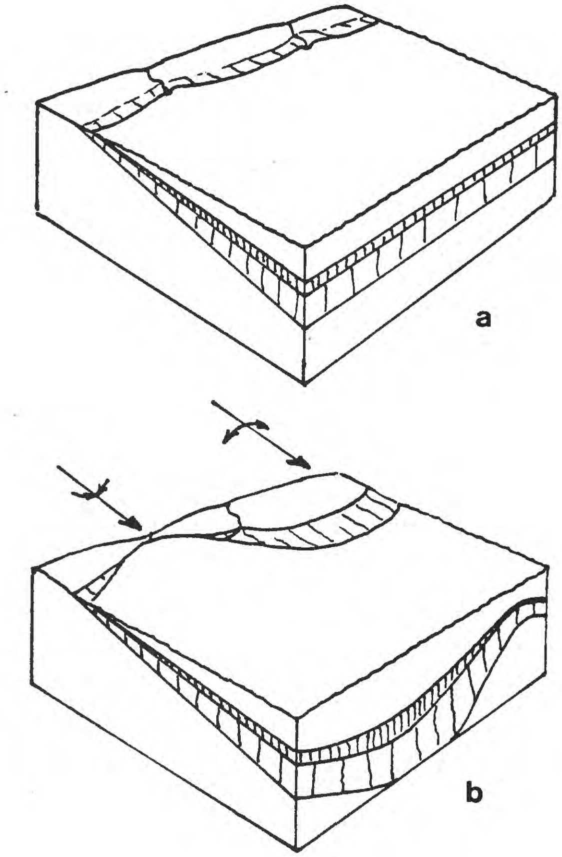

Figure 6. Block diagrams of coastal plain deposits on the east coast of the United States showing a, uniform deposits and b, with cross (northwest-trending) sag (syncline) and swell (anticline).

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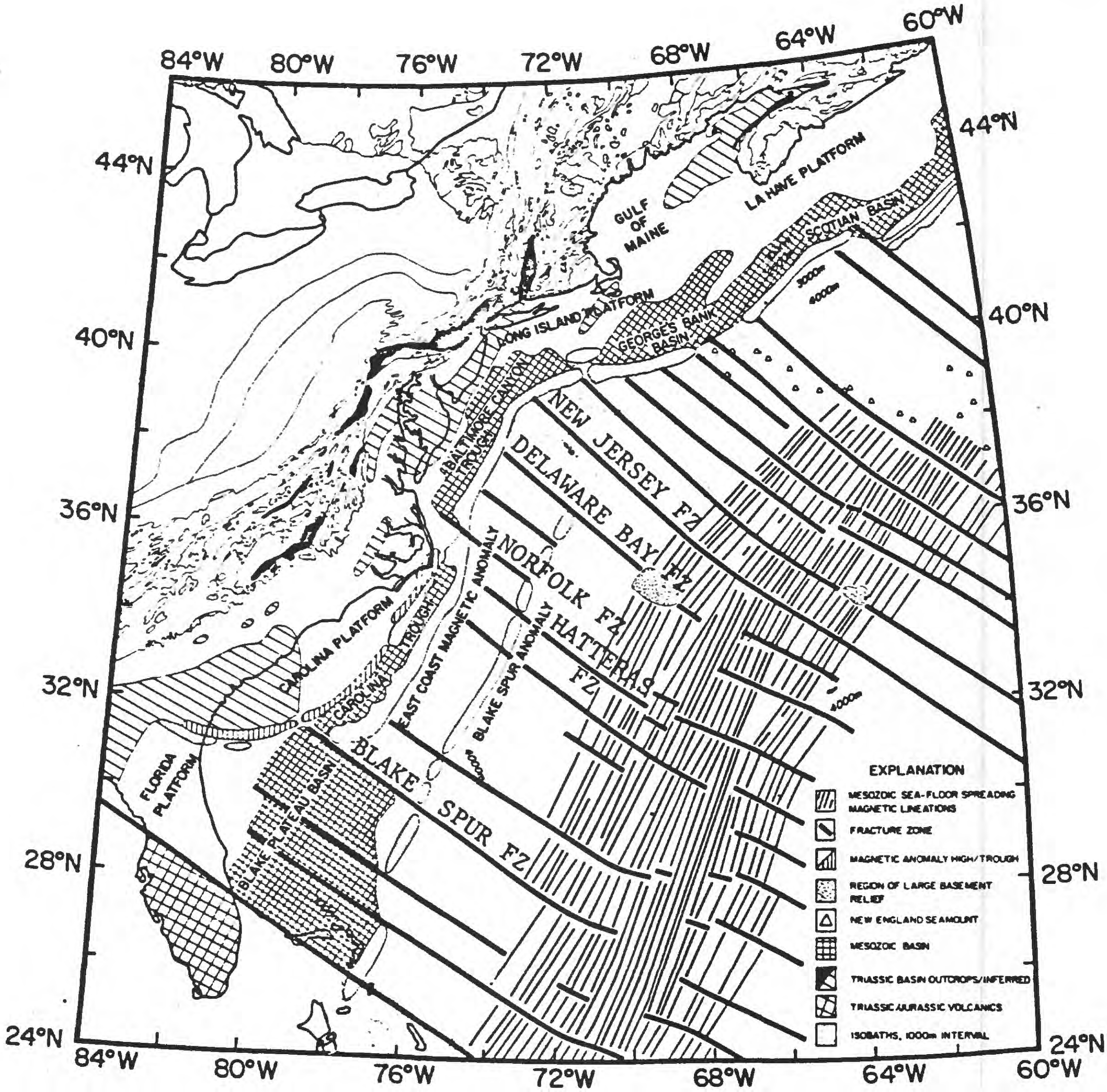

Figure 7. Map of the western North Atlantic Basin adjacent to the East Coast of the United States and Maritime Canada showing oceanic fracture zones and selected geologic features (Kiltgord and Behrendt, 1979, Fig. 2).

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youngest fault zones in the seismically active areas on land in the northeast United States also trend northwest and their movements are probably related to those of the offshore fracture zones. Some of the fault zones can be seen to be reactivations of very old deep seated fracture zones on land. These old zones are revealed by the changes they cause in the pattern of magnetic and gravity values. They are also commonly followed by stream and river valleys indicating the fractures reach the surface and control the drainage. There are a number of these northwest-trending fault and fracture zones crossing New York (Fig. 8) and streams and rivers of the trend are common. It is where these zones intersect the areas of general movement related to the Atlantic basin opening, mentioned above, that the earthquakes occur. (Fig. 8).

North-trending faults accompany the young northwest-trending ones in places. Major fault zones of the trend occur in New York, such as the zone through Lake George and Lake Champlain and the Clarendon-Linden fault zone through Attica (Fig. 8). The Lake George-Lake Champlain zone contains extensional faults (caused by stretching of the crust) and the Clarendon-Linden may be also. Such faults may have been formed by strain created by night-lateral movement along the northwest-trending fault zones (the northeast side moving southeast in relation to the south west side). Post-glacial fault movement has been shown to be likely, although not proven, at several places along the Lake George-Lake Champlain zone.

Earthquakes in New York are thus localized where northwest and north-trending fracture zones cross belts in which vertical movement, mainly subsidence, is occurring apparently due to the continual stretching of the crust and widening of the Atlantic basin. Areas shown to be stable for a long time and not crossed by any of the known fracture zones, such as the Catskill Mountains, are almost devoid of earthquakes. These are the apparent geologic features that control where earthquakes do or do not occur. Earthquakes are

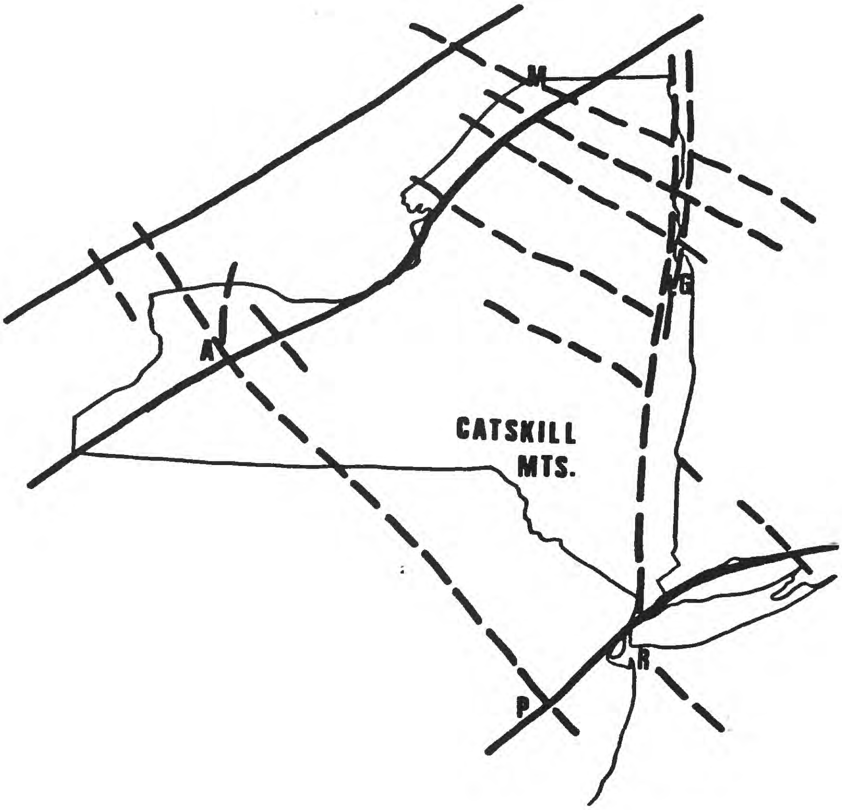

Figure 8. Sketch map of New York showing probable fracture and fault zones that may have localized present-day movement causing earthquakes. Explanation, dashes, fracture and fault zones; solid lines and letter symbols from Fig. 4.

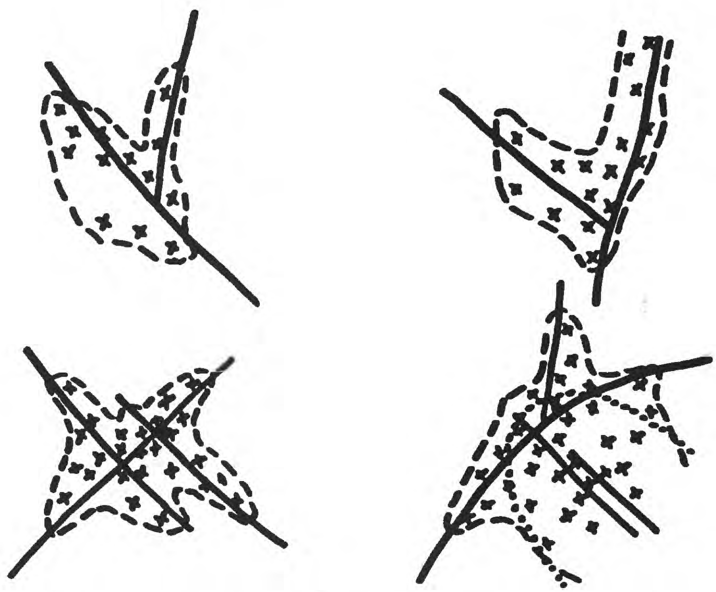

Figure 9. Sketch maps showing differences between delineation of seismotectonic structures (solid lines), areas of local subsidance (partially enclosed by dotted line), earthquakes (crosses), and earthquake zonation (dashed lines).

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therefore not random in their occurrence and a basis exists for meaningful earthquake zonation.

EARTHQUAKE ZONATION

Once a reasonable cause is established as to why earthquakes occur at a certain place it is then necessary to delineate the boundaries of the area in which earthquakes might be expected and estimate their maximum size to create an earthquake zonation map. Such a map presents the information in a form that is useful in preparing for the earthquake hazard.

Identification of the active geologic elements, the seismotectonic features, is not sufficient to delineate the earthquake hazard as the distribution of frequency and size of earthquakes varies along them. First, the geologic elements are commonly only locally active in the east, usually at intersections with other structures. Second the distribution of earthquakes generally have a greater width than the identified structural zones. This may be due to a dip to the structural zone that causes an earthquake at depth to be displaced from the surface trace of the zone, earthquakes from adjustments of the adjacent rock to changing strain along the active element, a greater width of the structural zone then presently known and earthquakes that occurred on the structural feature, but have been inaccurately located off to the side. Thus maps showing seismotectonic elements and earthquake zonation differ (Fig. 9). With more accurate location of earthquakes and structures the difference will decrease.

The size of earthquakes in a region appears to have definite limits set by the amount of strain that builds up before brittle deformation occurs. This is usually a matter of overcoming friction on an existing fault. The amount of strain build up is governed by the geologic environment. There is no evidence to suggest that great earthquakes may occur everywhere.

The maximum expected size of earthquakes in an active area can be estimated by reviewing the earthquake history of the area and by comparison to other similar areas. Long time intervals elapse between large earthquakes on the east coast and although most areas have not experienced their maximum earthquake since records have been kept, a few have. The one or two larger earthquakes in areas, that are otherwise similar to a group of other active areas, that have experienced slightly lesser earthquakes, may be taken as the maximum expected for all of them. Another approach is analyzing the earthquake history of a single active area. Characteristically an active area has many more small earthquakes than large ones; a plot may be likened to a pyramid with a great number of small earthquakes at the base and progressively fewer of each larger-sized earthquake. The apex, or maximum earthquake, can be predicted even though it has not occurred. Care must be taken not to mix earthquakes from different, but nearby, source areas or a wide range of values might result. Both methods for obtaining the maximum expected earthquakes usually yield the same result along the east coast and provide greater confidence in the results.

The size of the earthquake still appears best presented in terms of Maximum Intensity, that is the greatest effects of the earthquake. This is done as most data on earthquakes is in terms of intensity and it is the effects of an earthquake that directly concern planners trying to mitigate the earthquake hazard. Presentation of size on terms of magnitude, a function of the energy released, is a relatively recent development, and requires the older records, in terms of intensity, to be converted into magnitude and then eventually reconverted into a useful term for planners. These conversions are very imprecise and needlessly introduce errors. The size given in terms of acceleration is useful to engineers for building codes, but generally requires even more imprecise conversions from intensity, and varies greatly with local site conditions. It seems better to retain the intensity value and convert to acceleration as needed, changing the conversion factor as it became better known and more of the type of seismic records (strong-motion records) suitable for determining acceleration become available from earthquakes.

The zonation presented (Fig. 10) is in terms of maximum expected epicentral intensity, that is intensity expected above a local earthquake. The intensity varies with local ground conditions and the value given probably represents relatively firm ground. Sites with very poor conditions might possibly be two units higher and those on solid rock one less.

This zonation is for earthquakes in New York and does not include the distant effects from large earthquakes along the St. Lawrence River in adjacent Canada. Such events may produce damage in northern New York. Tall buildings may be especially susceptible to the long-period wave motion arriving from these distant earthquakes.

RETURN TIMES

When will the next "big one" occur is usually the query after indicating the location and expected size of earthquakes. This is very poorly known on the east as the long interval between earthquakes has not provided enough data to evaluate the return time, despite the longer record than the West Coast. Various statistical approaches have varied so greatly in their results for active areas in the eastern United States as to cast doubt on the validity of the method at this time. A comparison to an area with a longer record may provide as good results as any. The large earthquake that struck northeastern Massachusetts in 1755 was about two weeks after the Great Lisbon earthquake in Portugal. It is possible that both these earthquakes were triggered by increased strain from some movement in the Atlantic basin and are related. Lisbon is reported to have suffered two previous devastating earthquakes separated by about 400 year intervals. This probably provides the best

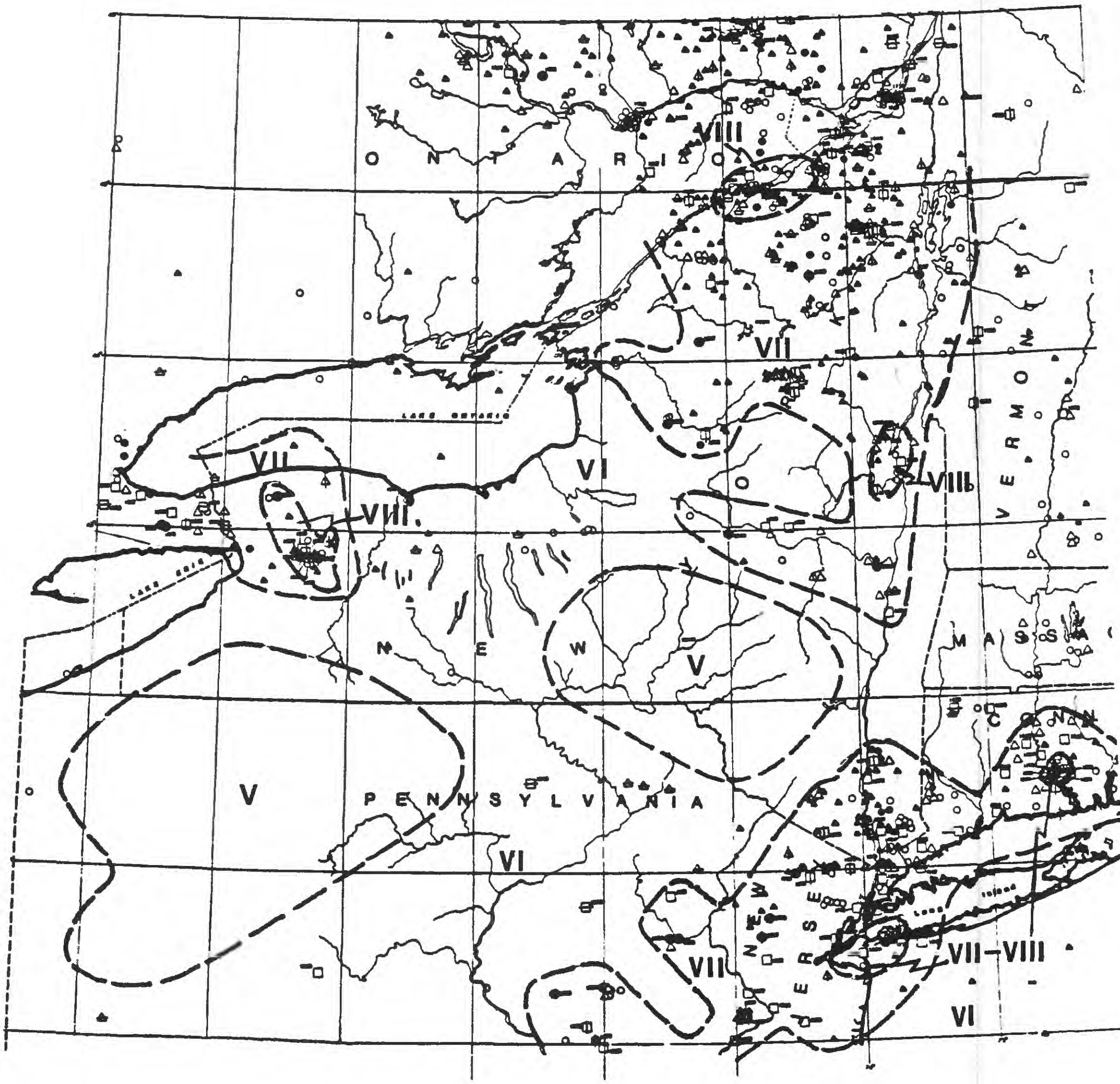

Figure 10. Earthquake zonation map of New York and adjacent area showing maximum expected intensity from local earthquakes (epicentral intensity) in the Modified Mercalli intensity scale (see Table 1).

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estimate for return times of large earthquakes near Boston, Massachusetts, and perhaps also at other sites in the northeast United States. Large earthquakes in the more active St. Lawrence River valley, northeast of Quebec are probably more frequent.

A more important consideration for planners in New York than the return time of earthquakes at a particular site is the return time for a damaging earthquake anywhere in New York; this is a much shorter interval. The earthquake record for New York covers about 250 years of which the last 150 years appears adequate for moderate-sized earthquakes. The largest earthquake on record, an intensity VIII (Tables 1 and 2) occurred at Messena, N.Y., in 1944. In the last 100 years earthquake producing intensities of VII or greater have occurred about every 25 years (Table 2) and it has been 40 years since the last one. However, in the 50 years prior to 1884 no intensity VII earthquakes happened, although six intensity VI earthquakes occurred. In all, 17 earthquakes of intensity VI or greater have struck New York in the past 150 years, usually between December and April, at intervals ranging from 1 to 22 years and averaging slightly less than nine years (Table 3). This demonstrates that an earthquake causing at least slight damage may occur in New York at any time.

Table 1 Intermediate Earthquake Intensities that may occur as the maximum in different areas of New York. From Modified Mercalli intensity scale of 1931

INTENSITY	EFFECTS
V.	Felt indoors by practically all, outdoors by many or most: outdoors direction estimated. Awakened many, or most. Frightened few--slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows--in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors, shutters, abruptly. Pendulum clocks stopped, started, or ran fast, or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes, shaken slightly.
VI.	Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes, shaken slightly to moderately. Liquid set in strong motion. Small bells rang--church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks, chimneys in some instance. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.
VII.	Frightened all--general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, abode houses, old walls (especially where laid up without mortar), spires, etc.

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Table 1 (continued)

VII. (continued)

Cracked chimneys to considerable extent, walls to some extent.
Shook down loosened brickwork and tiles.
Broke weak chimneys at the roofline (sometimes damaging roofs).
Fall of cornices from towers and high buildings.
Dislodged bricks and stones.
Overturned heavy furniture, with damage from breaking.
Damage considerable to concrete irrigation ditches.

VIII. Fright general--alarm approaches panic.
Disturbed persons driving motor cars.
Trees shaken strongly--branches, trunks, broken off, especially palm trees.
Ejected sand and mud in small amounts.
Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters.
Damage slight in structures (brick) built especially to withstand earthquakes.
Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling.
Fall of walls.
Cracked, broke, solid stone walls seriously.
Wet ground to some extent, also ground on steep slopes.
Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers.
Moved conspicuously, overturned, very heavy furniture.

Table 2. New York Earthquakes reaching Modified Mercalli Intensity of VII or greater.

Date	Intensity	Town
1884, Aug 10	VII(very local)	Rockaway Beach
1929, Aug. 12	VII	Attica
1931, Apr. 20	VII	Warrensburg
1944, Sep. 5	VIII	Massena

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Table 3. Earthquakes in New York of Modified Mercalli intensity VI or greater (Nottis, 1983 and oral commun.)

DATE	EPICENTRAL INTENSITY	LOCALITY	EPICENTER N. LAT	EPICENTER W. LONG
1737, Dec. 19	6	New York	40.60	73.80
1840, Jan. 16	5-6	Herkimer	43.00	75.00
1853, Mar. 12	6	Lowville	43.70	75.50
1857, Oct. 23	6	Buffalo	43.20	78.60
1867, Dec. 18	6	Canton	44.05	75.15
1874, Dec. 11	6	Tarrytown	41.00	73.90
1884, Aug. 10	6 (local 7)	Rockaway Beach	40.59	73.84
1893, Mar. 08	5-6	Astoria	40.78	73.92
1897, May 28	6	S. of Plattsburg	44.50	73.50
1916, Feb. 03	5-6	Mohawk Valley	42.80	73.90
1928, Mar. 18	5-6	Saranac Lake	44.50	74.30
1929, Aug. 12	7	Attica	42.90	78.40
1931, Apr. 20	7	Warrensburg	43.50	73.80
1934, Apr. 15	5-6	Dannemora	44.70	73.80
1944, Sep. 05	8	Massena	45.00	74.70
1966, Jan. 01	6	Attica	42.84	78.25
1967, Jan. 13	6	Attica	42.84	78.23
1983, Oct. 07	6 (local 7?)	Goodnow Flow	~ 43.90	~ 74.20

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SUMMARY

Earthquakes in New York occur near Lake Ontario, in and around the Adirondack Mountains, Raritan Bay and the Hudson Highlands. Remarkably few occur in the Catskill Mountains. The earthquakes appear to be related to forces causing further opening of the North Atlantic basin. This movement is accompanied by downwarping of the coast, uplift of the Hudson Highlands and Adirondack Mountains and a probable subsidence along the Lake Ontario-St. Lawrence lowland. Earthquakes are localized within these areas of vertical movement along northwest and north-trending fracture zones. A delineation of the active areas and an evaluation of the maximum expected effects from local earthquakes (epicentral intensity) indicates the areas of known and probable vertical movement might expect intensity VII, with intensity VIII occurring around Attica, Messena, and Lake George and intensity VII-VIII around Raritan Bay. The rest of the state might experience intensity VI, except for the Catskill Mountains that may not exceed V. The largest local earthquake recorded in the state is the intensity VIII 1944 Messena Earthquake, In the last 150 years local intensity VI or greater earthquakes have occurred about every 9 years and usually between December and April. For the last 100 years intensity VII or greater earthquakes have occurred approximately every 25 years.

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PUBLIC AWARENESS OF AND PREPAREDNESS FOR EARTHQUAKE EVENTS IN THE EASTERN UNITED STATES

by

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I. Recent social science research has found a much higher awareness of seismic threat, among both the general population and decisionmakers, than was previously believed to exist.

   A. These results are from research conducted by myself and Alvin Mushkatel in 1984 in the Central United States.

   B. This research had two components:

      1. A community survey with 2100 residents of nine cities in High Risk Zones (MMI IX+) in six states--Arkansas, Illinois, Indiana, Kentucky, Missouri, and Tennessee.

      2. A survey of "key actors" (elected and appointed officials) in 120 cities and counties in those states.

II. Salience of earthquake threat.

   A. It is frequently believed that because earthquakes occur very infrequently in the Eastern United States, residents are not aware that they constitute a threat.

      1. We used the five most common natural hazards in the Central States' area:

         - blizzards or severe storms
         - tornados or cyclones
         - floods
         - droughts
         - earthquakes

      2. This question was asked of all community residents:

         "Thinking about the chances of property damage, injuries, and loss of life, how serious a threat are <u>floods</u> to your

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community? Are they: a very serious threat, a serious threat, a lightly serious threat, or no threat at all?"

3. Their rankings (serious or very serious threat) were:

- droughts	50%
- tornados, earthquakes, and floods	25%
- blizzards	18%

B. However, awareness of a serious threat is not sufficient to motivate either preparedness or mitigation activities if people do not believe they are "at risk" (that is, likely to experience the effects of an earthquake). To discover whether people felt they were living at risk, three questions were asked:

1. To determine how concerned they were about a damaging earthquake affecting their community:

   a. Question: "How concerned are you about the possibility of a damaging earthquake striking (city name)? Would you say you are: very concerned, somewhat concerned, hardly concerned, or not concerned at all?"

   b. Almost half (49 percent) of the residents were very or somewhat concerned; as were 42 percent of the key actors.

   c. Concern about a damaging earthquake was higher for residents in larger cities than in smaller ones.

2. To determine whether they perceive an earthquake threat to be imminent; if not, no motivation to prepare exists:

   a. Question: "How likely do you think it is that a damaging earthquake will strike (city name) before the year 2000? Would you say there: definitely will be, probably will be, probably will not be, or definitely will not be a damaging earthquake in the next 16 years?"

   b. Over two out of every five (42 percent) residents and almost one in every three (31 percent) key actors believe there definitely or probably will be a damaging quake in their community before 2000.

3. To determine if the threat is personally relevant--are they likely to be affected?

   a. Question: "Which of the following best describes your own feelings about the chance you will be in a damaging earthquake? Would you say you are: very worried, somewhat worried, not very worried, or not worried at all?

   b. Almost 40 percent of the community residents and 30 percent of the key actors are somewhat or very worried that they are personally going to experience a damaging earthquake.

4. Summary--for a substantial proportion of both the general population and the key actors:

   a. They know threat exists,

   b. They are concerned about their communities being affected by a future event,

   c. They anticipate that a damaging earthquake will affect their communities in the next decade or so, and

   d. They are worried about personally experiencing a damaging event.

III. Household preparedness.

A. Given the extent of earthquake-threat salience, how prepared were citizens to respond to a major earthquake event?

   1. In terms of general readiness for any emergency, there was a relatively high level of preparedness; however, earthquake-specific measures were much less frequently taken (Table 1).

   2. For those who owned their own homes (Table 2) and for households with children (Table 3), few earthquake-specific preparations had been taken.

   3. Overall, each household had only taken about one-fourth of the preparedness measures possible.

B. But how prepared did people <u>feel</u> they were?

   1. 19 percent felt they personally were somewhat or very prepared.

   2. When their perception was compared to the actual number of measures they took, there was a good fit.

   3. However, there was a tendency for those who live in larger cities to believe they are better prepared than people in smaller cities.

   4. Also, the less prepared people believe they are, the less well prepared they believe both the general public and government are for a damaging earthquake.

      a. However, 74 percent of the residents felt it was <u>very</u> important for the government to reduce earthquake hazards by educating the public about preparedness (even when it meant spending money to do so).

      b. This finding is not related to city size--those in rural areas were as supportive as those in larger communities.

IV. Mitigation activities.

A. Both key actors and community residents were asked to assess three mitigation measures that could reduce injury and loss of life in a major earthquake event.

1. An important consideration--to determine whether there is popular sentiment for such actions, otherwise no constituency will support key actors' decisions to change construction or land use policies.

B. Strengthening building codes for new structures.

1. When asked how important it was to strengthen building codes for new structures, over 60 percent of the residents felt this measure was very important; and 85 percent of them remained supportive even if it meant that government would have to invest substantial amounts of money to do so.

2. Although 80 percent of key actors felt that strengthening codes for new structures was a generally effective mitigation measure, only 37 percent of them felt it was very important in their communities.

C. Strengthening building codes for existing structures.

1. Again, over 60 percent of the residents surveyed felt it was very important to strengthen building codes for existing structures; and 83 percent remained supportive even if increased government funding was necessary.

2. Although 42 percent of the key actors believed that such a technique would be generally effective, only 26 percent of them felt such measures were necessary in their communities.

D. Land use policies.

1. Almost half (48 percent) of the residents believed it was very important to implement land use policies to reduce seismic risk; and, again, over 80 percent remained supportive even if additional government investment was required.

2. While 56 percent of the key actors saw land use as a generally effective mitigation technique, only 25 percent believed such practices were warranted in their communities.

E. In general, the general population was more supportive of these mitigation techniques than were the key actors.

V. While the Central States are clearly different from New York and other Northeastern States in terms of earthquake history and current seismic threat, it is important to remember that:

A. Until four or five years ago, few people were concerned with earthquake threat outside of California, Alaska, and possibly the state of Washington.

B. In 1980, social science research in Missouri found little activity at the governmental level for either preparedness for or mitigation of seismic threat.

C. Key actors in Missouri believed that the general population was totally unconcerned about and unaware of the earthquake threat and that there would be no support for governmental planning for an earthquake event.

D. Perhaps the Northeastern States today reflect an awakening seismic awareness that the Central States experienced in the late 1970's and early 1980's.

TABLE 1

PERCENTAGES OF HOUSEHOLD PERRPAREDNESS MEASURES TAKEN BY ALL HOUSEHOLDS

PREPAREDNESS MEASURES	TOTAL SAMPLE (N=2089)
Store water	10%
Store food	32
Working battery-operated radio	63
First-aid supplies	66
working flashlight	88
Any other supplies	34
Rearranged cupboards to make them safer	12
Have safe cupboard latches	25
Know emergency procedures at resident	23
Contacted neighbors about emergency measures	3
Made neighborhood responsibility plans	4
Attended block meetings	1

TABLE 2

PERCENTAGES OF HOUSEHOLD PREPAREDNESS MEASURES

TAKEN BY OWNER-OCCUPIED HOUSEHOLDS

PREPAREDNESS MEASURES	TOTAL SAMPLE
Reinforced home	13%
Inquired about earthquake insurance	17
Purchased earthquake insurance	13

TABLE 3

PERCENTAGES OF HOUSEHOLD PREPAREDNESS MEASURES

TAKEN BY HOUSEHOLDS WITH CHILDREN

PREPAREDNESS MEASURES	TOTAL SAMPLE
Instructed children what to do during an earthquake	14%
Made plans for household reuniting	8

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AGENDA SETTING FOR EARTHQUAKE PREPAREDNESS: LESSONS FOR NEW YORK STATE

by

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We have recently completed a study of three states (California, Nevada, and South Carolina) from the standpoint of their policy making for earthquake preparedness.[1] In addition, we have engaged in another study of one nation--Japan--from the same perspective. It is clear that societies fall into one of three categories where earthquake policy is concerned. These categories are "levels" or "degrees" of policy development. Policies and policy making strategies should be equated to these levels.

Japan is best conceived as being at an advanced level of policy development where earthquake preparedness is concerned. Here the threat is relatively well established and so is the policy framework for dealing with that threat. Hard and soft preparedness technologies are institutionalized through government agencies and programs that have a high priority and stability. There is even a large-scale project involving sums of well over $2 billion to predict and prepare for a specific earthquake (the Tokai earthquake). The main point regarding earthquake preparedness in an advanced policy setting is that it is on the society's continuing agenda and as a reasonably high priority.

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One step below the advanced setting is a society like California, which could be said to be on an intermediate level of policy development. There are policies and existing institutions to deal with the earthquake threat, a threat that is recognized by state government as being sufficiently real to be worthy of some investment of resources. However, it is clear, in comparing California to Japan, that the policy system in the former is still not mature. Funding is low and/or uncertain. Institutions are precarious. There is a sense of tentativeness about political commitment, and issues of who does what, when, and how are frequently uncertain. Earthquakes are more an episodic issue of less than major priority. Changes in individuals holding strategic governmental positions can make a large difference where a policy area is vulnerable.

Finally, there are societies like South Carolina or Nevada, which we have studied, and New York, which we have not observed, at least from the point of view of earthquake policy. These are emergent in terms of policy development. The problem is to get earthquake preparedness on the governmental agenda, whereas in advanced and intermediate systems the issue becomes how high on the agenda. In emergent policy systems, there are seismic threats, but these are neither well understood (a scientific problem) nor widely perceived (a political problem). Policy and institutional development reflect this fact.

The key difference in the three types of systems is the identity of the institutional advocate for earthquake preparedness and the relative influence of this advocate. We call this advocate an earthquake entrepreneur. In Japan, there are many such entities which include powerful elected officials (including governors) and strong agencies. In California, they key earthquake entrepreneur has been a temporary organization called Southern California Earthquake Preparedness Project (SCEPP). There are others in California such as Seismic Safety Commission (SSC) and Office of Emergency Services (OES). However, none of these organizations loom large from the standpoint of bureaucratic power in their respective systems. Only recently has SSC gained a sense of permanence. Further, the commitment of elected officials is higly suspect.

In advanced policy settings, the principal entrepreneurs are politicians; in the intermediate setting, they are bureaucrats; in emergent policy settings they tend to be technical professionals. For a brief moment, the governor of Nevada was interested. Then he was replalced by an uninterested successsor. An indifferent political leader is the norm in emergent settings. A review of recent experience in two emergent policy states--Nevada and South Carolina--may be relevant to New York. They reveal two different approaches to earthquake entrepreneurship in emergent settings.

In Nevada, there was an attempt to get action from the "top-down". In South Carolina, a "bottom-up" or "inside-outside" approach is being used. The process of policy making in Nevada, a seismically active state, began in July 1978. The governor, stimulated by a conversation with a California official, had his science advisor establish an Ad Hoc Panel on Seismic Hazard Mitigation to determine the status of preparedness in the state and needed steps to improve the situation. A "blue ribbon" committee was set up and produced an interim report in December 1978, just before the governor who commissioned the study left office. The report indicated the earthquake threat was real; Nevada was unprepared and needed a Seismic Safety Council to be set up for a five-year life to try to bring "order out of chaos." When the new governor came in, in January 1979, he let the earthquake matter drop. The Ad Hoc Panel had no user for its product. Nor was the new legislature interested. A final report was completed and the Ad Hoc Panel went out of existence in June. The science advisor went back to his position with the University of Nevada, and sought to keep the issue alive through various professional associations, such as the Nevada Society of Professional Engineers. Some pressure on the legislature continued but, after a few years of trying, the momentum petered out.

In South Carolina, the effort has been all from the ground up. The aim is to build a constituency among influential people so that the political levels will have to react in a positive manner due to public demand when the time is ripe. In South Carolina, there have been two earthquake entrepreneurs: a university-based geologist and a university-based civil engineer. Both began their entrepreneurial activities following a conference they attended on "Eastern Earthquakes" which was co-sponsored by U. S. Geological Survey (USGS)

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and Federal Emergency Management Agency (FEMA). They have worked to establish a South Carolina Seismic Safety Consortium as part of a larger Southeastern United States Seismic Safety Consortium. The South Carolina constorium aims at creating a coalition of interest among government, industry, universities, and public representatives. This consortium, aided by federal funds (the outside-inside connection), has produced threat analyses, held workshops, and in other ways sought to raise general earthquake consciousness. In addition, the two earthquake entrepreneurs, as individuals, have made efforts to increase awareness. The geologist, in particular, has carved out a role vis-a-vis earthquake education in the school system. Neither entrepreneur has engaged in lobbying the state government, preferring this slower, constituency building strategy. Ultimately, perhaps, the consortium could play this pressuring role. However, the earthquake entrepreneurs are going slowly in this respect.

The advantage of the Nevada top-down strategy is that it makes for rapidly initiated activity. The disadvantage is that if that activity rests on a narrow support base, it is highly vulnerable to the vagaries of political change. The South Carolina bottom-up strategy is slow (a disadvantage), but probably will reap greater benefits ultimately. The key is a constituency. Leadership from the top is desirable and can aid in constituency-building. But that leadership is unusual and evanescent in an emergent policy setting.

There is another point that might be mentioned. The Ad Hoc Panel proposed a version of California's Seismic Safety Commission for Nevada. The transfer of mechanisms from one state to another must be handled with care. What works in a state at the intermediate level may not work at one where earthquake policy is still emerging as an issue.

Thus, such considerations as those discussed must be kept in mind as New York examines its own state of earthquake policy and alternative mechanisms for improving its preparedness.

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WHAT LESSONS WILL
LOCAL, STATE, FEDERAL OFFICIALS, AND OTHERS
LEARN FOLLOWING A MAJOR EARTHQUAKE IN NEW YORK?

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POTENTIAL EFFECTS ON A COMMUNITY

A major earthquake in the New York area has the potential for causing great sudden loss through ground shaking, earthquake-induced ground failure, tectonic deformation, and possibly surface fault rupture. The effects of an earthquake having an epicentral intensity of VIII on the Modified Mercalli Intensity Scale (see glossary, Appendix C) will differ according to the time of day and the season in which the earthquake takes place, the proximity of the earthquake to the urban area, the soil and foundation conditions underlying buildings, lifeline systems, and other facilities exposed to the earthquake ground shaking, and the age and quality of design and construction. Figures 1-8 illustrate the kind of damage that can occur in an earthquake. Damage at a location will vary depending upon the level of Modified Mercalli intensity:

1) Intensities of IV-VI will affect the contents of the building or facility (e.g., broken china and other glassware, displaced paintings and other collectibles, etc.).

2) Intensities VI-VII will cause architectural damage (e.g., cracked and leaning chimneys, cracked and fallen plaster, fallen light fixtures in ceilings, overturned water heaters and bookcases, and displaced contents of pantry shelves, etc.).

3) An intensity of VIII will cause minor to major structural damage (e.g., houses shifted on their foundation, major cracks to partial collapse in buildings, broken pavement, disrupted utilities, etc.).

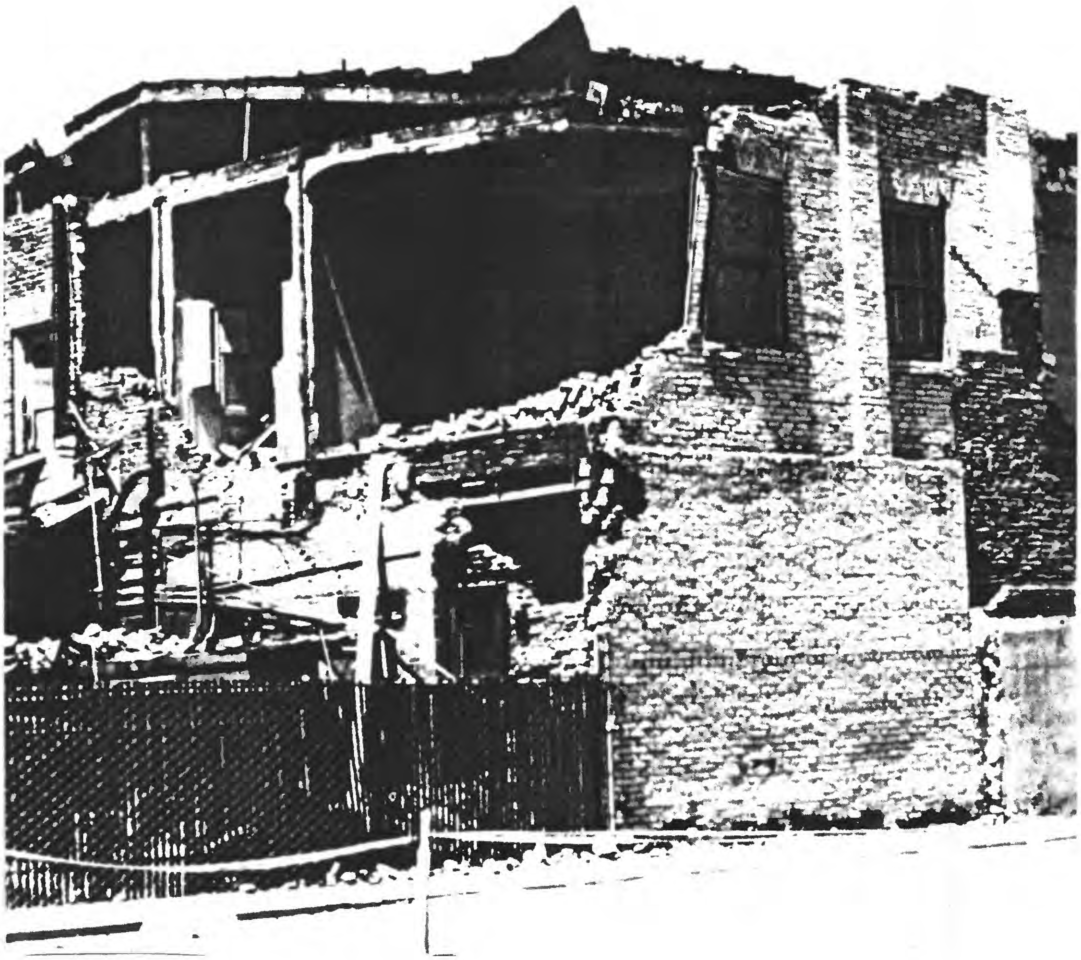

Figure 1.--View of the damage in Coalinga, California, caused by the March 2, 1983, earthquake. All these houses were constructed with nonreinforced brick and brick facades (Modified Mercalli intensity of VIII). (Photographed by Katherine Harms).

Figure 2.--This house was damaged by displacement along a thrust fault during the San Fernando earthquake on February 9, 1971. The house, which sits astride the fault (note humocky fault rupture), has been shortened and racked by compressional movement across the break. The garage, on the left side of the fault, has been carried toward the opposite end of the house, built on the right side of the fault break (Modified Mercalli intensity of VIII).

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Figure 3.--In the aftermath of the Coalinga, California, earthquake, a woman sits alone amid the wreckage of what once was her home--an experience particularly devastating and frightening for senior citizens, who are on fixed, and generally low, incomes (Modified Mercalli intensity VIII). (Photograph, Rick Brown/Picture Group).

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Figure 4.--Collapsed Freeway Overpass. Two motorists were killed by a freeway bridge collapse in this area (Modified Mercalli intensity VIII). (Los Angeles Department of Water and Power photo).

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Figure 5.--Partially Collapsed Old (1911) Lower Van Norman Dam. Eighty thousand people were evacuated from the area below the dam; however, the reservoir water was successfully contained by the damaged dam (Modified Mercalli intensity VIII). (Los Angeles City Fire Department).

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Figure 6.--Typical Industrial Building Damage in City of Sylmar. Average damage of this type of construction in the heavily shaken areas was about 17 percent of value. (Modified Mercalli intensity VIII). (Los Angeles City Department of Building and Safety photo).

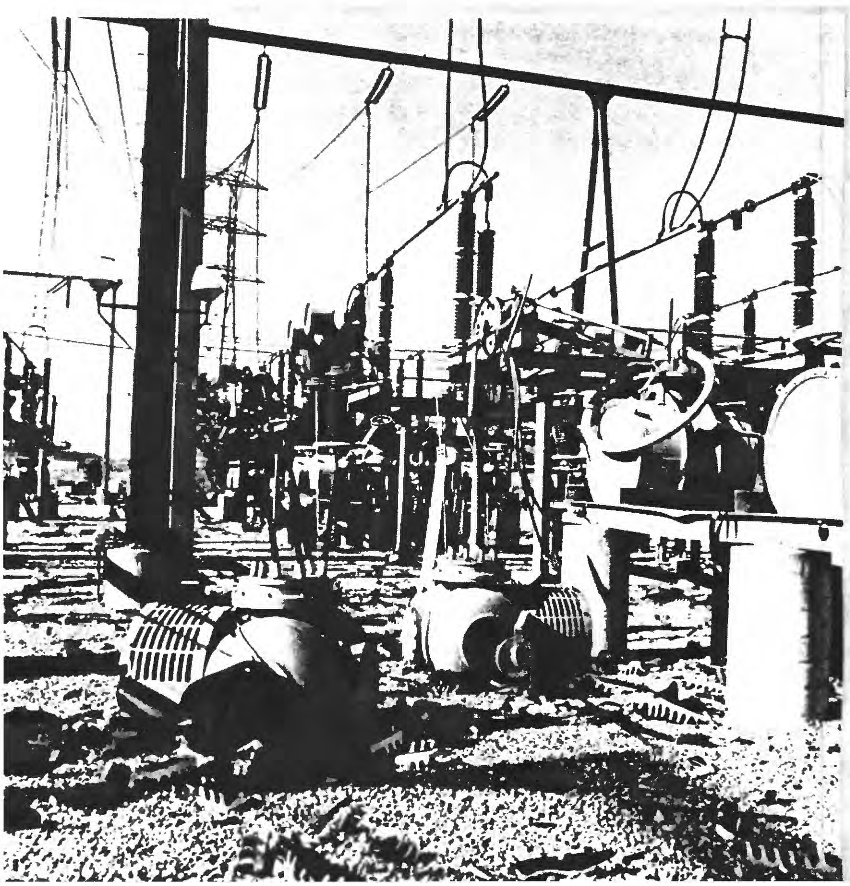

Figure 7.--Damaged Electrical Circuit Breakers at the Sylmar Converter Station. Total damage at this station was about $25 million and required about one year to repair (Modified Mercalli intensity VIII). (Los Angeles Department of Water and Power photo).

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Figure 8.--Example of damage from landslides triggered by ground shaking in the 1964 Prince William Sound, Alaska, earthquake (Modified Mercalli intensity VIII). Ground failure can occur in ground shaking ranging from Modified Mercalli intensity of VI to XII.

4) intensities of IX-XII will cause severe structural damage (e.g., total collapse of buildings and other facilities, etc.).

5) Ground failures (liquefaction, landslides) can occur at intensities ranging from VI-XII.

Fatalities are largest where collapse of buildings is involved. Also, even though the level of intensity may be low (MMI IV) at a distant location, damage can still occur to tall buildings because ground motion in the East tends to attenuate slowly away from the epicenter and to be charcterized by long duration and low frequencies. Therefore, there is a potential for damage to tall building (10 stories or greater) located a few hundred miles away from the epicentral area.

Frequent and recent experience in responding to an earthquake is lacking in New York; therefore, this paper will simply explore some of the issues that an actual earthquake would raise and some of the lessons that would be learned from experiencing an earthquake in New York. An actual earthquake will provide insight into the response and recovery phases, the two most difficult periods following an earthquake. What to expect during these phases and the activities that take place are discussed below.

RESPONSE TO AN EARTHQUAKE

The response to an earthquake will depend on its epicentral intensity and will generally increase in its complexity and comprehensiveness as the epicentral intensity increases. An earthquake having an epicentral intensity of VIII on the edge of a metropolitan area will require a comprehensive response by disaster and emergency service agencies (see Table 1). A number of important activities involving a wide variety of individuals, groups, and agencies will be required (Gori, et. al., 1982). These are discussed in the following two sections.

Table 1

Activities Involved in Responding to Earthquakes[1]

PROBLEM	RESPONDERS	RESPONSE
Search and Rescue	1. Rescue Squads	Activate search teams to look for victims.
	2. Fire departments	Activate personnel to fight fires, provide first aid, and search for victims.
	3. Construction companies	Use equipment and trained operators to clear roads and move debris.
	4. National Guard	Activate units to search for victims, provide first aid, and move debris.
	5. Forestry departments	Clear roads, fight forest fires.
	6. Local governments	Activate Emergency Operation Centers (EOC) to coordinate activities.
Medical	1. Rescue squads	Activate teams to provide first aid and life support. Use ambulances to transport (if possible) victims to medical facilities.
	2. Hospitals, clinics	Activate emergency plans, call in staff, provide triage, and treat victims.
	3. Private ambulance companies	Transport victims and provide on scene first aid.
	4. American Red Cross (ARC) first aid stations	Establish first aid stations with trained personnel and alert nurses to assist in hospitals.
	5. Doctors, nurses	Work in medical facilities and treat injured.
	6. Health departments	Provide personnel to medical facilities and check water quality.
	7. Military	Establish med-evac service for victims injured or burned.
Security	1. Police	Activate personnel to protect life and property.
	2. National Guard, military	Call out units to assist local government in protection of life and property.
Transportation	1. Departments of transportation	Call up personnel to inspect, repair, and restore roads, bridges, and other transportation facilities.
	2. Private road-building companies	Work with local government to repair roads and bridges.
	3. Railroads	Repair railroad damages and restore service to affected areas.
	4. Shipping companies	Repair piers and storage areas. Restore normal service.
	5. Trucking lines	Assist in movement of emergency supplies and materials.
	6. Bus lines	Transport emergency supplies and materials. Move victims to shelters.

1 From Gori, et al, 1982, pp 56-57.

Table 1 (Continued)

PROBLEM	RESPONDERS	RESPONSE
Communications	1. Power companies	Call out emergency work crews. Restore power to essential facilities (hospitals, government offices, shelters). Repair power plants and transmission lines.
	2. Phone companies	Repair communication links at emergency facilities. Restore normal service to customers.
	3. Radio stations	Those on the Emergency Broadcasting System (EBS), disseminate any essential notices and news bulletins which would be needed. Other stations work to restore normal operations once power supply returns.
	4. TV stations	If power is cut, TV stations will not operate. Few, if any have emergency power capable of restoring normal service.
	5. Newspapers	Newspapers will not be able to print until power is restored. Once printing, they can print notices on first aid, search and rescue, shelters, and other important messages.
	6. CB operators	Most mobile units will be able to broadcast. Air waves will be jammed with traffic. Emergency messages may be transmitted.
	7. Ham operators	Emergency networks will be activated, messages passed, welfare inquiries answered. This may be local and State governments' form of communication.
	8. Local government	Activate local Emergency Operations Center communication system.
Water	1. Utility companies	Will inspect and repair dams, reserviors, and water main lines.
	2. National Guard	Personnel will make tank trucks of water available to areas where the supply has been damaged.
	3. Tank truckers	Will provide vehicles to move tanks of water to needed areas.
	4. Army Corps of Engineers	Inspect dams and water conditions for damage. May make necessary repairs to restore normal service.
Electricity	1. Utility companies 2. Electric contractors	Activate emergency crews and assess damage to transmission and generating equipment. Restore power to priority customers throughout area.
Shelter and Food	1. American Red Cross and disaster relief agencies	Activate emergency shelter plan. Staff shelters and feed victims and workers.
	2. Schools	Call up personnel to open schools as shelters. Prepare meals for victims and workers. Have staff assist with operation.
	3. Churches, civic buildings	Open buildings as shelters and feeding facilities. Provide staff to assist in operation.
	4. Private industry	Use some suitable structures as shelters.
	5. USDA	Provide commodity foods for use in shelters and mass feeding.
	6. Supermarkets, food wholesalers	Provide food for shelters and feeding centers.

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Table 2.--Representative Data, Applications, and Information Transfer Resulting from Post-Earthquake Investigations[1]

Type of Field Investigation	Data Obtained	Application	Information Transfer
Temporary network of portable high sensitivity seismographs	Improved locations of aftershocks; corrections to travel times of seismic waves to seismic stations of the global network; mechanism of aftershocks	Identification of earthquakes with tectonic elements; direction of faulting in earthquakes; Identification of active tectonic elements through relocation of known earthquakes in the area	Technical papers; hazard maps
Temporary network of strong motion seismographs	Records of strong ground motion at short distances from earthquakes	Improved knowledge of ground motion parameters; Correlation of ground motion with damage; improved building design	Technical papers; hazard maps; building codes
Damage survey	Nature, degree, and distribution of damage to buildings, lifeline facilities and other facilities	Improved design and construction practice	Technical papers building codes; disaster preparedness studies;
Geological studies	Nature, degree, and distribution of geological effects such as faulting, landslides, liquefaction, etc.	Improved understanding of the mechanism of occurrence of faulting and other geological effects	Technical papers and popular articles; land use planning, hazard and risk studies; zoning and microzoning disaster preparedness studies

[1]From Algermissen, 1978, pp 203.

Technical Evaluations

Damaging earthquakes create a number of technical problems which will need to be addressed by scientists and engineers in order to provide critical information needed by public officials, decisionmakers, and emergency managers during the response and rescue phase. The kinds of questions that officials will ask are as follows:

1. How big will the aftershocks be and how long will the aftershocks last?

2. Which buildings are unsafe and, therefore, will need to be demolished?

3. Is dam "X" in immediate danger from future aftershocks? What do we tell the officials and people living in the area?

Earthquakes also provide unique opportunities for improving the understanding of the nature and distribution of earthquake losses. Table 2 shows the kinds of technical problems which are typically encountered following a major earthquake.

Rescue and Aid

Life saving and medical groups such as rescue squads, hospitals, clinics, fire departments, National Guard, and other military units will take part in rescuing people and giving first aid and care to the injured. Individuals usually will respond spontaneously to help search for and rescue victims buried in rubble. Construction companies with heavy equipment will also be very active in this time.

Protection of Property

Families are concerned about the safety and security of their property following a disaster, and as a result, one of the primary duties of government would be protection of homes and belongings. Police, National Guard, department of corrections, and other law enforcement agencies will have responsibility for this function.

Restoration of Transportation

Another immediate concern throughout the stricken area will be the tie-up in transportation systems which will affect the delivery of many essential services. Roads, bridges, tunnels, runways, train tracks, and piers will all possibly be altered to some extent. Government will have to be prepared to provide alternate means of transporting necessary supplies and services into and out of the earthquake zone. Private industry will be concerned with keeping their fleets active during the emergency period, both for assistance and normal business purposes. Evacuation of medical cases will be a problem of great significance that should be planned for in advance.

Restoration of Communication

Communications are another lifeline that will be hampered by an an earthquake with an epicentral intensity VIII in this region. Local power failures will be extensive. Telephone communication will be limited in many areas. Emergency responders will have to depend on radio communication through private channels, CB, and ham operators. Air waves will be jammed with all nature of important traffic. (Commercial TV and radio stations should have some sort of disaster plan which they could implement for emergencies, to include the emergency broadcast system, but most are still dependent upon the power companies to supply the electricity.) Newspapers will probably not be able to print any copy until normal power is restored, particularly with the advent of electronic word processing equipment. (Few commercial communications enterprises have emergency power supplies. Those that do need to examine the facility in which the generators are housed to be certain that they will survive the quake.)

Restoration of Water Supplies

Another lifeline of major importance is the provision of water. Water needs will be for drinking, sanitation, clean ups, fire fighting, shipping, and transportation. In order to be able to provide water in sufficient quantities, the established road system will have to be in good working order. (Tank trucks loaded with water, provided by the National Guard and perhaps even private business, could be placed in strategic locations in each community. Well water could be used once electrical power to run the pumps had been restored.)

In a disaster of this size, the resources of the local and State governments will be seriously taxed, and there will probably be a request sent to the President for a Presidential Declaration for the counties that are affected by the earthquake. This would enable a multitude of Federal agencies to respond by providing assistance to individuals, business, and local governments. Local and regional disaster relief organizations will continue to repond as in a small quake to meet emergency and immediate needs. Table 1 provides a complete discussion of the problems response groups could be asked to tackle, who would need to respond, and what type of response would be appropriate.

RECOVERY FROM AN EARTHQUAKE

Recovery from an earthquake is similar to recovery from other natural disasters. The Academy for Contemporary Problems in their Monograph, "Natural Disaster Recovery Planning for Local Public Officials," by Claire Rubin, identifies the key elements for the recovery process.

Emergency Period

For the first few days to a few weeks, attention is focused on the dead, injured, homeless, and missing. The primary activities are search and rescue, emergency mass feeding and housing, and debris removal. During this time, normal social and economic activities are disrupted.

Restoration Period

The main activity during this period is restoration of repairable public utilities, housing, and commercial industrial structures. This phase usually lasts for several months, and the end of which is marked by the return to relatively normal social and economic activities.

Reconstruction I

During this period the emphasis is on replacement of buildings with capital stock rebuilt to at least predisaster levels. During this time, social and economic activities usually return to predisaster levels or higher.

Reconstruction II

During the long-range phase, the activities focus on commemorative, betterment, and development reconstruction. The three different, but often interrelated functions of this final phase of restoration, are to memorialize or commemorate the disaster, mark the city's betterment or improvement, and serve future development.

Figure 9 depicts how long in weeks each phase generally lasts and identifies the activities which take place in each phase.

INTERGOVERNMENTAL RELATIONSHIPS

Earthquake preparedness and response requires the cooperation and coordination of many organizations, agencies, and levels of government. Coordination is difficult because of the different political and fiscal constraints, and State and Federal jurisdictions' motives, limitations, and requirements. Problems of intergovernmental coordination may be great in the Northeastern United States because the seismic risk is shared among States and Federal jurisdictions.

Local agencies involved in emergency response include those responsible for day-to-day emergency (i.e., police, fire, and emergency medical services), those responsible for planning and coordination disaster response plans (i.e., county disaster preparedness officials, the disaster preparedness offices of utilities and the director of security for the school district), and those less directly related to public safety (i.e., transportation, and city and county administratators). Also included are the quasi-public and private agencies involved in first-response (i.e., Red Cross and Salvation Army). The

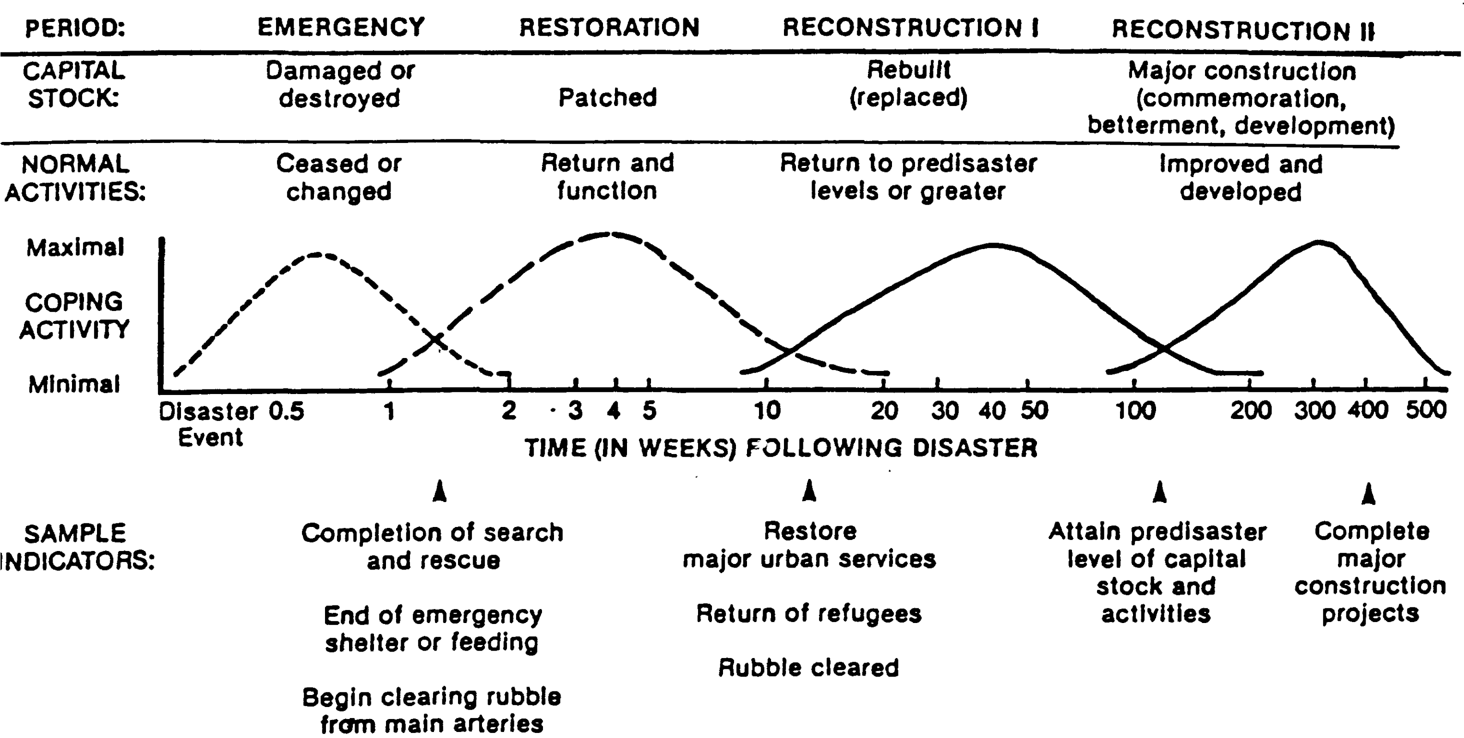

Figure 9.--Phases of Disaster Recovery (From: Natural Disaster Recovery Planning for Local Public Officials, Academy for Contemporary Problems, Washington, D.C., 1979).

services which must be provided in event of an earthquake include rescue, medical, fire fighting, shelter, food, debris, and evacuation. More coordination is necessary to reduce duplication of services, possible conflicts, and confusion, and to delineate avenues of assistance and responsibilities on local, county, State, and Federal levels.

Intergovernmental cooperation and relationships can be improved once the existing relationships between the Federal, State, and local levels of government have been clearly identified and information exchange channels between scientific and emergency preparedness communities and governmental agencies have been improved. A plan for earthquake preparedness and response will probably be a part of an all-hazards program, utilizing and coordinating existing agencies and plans.

IMPORTANT LESSONS THAT MAY BE LEARNED FOLLOWING A MAJOR EARTHQUAKE IN THE NEW YORK AREA

Since the 1964 Prince William Sound, Alaska, earthquake, many people have recognized that earthquakes provide fundamental knowledge and new insights (i.e., LESSONS). Every major earthquake teaches important lessons which scientists, planners, architects, social scientists, engineers, emergency management managers, and public officals can use to devise corrective measures. These measures can be put into practice through reseach, mitigation, response, and recovery activities.

The following list contains a summary of some of the potential lessons that may be provided by one or more major earthquakes occurring in New York during the remainder of the twentieth century or the twenty-first century on the edge of a densely populated center. These potential lessons are posed to stimulate preparedness planning; an actual earthquake will determine the extent to which the postulated lesson is accurate.

Scientific Lessons

1) Aftershocks--Major earthquakes in New York have a long aftershock sequence which caused collapse of buildings and structures which were

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weakened during the main shock. They also frightened the populace and disrupted all of the response functions. The characteristics of the aftershock sequence cannot be predicted except in general terms.

2) Epicentral Ground Shaking--Although accelerograms of ground shaking in the epicentral area of a major earthquake in New York have not yet been recorded, investigation of the types and characterisitics of damage suggest that the level of peak horizonal ground acceleration in the epicentral area has exceeded 0.25 g.

3) Soil Amplification--Damage data suggest that local soil deposits caused amplification of ground motion in selected frequency bands, causing greater damage to certain classes of structures at some locations (i.e., "hot spots"). Amplification was particularly significant at the edges of sedimentary basins.

4) Surface Fault Rupture--Surface fault rupture was a minor threat.

5) Ground Failures--More areas than originally thought have had a high potential for liquefaction and a high susceptibility for landslides.

6) Tsunamis--Tsunamis were not a threat in the New York area.

Building Damage

1) Seventy-five percent of the buildings not designed in accordance with the seismic design provisions of a building code sustained damage. Buildings designed to resist wind also suffered damage, but to a lesser degree.

2) Tall buildings located some distance from the epicentral area were prone to damage from ground shaking as a consequence of two factors: a) the low rate of attenuation of low frequency seismic waves and b) amplification of these waves by thick soil deposits, when present as part of their foundation.

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3) Critical facilities, such as dams and nuclear power plants, which were designed to withstand many types of natural and manmade disasters, performed well. Facilities needed to operate during the response phase suffered damage and reduced the efficiency of the response. Twenty percent of the hospitals, rescue squads, emergency operation centers, and police and fire departments were out of commission.

4) Single-family dwellings suffered minor damage, the most common problems were shifting on the foundation, overturned water heaters, cracked chimneys, and irrepairable damage to the contents.

5) Fires occurred in several areas simultaneously. The threat of conflageration was very great in the first 48 hours and more severe than expected, partially due to the widespread severing of waterlines.

6) Although highways were not heavily damaged, almost all the interstate traffic stopped because bridges sustained 15-35% losses due to the lack of earthquake resistant design.

Response Functions

1) The resources of State and local emergency response organizations were inadequate because prior planning had underestimated the impacts.

2) Help from the National Guard was a valuable resource to supplement all emergency response activities.

3) Individuals responded with unusual speed and initiative during the first 24 hours of the response phase, performing activities which reduced loss of life and injuries.

4) Voluntary agencies, which respond to disasters annually and which have support throughout the Nation, responded very efficiently.

Communication

1) Rumors and misinformation were the norm. Newspapers and television stations were not operating during the first 48 hours.

2) Telephone service was unavailable for 72 hours.

3) Ham operators performed a valuable service in responding to the need for communication.

Intergovernmental Relations

1) Relations between local, State, Federal governments, and Canada were ineffective during the first week due to the lack of prior agreements, intergovernmental planning, and disruption of normal communication lines. After the first week, governments began to function efficiently.

CONCLUSIONS

New York has two basic alternatives, to wait for the damaging earthquake or to learn from hypothetical scenarios. Hypothetical scenarios can be made very realistic if the lessons learned from actual earthquakes in other parts of the United States and in other Nations are incorporated into the overall planning process. Experience can be gained by visiting the location of a recent earthquake and by following the experiences of those who have "scars" from going through the real thing.

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GEOLOGICAL AND SEISMOLOGICAL METHODS FOR ASSESSING POTENTIAL EARTHQUAKE DAMAGE

by

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INTRODUCTION

Before earthquake preparedness plans can be made, it is necessary to assess the potential for earthquake damage in an area. Before this potential damage assessment can be made, it is necessary to define the expected earthquakes to be considered. In order to do this we need to know: (1) where in the area do earthquakes occur?, (2) how large may they be?, (3) how often do they occur?, and (4) how far away from the epicenter may they cause damage (i.e., what is the distribution of effects, or how fast do the intensities attenuate?) In a simulation study, a hypothetical earthquake is chosen for study based on knowledge of the seismicity of the area, that is, on the first three of these items. An isoseismal map for that hypothetical earthquake is then created based on information about the intensity distributions of historical and modern earthquakes in the area, that is on the fourth item. To see how this information is obtained we will look at: (1) geological evidence of earthquakes and their effects, (2) historical evidence of earthquakes and their effects, (3) modern evidence of earthquakes and their effects, and we will use this evidence for (4) choice of simulated earthquakes and estimation of their effects.

CHOOSING THE EARTHQUAKE TO SIMULATE: WHERE, HOW LARGE, AND HOW OFTEN

Evidence from geology and from historical and modern seismicity and seismic intensities can be used to estimate the potential locations, magnitudes, recurrence rates of simulated earthquakes.

Location, magnitude, and recurrence rate of earthquakes using geological evidence. Earthquakes occur on faults, and studies of those faults can tell us much about the earthquakes that occur on them. Locations of the faults can be used to delimit seismic source zones. Magnitude of a fault's offset or length of fault break can be used to estimate how large an earthquake can occur on the fault. A recurrence rate for earthquakes on the fault can be estimated by dating offset structures. Faults at depth beneath the surface of the earth can be studied using geophysical means, such as seismic reflection profiling.

Location, magnitude, and recurrence rate of earthquakes using historical seismicity and intensity studies. Historical seismicity maps show earthquakes plotted where their greatest effects were reported, not necessarily where the epicenters really were. Similarly, the maximum intensity is often the maximum intensity reported, not necessarily the true maximum intensity. Often earthquakes occurred in wilderness areas with no one available to record an account. Even with well-studied earthquakes today, an instrumental epicenter may be as much as 50 km from the location of greatest effect or maximum intensity. Therefore, historical earthquakes give a very good general idea of the areas of most important seismicity, but are not very accurate for defining the boundaries of seismic source zones. Modern researchers compiling catalogs and isoseismal maps of historical earthquakes will frequently try to locate the epicenters of such shocks on nearby known active faults. In many cases the previously listed epicentral location was precisely on the latitude and longitude degrees, or the earthquake was placed at the latitude and longitude of the city reporting the greatest effects. The shock may be mislocated by more than a degree (over 100 km, over 60 miles).

Magnitudes of pre-instrumental earthquakes are most frequently estimated from the maximum intensities of the earthquakes. This is the easiest method, but not the most desirable. The maximum intensity may not have been reported, because no one was at the point of maximum effect to report it, making the shock appear in the catalog as smaller than it actually was. Conversely, a value higher than the actual maximum intensity may have been assigned by modern researchers to old accounts because the accounts often tend to exaggerate, and report only the most exciting happenings, and the most

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spectacular damage, ignoring that which was not damaged. Error can also result from conversion from other intensity scales, such as the Rossi-Forel Intensity Scale, which was widely used in the United States before 1931. In some cases, assigned Rossi-Forel intensities survive, while the original accounts of the earthquake effects are lost. This is especially a problem when the original intensities (Rossi-Forel or Modified Mercalli) were assigned on the basis of ground effects alone, which are listed in the intensity scales at much higher levels than the lowest intensities that can cause those ground effects. When this happens with large, old earthquakes it commonly leads to higher intensities than probably would have been assigned had there been damaged structures in the area on which to base intensity estimates. Differences in estimating magnitudes based on such intensities may be as much as one magnitude unit (and in extreme cases as much as two magnitude units). Better estimates of intensities of old earthquakes can be made if all the original accounts are available. If enough evidence remains to make a map of the felt area of an old earthquake, a better estimate of that shock's magnitude can be obtained by comparing that felt area to the felt areas of modern earthquakes of known magnitude in the same region. Similarly, an even better comparison can be made from an isoseismal map of the old shock.

Recurrence rates, or return periods, of earthquakes of various sizes can be obtained from catalogs of historical shocks in a region. A recurrence curve is a plot of cumulative number of earthquakes for each magnitude. In using a recurrence curve for a region it should be kept in mind that the catalog is not as complete for small shocks as it is for large shocks. That is, in a given region, all the earthquakes of maximum intensity VIII M.M. may be known back to 1600, while the maximum intensity V shocks are thought to be known completely only back to 1920. In another part of the country, settled later, the comparable dates, might be 1890 and 1940. Conversely, the largest shock that can occur in a region may not have occurred during historical times at all. It is useful to have an estimate of the completeness of the catalog for each size of earthquake.

<u>Location, magnitude, and recurrence rate of earthquakes using modern seismicity and intensity studies</u>. Instrumentally located epicenters are much more precise than those located from reported effects. Seismic networks

deployed immediately after moderate to large earthquakes today can locate aftershocks to within one to two kilometers in horizontal location and two to four kilometers in depth, depending on the site and placement of the network. The plane of the rupture and the direction it moved can be established with such a network by plotting depth cross sections and focal mechanisms. Seismic source zones for active areas can be established with much more precision than was possible with only pre-instrumental earthquake epicenters.

Magnitudes are commonly calculated both from the short-period waves that travel through the body of the earth (m_b), and from the long-period waves that travel along the surface (M_S). The same type of magnitude calculated by two different stations will usually agree with each other to within 0.5 of a magnitude unit. This is a considerable improvement over the worst case of magnitudes estimated from historic maximum intensities.

In many regions of the United States local seismic networks have been established because of siting requirements of critical facilities such as nuclear reactors. Accumulation of data from these networks gives a very good description of the low-magnitude end of the recurrence curve for the region. Evidence about the recurrence rates for the larger shocks is being found from modern techniques of geological and geophysical research.

Location, magnitude, and recurrence rate of simulated earthquakes. It is assumed that locations of past earthquakes are likely to be locations of future earthquakes. This is reasonable since the strains in a region, resulting from tectonic changes in the crust, or plate movements, happen on a geologic time scale. Thus an historical record of a few hundred years will not be significantly affected by such changes. However, all locations having strain accumulation sufficient to cause a future large earthquake are not known. Occasionally, a large earthquake occurs on a previously unknown fault. Occasionally also, a large earthquake occurs on a known fault that was not previously thought to be active.

The size of an earthquake can be described in terms of its magnitude, or in terms of the maximum of the intensities known to have been produced by the shock. Maximum intensity can be converted to magnitude for uniformity of

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notation between historical, or pre-instrumental, and modern earthquakes. If an area has experienced a great earthquake, such as the New Madrid earthquake of 1812, then the largest earthquake likely in that region is already known. The potential for smaller magnitude shocks in the same region can be judged from the recurrence curve for the region. Additional estimates can be made from the lengths of known faults in the region, both mapped surface faults and faults inferred from other methods such as seismic reflection profiling.

The recurrence curve for a region will give the return period of the shock to be simulated. Simulation of several sizes of shocks in the same location is desirable, since the largest potential earthquake will have a very long return period, but smaller shocks occur more frequently.

INTENSITY DISTRIBUTION FOR THE SIMULATED EARTHQUAKE: ATTENUATION

Once the earthquake to be simulated has been chosen, the distribution of its effects, or attenuation of its intensities must be estimated. Attenuation of intensities depends on the source (magnitude, focal mechanism, etc.), the path from the source to the site of the effect (distance, geology, region, etc.), and the site itself (amplification of vibrations due to geologic, hydrologic, and topographic factors, etc.).

Attenuation of intensities using geological evidence. How far may damaging intensities extend? Evidence of ground effects, such as landslides or liquefaction, from very large and great earthquakes is often still visible. Since the effects leaving traces are usually indicators of fairly high intensities, the extent of their occurrence can be used to limit the distribution of the higher intensities in areas susceptible to these effects.

Attenuation of intensities from historical earthquake intensity studies. There are a few large old earthquakes in the United States for which there exist only one to three accounts at different locations. For these, no isoseismal map can be made, and even the epicenter is in considerable doubt. For the rest of the historical earthquakes, at least a smooth, undetailed isoseismal map can be plotted. At minimum, such a map shows the felt area and the epicentral region. At best, it may have contours for each intensity level. The isoseismals, or contours, on maps of older earthquakes are usually smooth, because of a lack of sufficient data to contour in detail.

Isoseismals of the largest old earthquakes are invaluable for calculating the attenuation, or rate of fall-off with distance, of intensities for large shocks in a region. The largest magnitude shock in the earthquake catalog of a region is usually an old one. In most cases, outside of California, there is no large, modern shock of comparable magnitude to use for estimating intensity attenuation rates in an area. Therefore, the rate of intensity attenuation for a great earthquake must usually be obtained from an old earthquake. For more detail in the intensity attenuation pattern, better studied modern shocks must be used.

Attenuation of intensities using modern earthquake intensity studies. The U.S. Geological Survey sends out intensity questionnaire cards to post offices after all felt earthquakes. The returned cards are assigned intensities and, for the larger shocks, plotted on a map and contoured to make isoseismal maps. Larger shocks are also investigated in the field by damage surveys. Intensity attenuation for these earthquakes is well known, not only the rate of intensity attenuation, but also the patterns that develop, such as high intensities for unusually long distances along alluvial river valleys. Isoseismal maps for modern, carefully studied earthquakes can be detailed enough to show interesting patterns, rather than being smooth and generalized as the isoseismals for the old earthquakes had to be. As more such maps become available, better estimates can be made of the areas prone to high or low amplifications from regional or distant earthquakes.

Attenuation of intensities of simulated earthquakes. Estimates of intensity patterns for hypothetical earthquakes are based on several different factors. Once the size and location of the shock to be studied have been decided, isoseismal patterns of real earthquakes (often smaller than the earthquake to be simulated) are gathered. The rate of attenuation from these known shocks, and the isoseismal patterns themselves can both be used to estimate the isoseismals for the simulated earthquake. Geologic information can also be used to determine areas of potentially higher or lower susceptiblilty. Areas prone to landsliding or possible liquefaction can also be included. Together these factors can be used to generate an isoseismal map for a hypothetical earthquake.

CONCLUSIONS

In many areas of the United States the largest earthquake that is thought possible in the region either has not been experienced in historical times, or was experienced so long ago that the area was sparcely inhabited and there were few structures to be damaged and few records kept. Areas that have been built up since the last earthquake large enough to cause structural damage (maximum intensity VIII or greater), are particularly susceptible to future earthquake damage. Outside of California, few such areas have building codes requiring design for earthquake resistance, and most do not have plans for earthquake preparedness.

Studies simulating the potential damage patterns for hypothetical earthquakes in an area are useful tools for disaster planners. Such simulations should include not only the largest earthquake deemed likely in the area, but also one or more of the smaller, but more frequent, earthquakes capable of causing damage in the area.

Fragility Curve Characterization

of

Earthquake-Induced Damage

by

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Background

In order to assess emergency management needs immediately after a major earthquake, it is necessary to make some determination of the potential number of casualties, the availability of major life-line systems (such as highways, communication networks, and water supply systems), the availability of emergency services (such as hospitals), and the consequences of possible secondary disasters (such as seismically-induced dam failures). Management planning also requires an assessment of the expected long-term needs for restoration of damaged facilities. To do this, a methodology that is equally capable of assessing the likelihood and degree that hospital services will be available after an earthquake, and estimating the financial impact of hospital losses is required. A procedure is described that possesses these capabilities and is applicable to regional and structure-specific loss estimation.

Although earthquake-induced damage and failure of a structure may result from a variety of mechanisms (i.e., foundation failure due to liquefaction, foundation displacement caused by fault break or landslide, etc.), damage is principally due to ground shaking. As a result of ground shaking, vibration is developed in a structure. Due to their inherent dynamic characteristics, the level of vibration in a structure is generally greater than the level of shaking in the ground. When the level of vibration in a structure is small, damage is minor or does not occur at all. At larger levels of vibration, damage becomes more significant and failure more likely.

It is difficult to predict the actual damage that a structure will incur when exposed to a particular level of ground shaking. The difficulty arises because of, (1) the uncertain influence of design and construction irregularities, (2) variability in material properties, (3) uncertainty in structural response to earthquake-induced shaking, and (4) uncertainty in the level of ground shaking that will cause a structure to fail. However, it is possible to define a range of ground shaking over which damage and failure can occur. Within this range, the assessment of the likelihood of damage increases from a probability of zero (i.e., no chance of damage) to a probability of one (e.g., certain failure).

The relationship which describes the probability of failure at various levels of ground shaking is known as a fragility curve. Figure 1 shows an example of a fragility curve. For the purpose of emergency management planning, fragility curves can be used in conjunction with estimates of the severity of ground motion intensity, to predict the probability that a structure will be damaged or fail.

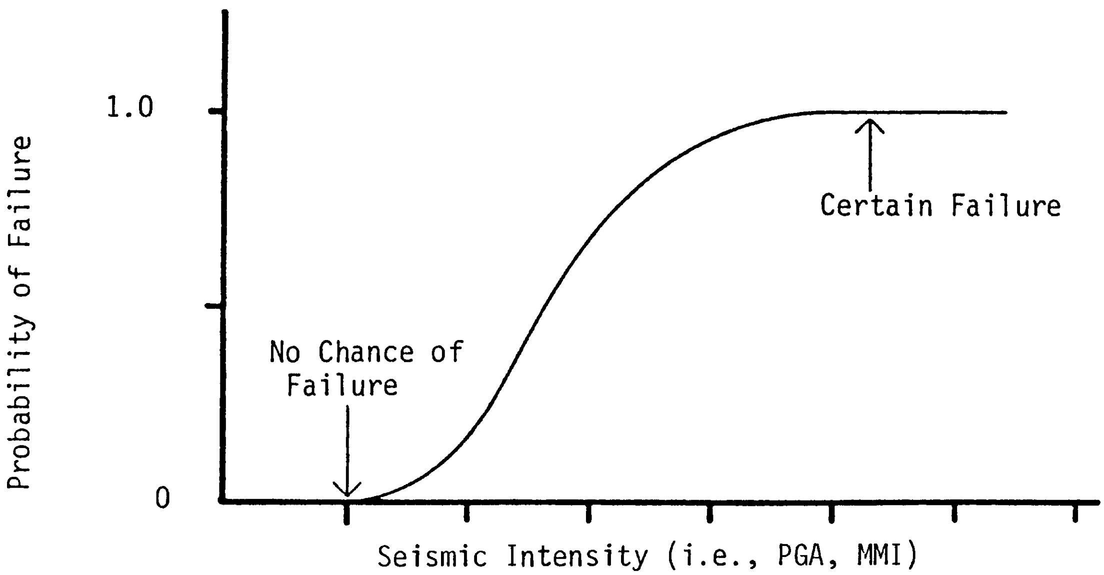

FIGURE 1 EXAMPLE OF A FRAGILITY CURVE

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The intensity of ground shaking is most commonly expressed in terms of the peak ground acceleration (PGA); however, Modified Mercalli Intensity (MMI) can be used as well. Peak ground acceleration is the maximum value of ground shaking recorded by an instrument known as an accelerograph. It is preferred by engineers to describe seismic loads and is the most commonly used parameter to characterize ground shaking. Modified Mercalli Intensity on the other hand is a subjective measure of the level of ground shaking that ranges numerically from I to XII. Each value on the MMI scale corresponds to observations of damage and sensations experienced as a result of an earthquake. For earthquakes with recordings of PGA and MMI, a correlation between these parameters has been observed. Table 1 provides a description of the Modified Mercalli Intensity scale and a range of PGA values for each intensity.

As part of the Central United States Earthquake Preparedness Project (CUSEPP) sponsored by the Federal Emergency Management Agency (FEMA), fragility curves were developed as the principal means to predict the likelihood of damage. For CUSEPP maps of the ground motion intensity (MMI) corresponding to a New Madrid earthquake were provided by the U.S. Geological Survey.

Fragility Curve Description

A fragility curve can be used to represent failure of a specific structure, a structural system, or a generic structure type. Fragility curves can be prepared in two basic formats: one format which describes the probability of failure for "all" structures of a given type (e.g., all bearing wall

TABLE 1
MODIFIED MERCALLI INTENSITY SCALE

Intensity	Description	PGA Interval [1] (g units)
I.	Not felt except by a few under especially favorable conditions.	< 0.03
II.	Felt only by persons at rest in places such as upper floors of buildings. Delicately suspended objects swing.	< 0.03
III.	Felt by many persons in places such as upper floors of buildings but of a degree that most persons do not recognize it as an earthquake. Standing automobiles may rock slightly as if from vibration caused by a passing truck. Duration may be measured.	< 0.03
IV.	In daytime, felt by many indoors but by only a few outdoors. Dishes, windows, doors disturbed, and walls creak. Sensation like a heavy truck striking a building. Standing automobiles rocked considerably.	0.03
V.	Felt by all, many awakened. Some dishes and window glasses broken, wall plaster may crack. Unstable objects overturned. Disturbance of telephone poles, trees and other tall objects sometimes noticed. Pendulum clocks stopped.	0.03-0.08
VI.	People are frightened and run outdoors. Heavy furniture may be moved; some instances of fallen plaster and toppling of chimneys. Slight damage.	0.09-0.15
VII.	Everybody runs outdoors. Damage negligible in buildings of good design and construction, slight to moderate in ordinary structures, and considerable in poorly built or badly designed structures. Chimneys broken. Felt in moving automobiles.	0.16-0.25

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TABLE 1 (CONTINUED)
MODIFIED MERCALLI INTENSITY SCALE

Intensity	Description	PGA Interval [1] (g units)
VIII.	Some damage even in buildings of good design and construction. Considerable damage in ordinary buildings, with some collapsing. Great damage in poorly constructed buildings. Panel walls thrown out of frame structures. Falling of houses and factory chimneys, columns, monuments and walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Hinders driving of automobiles.	0.26-0.45
IX.	Damage considerable in buildings of good design and construction. Structures thrown out of alignment with foundations. Ground cracked conspicuously. Underground pipes damaged.	0.46-0.60
X.	Wooden houses of good design and construction collapse. Most masonry and frame structures destroyed together with foundations. Ground cracked causing damage. Rails bent. Slopes and embankments slide. Water surface rises.	0.61-0.80
XI.	Almost all masonry structures collapse. Bridges destroyed. Fissures over entire surface of ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent prominently.	0.81-0.90
XII.	Damage total. Waves seen transmitted at ground surface. Topography changed. Objects thrown into air.	>0.91

1 Acceleration ranges taken from Reference 1.

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buildings), and on a structure-specific basis. Fragility curves developed for "all" structures of a given type are useful in performing regional earthquake damage studies where the objective is to make global, as opposed to specific, loss estimates. As discussed in the next section, the methodology to develop structure fragility curves can also be responsive to the need to make damage assessment for individual structures. In this case, the specific structural capacity of a building to withstand the effects of earthquake ground shaking are taken into account.

Traditionally, fragility curves assume a structure to be in one of two possible states: completely failed or not failed. For some structure types, such as electrical switchyard equipment, two-state modeling accurately represents observed failure patterns. However, for most structures, and especially buildings, damage occurs in varying degrees from no damage to collapse.

To describe multiple damage states for buildings (and other structure types), fragility curves can be developed which quantify the probability of reaching one of five damage states: nonstructural, slight, moderate and severe structural damage, and collapse. These five damage states are described in Table 2. As mentioned previously, for structures such as electrical switchyard equipment, which respond with either no damage or complete failure, a single damage state (i.e., collapse) was used.

The function of each fragility curve is to quantify the likelihood of reaching or exceeding a particular damage state, given the severity of the ground motion. For example, the likelihood of building collapse (and,

TABLE 2
DAMAGE CATEGORIES[1]

Response Level		Damage Category	Extent of Damage in General	Suggested Post-Earthquake Actions
	0	No Damage	No Damage	No Action Required
Elastic	I	Slight Non-structural Damage	Thin cracks in plaster, falling of plaster bits in limited parts.	Building need not be vacated. Only architectural repairs needed.
Inelastic (yielding of some elements)	II	Slight Structural Damage	Small cracks, in walls, falling of plaster in large bits over large areas; damage to non-structural parts like chimneys, projecting cornices, etc. The load carrying capacity of the structure is not reduced appreciably.	Building need not be vacated. Architectural repairs required to achieve durability.
Inelastic (general yielding)	III	Moderate Structural Damage	Large and deep cracks in walls; widespread crack of walls, columns, piers and tilting or falling of chimneys. The load carrying capacity of the structure is partially reduced.	Building needs to be vacated, to be reoccupied after restoration and strengthening. Structural restoration and seismic strengthening are necessary after which architectural treatment may be carried out.
Ineleastic (ultimate of some elements)	IV	Severe Structural Damage	Gaps occur in walls; inner or outer walls collapse; failure of ties to separate parts of buildings. Approximately 50% of the main structural elements fail. The building takes a dangerous state.	Building has to be vacated. Either the building has to be demolished or extensive restoration and strengthening work has to be carried out before reoccupation.
Inelastic (ultimate all main elements)	V	Collapse	A large part or the whole building collapses.	Clear the site and rebuild.

[1] Damage Categories taken from Reference 2.

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consequently, the likelihood of related casualties) is dependent on the level of ground shaking. At very low levels of ground shaking, one can be almost certain that the building would not collapse. Conversely, at very high levels of shaking, one can be reasonably sure that collapse would occur. Between these extremes it is uncertain as to how severe the damage to a building would be. The absolute likelihood of collapse at any level of shaking depends on details of design, construction, and earth movement that are not known exactly for a hypothetical earthquake. The function, in this case, of the fragility curve is to assign probabilities of collapse, taking into account each source of uncertainty.

Fragility Curve Development

A fragility curve can have any shape that increases in value from 0 to 1. It is generally assumed that the peak ground acceleration at which a structure is damaged has a lognormal distribution. The lognormal distribution is a smoothly varying function defined by two parameters: a median value and a standard deviation. The median peak ground acceleration establishes where the fragility curve is centrally located and corresponds to the acceleration level resulting in a 0.50 probability of failure. The standard deviation, on the other hand, establishes the spread or range of the fragility curve and accounts for the variability in the estimate of structural capacity.

It is difficult to estimate the likelihood of damage to structures exposed to ground shaking. For the most part, there is limited data with which to develop empirical damage prediction models. A useful approach is to develop fragility curves based on a combination of calculations, engineering judgment, and damage data from past earthquakes. In essence, two parallel assessments can be made, one based on calculations and one based on data, to determine the fragility parameters. The first approach relies on calculations (and engineering judgments) to develop fragility parameters for specific building geometries, materials, etc., which were deemed to best represent the characteristics of structures found in a given region. The second approach relies on the analysis of damage data from past earthquakes. The results are used to establish a composite estimate of the fragility curve parameters by subjectively weighting the individual parameter estimates. In this manner, the fragility curves developed for structures in a region represent the seismic design characteristic specific to that area, while being calibrated by the general pattern of observed earthquake damage.

Fragility Curve Illustration

Figure 2 illustrates fragility curves developed for the CUSEPP for "all" wood frame buildings. The meaning of the fragility curves may be illustrated by examining values extracted from the slight structural damage fragility curve shown in Figure 2. Referring to the figure, consider an earthquake intensity of MMI VI. According to the fragility curves shown, it is almost certain that only nonstructural damage would occur to a typical wood frame building. Therefore, the probability of slight structural or greater damage at MMI VI is 0.0. For an earthquake intensity of MMI XII, it is almost certain that there would be at least slight structural damage to a wood frame building. Therefore, the probability of slight damage at MMI XII is 1.0. At

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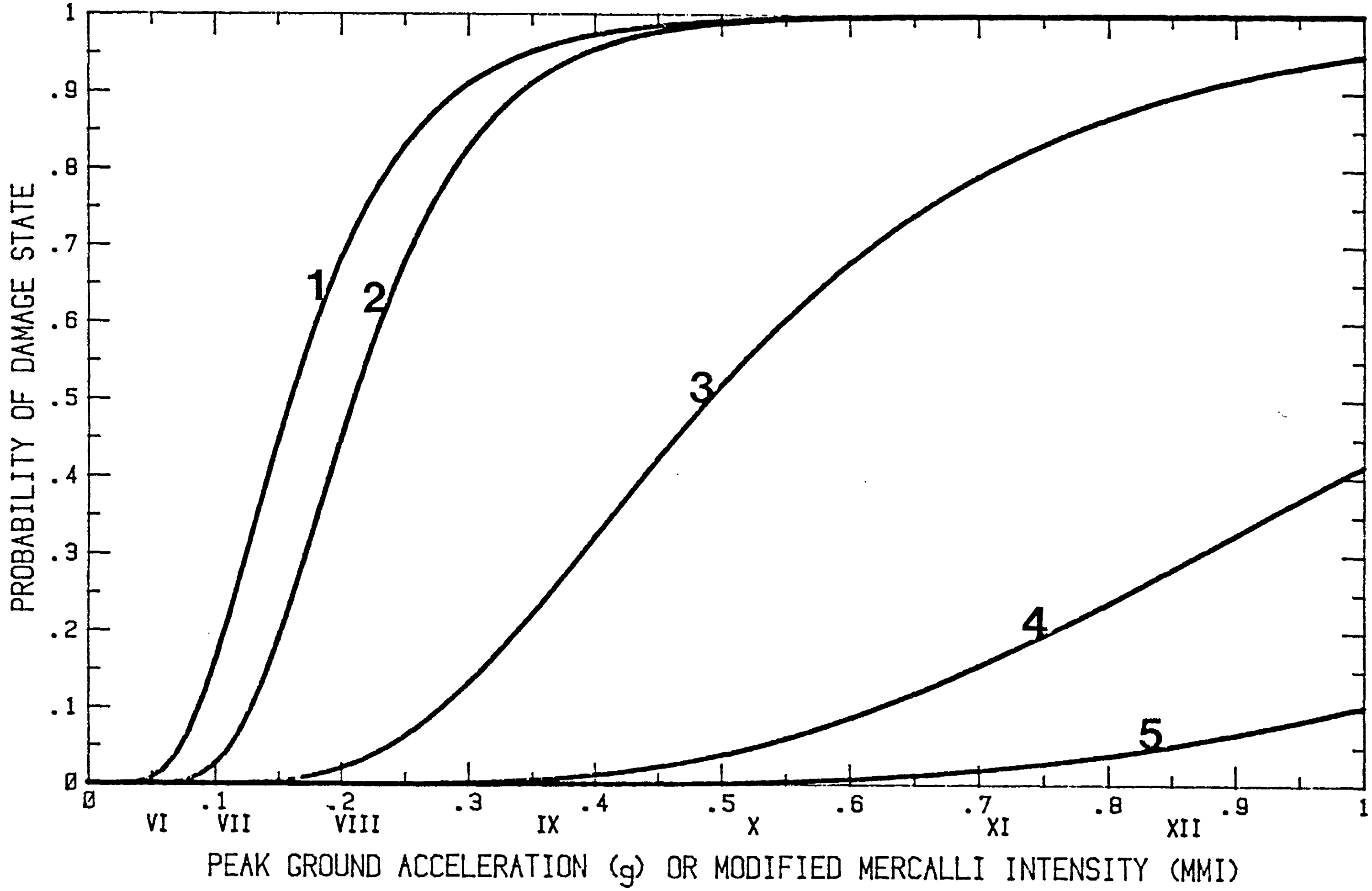
STATE	1 - NONSTRUCTURAL	2 - SLIGHT	3 - MODERATE	4 - SEVERE	5 - COLLAPSE
MEDIAN	Ø.16g	Ø.21g	Ø.49g	1.1Øg	1.76g
STD. DEV.	Ø.47	Ø.38	Ø.44	Ø.45	Ø.45



STRUCTURE TYPE : ALL WOOD FRAME BUILDINGS

FIGURE 2 FRAGILITY CURVES FOR "ALL" WOOD FRAME BUILDINGS

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intermediate earthquake intensities, the probability of slight damage is greater than 0.0 and less than 1.0. For example at MMI VIII, the probability of at least slight damage is approximately 0.45. This means that if a wood frame building is subjected to an MMI VIII shock 100 times, it would be reasonable to expect at least slight structural damage on 45 of those occasions. Similarly, if one had 100 wood frame buildings in a region that were all subjected to an MMI VIII shock, then one might reasonably expect that 45 of the buildings would suffer at least slight structural damage.

At any given intensity there is a higher likelihood of moderate structural damage than of severe structural damage, a higher likelihood of slight than moderate, etc. Thus, for a wood frame building of unknown quality (i.e., Figure 2) and earthquake intensity MMI IX, there is:

a 0.95 probability of at least nonstructural damage,
a 0.91 probability of at least slight structural damage,
a 0.23 probability of at least moderate structural damage,
a 0.01 probability of at least severe structural damage,
a 0.00 probability of collapse.

Hence, for a given earthquake intensity, the fragility curves provide a measure of the likelihood of reaching or exceeding each damage category.

For purposes of estimating long-term emergency management needs (e.g., disaster relief for restoration) it is equally important to estimate the expected financial losses. With appropriate information on the replacement value of each structure type, the fragility curves can be used directly to estimate the financial impact of an earthquake. The expected financial loss associated with the damage to a structure can be computed at a given intensity level as the sum of the average dollar loss for each damage state (i.e., the average damage ratio for a damage state times the replacement value of the structure), weighted by the probability of the damage state. The total expected loss due to structural damage is a sum of the expected losses for all structures of a given type and all structure types.

Summary

A methodology to estimate the damage associated with earthquake ground shaking based on the concept of seismic fragility was described. A seismic fragility curve provides an estimate of the likelihood that a structure will experience a particular level of damage as a function of peak ground acceleration. It is based on a combination of calculations, engineering judgment, and damage data from past earthquakes. In a recent application, fragility curves were developed for a total of 16 structure types for the CUSEPP.

The fragility curve format of estimating earthquake damage is advantageous in that it can provide an evaluation of the likelihood that levels of damage would be incurred, as well as offer an estimate of the expected financial losses. Each type of information is a necessary part of short- and long-term emergency management planning.

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AN OVERVIEW OF THE MASSACHUSETTS
EARTHQUAKE PREPAREDNESS PROJECT

by

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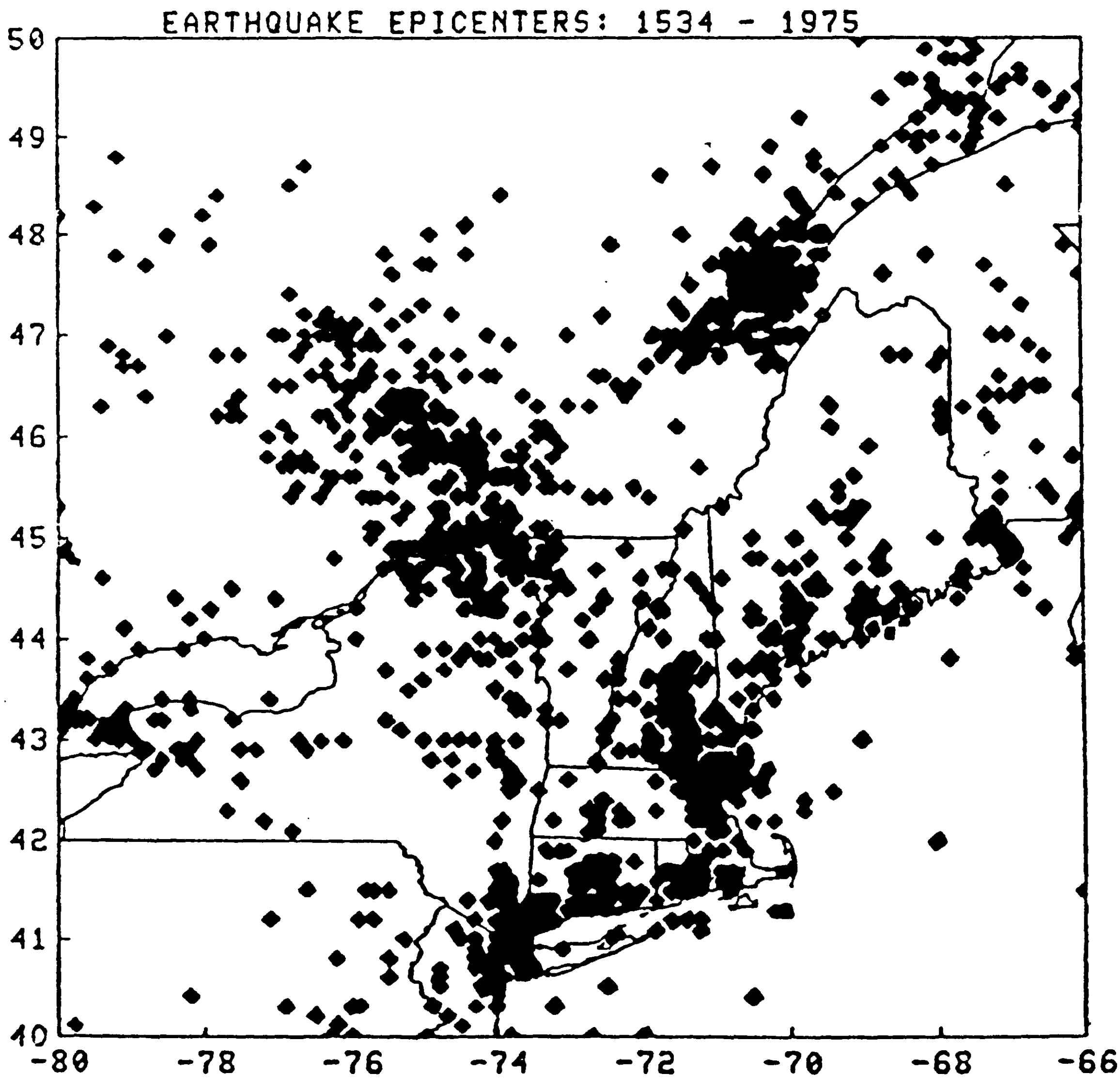
With most of the earthquake attention in the United States centered in California around the San Andreas fault, the question of the earthquake potential in New England has been largely a neglected subject.

The New England area, including the State of Massachusetts, has one of the longest histories of reported earthquake activity in the nation. Accounts of earthquakes can be found in the diaries and journals of the first explorers of the area. This 350 year record of seismic activity, including both the historic record and high quality instrumental data gathered over the past ten years, clearly document the earthquake hazard in Massachusetts (see attachment 1). This long history includes many small and a number of more significant events. Perhaps more than any other events, the earthquakes off Cape Ann on November 9, 1727 and November 18, 1755, have served to classify eastern Massachusetts as an area with the potential to suffer future damaging earthquakes.

Based on those earthquakes and a continuing history of lesser seismic events in the Massachusetts region, studies have shown that there is a recognized potential for a serious earthquake. Reviews of sites and construction types in the area demonstrate that most buildings and the surrounding infrastructure were designed and build before there was any serious concern for the effects of a damaging earthquake. Consequently the region may have a serious risk of damage, injury and disruption if subjected to an earthquake equal to or greater than the one that occurred in 1755.



Attachment 1

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In recognition of the need for comprehensive plans for a major earthquake catastrophe, in 1981, the Massachusetts Civil Defense Agency and Office of Emergency Preparedness (MCDA) applied for and was awared an Earthquake Vulnerability and Loss Analysis Grant from the Federal Emergency Management Agency (FEMA) to initiate an Earthquake Preparedness Project.

The major objectives and goals of the project are as follows:

1. To prepare a detailed Risk Analysis Study for New England with a special focus on eastern Massachusetts.

2. To prepare isoseismal maps for eastern Massachusetts.

3. To conduct a detailed Loss Analysis Study in eastern Massachusetts.

4. To increase earthquake hazard awareness.

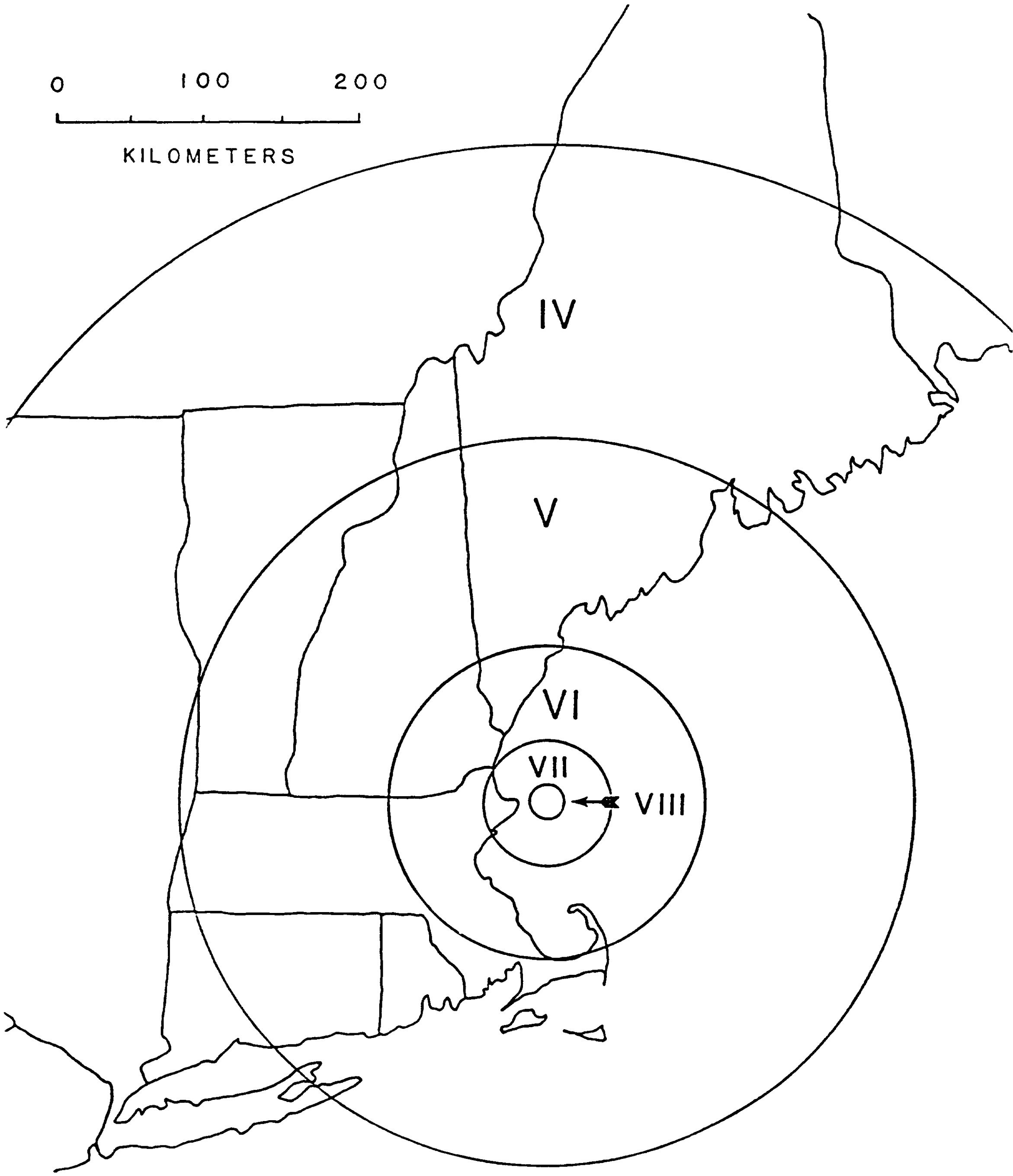
5. To develop comprehensive earthquake preparedness plans at the state and local levels.

The State of Massachusetts began this project by assembling a 15 member committee consisting of prominent engineers, architects, seismologists, and earth scientists from Harvard University, Massachusetts Institute of Technology, Weston Observatory and Weston Geophysical Research, Inc.

The Committee began its work by initially establishing a Seismic Risk Analysis Subcommittee. The Subcommittee, chaired by Dr. Nafi Toksoz of MIT, was assigned the task of completing the Risk Analysis Study with a special focus on eastern Massachusetts. After numerous meetings and several months of intensive work, the Subcommittee issued a final report titled, The Seismicity of New England and the Earthquake Hazard in Massachusetts.

The Subcommittee's findings supported the earlier classification that Massachusetts and New England are regions of moderate earthquake hazard and recommended that a full Loss Analysis Study should be undertaken for the eastern Massachusetts area. The Subcommittee recommended that the project earthquake should be the November 18, 1755 Cape Ann event (see attachment 2). Based upon this recommendation the MCDA, in conjunction with FEMA Region I, decided to proceed with the Loss Analysis Study.

SOURCE AREA: OFF MA COAST
MAGNITUDE 6 1/4 mb
INTENSITIES ON AVERAGE FOUNDATION CONDITIONS



Attachment 2

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As the first phase of the Loss Analysis Study the MCDA awarded a contract to the geotechnical consulting firm of Haley & Aldrich, Inc. to prepare detailed isoseismal/geologic conditions maps of eastern Massachusetts.

The purpose and intent of these maps was to expand upon the preliminary isoseismal maps contained in the Final Report of the Risk Analysis Subcommittee. Those maps indicated the predicted isoseismal intensity rings along with predicted unit increases due to soil and geologic conditions.

These more detailed maps expanded upon the preliminary maps in the following specific areas:

1. A more accurate (scale) representation of the varying Modified Mercalli Intensity zones, based upon a replication of the Cape Ann event on November 17, 1755.

2. The region analyzed was expanded to include all of eastern Massachusetts.

3. The scale of the maps was 1:250,000 for regional maps, and 1:25,000 quadrangle sheets for all areas identified on the 1:250,000 map as having a potential of MII VIII or greater.

This mapping study was required to preliminarily identify and quantify potential communities and regions for Loss Study purposes. They will also be extensively utilized by the contractor to assess the location of critical facilities (ie. gas lines, roadways, hospitals, etc.) in reference to Modified Mercalli intensity zones. Finally, they will be incorporated into future contingency planning so that the State and affected communities have a hazard mapping for earthquake.

It should be noted that while the scale of the 1:25,000 maps denotes street level data, site specific engineering studies to be conducted in the Loss Study will more accurately determine the seismic vulnerability of critical facilities and lifelines. The maps will be used only to approximate potential impact.

At the present time the status of the Earthquake Preparedness Program in Massachusetts is that a Request for Proposals for the Loss Study has been prepared and will be offered early in 1985. This will be followed by acceptance of bid proposals and the final awarding of the contract. It is anticipated that Phase II of the Loss Study involving Metropolitan Boston will take 12-18 months to complete.

The Metropolitan Boston area was chosen as the study area primarily because of the unstable soils conditions, high population density and the character of the building stock which includes many masonry buildings which date from the 19th and early 20th century. This study is necessary to provide some of the basic information required by MCDA to formulate state and local earthquake disaster preparedness plans consistent with the FEMA Integrated Emergency Management Systems (IEMS) concept. In order to be useful and provide realistic information, the disaster preparedness plans must reflect the consequences of a credible earthquake within the region under study. Accordingly, the emergency response plans are not intended to be checklists of generalized conditions which must be addressed, but rather represent strategies that are directly related to the special character and circumstances of the area for which they are designed. The emergency response plans required to be effective in coping with a magnitude 6.2 earthquake occurring off of the coast of Massachusetts would be expected to be significantly difference from those appropriate to a similar sized event on the San Andreas fault. Because of the different building stock, soil character, construction methods, infracstructure development, transportation network and many other special characteristics of the area, this study will reflect the consequences of the postulated earthquake as they affect the Metropolitan Boston area. Subsequent phases involving the areas north and south of Boston will be dependent upon the availability of Federal funds.

In addition to these technical accomplishments of the Earthquake Preparedness Program in Massachusetts, we are proud to be taking a leadership role in earthquake hazard awareness in New England and the Northeast.

In November of 1984 FEMA Region I, the New England Governor's Conference and MCDA held a regional conference designed to provide a forum for discussion of the appropriate roles of various levels of government, private industry and other institutions in New England regarding earthquake hazards management. The conference was extremely successful and productive and a final report is being prepared for publication early in 1985.

One of the major recommendations of the conference was to establish a New England based seismic advisory committee similar to those in other parts of the country. This committee will provide technical assistance and increased public awareness to the New England region in many areas including, but not limited to, the following:

1. Defining and understanding the seismic hazard in New England
2. Building Code and Building Design Practices
3. All phases of Emergency Management including mitigation, preparedness, response and recovery.
4. Earthquake Hazard Awareness

Finally, the MCDA had pending for Federal funding a proposal to establish a "Multi-Point Dedicated Emergency Earthquake Communications Link."

This proposal resulted from the January 1982 events in New Brunswick, Canada and Laconia, NH. At that time contact with the seismological observatories in Massachusetts was next to impossible due to their phone lines being jamm3ed by calls from the news media, concerned citizens as well as other inquiries.

This proposed link will alleviate this breakdown in communication between the MCDA, FEMA, Weston Observatory and Massachusetts Institute of Technology. The observatories can provide critical information in a short time as to the location of the earthquake, its magnitude, anticipated aftershocks, etc. This information is essential if the government is to advise the public with timely factual and accurate public information.

In summary, the Massachusetts Earthquake Preparedness Project was made great accomplishments. We have developed a comprehensive program that

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simultaneously integrates both the technical and public awareness aspects of an Earthquake Preparedness Program.

This task is challenging in Massachusetts where the earthquake risk is not well recognized and preparedness efforts are new and uncommon. However, we feel that this innovative approach will provide a solid foundation for the development of workable emergency preparedness plans designed to protect the public safety, should a damaging earthquake once again affect Massachusetts.

EMERGENCY RESPONSE PLANNING
IN NEW YORK STATE

by

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I. INTRODUCTION

Today we will look at the status of emergency planning as it pertains to developing response capabilities which could be applied to earthquake occurrences. Our review will focus on three areas:

1. The Integrated Emergency Management System (IEMS) and FEMA's all-hazard philosphy.

2. The Hazard Identification Capability Assessment (HICA) and Multi-Year Development Plan (MYDP).

3. The status of Federal, State and local emergency planning.

II. IEMS

In the past, Federal emergency planning has been hazard specific concentrating primarily on attack or wartime preparedness. Over recent years, however, a philosophy developed at the Federal level that previously existed at the State and local government level.

- That planning for events that really happen develops capabilities better, than planning for events that rarely happen.

Thus began the Integrated Emergency Management System. A strategy that says to State and local governments: Plan for what you want, use it for what you get! This policy allows States to develop all-hazard generic plans to be tested and applied to those hazards affecting them on a day to day basis. No longer are these plans soley attack oriented.

This approach also recognizes our experience - if you have seen one disaster you've seen them all; and that there are certain generic elements common to any incident. Such elements include: emergency management organization, direction control and warning functions, population protection measures, public education and others.

Furthermore, this strategy recognizes that skills developed in these functional areas are transferrable to other incidents and response operations. While we admit there are certainly differences in magnitude and scope, specific nuances incidental to a particular hazard, our experience has shown most response functions are similar. This has been borne out by my own role in such diverse operations as Love Canal, Cuban Refugee Relief operation, Ginna Nuclear Power Plant Accident, blizzards, droughts, hurricanes, etc.

III. HICA/MYDP

This is the latest FEMA policy affecting emergency planning. It is a comprehensive effort which encourages each State and local government participating in FEMA Programs to:

- Identify hazards in their community
- Determine if their hazard is significant, and
- Develop a listing of planning objectives and priorities that should be met to address the specific hazard.

Earthquake is listed in this planning process as a specific hazard and New York is singled out as one of the high risk seismic areas:

If a community indicates earthquake is a significant hazard:

- This planning process allows the identification of plan requirements that should be included in the local Emergency Operations Plan (EOP).

- The process also suggests to the jurisdiction, to report shortfalls and areas requiring additional Federal and State technical and financial support.

- The State and FEMA will then work with communities to address requirements, such as those who wish to update their basic EOP to include appendices on specific hazards such as earthquakes.

IV. Status of Emergency Response Planning/Federal level - the region has an Emergency Response Team (ERT) Plan which serves as planning guidance for regional staff response to emergencies. This basic plan has several annexes to address certain hazard specific response operations.

State level - FEMA fully funds some eight planners in New York State. Their mission is to develop all hazard population protection plans in New York. There are some 62 counties in New York requiring all-hazard plans. The State is scheduled to complete twelve plans in FY'85. The State also provides planning guidance to local governments.

Local level - those communities participating in FEMA programs are required to update their basic Emergency Operation Plans each year. While all have a plan, about half are really up to date. We continue to work with the State to assist local governments in plan development. We hope the HICA/MYDP process will rejuvenate the planning process at the local level to ensure proper emergency preparedness.

SUMMARY

1. Federal emergency planning policy emphasizes development of all-hazard plans containing generic response elements.

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2. This January, FEMA begins a nationwide Hazard Identification Capability Assessment and Multi-Year Development Plan process which will highlight and priortize emergency response requirements.

3. Plan development exists at the Federal, State and local level - but, we all have a way to go to accomplish our objectives and be fully prepared for emergencies.

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LAND USE PLANNING AND BUILDING CODES

by

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INTRODUCTION

Two concerns which merit consideration in any review of the effects of earthquakes on the built environment are the following:

1) The ability of the structure to withstand the anticipated forces generated by an earthquake.

2) The anticipated intensity and character of the shaking at any location.

Item 1 relates to the charactr of the built environment in terms of age, type of construction, quality of construction and types and uses of structures. Generally, building codes are used to control these characteristics. In addition, the building codes represent certain philosophies of life safety, property maintenance and preservation, and affect general health and welfare. There is implied certain balances between economics and life preservation, property protection and construction quality. Legislative bodies alter these balances based on their perception of risk and benefit. The results of these perceptions produce emphasis or lack of emphasis related to certain physical and structural characteristics of the buildings in that jurisdiction.

Item 2 is related to geographical location and may affect certain perceptions about structures as referenced above. For instance, cities and towns located along the shore and subject to coastal flooding and storm hazards would be expected to impose both building code and land use controls in fulfilling its obligations for public safety, health and welfare. The extent to which these implied obligations are fulfilled is a result of legislative action which may be imposed at a local state or federal level. Logically, one would assume that a legislative body would also impose certain restrictions on construction on or near an active fault. It is clear that land use controls can be used to affect the results of earthquakes on structures. However, again, there is likely to be a balance between economics and life safety, health and welfare.

Building Codes

Building codes are the means for controlling the construction of structures. Within the context of the building code are included many implicit decisions and philosophies which emerge only as specifications and regulations. It has been estimated that as much as 80% of the provisions of some typical building codes are included to provide safety from fire. Building codes traditionally include the means for regulating such things as quality of construction, light and ventilation, and even energy conservation. The BOCA model code published by the Building Officials and Code Administrators International Inc., includes an introductory section which reads as follows: "This code shall be construed to secure its expressed intent, which is to insure public safety, health and welfare insofar as they are affected by building construction, through structural strength, adequate egress facilities, sanitary eqiupment, light and ventilation, and fire safety, and in general, to secure safety to life and property from all hazards incident to the design, erection, repair, removal, demolition or use and occupancy of buildings, structures or premises. This preamble is true to the extent to which it is perceived as being economically realistic and useable. There is no question that we could impose restructions on all buildings to make them far more fire resistant and implicitly safer. However, despite the unlimited value philosophically placed on life, pragmatically such buildings are subject to other contending considerations. For instance, one can assume that the cheaper we make new housing by reducing building code standards, the more people we are able to provide with new or rehabilitated housing facilities.

Seismic building codes are faced with the same concern. In Massachusetts a mandatory state seismic building code was imposed with the philosophy that by virtue of the seismic provisions no building would cause loss of life by collapse. The legislative body was willing to sacrifice all buildings but no loss of life. However, this applies only to new buildings. There are no requirements for existing buildings, and only limited applications to buildings being rehabilitated.

On December 10, 1976, the day that a seminar was being held in San Diego entitled "Living with Seismic Risk: Strategies for Urban Conservation", the following item appeared in the San Diego Union newspaper: "L.A. rejects earthquake safety rules. The City Council yesterday told its Public Works Committee that its proposed building safety earthquake ordinance is too harsh and would cause greater economic harm than precautionary good. As hundreds of angry property owners looked on, the council directed the committee to redraft the law".

Land Use Planning

Land use planning is conventionally implemented by such devices as Zoning, wetland and flood plain controls, coastal high hazard area restictions and green belts. Such controls generally do three things:

1) Control density - height and area
2) Control use of the land
3) Control location of structures

In some of these controls there is an intent to protect the environment rather than the structure or the occupants. However, in the case of all the devices listed, the characteristics of the geography are delineated in fine detail to define the limits of control. When we deal with the earthquake characteristics of certain small areas we refer to this as microzonation. Because of various geophysical characteristics the areas under consideration may be as small as any normal municipal zoning district and have characteristics which are distinct and have the ability to significantly alter the effects of an earthquake in that area compared to adjacent areas.

In addition to very localized geophysical characteristics we are also concerned about such things as location and distance of any structure from a known source of seismic activity.

If we analyze the three controls listed with respect to effects of microzonation and attenuation from distant earthquakes we can see some possible applications of land use planning:

1) Control Density

Control the height and number of structures in certain areas or impose more restrictive building code regulations.

2) Control Use of Land

Limit certain uses - for instance prohibit or control the construction of fire stations, hospitals, nursing homes, hazardous facilities, etc.

3) Control Location of Structures

Prohibit all or some construction in some areas which appear especially hazardous. Spread out structures so that shaking of one structure will not affect another, or so the buildings do not impose dangers to people outside or to other facilities or infrastructure.

In all cases there are two preliminary steps to the process of land use control. One is localized mapping of geophysical conditions and the other is evaluating likely areas for an epicenter and evaluating the attenuation characteristics of the regions affected. Once these two steps are taken and such evaluations of the hazard exists, it is then necessary to seek legislative solutions which balance the interests of economics and safety.

RESEARCH REQUIRED IN SUPPORT OF A COMPREHENSIVE EARTHQUAKE PLANNING AND PREPAREDNESS PROGRAM FOR NEW YORK

by

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INTRODUCTION

At the present time, the scientific community is unable to predict either in space or time, the occurrence of the next major earthquake in New York State or adjacent regions. Moreover, no encompassing mechanism for earthquakes in New York State and adjacent areas has been identified and the same statement is true for the entire Eastern and Central United States. Finally, no tectonic structures have been identified either geologically or geophysically that can be uniquely associated with earthquake occurrences. In short, the current state of knowledge on the causative factors of earthquakes in the New York region is abysmal. In the face of this uncertainty, best estimates or "expert" opinion on seismic hazards have been and will continue to be important and useful. It is the purpose of this paper, however, to identify areas of research required to enhance our understanding of earthquakes so that, in the future, the seismic hazard estimates discussed in the conference, can be updated and improved.

POSSIBLE MECHANISMS FOR NEW YORK STATE EARTHQUAKES

Suggested associations and causes for Eastern United States earthquakes in general include the following.

Reactivation of Old Fault Systems

- Paleorifts
- Detachment surfaces and related splay thrust faults
- Deep seated crustal weakness that influenced development of oceanic fracture zones during the Mesozoic breakup of the continent
- Ductile shear zones
- Cenozoic reverse faults
- Faults caused by meteorite impact

More Zones of Weakness and/or Stress Concentrators

- Intrusive rocks
- Structural intersections

Vertical Tectonics

- Isostasy
- Epeirogeny
- Thermal expansion/contraction
- Block tectonics

Other Ideas

- Fresh faulting occurs
- Seismicity is random
- None of the above

Though a number of possible causes and associations for Eastern United States earthquakes have been proposed, there are probably many remarkable simple relationships yet undiscovered. Data synthesis and hypothesis testing are both important, but more progress might be made from experiments designed to obtain new observations. We do know that faulting occurs in response to an applied stress. The challenge of understanding earthquakes in intraplate regions such as New York State is to relate faulting to the physical conditions required for rock failure. Ideally, we need to know much more about both the earth's crust and the stresses applied to it. Future research must focus on gathering and analyzing data that will provide details of inhomogeneities in crustal composition, thickness, and mechanical properties and the applied stresses, particularly in and around regions of significant earthquakes that are well located by instrumental networks.

Some of the data that may contribute in important ways to understanding the puzzles of earthquakes in New York State and adjacent areas are outlined below. The list is by no means exhaustive. Though it is true that many of the existing data are not detailed enough, there is also the suspicion that much remains to be discovered. Funding agencies should continue to search for new kinds of data and techniques.

SEISMOLOGICAL RESEARCH

Earthquake Studies

Focal mechanisms provide evidence of the geometry of fault planes and they indicate the general directions of principal stresses. Focal mechanisms can be determined from P wave first motions, P to S wave amplitude ratios, SH polarization and surface wave studies. With the high quality digital data now available in New York and surrounding areas, it is also possible to determine moment, stress drop and corner frequency for earthquakes. The depth distribution of earthquakes is important to establish the seismically active structures. Aftershock locations are extremely important data for mapping the volume of post-seismic stress relaxation, choosing the correct fault planes from focal mechanisms studies of the main shocks, and examining details of the faulting process. A number of Eastern earthquakes with good aftershock surveys are showing conjugate or orthogonal fractures as well as perhaps small en echelon fractures. This kind of geometry may be characteristic of mid-plate faulting and an important clue to the processes.

Crustal Studies

Seismograms of local and teleseismic earthquakes as well as manmade energy sources can be analyzed for attenuation properties (Q) of the crust and upper mantle. Seismic reflection data provide a map of sharp contrasts of discontinuities in the velocity structure of the crust. In general, deeper structures such as depth to the Moho are better obtained from refraction data. In addition to the determination of crustal properties, refraction and surface wave measurements will enhance earthquake location capability.

GEOPHYSICAL RESEARCH

Although interpretations of potential field data are non-unique, gravity and magnetic data are a valuable source of information on the properties of the crust. Existing data for New York and surrounding areas should be digitized and filtered maps can then be prepared to emphasize deep crustal features. Structural interpretations based on modeling of gravity and magnetic data will be improved by detailed data at a one half to one kilometer spacing. Interpretations can be constrained by geologic and seismologic data.

GEOLOGIC RESEARCH

Detailed geologic investigations are required to evaluate ground shaking hazard.

Surface Mapping

Analysis of the distribution of sediment cover overlying bedrock and its correlation with isoseismal data gives a qualitative measure of the effects of sediments on ground acceleration and the hazards associated with it. Searches for pre-historic earthquakes as evidenced in soft sediment deformations such as glacial varve disturbance and paleo-liquefaction sites are about the only way we know of today to obtain average recurrence rates of high intensity ground shaking. To determine what (if any) are the surface or near surface effects of earthquakes, detailed investigations of bedrock in the vicinity of significant earthquakes ($> m_b=3.5$) could include trenching, mapping joint and fracture systems, and coring lake bottom sediments.

Stress and Strain

Measurement of both stress and strain are difficult but extremely important if fundamental processes are to be understood. Hydrofracturing of rocks is the best measurement of stress we have to date, but unfortunately measurements taken at the depth of earthquakes are rare. New techniques for measuring vertical strain in interplate regions may eventually be suitable for area such as Eastern United States. Recently, Zoback et al. (1984) have analyzed

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repeated triangulation measurements in an attempt to find evidence of localized horizontal strain anomalies near intra-plate fault zones. Preliminary results suggest that the strain rates in the region of the Ramapo Fault in New York and New Jersey are high and perhaps aseismic displacements are occurring in the lower crust.

An important aspect of each of these investigational areas is to correlate results with the other investigations and synthesize all of the available data. New York State is in a unique position to carry out this coordination because of the broadly based activities of the New York State Geological Survey which should be utilized in the implementation of the studies suggested here.

As these reasearch programs are carried out, the basis for seismic hazard evaluation will be significantly enhanced.

REFERENCE

Zoback, M. D., S. W. Krueger, W. H. Prescott, 1984, Lower Crustal Ductile Strain Localization and Intraplate Seismicity: Anomalous Crustal Deformation in Southern New York, submitted to Science.

PREPARING FOR AND RESPONDING TO DAMAGING EARTHQUAKES IN THE NORTHEASTERN[1] UNITED STATES; DRAFT OF A 5-YEAR PLAN FOR IMPROVING EARTHQUAKE PREPAREDNESS

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FOREWARD

This draft 5-year action plan contains recommendations for improving the state-of-earthquake-preparedness in the Northeastern United States. It was developed in discussions among members of Panel 3 of the workshop held at Knoxville, Tennessee. The plan is intended to serve as a guide that individuals in the political and scientific-technical communities can use to evalaute their current research and preparedness programs, to devise new programs and plans, and, ultimately, to develop a seismic safety policy in the Northeastern United States. The membership of the panel included:

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[1] in Proceedings of Conference XV, a workshop on "Preparing for and responding to a damaging earthquake in the Eastern United States:" U.S. Geological Survey Open-File Report 82-220, 197 p.

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INTRODUCTION

The probability of a major earthquake occurring in the Northeastern United States is quite low, but moderate to severe earthquakes have occurred in the region in the past and certainly, will occur in the future. More than in most other parts of the United States, the earthquake hazard problem is compounded by a high population density, many old large buildings, and a high degree of modern industrialization. At present, in the northeast, no specific plans exist for response to a major earthquake other than the general disaster response plans of the Federal Emergency Management Agency (FEMA).

The Northeastern United States is perhaps unique in that many of the governmental units already involved in emergency preparedness and response are interknit in regional councils, interstate cooperative agreements, etc. Thus, the precedent for cooperation on an earthquake preparedness plan is well established.

The most important recommendation of this Panel was that a Northeast Regional Seismic Safety Advisory Council (NERSSAC) be established. The Council, which should be made up of representatives of State and local government, Federal officials and industry and academic representatives, will be responsible for the implementation of most of the tasks outlined below. Action for its establishment should be as soon as possible. Currently a strong emergency preparedness community exists along with a scientific community which has earthquake hazard responsibilities. However, there is a definite need to improve the liaison between these groups in order to improve the state-of-earthquake preparedness in the Northeastern United States.

Because of the relatively small size of the Panel to develop a draft 5-year action plan for improving earthquake preparedness in the Northeast, it was possible for the entire panel to consider and to discuss the proposed overall program. From these discussions, the Panel recommended activities in five task areas. These are described below.

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TASK I: HAZARD AWARENESS AND PUBLIC INFORMATION

The Nuclear Regulatory Commission, the U.S. Geological Survey, and the Federal Emergency Management Agency all have on-going programs that identify earthquake hazards or provide general response capability. The Panel concluded that existing information and data provide a sufficient basis for earthquake hazard reduction planning. Moreover, all members of the Panel felt strongly that earthquake hazard reduction planning should be part of a comprehensive emergency planning effort. It became clear in the discussions that a high level of awareness of the earthquake hazards in this region existed among the scientific community, but the level of knowledge of earthquake hazards among disaster planners and responders is very low.

Particular goals under this task include:

1) Establish a level of interest and identify the level of the hazard.

2) Increase the earthquake awareness of the nonscientific community by:

   a) identifying target populations.
   b) designing a public awareness campaign.
   c) implementing and evaluating the campaign.

The second goal has been criticized as vague, yet we all realize what is needed in such a campaign--the problem is to implement it.

Responsibility for the implementation of these goals should rest entirely with the Northeast Regional Seismic Safety Advisory Council (NERSSAC).

TASK II: INTERGOVERNMENTAL RELATIONS AND COOPERATION

The Panel feels that two goals are particularly vital in this task area; namely:

1) Identify all currently existing relationships at the Federal, regional, State, and local levels of government.

2) Improve liaison and information exchange between the scientific and emergency preparedness communities and among all intergovernmental entities.

Responsibility for the implementation of these goals was also placed with the NERSSAC.

TASK III: LOCAL EARTHQUAKE-RESISTANT DESIGN

The Panel felt that building design problems were particularly acute in the Northeast. Massachusetts is the only State in the region to have specific modern earthquake-resistant design provisions incorporated into its building codes. Although the code in Massachusetts can serve as a model for other parts of New England, differences in adopted codes may be warranted in different parts of the northeast. However, each States and Federal and local governmental unit should require that its own structures and facilities meet specific earthquake-resistant design requirements.

The following six goals were established:

1) Define the level of hazard in quantifiable terms that are usable by the design professions.

2) Inform pubic officials (particularly code writers and enforcers) of the earthquake hazards.

3) Implement a policy that requires public buildings and facilities in appropriate areas of seismic risk to be built to seismic codes appropriate for the level of risk.

4) Define "low-cost" or "cost-effective" solutions to problems associated with earthquake-resistant design.

5) Review design and construction of existing critical facilities such as power facilities, hospitals, schools, fire stations, communication facilities, sewage and water systems in hazardous areas. Make and

implement recommendations to reduce the seismic risk associated with these existing facilities, and

6) Review design and construction of existing buildings and devise cost-effective schemes to reduce losses.

Implementation of these goals should be the responsibility of NERSSAC.

TASK IV: LAND USE

Although local zoning laws exist in most areas of the northeast, they do not contain provisions relating to reduction of earthquake hazards. Zoning regulations that are seismically related should be added to the zoning laws particularly in areas of relatively high seismic risk, but the Panel recognizes a natural distaste for any increase in the complexity of zoning in the northeast. Since zoning is a local function, the impetus for adding the proposed seismic regulations must come from the State through incentives to local governing bodies for adoption.

Two specific goals are:

1) The identification of high hazard areas. Identification will be done primarily by means of all-hazard geologic mapping and should be a cooperative program between the private sector and the State and Federal governments. This is an on-going effort which will extend beyond the five year scope of this plan.

2) Define land use. This task should be carried out by the NERSSAC. Maximum use should be made of existing data and the NERSSAC should ensure that new information is rapidly disseminated throughout the scientific and planning communities.

TASK V: RESPONSE TO A DAMAGING EARTHQUAKE

The Panel noted that a number of multihazard emergency preparedness and response plans already exist. These are applicable to the earthquake hazard in the northeast. The responsibility for maintaining and exercising these plans rests with FEMA. It is not clear whether specific earthquake planning in the category of emergency response is necessary in the northeast, and one of the responsibilities assigned below to the NERSSAC is to ascertain that need.

Specific goals include

1) Identification of the existing plans. (Most people are unaware not only of the implementation procedures but even of their existence.) FEMA should take the lead responsibility here and provide the information to the NERSSAC.

2) Exercise the existing plans. This clearly is a joint responsibility of Federal, State, and local authorities.

3) Ascertain the need for creating specific earthquake disaster preparedness and response plans or for modification of existing plans for the northeast.

The last goal is assigned to the NERSSAC.

SUMMARY

Because of a number of factors unique to the northeast, **the appointment of a properly constituted Northeast Regional Seismic Safety Advisory Council (NERSSAC) is critical to the accomplishment of these tasks recommended in the draft five-year plan outlined above.** The Council, once appointed, should have the primary responsibility for the development of a seismic safety policy and the coordination and enactment of the five-year effort. The Council should have the political authority to ensure that its recommendations will be carried out and must have the personnel and financial resources to move forward. Once the Council is in place, specifics in each of the 5 task areas can be addressed.

The northeast is fortunate in that many regional cooperative programs, both political and scientific, are already in place and the precedent for regional cooperation is well established. Moreover, a number of responsible, concerned individuals are already working to enhance awareness of the earthquake risk in this area of low probability of occurrence. The success of any program such as this, requires the active, long-term participation of these and other individuals (as well as corporate entities).

Because of the high degree of industrialization, the large number of older buildings, and the high population density in the region, the occurrence of a major earthquake in the Northeast would result in major loss of life and property. The earthquake preparedness program outlined here would result in a major reduction of these losses.

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GLOSSARY OF TERMS USED IN EARTHQUAKE HAZARDS ASSESSMENTS

Accelerogram. The record from an accelerometer showing acceleration as a function of time. The peak acceleration is the largest value of acceleration on the accelerogram.

Acceptable Risk. A probability of occurrences of social or economic consequences due to earthquakes that is sufficiently low (for example in comparison to other natural or manmade risks) as 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 is active if, because of its present tectonic setting, it can undergo movement from time to time in the immediate geologic future. This active state exists independently of the geologists' ability to recognize it. Geologists have used a number of characteristics to identify active faults, such as historic seismicity or surface faulting, geologically recent displacement inferred from topography or stratigraphy, or physical connection with an active fault. However, not enough is known of the behavior of faults to assure identification of all active faults by such characteristics. Selection of the criteria used to identify active faults for a particular purpose must be influenced by the consequences of fault movement on the engineering structures involved.

Attenuation. A decrease in seismic signal strength with distance which depends not only on geometrical spreading, but also may be related to the physical characteristics of the transmitting medium that cause absorption and scattering.

Attenuation law. A description of the average behavior of one or more characteristics of earthquake ground motion as a function of distance from the source of energy.

b-value. A parameter indicating the relative frequency of earthquakes of different sizes derived from historical seismicity data.

Capable fault. A fault along which future surface displacement is possible, especially during the lifetime of the engineering project under consideration.

Design earthquake. A specification of the ground motion at a site based on integrated studies of historic seismicity and structural geology used for the earthquake-resistant design of a structure.

Design spectra. Spectra used in earthquake-resistant design which correlate with design earthquake ground motion values. Design spectra typically are smooth curves that take into account features peculiar to a geographic region and a particular site.

Design time history. One of a family of time histories used in earthquake-resistant design which produces a response spectrum enveloping the smooth design spectrum, for a selected value of damping.

Duration. A qualitative or quantitative description of the length of time during which ground motion at a site exhibits certain characteristics such as being equal to or exceeding a specified level of acceleration such as 0.05g.

Earthquake hazards. The probability that natural events accompanying an earthquake such as ground shaking, ground failure, surface faulting, tectonic deformation, and inundation, which may cause damage and loss of life, will occur at a site during a specified exposure time. See earthquake risk.

Earthquake risk. The probability that social or economic consequences of earthquakes, expressed in dollars or casualties, will equal or exceed specified values at a site during a specified exposure time.

Earthquake waves. Elastic waves (P, S, Love, Rayleigh) propagating in the Earth, set in motion by faulting of a portion of the Earth.

Effective peak acceleration. The peak ground acceleration after the ground-motion record has been filtered to remove the very high frequencies that have little or no influence upon structural response.

Epicenter. The point on the Earth's surface vertically above the point where the first fault rupture and the first earthquake motion occur.

Exceedance probability. The probability (for example, 10 percent) over some period of time that an event will generate a level of ground shaking greater than some specified level.

Exposure time. The period of time (for example, 50 years) that a structure is exposed to the earthquake threat. The exposure time is sometimes related to the design lifetime of the structure and is used in seismic risk calculations.

Fault. A fracture or fracture zone in the Earth along which displacement of the two sides relative to one another has occurred parallel to the fracture. See Active and Capable faults.

Focal depth. The vertical distance between the hypocenter and the Earth's surface in an earthquake.

Ground motion. A general term including all aspects of motion; for example, particle acceleration, velocity, or displacement; stress and strain; duration; and spectral content generated by a nuclear explosion, an earthquake, or another energy source.

Intensity. A numerical index describing the effects of an earthquake on the Earth's surface, on man, and on structures built by him. The scale in common use in the United States today is the Modified Mercalli scale of 1931 with intensity values indicated by Roman numerals from I to XII. The narrative descriptions of each intensity value are summarized below.

I. Not felt--or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds and

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animals reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway--doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds and animals reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body of striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink or clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V. Felt indoors by practially all, outdoors by many or most; outdoors direction estimated. Awakened many or most. Frightened few--slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes and glassware to some extent. Cracked windows--in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors and shutters abruptly. Pendulum clocks stopped, started or ran fast, or slow. Move small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees and bushes shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees and bushes shaken slightly to moderately. Liquid set in strong motion. Small bells rang--church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knickknacks, books, pictures. Overturned furniture in many instances. Move furnishings of moderately heavy kind.

VII. Frightened all--general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows and furniture to some extent. Shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general--alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly--branches and trunks broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse, racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls, cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changes level of water in wells. Threw water on banks of canals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipelines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage

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severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments often for long distances. Few, if any (masonry) structures, remained standing. Destroyed large well-built bridges by the wrecking of supporting piers or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipelines buried in each completely out of service.

XII. Damage total--practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.

Liquefaction. Temporary transformation of unconsolidated materials into a fluid mass.

Magnitude. A quantity characteristic of the total energy released by an earthquake, as contrasted to intensity that describes its effects at a particular place. Professor C. F. Richter devised the logarithmic scale for local magnitude (M_L) in 1935. Magnitude is expressed in terms of the motion that would be measured by a standard type of seismograph located 100 km from the epicenter of an earthquake. Several other magnitude scales in addition to M_L are in use; for example, body-wave magnitude (m_b) and surface-wave magnitude (M_s), which utilize body waves and surface waves, and local magnitude (M_L). The scale is open ended, but the largest known earthquake have had M_s magnitudes near 8.9.

Region. A geographical area, surrounding and including the construction site, which is sufficiently large to contain all the geologic features related to the evaluation of earthquake hazards at the site.

Response spectrum. The peak response of a series of simple harmonic oscillators having different natural periods when subjected mathematically to a particular earthquake ground motion. The response spectrum may be plotted as a curve on tripartite logarithmic graph paper showing the variations of the peak spectral acceleration, displacement, and velocity of the oscillators as a function of vibration period and damping.

Return period. For ground shaking, return period denotes the average period of time or recurrence interval between events causing ground shaking that exceeds a particular level at a site; the reciprocal of annual probability of exceedance. A return period of 475 years means that, on the average, a particular level of ground motion will be exceeded once in 475 years.

Risk. See earthquake risk.

Rock. Any solid rock either at the surface or underlying soil having a shear-wave velocity 2,500 ft/sec (765 m/s) at small (0.0001 percent) strains.

Seismic Microzoning. The division of a region into geographic areas having a similar relative response to a particular earthquake hazard (for example, ground shaking, surface fault rupture, etc.). Microzoning requires an integrated study of: 1) the frequency of earthquake occurrence in the region, 2) the source parameters and mechanics of faulting for historical and recent earthquakes affecting the region, 3) the filtering characteristics of the crust and mantle constituting the regional paths along which the seismic waves travel, and 4) the filtering characteristics of the near-surface column of rock and soil.

Seismic zone. A generally large area within which seismic design requirements for structures are uniform.

Seismotectonic province. A geographic area characterized by similarity of geological structure and earthquake characteristics. The tectonic processes causing earthquakes have been identified in a seismotectonic province.

Source. The source of energy release causing an earthquake. The source is characterized by one or more variables, for example, magnitude stress drop, seismic moment. Regions can be divided into areas having spatially homogeneous source characteristics.

Strong motion. Ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage due to earthquakes or in earthquake-resistant design of structures.