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PRIMER ON IMPROVING THE STATE-OF-EARTHQUAKE HAZARDS MITIGATION AND PREPAREDNESS

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BACKGROUND AND HIGHLIGHTS OF
"PRIMER ON
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by

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INTRODUCTION

Since 1977, the U.S. Geological Survey has convened, in cooperation with other sponsoring agencies, a series of workshops under the auspices of the National Earthquake Hazards Reduction Program. The workshops were designed to foster and to strengthen cooperation between Federal agencies, State and local governments, universities, and the private sector. Workshops have been held throughout the United States, including:

1. Denver, Colorado, on "Communicating Earthquake Hazards Reduction Information" (Conference V),
2. Los Angeles, California, on "Earthquake Prediction Information," (Conference XII),
3. Santa Fe, New Mexico, on "Evaluation of Regional Seismic Hazards and Risk," (Conference XIII),
4. Knoxville, Tennessee, on "Preparing for and Responding to a Damaging Earthquake in the Eastern United States," (Conference XV),
5. St. Louis, Missouri, on "Continuing Actions to Reduce Losses from Earthquakes in the Mississippi Valley Area," (Conference XVIII),
6. Charleston South Carolina, on "The 1886 Charleston, South Carolina Earthquake and Its Implications for Today," (Conference XX),
7. Boston, Massachusetts, on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in the Northeast," (Conference XXI),

8. Little Rock, Arkansas, on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in Arkansas and Nearby States," (Conference XXIII),
9. San Juan, Puerto Rico, on "Geologic Hazards in Puerto Rico," (Conference XXIV),
10. St. Thomas, Virgin Islands, on "Earthquake Hazards in the Virgin Islands Region," (Conference XXV),
11. Salt Lake City, Utah, on "Evaluation of Regional and Urban Earthquake Hazards and Risk in Utah" (Conference XXVI), and
12. Albany, New York, on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in New York and Nearby States"

The papers which appear in this primer have been chosen from the proceedings of the above workshops which the U.S. Geological Survey conducted with the general goal of improving knowledge utilization by bringing together knowledge producers and users. These papers present some of the best practical information available on improving earthquake hazard preparedness and mitigation. They emphasize: 1) increasing public awareness of earthquake hazards and personal and private industry preparedness, 2) improving land-use in hazard-prone areas, 3) increasing earthquake resistance of buildings and lifelines, 4) using scientific and technical information in hazard reduction actions, 5) and formulating seismic safety organizations. The papers were written to address the earthquake hazards in specific regions of the United States; however, the information contained in each paper is transferrable to other parts of the United States and to other parts of the world with only some fine tuning.

This "primer" can be considered as a snap shot of the current state-of-earthquake preparedness and mitigation in the United States. The workshops which produced the papers contained in this document, and the "primer" itself, were planned, in part, in response to recommendations made by the Working Group on Earthquake Hazards Reduction, Office of Science and Technology Policy, Executive Office of the President. Issue 32 of that group's report states:

Dissemination of technical information is not a one-way process. Research has demonstrated that generally the process is less successful where there is an active producer and a passive potential user. This situation is certainly true when attempts are made to provide Federal information to State and local governments. State and local government officials sometimes fail to see the relevance of new Federal information to their problems. Also, Federal agencies sometimes use ineffective ways to convey technical information to the State and local governments, or to interpret its meanings for their programs. It is crucial, then, that Federal agencies that produce hazards information collaborate with State and local officials as they develop policies and procedures. Furthermore, research shows that whenever possible interaction among Federal, State, and local officials should take place on a face-to-face basis.

HIGHLIGHTS

This "primer" can be used as a basic textbook (hence the name "primer") by the many individuals faced with taking specific actions, making decisions, and conducting research on earthquake and other natural hazards. It is one way in which information from many diverse disciplines can be integrated and utilized to solve the complex problems of natural hazards preparedness and mitigation. It provides practical answers to the questions, "what can I do?" and "what can we do?"

Effective earthquake hazards mitigation utilizes three interelated strategies: 1) earthquake hazards preparedness, 2) land-use planning and regulation, and 3) earthquake-resistant design. Eleven papers describing aspects of these three strategies are listed below:

Earthquake Hazards Preparedness (A goal of increasing the capability of an individual, and community, and the government to respond to a damaging earthquake):

1) "Societal Response to the Earthquake Threat in the Eastern United States: Issues, Problems, and Suggestions" by Joanne Nigg,
2) "Earthquake Predictions and Their Effects of Preparedness: A Public Education Perspective" by Shirley Smith,
3) "How to Gain the Attention and Commitment of Political Officials: An Earthquake Politics Primer" by Douglas Nilson,

4) "How to Gain the Attention and Commitment of Business and Industry" by Anthony Prud'homme,
5) "Gaining Commitment of Voluntary Agencies" by Daniel Prewitt, and
6) "Recovery Following an Earthquake: A Prospective Assessment for Arkansas Following a Central United States Earthquake" by Charles Thiel,
7) "The Puget Sound Earthquake Preparedness Project" by Richard Buck.

Land-use Planning and Regulation (A goal of ensuring a use of land in hazard-prone areas that is commenusrate with the level of hazard):

8) "Reducing Earthquake Damage Through Land-use Planning" by Donald Nichols.

Earthquake-Resistant Design (A goal of improving the capability of existing as well as new buildings to withstand earthquakes):

9) "Primacy, Decline, and Decrepitude: The Building Life Cycle, and Its Relationship to Earthquake Hazard Reductions Strategies" by Christopher Arnold,
10) "Seismically Safe Structures and Their Cost-Effectiveness" by Clarke Mann, and
11) "Seismic Retrofit" by Lawrence Kahn.

To be successful in each of the above strategies, scientific and technical information is required. Two papers have been chosen as examples of the types of scientific and technical information that are necessary to mitigate earthquake hazards. They are "Evaluation of the Earthquake Ground-Shaking Hazard" by Walter Hays and "Procedures and Data Bases for Earthquake Damage Prediction and Risk Assessment" by Roger Scholl and Onder Kustu.

The last paper, "Forms and Functions of Seismic Safety Organizations" by Claire Rubin and Paula Gori, has been included to provide guidance for States and regions who are considering the formation of seismic safety organizations as one method of overseeing earthquake hazards preparedness and mitigation functions.

Earthquake hazards mitigation is a dynamic field; therefore, the details of the strategies given in this "primer" are expected to change with time. However, there is no doubt that application of the information contained in this document could greatly reduce losses from earthquake hazards in the United States.

Glossary

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

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 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 on geometrical spreading and 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 capable fault is a fault whose geological history is taken into account in evaluating the fault's potential for causing vibratory ground motion and/or surface faulting.

Design earthquake. A specification of the ground motion at a site based on integrated studies of historic seismicity and structural geology and 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. A design spectrum is typically a broad band specturm having broad frequency content. The design spectrum can be either site-independent or site-dependent. The site-dependent spectrum tends to be less broad band as it depends at least in part on local site conditions.

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 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. 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 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 value of peak ground acceleration considered to be of engineering significance. It can be used to scale design spectra and is often determined by filterng the ground-motion record to remove the very high frequencies that may 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.

Exceedence probability. The probability (for example, 10 percent) over some exposure time that an earthquake 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 or facility is exposed to earthquake hazards. 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 earthquake hypocenter and the Earth's surface.

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 an earthquake, a nuclear explosion, 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 specially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds and 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 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. The primary factors used to judge the potential for liquefaction, the tranformation of unconsolidated materials into a fluid mass, are: grain size, soil density, soil structure, age of soil deposit, and depth to ground water. Fine sands tend to be more susceptible to liquefaction than silts and gravel. Behavior of soil deposits during historic earthquakes in many parts of the world show that, in general, liquefaction susceptibility of sandy soils decreases with increasing age of the soil deposit and increasing depth to ground water. Liquefaction has the potential of occurring when seismic shear waves having high acceleration and long duration pass through a saturated sandy soil, distorting its granular structure and causing some of the void spaces to collapse. The pressure of the pore water between and around the grains increases until it equals or exceeds the confining pressure. At this point, the water moves upward and may emerge at the surface. The liquefied soil then behaves like a fluid for a short time rather than as a soild.

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 theoretically open ended, but the largest known earthquakes 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 naturally occurring, hard, consolidated material, located either at the surface or underlying soil. Rocks have a shear-wave velocity of at least 2,500 ft/sec (765 m/s) at small (0.0001 percent) levels of strain.

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 along 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 are believed to be similar in a given 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.

SOCIETAL RESPONSE TO THE EARTHQUAKE THREAT IN THE EASTERN UNITED STATES
SOME ISSUES, PROBLEMS, AND SUGGESTIONS[1]

by

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INTRODUCTION

Recent research endeavors have broadened our knowledge about how individuals and communities assess the earthquake threat and risk, understand forewarnings and predictions, and prepare themselves for future quakes (Haas and Mileti, 1976; Wyner and Mann, 1981; Turner *et al.*, 1980; Olsen and Nilson, 1980). Our knowledge, however, is limited by the choice of California as a primary study area. The magnitude 5.1 Kentucky earthquake felt along the eastern seaboard in July 1980 and Professor Nuttli's high probability scenario of a New Madrid quake before the end of the century (Nuttli, 1980) provide reminders that there are seismically hazardous areas in the United States other than those popularly thought of as "earthquake country."

Since my task at this workshop is to present the societal aspects of the earthquake threat in the Eastern United States, I have organized my remarks around four key social response issues:

1. Hazard Awareness
2. Understanding and Assessing Earthquake Threat
3. Preparedness and Hazard Mitigation
4. Response to an Earthquake Event

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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.

Because of the need to draw on research and experience with earthquake events from seismically active areas, the underlying question is whether these findings are applicable to the Eastern United States. Do individuals and communities in these other areas of the country, with high threat and low seismic activity, assess earthquake risk and respond to it in the same way?

EARTHQUAKE HAZARD AWARENESS

Obviously, before a person can respond to a situation, he or she must know that it exists. In areas of the world where seismic activity is high (e.g., California, Japan, Italy, Guatemala), popular knowledge of earthquake threat is often taken for granted by researchers and planners. People who live in these areas, even for a short time, are likely to have personally felt small magnitude quakes and many may have experienced or heard about the effects of locally destructive quakes. Research findings indicate that a substantial proportion of residents in these areas also believe that a damaging earthquake is likely within the near future (Turner et al., 1980). This awareness of threat, then, can provide a basis from which preparedness actions can be taken.

We must know, however, if easterners are even aware that an earthquake threat exists in these regions. If they are aware, how real does the possibility of a quake within the near future seem to them? Without some awareness, no preparedness--at either the individual or community level--will take place.

If earthquake hazard awareness exists, it probably does so in the Central States area where some community issues have been raised and attention has been directed toward seismic safety issues--including, among others, the meaning and significance of the high probability of a future quake in the New Madrid region, the formation of the Missouri Earthquake Hazard Mitigation Panel, the controversy concerning the use of a seismic element in St. Louis, building code requirements,, and the establishment of the Tennessee Earthquake Information Center in Memphis. In Missouri, Drabek and Mushkatel (1980) found an indication that elected officials are aware of the earthquake threat, although actual mitigation efforts have been few, and that substantial press coverage was given to earthquake threat, especially in the Boot Heel area.

With the exception of Missouri and Tennessee, there appears to be little public discussion of seismic safety policies, issues, or geologic information. Without this public discourse, especially when it becomes "news" for the media, widespread awareness of the earthquake threat is not likely to come about.

UNDERSTANDING AND ASSESSING EARTHQUAKE THREAT

Merely being aware that a destructive magnitude earthquake could occur in one's region of the country is not sufficient to motivate either individuals or communities to take preparedness or mitigation actions. Several variables mediate awareness and response, determining how the earthquake threat will be interpreted. These variables, in part, determine the seriousness and importance which people attribute to the prospect of a local earthquake.

Fear and Concern

Althought the people in the East have not been exposed to scientific predictions or near-predictions to the extent that southern Californians have, those in the Central States at least may have been exposed to the possiblity of earthquake threat and risk during the last few years. Whether this exposure was sufficient to raise their concern over the prospect of a quake is important since the consequences facing them are serious if a large magnitude quake does occur. Feelings of fear and concern over the prospect of a coming quake in southern California were important in predicting the extent to which households had taken preparedness measures. However, the relationship was curvilinear; that is, low and moderate levels of fear produced a more positive response to preparedness, while having either a high or low level of fear was associated with being less well prepared.

Any efforts to educate the public will rely, in part, on reaching some optimum level of concern, raising the level of concern but not to the extent that people feel overwhelmed by the task facing them.

Frameworks of Knowledge About Earthquakes

Before people can interpret novel information and decide how they are going to react to it, that information must be categorized in some way to make it meaningful. Since earthquakes, even damaging ones, are not common events in the lives of easterners, we must look at the frameworks within which this information may be interpreted in order to hypothesize how it will be responded to.

Disaster Lore and Popular Beliefs. What awareness there is may be influenced by earthquake lore and folk beliefs. In California, the popular belief still exists that a major earthquake along the San Andreas fault could result in California's breaking off and falling into the Pacific Ocean. Beliefs that some animals can predict earthquakes and that some psychic premonitions are valid exist alongside understandings of the theory of plate tectonics. In our southern California study when people were asked why earthquakes occur, a small proportion of the sample (about seven percent) mentioned nonphysical causation, attributing earthquake occurrences to a Divine Plan, punishment for the sins of mankind, and the secular theme of interfering with nature (Turner *et al*., 1979).

Without frequent seismic events which prompt the retelling of such lore and folk beliefs, popular knowledge about the causes of earthquakes and what happens when they occur may be meager in the Eastern United States. But some such lore must exist, especially with regard to the 1811 and 1812 New Madrid quakes.

It is important to recover these beliefs and tales of local earthquake lore because they can provide a basis from which one component of a public education program could be developed--the establishment of realistic expectations of earthquake threat. For example, by reviewing the popular lore about the consequences of the 1811-1812 New Madrid quakes--the Mississippi River flowing backwards, whole communities collapsing, rivers changing their course of flow--residents could be reminded of the region's seismic history and a "then-now" comparison could be made. The important point here is to build on the familiar, correcting the glaringly erroneous popular perceptions and extrapolating to the present from the valid recollections of past local events.

Disaster Subcultures. More so than in the West, the three regions in the Eastern United States with high seismic risk are frequently threatened by other natural disasters. The New Madrid fault zone is almost entirely overlapped by one of the highest tornado death index areas in the country (Sims and Baumann, 1974). The south Carolina coast and the Boston-New York areas have been threatened by hurricanes, the actual occurrence of these events has failed to affect the eastern coast in the past several years. Since there have been no recent disasters in these areas, it is unlikely that fully developed disaster subcultures exist. The following discussion, then, will be most applicable to the Central States region where a tornado disaster subculture does exist.

The recurrent, destructive nature of this hazard has led to the development of warning systems, mitigation measures, and emergency response planning. Normal social relationships are replaced during these periods of imminent danger with another set of expected behaviors and organizational responsibilities that last as long as does the disaster threat or its aftermath. These areas, then, have disaster subcultures that aid people in knowing what to expect and how to respond.

Are the adaptive responses associated with a tornado disaster subculture transferable to earthquake threat situations? It is possible that experience with tornado warning systems and taking precautionary actions to protect one's household during watches and warnings may have some carryover effects which sensitize people to the importance of earthquake forewarning and hazard mitigation programs.

It has been claimed that in well-developed disaster subcultures, both individuals and organizations have developed the ability to take precautionary and adaptive measures quickly and successfully. However, the literature on disaster subcultures is somewhat contradictory (Wenger, 1978). Some researchers have found that in areas that are threatened by a frequently recurring type of disaster agent, those organizations responsible for issuing warnings and safeguarding the populace become more competent and better integrated; while the individuals in the area become more lax and personally less well prepared for that disaster (Hannigan and Kueneman, 1978). This paternalistic orientation--characterized by the statement, "let the government do it"--was found to be particularly strong with respect to earthquake hazard mititation and preparedness in southern California.

Research on tornado disaster subcultures has also indicated that there are regional variations in communities' adaptive responses to threat, with the Central States having lower fatality rates than do southern States (Sims and Baumann, 1974). Since no substantial differences between regions were found in the number, duration or velocity of the tornados, when they hit, the types of residential structures, or the quality of the warning systems, the researchers investigated how the populations of the two regions differed.

Two significant differences were found in the ways people interpreted and coped with threat of disaster. First, Central States residents expressed the belief that they were more in control of their own lives than did southerners who were more likely to identify some force external to themselves. (e.g., luck or God) as a causal agent in their lives. Second, southerners were more likely to rely on their own senses to keep themselves informed about the impending disaster opposed to Central States residents who relied heavily on the media.

Whether local disaster subcultural procedures and behaviors can be adapted to cope with earthquake threat, then, may not be just a question of how much overlap there is between the mitigation and preparedness needs associated with both types of disasters. Regional variation in interpreting and responding to any threatening situation will have to be taken into consideration.

Ethnic Subcultures. These indications of regional differences point to another feature of social life that affects the ways people understand and respond to threat--their ethnic or racial group identification.

In southern California, substantial differences in perception and response were found among Anglos, Blacks, and Mexican-Americans in several areas--the amount of fear and concern they had about a future damaging quake; fatalistic attitudes about the importance of preparedness; differences in knowledge about and attitudes toward science and prediction; trust in government officials; use of the media for information on earthquake threat; extent of informal communication on earthquake-related topics, degree of personal preparedness for a coming quake; awareness of specific endangering conditions; and support for governmental expenditures for mitigation efforts (Turner et al., 1980, especially Part Six). Even after taking socioeconomic factors into consideration, ethnic subcultural effects remained strong.

It seems reasonable to assume that ethnicity will also have substantial effects on preceptions of earthquake threat in the Eastern United States. What those effects will be, however, is largely unknown since there is likely to be a great deal of difference in orientations to earthquake threat between, for example, Black communities in highly urbanized southern California and those in rural South Carolina. Without more information about the frameworks that ethnic groups use to interpret earthquake threat, it will be difficult to develop public education programs that were meaningful to these special populations.

PREPAREDNESS AND HAZARD MITIGATION

Earlier in this paper, I talked about a general awareness of earthquake threat being necessary (but not sufficient) for the development of a general concern about preparedness and hazard mitigation. Let us now turn our attention to the problem of actually getting people to take action.

The problem of motivating people to take preparedness actions is, first of all, an informational problem at both the personal and organizational levels.

Personal or Household Preparedness

Without knowing what the level of awareness is in the East and how that threat has been evaluated, it is difficult to guess at the level of knowledge people have about earthquake preparedness measures; but we can predict that their actual level of preparedness is low.

Even in southern California where there are relatively frequent small magnitude quakes and where there is continuing media attention to earthquake-related topics, people are inadequately prepared to handle the effects of a damaging earthquake. Other than having a working flashlight, a battery-operated radio, and first aid supplies, little has been done (Turner *et al.*, 1979). Often when preparedness measures have been taken, they were more likely initiated to improve the family's general ability to handle *any* type of emergency.

Several recommendations for improving public preparedness were made following the southern California study (Turner *et al.*, 1980, Part Ten). I will briefly review those preparedness recommendations that might provide some preliminary ideas for educational efforts in the Eastern United States intended to develop a knowledgeable populace. Those four recommendations are:

1. Carefully prepared and selected advice concerning earthquake preparedness for individuals and households should be given widespread and repeated public distribution through the media as well as through other channels.

2. This preparedness advice should come from some authoritative government agency and should be endorsed by well-known local government officials and public personages.

3. Each recommended preparedness measure should be presented in conjunction with a brief but credible explanation justifying that recommendation and suggesting how it can be implemented.

4. Some responsible State agency should develop a program to promote earthquake safety in the household, making use of local government, private agencies, and citizen groups. An especially useful program of this type would be one that conducted household safety inspections.

Although these recommendations may sound obvious or simplistic they are not easy to implement without a commitment from local and State governments to engage in a joint continuing planning effort. To what extent this effort could piggyback on other disaster information systems or could draw on the resources of already existent planning bodies is unknown. But the question gives us a place to begin looking for some structures within which these recommendations could be considered.

Organizational Preparedness

Since people often spend large parts of their days away from home, earthquake preparedness must not be oriented only around the home. Consideration must also be given to the preparedness of schools, hospitals, offices, stores and entertainment facilities.

Preparedness of public sector organizations involves two components which require different approaches. The first component concerns the safety of the physical structures themselves and is often handled by using building codes with seismic design provisions. The second component concerns the policies and procedures that safeguard the people who use those structures. Because building codes will be discussed elsewhere, I will concentrate on organizational concerns with personal safety.

Large, private-sector corporations often has active safety programs for their employees. Seismic safety components can easily and effectively be built into these on-going programs as long as safety officers have access to informational resources (a point to which we will return). Although the focus of these programs usually revolves around the workplace, some research findings indicate that this exposure may be influential in improving household preparedness as well (Nigg, 1979).

Public service organizations--schools, hospitals, utility companies, fire and police departments--are excellent potential users of seismic safety information because of their need to safeguard those entrusted to them and those who are unable to respond fully to an emergency on their own.

Small businesses, usually not having safety officers or safety committees, don't appear to be as actively concerned about emergency preparedness in general. Some thought should be given to how to get preparedness information to those organizations and companies, especially those that use toxic or flammable chemicals or that use manufacturing processes that could become dangerous in an earthquake.

Social and civic groups may disseminate earthquake information to their members, but their interest is often sparked by dramatic events or media attention to prediction and seismic safety issues. Their concern seldom continues over time. Their attention usually takes the form of a one-time only meeting at which an outside "expert" is asked to talk to the group. Unlike the preparedness focus in large companies (for their employees) and in public service agencies (for those being served), social and civic groups often provide information on making one's home safer.

Information Resources

For both types of preparedness discussed above, people should be able to draw on existing information resources to assist them in developing and implementing their plans.

Particularly useful for large organizations and public service agencies would be plans developed in southern California that could be modified to meet the exigencies of local areas. Whether such plans are currently available in a form that would make them useful to planners and safety officers, however, is unknown. Perhaps by scheduling sessions on emergency response planning and hazard mitigation at annual meetings of professional organizations or at regional planning meetings, this information could be distributed, finding its way into the eastern communities that are just now starting their own earthquake planning endeavors. There should be no need for these communites to "start from scratch" when other areas of the country, southern California in particular, has been giving seismic safety planning a great deal of attention during the past ten years.

Concerning the availability of information for the general public, a major problem was identified in the southern California study--"resource scarcity."

Once public awareness begins to increase and people start to ask what they can do to reduce the hazardousness of their immediate environment, they engage in information-seeking activities. They turn to the media, to public service agencies (e.g., fire and police departments), to emergency preparedness agencies and organizations (e.g., Civil Defense offices, State offices of emergency services, the Red Cross), to local government officials, and to scientific organizations and universities that are engaged in earthquake research for clarification of the threat and for suggestions about what to do to prepare themselves.

The effect of this information-seeking activity (especially if it occurs in response to the announcement of an earthquake warning or prediction) is to overwhelm these agencies with requests for written materials or speakers. For all of these organizations, the dissemination of earthquake preparedness information is a very small part of their overall functioning. In many cases, agencies refer information seekers to other agencies that they assume have better information or more resources available; an assumption that is often unfounded. When agencies do have some information available, it is frequently of a very general nature that could be used in any type of emergency or its suggestions are superficial.

Even when organizations have speakers available to talk on earthquake threat and preparedness, their time and resources are frequently voluntary. The use of volunteers as an information resource has two effects--(1) it detracts from speakers' ongoing normal duties (which in southern California were related to either earthquake prediction or community-wide preparedness for disastrous event), and (2) it frequently produced a "lag" time of several weeks to several months between the time the request was made and when the volunteer could fit the request into his/her schedule. Any momentum that had motivated the group to seek out preparedness information may have been lost by the time a meeting could actually be held.

Resource scarcity is a major informational problem related to the public's ability to prepare itself. How this problem can best be solved may involve creative collaboration between the private and public sectors, both of whom will benefit from the dissemination to timely and specific information.

RESPONSE TO AN EARTHQUAKE EVENT

While it is important to inform people about hazard mitigation and preparedness measures, it is equally important for people to know what to do during and immediately following a damaging earthquake. Southern Californians were quite knowledgeable of adaptive behaviors that could be taken during a quake (e.g., standing in a doorway or staying away from windows) and of prescribed behaviors to avoid after a quake (e.g., not tying up the telephone for personal calls).

In an area like the Central States where a disaster subculture exists, it will be important to determine whether any adaptive behavior taken during or immediately following a tornado may be dangerous or beneficial if employed following an earthquake event. In the areas where no other disasters are common, the problem will be to introduce the appropriate behavioral responses in a meaningful way to populations that have no disaster frameworks within which the information can be categorized.

SUMMARY

These are some of the major problems and issues that must be addressed when societal response to the earthquake threat in the Eastern United States is considered. Clearly, a major question that still remains unanswered is the applicability of lessons learned from southern California to the Eastern United States. Without information on the level of community awareness of earthquake threat, the evaluation of earthquake risk, and knowledge about preparedness and response measures, our planning efforts during this workshop must be seen as preliminary. The focus of these efforts, however, should be directed toward the assessment of current disaster information, preparedness, and response systems and the adaptation of those systems for public education in the area of earthquake preparedness and hazard mitigation.

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EARTHQUAKE PREDICTIONS AND THEIR EFFECTS ON PREPAREDNESS: A PUBLIC EDUCATION PERSPECTIVE[1]

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INTRODUCTION

Statement of the Problem. Credible earthquake prediction is a proverbial double-edged sword. While early warnings will save lives and reduce property damage, these same warnings present us with social and economic problems of massive proportion. Several of the foremost earth scientists agree that reasonably credible prediction capability may be no more than ten years away (Allen, Bolt, Council of State Governments, Dunn, Raleigh). Once credible predictions are a reality, we will never be able to go back to the centuries when earthquakes suddenly erupted like sleeping giants and we dealt with their consequences after the fact. Soon, we will have to order our lives according to ever more accurately anticipated earthquakes.

Earthquake predictions force us to evaluate our response capabilities, both collectively and individually. As population patterns create vast megalopolises, the problems and demands associated with disasters have become correspondingly complex and expensive. Disaster preparedness has thus become the responsibility of the local, State, and Federal agencies that can handle such demands. A majority of the budget, manpower, and emphasis today goes toward hazard reduction measures or post-impact response at the community and state levels. Instruction to help the public prepare and survive is a small part of the overall effort.

[1] in Proceedings of Conference XII, "Earthquake prediction information," U.S. Geological Survey Open-File Report 80-843, p. 307-328.

Predictions will cause community as well as personal and household responses. The greater the lead time for a forecasted earthquake, the more potential disruption that will result from these responses (Dunn, p. vi). Prepared people contribute to community stability in the face of impending crisis. Since individual response to an earthquake and its prediction is a critical factor in the aggregate community's ability to cope (National Research Council, p. 38), it is important to plan for optimal responses from the public also.

A wide chasm exists between the sophisticated technology involved in predictions and society's abilities to cope with warning, impact, and recovery. Public preparedness education has a great potential for narrowing this gap, but present programs are weak and outdated or nonexistent in many places.

In these early stages of planning for the potential problems created by all manner of predictions, experts recognize the critical role of public information (Dunn, Haas and Mileti). But the planning for citizen information and education is not explicit or complete enough. It often stops short with general recommendations that basic information be made available when the public requests it or that the mass media assume the role of public information disseminator. References to any kind of active education program out in the community for people and households are vague or nonexistent.

Thesis and Goal. The immense amount of interest and planning surrounding the coming of reliable earthquake predictions lays the groundwork for long-needed improvements in public disaster education. The time is appropriate for expanding hazard mitigation to include effective personal preparedness education. Community level preparedness is only half of the total preparedness equation: personal and household preparedness is the other half. Therefore, preparedness education should include a strong household orientation.

It appears that regardless of the emergency, prepared people are more likely to survive, respond appropriately before and after, and suffer less trauma (Figley). In this paper, it is argued that planners should expand public information components to include live preparedness training that is home-oriented and conducted in local settings. This household-based training should be specific, understandable, realistic, motivating, and personally involving. Effective preparedness instruction should reach a substantial number of homes in the projected impact area. Facilitators can be used to provide interface between the highly technical nature of much earthquake research and its application to the individual household. Local audience participation workshops are effective training vehicles where this facilitation can take place. The overall education program should be based on social science insights and should use some nontraditional resource people as developers and disseminators.

Basic knowledge of how to survive and cope in an earthquake situation applies to many other kinds of disasters and emergencies. Thus, the community benefits from wider applications of earthquake survival education. Disaster prevention and mitigation programs like preparedness education would seem a more humane and cost efficient alternative than disaster relief programs. In reality, both are needed.

The goal of this paper is to present arguments that development of a strong program of preparedness education, centered around the home and family, can be one of the most constructive measures available to mitigate the negative effects of early warnings.

Overview. The paper is divided into four sections. Section I examines educational programs of the past and present for earthquakes, other natural hazards, and successful mass education campaigns for some areas outside of natural disasters. Section II presents a brief history of an effort at public education in Southern California. This "field experience" illustrates some promising techniques for home-centered preparedness training. Section III brings together implications and recommendations for personal preparedness education. Section IV presents some issues for future consideration.

PUBLIC PREPAREDNESS EDUCATION PROGRAMS - PAST AND PRESENT

Lessons for planning may be drawn from public preparedness programs of the past and present. Most hazard mitigation and disaster preparedness programs in the past have failed or proved to be grossly inadequate (Council of State Governments, p. 54). These public information programs, aimed at teaching personal skills to cope with massive threat, have been spotty and often tied to the policies of political figures in power at the time. A nationwide program for citizen preparedness last existed during the period of nuclear confrontation two decades ago. At that time, many Americans were alarmed at the threat and, together with an aggressive federal Civil Defense program, almost every household paid more attention to preparedness. During more peaceful days, preparedness training has languished.

Earthquake Education Programs. Historically, public earthquake education has consisted of a simple understanding of the physical phenomenon, a knowledge of basic safety procedures, and admonitions to store water and food. Most informational messages at present are transmitted through the mass media. They may reach more people that way, but the messages are too general in nature and lack motivational impact. More importantly, they present survival information from the unpredicted perspective. Saarinen suggests that more than distribution of information is necessary to improve adjustments to hazards (Saarinen, p. 15). Much is known in the social sciences about human reactions to emergencies, yet little has been applied in effective, systematic public education programs. Even though the current planning for prediction response is excellent in terms of conceptualization and proposed organization, it does not give enough attention to the specific problems of the individual family-home unit.

Regulska (1979) has gathered information on public awareness programs for natural hazards in this country. She describes several examples from California related to earthquakes. California telephone books now contain several pages of survival helps. However, the information deals mostly with first aid and gives only the usual sketchy basics of earthquake behavior. Utility bills also contain information relating to earthquakes, but typically only the bill-paying family member sees this example. The State Office of Emergency Services sends out public service spots for television and radio. To illustrate their catch-you-by-chance nature, the author does not remember ever seeing or hearing any of these information spots during thirteen years of living in Los Angeles.

One of the more prolific sources of information is the news or public interest reporter. Radio, television, newspapers, and magazines offer features on various aspects of earthquakes with some frequency. Interviews with scientific experts on the current state of affairs and suggestions for simple preparations are fairly common. Commercial film companies realize the attention-riveting value of disaster subjects and so produce documentaries with some regularity. Some of these films are excellent, others exploitive.

The California State Seismic Safety Commission initiated a Disaster Preparedness Project in 1977. The main objective is to find ways to induce local and state government leaders to develop and maintain response capabilities (Regulska, p. 16). Presumably, these disaster response capabilities would include various forms of household preparations.

The California school system dropped systematic disaster preparedness education several years ago and is only now considering putting some earthquake education back into the curriculum. "Your Chance To Live" (Defense Civil Preparedness Agency, 1973) was the last program to be administered to substantial numbers of children at the junior high level. The program has received mixed reactions.

The Department of Geosciences at San Francisco State University, using a National Science Foundation grant, is developing an institute in earthquake education. The purposes of the institute are to provide elementary and secondary teachers with a background and curriculum in earthquake studies, to increase awareness, to create an interdisciplinary approach, and to equip these teachers to be resource people in their schools (Regulska, p. 15). Again, the emphasis is on the scientific understanding of earthquakes with minimal attention to the specifics of personal response.

These examples of the more visible educational programs and sources of information end conspicuously short of any mention of a clear preparedness program intended for adults as well as children, aimed at measurable results. The National Earthquake Hazards Reduction Program (MacCabe, 1978), managed jointly by the U.S. Geological Survey and the National Science

Foundation, is creating the concerted focus necessary to generate constructive action on the earthquake problem. But the man in the street is only indirectly affected by the life-saving planning being done on his behalf. He has probably never even heard of this national program and certainly is not aware of the enormously destructive potential that is causing this scope of effort.

Other Natural Hazard Public Preparedness Programs. Several other natural hazard threats have led to creation of successful public preparedness education programs. The successful program is defined as one that (1) raises the awareness of substantial numbers of people, (2) brings out moderate adaptive behavior (Janis, p. 125), and (3) induces preparedness actions and cooperation with authorities. These hazards have generic components similar to earthquakes in that they are life-threatening and can be enormously disruptive. Most of the programs are addressed to heightening awareness which, it is projected, will lead to preparations before impact.

The National Oceanic and Atmospheric Administration (NOAA) is a leader in the encouragement and production of effective public survival information. They sponsor or coordinate several programs through the National Hurricane Center and the National Weather Service. Hazards created by severe weather happen so often and so visibly around the nation that the public is repeatedly reminded of the potential dangers. Floods, hurricanes, tornadoes, and winter storms receive regular attention from the mass media. With multiple and visible threats, people are more likely to heed warnings and take preparedness actions. NOAA, the Defense Civil Preparedness Agency, the Federal Disaster Assistance Administration, the Red Cross, and others have produced, individually or cooperatively, a large number of films, videotapes, radio and television spots, pamphlets, etc., all available for public information purposes (Regulska, pp. 28-31).

The state of Texas has developed a comprehensive program for public hurricane awareness. The Texas Hurricane Awareness Program began in 1974. Major elements of the program are the distribution of informational brochures (over 750,000 copies distributed in 1978); the production and use of radio and television public service spots; development of a media kit; a coordinated program of lectures, meetings, slide and film shows; efforts at legislation and more hurricane-resistant building codes; hurricane evacuation models; and evaluation and feedback on the entire program (Regulska, pp. 18-20).

The state of Washington has an active disaster response education program centered in their Department of Emergency Services (Stoffel). Through this program, the people of Washington are more than typically aware of the need for preparedness and survival knowledge during severe weather- and water-related threats as well as for outdoor accidents requiring search and rescue.

On May 1, 1977, the National Safety Council sponsored a notable television program called "The National Disaster Survival Test." It used a format similar to the memorable "National Driving Test." The show described likely scenarios based on common problems related to disasters. The audience was presented with several possible choices of action in each case. Only one choice was the correct or 'best' answer. A well-known celebrity then gave a short explanation of the proper response. The show received high marks for raising awareness levels but, for many of us who watched, left the question of how to learn better disaster responses unanswered. In response to thousands of requests for further information, the National Safety Council mailed out a newspaper-type supplement to the inquirers. The opportunity for followup instruction as effective as the Survival Test itself was never utilized. Lack of funds prevented the NSC from keeping track of the requests or analyzing the effectiveness of the program (Regulska, p. 5).

In comparing earthquake awareness and information programs with those for other common natural hazards, it is the author's opinion that the public is more mentally and physically prepared for other natural hazard threats than they are for the earthquake and early warning threat.

Mass Preparedness Education Programs in Other Fields. Several other trauma-inducing events have generated attempts to lessen their effects through pre- or post-impact education. The purpose of such instructional programs is to intervene in the normal catastrophic event --> traumatic results process with training that will reduce or eliminate the physical threat and/or stress caused.

Many of us remember two decades ago when nuclear war seemed a real possibility. A massive educational program was developed at that time to prepare our nation for survival should nuclear war become a reality. To many families, the message and accompanying fear were highly motivational, producing varying kinds of preparations. This household readiness ranged from the construction of elaborate bomb shelters to discussions of emergency actions in case of nuclear attack. As peace continued, the vigorous Civil Defense programs and personal preparations dropped in priority. The potential for nuclear warfare seems at least as great today as it has even been. Enormous amounts of effort and dollars are still being poured into defense planning around various nuclear scenarios. The public is only vaguely aware of most of this planning. Since the level of devastation to normal life patterns during nuclear warning, impact, and post-impact is even greater than with a catastrophic earthquake, the complex research and planning for nuclear war should provide much applicable information for prediction planners.

Though many are unconcerned, some people and some community groups are eager to participate in personal preparedness activities. In fact, because of a national acceptance approaching fad levels, people in general are becoming more accustomed to training offered for coping with demanding situations -- the so-called "how to" courses such as how to prevent rape, how to quit smoking, how to cope with inflation, or how to survive in the wilderness. Witness the widespread growth of cardiopulmonary resuscitation (CPR) training in recent years. These classes rely on the kind of personal commitment that would make many disaster planners skeptical of success. They require the participant's time, travel, and sometimes money. The classes lead learners through repeated rehearsals. Many signs attest to the popularity and success of CPR. In Los Angeles, a self-help program was organized to cope with heart arrest victims in high-rise buildings with over 2,000 employees (Turpin, 1979). Another example is the observation that "if you are going to have a heart attack, have it in Seattle" because so many citizens of that city are trained in CPR.

Another outstanding example of widespread acceptance of a life-saving preparation is home ownership of smoke detectors. Through mutual cooperation among authorities and a vigorous and longstanding awareness campaign, smoke detectors are now a significant factor in saving lives (Los Angeles City Fire Department brochure). The National Fire Protection Association, along with other associations and local fire departments have done an impressive job with fire safety education in our country. Their EDITH (Exit Drills in the Home) program is a major effort to reduce the toll of dwelling fires.

The most seemingly unrelated example of successful preparedness education is the Prepared Childbirth program (see Hungerford). Yet, a closer look reveals several generic components common to disasters, emergencies, and childbirth: trauma, stress, uncertainty, anxiety, and feelings of helplessness. Childbirth can be traumatic for both the mother and father. It can introduce new stresses into the relationship. Anxiety and feelings of helplessness are created by the unknown, the uncertainties of especially first-time childbirth. The value of prepared childbirth is that it eliminates uncertainty as much as possible and gives parents the means to control their anxiety and feelings of helplessness. Classes for parents provide the antidote of preparedness to cope with these stressful experiences. They demonstrate techniques to better prepare mother and father for the actual birth process. They teach care of self and baby before and after birth. They encourage communication between husband and wife. They take the expectant parents through detailed scenarios of what to expect. These rehearsals let the parents do "the work of worrying" (Janis, pp. 100-105) and, through facing the stress-causing situation, free them to meet the anticipated event more constructively. (Hopefully, the parallels with earthquake preparedness education should be obvious to the reader.) The measure of success of this live education approach is that Prepared Childbirth classes are now offered in most major hospitals across the United States.

CONTRIBUTIONS OF A THREE-YEAR FIELD EXPERIENCE

This section first describes the historical development of an earthquake preparedness education effort in the Southern California area. The account is a chronicle of the author's personal experience. The concluding paragraphs point out features of the effort that have potential for future preparedness training.

It was approximately 6:00 a.m. on a dark morning in February of 1971. My professor husband and I were asleep in our San Fernando Valley home as were our two small daughters. Suddenly the bed and house were gripped by a terrifying rolling motion. The deep rending noises were even more frightening than the motion. Being a native Californian, I instantly realized -- EARTHQUAKE!! I bolted from bed and lurched down the short hall, banging from wall to wall with the violent rolling. I could hardly stand. My husband was right behind me, a sleepy child scooped up in each arm. I ran to the front door and frantically clawed to get it open. Within seconds of being awakened, all four of us were standing in the quiet front yard in the dawning morning. No one else was in sight. The only sign that something momentous had happened was the swimming pool water coursing down driveways into the street.

In retrospect, I am often amazed and appalled at our primitive reactions during those seconds. I especially should have been more mentally prepared to respond appropriately. After all, I had lived in California many years and had been through schools where earthquake education was taught - I think. I don't remember, and perhaps therein lies part of the problem. Impressions were not ingrained enough to cause me to react in the best way. Years passed and this vivid personal experience had little impact upon our family planning for future earthquakes.

However, the experience must have left a residual predisposition toward personal preparedness in me, for when a friend approached the subject in 1976, she found an eager listener. My business partnership of home economists was looking for innovative opportunities to develop programs of benefit to the home and community. About the same time, James Whitcomb issued his 'trial balloon' prediction and the Palmdale Bulge leaped into the headlines. The realization that none of our own families had taken any precautions for future earthquakes made us aware that the need for family preparedness planning must be widespread. We also realized that our professional skills were uniquely suited to teaching people home survival information.

So the members of Creative Home Economics Services (CHES) gathered a body of detailed information about earthquake survival and needed home emergency supplies. We created a workshop format to teach the basics of home and family earthquake preparedness for impact and the days to follow. We incorporated as much valid information as we could find and used our imaginations to expand beyond existing literature. We notified the governments of over 75 cities in the Southern California area that these public workshops were available. Only Los Angeles replied, referring us to the Civil Defense Director. A Palmdale city official, in response to my followup telephone inquiry, said they were not interested because they did not want to focus additional unfavorable attention on that area.

We thus embarked on our preparedness education effort without sponsorship or funding. We felt the need was great enough and what we had to offer was good enough that we should persist. And persist we did, for over three years. We expanded the workshop formats to include not only sessions suitable for the public but sessions for training the trainers to teach others. We sampled a broad cross section of potential future disseminating groups so we would be ready if community support ever materialized. Our list of contacts became wide and representative of opinion-making groups.

We produced an inexpensive spiral-bound handbook entitled HOW TO SURVIVE AN EARTHQUAKE: HOME AND FAMILY PREPAREDNESS. The workshops presented the main points of preparedness using a table talk, videotapes, slides, and transparencies. The handbook provided each family a more detailed guidebook for use at home with family discussions. The San Diego Union newspaper featured an article on home preparedness and mentioned our handbook, available only through mail order. We received nearly 900 orders, some several months after the article appeared. This experience alone attests to the concern of many private citizens over personal earthquake preparedness.

It is appropriate at this point to step back and analyze the strengths and weaknesses of this CHES 'field experience.' The overriding strength of a live education example like the CHES workshops is the relationship that develops between the teacher and his/her audience during that brief time. If education creates conviction, then live education does it better than passive education! A homely analogy is a live cooking demonstration. Even though millions of good recipes are in print, the homemaker is more apt to rush home and create a concoction she has just seen demonstrated 'in the flesh' than one she has read about. Also, people are used to learning better methods of performing tasks through the demonstration method which breaks down generalities into illustrated specifics. Home economists have a positive public image in relation to the home and this probably positively influences audience acceptance of the information.

The CHES workshops were successful because they used the family as a primary self-interest motivator. People could see the benefits of home preparedness training. Workshop attendees were interested and/or concerned since they had chosen to come. The word spread from enthusiastic participants to other groups, so that it appeared the effort could have enjoyed a domino effect in requests to give more workshops. The striking contrasts with most public earthquake education to date were the manner and environment of delivery, the material presented, and the use of nontraditional developers and teachers Saarinen reinforces this analysis through his observation that "for an effective educational program, random distribution of information on hazards to the public is not enough......Community action programs involving face-to-face contact in meetings and small groups may be necessary for optimal results." (Saarinen, p. 20)

Though the CHES effort received highly favorable response from both the public and emergency services officials, group members were limited by several factors: they worked outside the accepted disaster preparedness structure, though with its knowledge and endorsement; they needed to reproduce themselves, for the job of public education is a large one; they had no funding other than personal dollars; their lack of visibility and access to resources were also major problems. These contributed to the main weak points of the program -- valid research results, especially in the social sciences area, were not used as a basis for designing workshop components and there was no mechanism or opportunity to evaluate later behavior of workshop attendees. Also, the CHES workshops concentrated on the simple techniques of survival and existence during the first several days after impact. They did not deal with prediction lead times. Because of this narrow approach, they could not observe how people and audiences deal with an expanded approach, bringing in the psychological, social, and economic factors playing a role in the prediction lead time.

Contribution of Facilitators. A "facilitator" can be defined as a person who provides necessary interface between the research-technology community and the users of that knowledge (Rogers, 1979). Because of the widening gap between technical prediction capability and the ability of people to respond in an appropriate manner, facilitators are crucial as translators and disseminators of survival information. In the vertical mode of technology transfer (see Figure 1), two messages must flow through the system: information about the subject and a persuasion message urging use of that knowledge. The facilitator adds the important human dimension that often is missing in mass education. CHES members were examples of facilitators.

Contribution of Workshop Format. A useful format for live training is the audience participation seminar or workshop. It provides an ideal setting for the work of the facilitator. It seems especially suited to family attendance. Workshops can be tailored to a wide variety of situations, locations, or audiences as well as involve the audience in the proceedings.

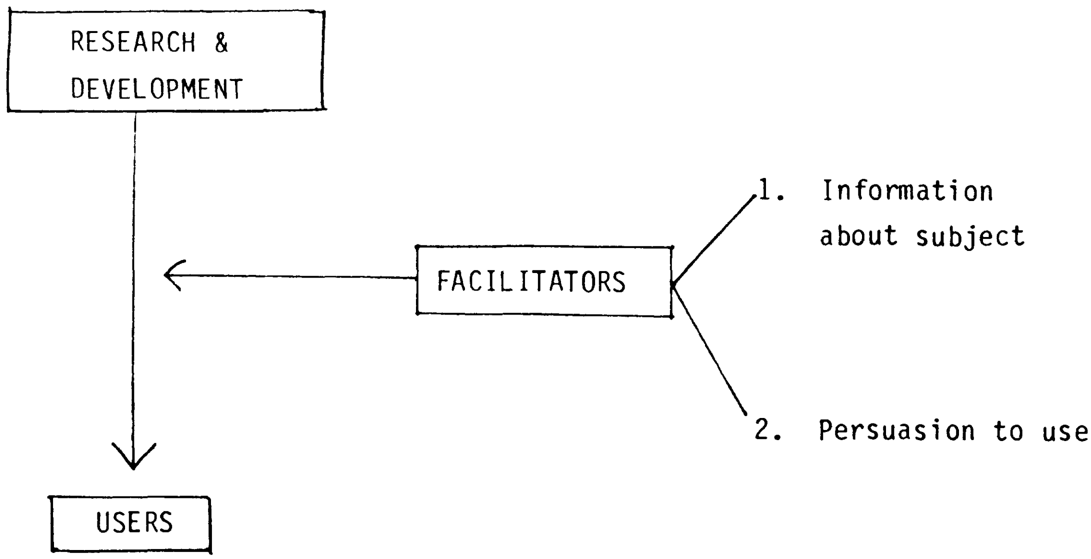

FIGURE 1

They are lively and flexible. They can be taught by one person with props and aids. They can be set up for easy and efficient duplication. Once assembled, they are generally inexpensive to reproduce.

Observations from Experience. From the CHES experience of May, 1976 to the present, the following few observations are valuable when considering personal preparedness education:

(A) A substantial number of people and influential groups are ready to learn about home preparedness NOW and spread the news to others.

(B) The mechanics or techniques of preparedness (i.e. gathering supplies and water, securing simple items around the house, imagining the correct survival behaviors during the quake, etc.) are relatively easy to teach. People seem to have little trouble identifying with this information and performing some of the suggested tasks.

(C) Families appear to use almost no organized methods in making decisions dealing with disaster-related risk.

(D) Suggestions that families rehearse their preparedness plans for both earthquake and possible fire encounter resistance.

(E) Self-interest is a powerful motivator. Questions people asked were almost always those dealing with their own person, family members, homes, or neighborhoods.

(F) Personal and family preparations have many parallels with community preparedness.

IMPLICATIONS AND RECOMMENDATIONS FOR PERSONAL PREPAREDNESS

Implications. A reliable prediction capability will be the catalyst that replaces uncertainty with difficult realities for us, individually and as a community. The first task may well be to redefine what "preparedness" means in terms of family responses during lead times. It is premature at this point to dwell on specific recommendations for household actions. Rather, a careful analysis of alternative courses of action should precede formulation of the specifics advocated through a concerted public education campaign. However, delay must not be interminable. Gilbert White advocates proceeding with prediction response planning even though "we don't have all the pieces of the puzzle yet" (White). The former Defense Civil Preparedness Agency concurs with a need for action based on a similar scenario, that of nuclear threat. In a 1979 information update, the agency asserted that the Crisis Relocation system, for example, does not have to be a perfect and complete system before it could be used to save millions of lives (DCPA Information Bulletin, pp. 20-21). We in earthquake preparedness planning should keep these time dimension admonitions in mind.

Household-oriented live preparedness training has a better chance of selling readiness than impersonal mass education formats. If enough individuals are convinced of the benefits of preparedness, they could start a movement that would overcome the inertia of many citizens. People who live in earthquake country could become as matter-of-factly aware and prepared as good pilots, sailors, or wilderness hikers are prepared for their environments. Because of intense media coverage of prediction news events, people are increasingly aware of earthquakes and possible warnings. Many are reaching the 'teachable moment' that presents a timely opportunity for training. But to date, leadership for widespread public preparedness, either within government or from the community,is not sufficiently visible or persuasive. (See Turner, p. 59).

The CHES experiences suggest the value of a home-centered workshop approach. But this type of program must be expanded beyond techniques for earthquake survival during and after impact. It must span the lead time phase as well and be grounded in social sciences research. The broader issues introduced by credible warnings will be harder to tackle. We can anticipate more resistance and lower levels of conceptualization about these complex issues. It will be more difficult to help people internalize these action recommendations. If they take the subject seriously and personally, it will produce stress.

Individual family decisions will have great impact on the readiness of a community to deal with a predicted quake. Family units make decisions of consequence every day. But it is probable that most households have no previous experience in making the excruciating choices and tradeoffs necessary with long lead times and high levels of expected devastation. It is also likely that their present decision process is incapable of handling these foreboding alternatives (Saarinen, p. 12). At present, without a proven prediction capability, earthquake seems to present an acceptable level of risk for many people (Council of State Governments, p. 34). With acceptable levels of risk, difficult decisions are not necessary. But credible prediction will raise that remote risk to a more alarming level , and people will be forced to start making these difficult choices. Therefore, a top priority job of public education is to make people aware of how complex this particular decision analysis will be and to provide them with the hopefully simple tools to make risk decisions. The areas of home management and consumer economics have used family decision analysis extensively. Some of the logic used in consumer or home management decision-making can be adapted and applied to earthquake risk deliberations. See, for example, Miller (1978), Troelstrup (1974), Oppenheim (1972), and Bratton (1971).

Home preparedness parallels community planning. The Los Angeles Task Force on Earthquake Prediction listed some examples of community responses to prediction (Dunn, p. 28). The list allows us to formulate a similar list of appropriate household responses (see Figure 2).

SHORT LEAD TIME

Community Responses	Family Responses
• Limited evacuation	• Limited evacuation plans
• Temporary shutdown of hazardous facilities	• Plan for temporary shutdown of home
• Increased on-call staffing	• Increased neighborhood interaction, response plan

LONG LEAD TIME

Community Responses	Family Responses
• Major upgrading	• Structural mitigation
• Extensive citizen education	• Extensive family member education
• Reduction of inventories	• Assembling of emergency supplies
• Shifting of personnel	• Plans for relocation, evacuation, vacation

FIGURE 2

The earlier observation on resistance to engage in simulated rehearsals brings up the question of stress. Stress occurs whether merely contemplating earthquakes and their possible personal impact or actually walking through a simulated response. The rehearsal can raise anxiety to uncomfortable levels. Thus, most people initially resist rehearsals. If they are encouraged to repeat the rehearsals, they will eventually feel more in control, less helpless. Their anxiety levels will decrease, the necessary "work of worrying" will be completed, and they can handle the threat constructively. This process has been aptly described as "emotional inoculation" (Janis, p. 103). Rehearsals also exercise critical physical behaviors.

Recommendations. The foregoing sections were intended to lay groundwork for the following recommendations. At this point in time, it is a difficult task to envision what individuals and families might do in response to the credible prediction of a high magnitude/probability quake (Council of State Governments, p. 19). It is a 'head trip' that taxes the imagination and awakens the personal fears of the planners as well. Turner concurs that we cannot take literally what people say they would do when asked in hypothetical terms about a situation they have never actually experienced (Turner, p. 48). Thus, it is emphatically repeated -- it is inappropriate to use only existing public education materials and methods in response to prediction because they were prepared for the unpredicted earthquake and are therefore incomplete. And it is premature to hurry out an updated substitute without thoroughly exploring the consequences of alternatives. In keeping with these cautions, these recommendations are general in nature.

The public education program must be carefully and sensitively developed. Public education planners should:

1. Update public information to reflect the coming age of reliable prediction technology. The needed educational program must produce responses beneficial to the individual, family and home, and community. Program development must be in phase with growing prediction capability and the advance publicity it engenders. Periodic updating of the program and materials should be a requirement.

2. Encourage local units (cities, communities) to direct the program with help from State and Federal governments if needed.

3. Coordinate the program with the area's overall disaster response planning.

4. Design the program to be flexible, graded to accelerating levels of need as impact nears. They should specify that information be tailored in several versions to meet the needs of various social, economic, and age groups.

5. Take advantage of the multi-disciplinary contributions already available to them. They should draw heavily from the social sciences in designing rational and persuasive messages. They should utilize more nontraditional professionals as facilitators in development and dissemination. Examples might be home economists, consumer economists, or family life educators. They should plan to use citizens and volunteer groups to teach and carry forward the bulk of the program at the local level.

6. Design the program to include mass media and live training components.

7. Work for alliances with major adult education facilities. Tailor much of the program for adults and families. Introduce adaptations into schools at all levels.

8. Be aware of the psychological costs of awareness. The awareness program must raise the anxiety level sufficiently to get the public's attention and encourage preparedness. But uncontrolled anxiety can lead to panic or immobility, thus the program must provide an antidote to excessive anxiety. That antidote is personal preparedness. It gives people the sense that they can manage or cope withy the anxiety-producing danger (Perry and Pugh, p. 109).

9. Consider long-term viability of the program. One two hour workshop raises awareness and may induce preparedness temporarily but commitment usually fades with time. The workshops should be repeated so that people have several oppotunities to receive training or review.

10. Recommend that workshop developers consider these points when designing the public package:

a) Use carefully planned publicity issued well ahead of the event.

b) Choose locations that offer neighborhood convenience, free well-lighted parking, cheerful room colors and lighting.

c) Enlist the support and participation of local leaders with whom the audience identifies.

d) Use reassuring nonthreatening figures as spokesmen and teachers.

e) Design the format in upbeat style, using 'show business' techniques that do not detract from the serious message.

f) Orient the message to home and family.

g) Use a variety of visual materials. Make them available for examination before and after the presentation (example, a table talk). Materials should reflect those found in typical homes in the area.

h) Limit the general public workshops to one to two hours at most, to keep boredom to a minimum.

i) Employ frequent changes of pace during the presentation.

Give the audience an opportunity to participate, appropriate for the size of audience.

Use simple, specific information packaged as self-help techniques, with better illustrations and more graphic demonstrations.

Base training information on realistic scenarios.

11. Envision a dual system of workshops where one version is designed to train the trainers. These trainers then go out and use a public version of the workshop with people in local settings.

12. Determine what services citizens can expect from the city or county and what responsibilities are the citizen's own. Make these expectations clear in training.

13. Be able, through the program, to clearly spell out the benefits of personal preparedness and the realities of earthquake scenarios (i.e. it won't be as bad as you think for these reasons.....).

14. Realize that time is not on the side of delay in implementing an educational program. The public education priority should be right behind building safety in urgency.

ISSUES FOR CONSIDERATION

This paper actually raises more questions than it answers about the complex and urgent area of personal earthquake preparedness. But since this is the appropriate time to raise such questions, it is hoped the ideas contained here will inspire new and imaginative attention to the problem. If a body of assembled interdisciplinary experts like the one at this Conference does not address the unmet needs for public education specifically and energetically, who will provide this leadership?

The experts charged with earthquake prediction/impact planning should keep in mind the admonition that personal preparedness planning deserves the same thorough and comprehensive treatment as community planning. Educational program developers should be working at the same time, in the same depth, and with extensive communication with all other prediction/impact planners. This exhortation raises the question -- Whose responsibility should it be to foster this "task force"?

The following issues are crucial to the consideration of large-scale personal preparedness programs. They also are issues needing further investigation.

A. What does "educate the public" mean? Historically -- local vs state vs national? Given the perspective of prediction capability?

Whose responsibility is it to make people aware? How far should that responsibility go?

B. Is it possible and/or desireable to develop a generic model for public programs that would apply to most disasters?

C. What are the costs and benefits in applying community or government dollars to disaster prevention programs versus disaster relief programs?

D. What are desireable adaptive behaviors for households and individuals during lead time, impact, and post-impact? What are the areas of difficulty in conceptualizing possible reactions?

E. Are there ways to help households with decision-making in relation to predictions? Can a generic model be designed for personal decisions of this kind?

F. How does the perception of risk affect rational response? (We must seek to make that perception more realistic.) How do you ensure appropriate risk perception without manipulation?

G. With realistic scenarios, characterized by probability of demand for emergency services far exceeding supply -- what is the responsibility of the household and neighborhood to care for itself? What is the capability?

H. How can households cope with the economic down-spiral expected with long lead predictions, if they elect to stay?

I. What can be learned from other successful preparedness programs? How does it apply?

J. How should we use nontraditional resource people to help develop and disseminate public information to large numbers of citizens in the most personal way possible?

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HOW TO GAIN THE ATTENTION AND COMMITMENT OF POLITICAL OFFICIALS: AN EARTHQUAKE POLITICS PRIMER[1]

by

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INTRODUCTION

Since socio-political climates and decisionmaker psychologies still interact to permit local officials to ignore earthquake responsibilities, nothing less than cleverly formulated strategies can induce approval of rudimentary measures in earthquake prone communities. Recent and prospective advances in geoscience and seismic safety will continue to enhance the credibility of earthquake specialists, while researchers and practitioners in the politics of disasters now can suggest ways to minimize conflict on mitigation and preparedness issues. Although the outcomes of impending deliberations will appear unimpressive as means to decrease vulnerability, any steps taken can at least increase receptivity to future information and--in so doing--facilitate later adoption of "second generation" seismic safety initiatives.

STRATEGIES

An approach consistent with these assumptions falls short of the optimal, yet remains practical and certainly an improvement over the status quo. The ensuing practical strategy consists of eight viable statements and explanatory commentaries. Substantial progress in winning local leader acceptance of these premises will assure endorsement of at least some aseismic activity.

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[1] *in* Proceedings of Conference XXI, a workshop on "Continuing actions to reduce potential losses from future earthquakes in the Northeastern United States": U.S. Geological Survey Open File Report 83-844, 129 p.

1. Earthquakes can strike during your term in office.

Dispel any beliefs that serious earthquakes cannot happen here and now. New and contemplated research will more precisely measure recurrence intervals. These can readily be converted into annual and cumulative probabilities (for "politically meaningful" time intervals). Where applicable, put public officials and "attentive publics" on notice that there is a "non-zero" probability of a damaging earthquake this year. Political matters must have some immediacy. Declaring a present threat--even with a low probability--grants some contemporary status to the problem. This advantage of currency exceeds the preparedness costs of reporting a low annual probability. Likewise, the confidence demonstrated by specifying a quantitative estimate exceeds the credibility costs of reporting the invariably large error term associated with each estimate. These errors suggest using high, middle, and low recurrence estimates to generate probabilities/time interval. Recommend the conservative course of using the most imminent "prediction" for planning purposes. Typically this provides a long time horizon, but still suggests "capping" programs well before the next damaging earthquake is due.

No mention of earthquakes should be devoid of reference to their devastating consequences. Abstractions characteristic of standard briefings must be accompanied by vivid portrayals. Cultivate skillful ways to "bring the emergency home." Either a historical earthquake in the same region or a contemporary earthquake in another community may be "borrowed." This earthquake can be "rerun" with a plausible local epicenter. In both cases interest in the "real" event would add salience to the projected consequences of the simulated quake.

2. Earthquake problems can be managed.

Earthquakes--however imminent and destructive--become meaningful public problems only when officials believe in the efficacy of countermeasures. To oversell the threat risks denial unless viable steps can be taken in response. Awareness that earthquake vulnerabilities stem from the location, design, and construction of the built environment sensitizes elites to recognize that seismic hazards are essentially manmade--and amenable to human solution. At a problem specific basis, earthquake specialists must carefully establish the modifiable causes of earthquake losses and clearly explain the ameliorating effects of seismic safety programs. An ability to describe the threat in quantitative terms reassures authorities about the problem's manageability. Plausible summaries of consequences in lost lives, dollars, and person-hours provide crucial baselines for comparisons. Expected gains--attributable to particular mitigation/preparedness investments--can then be expressed as reductions in deaths, damages, and down times. Finally, realistic, if inexact, costs must then be attached to selected mitigation/preparedness strategies. Such a formatting of information not only gives policymakers a simple calculus for making seismic safety decisions, but also strengthens their perceptions that emergency planners and managers really "understand" earthquake phenomena.

3. Earthquake consequences can unleash political reverberations.

Aside from numerous legal liability issues which remain to be resolved, elected and top appointed officials dread "political liability." Political liability varies with public perceptions of blame. Uncontrollable acts of God yield little attribution of fault. Preventable tragedies, on the other hand, produce harsh judgments--to the chagrin of officials deemed responsible. As elites, specialists, and key publics increase their threat and adjustment-to-threat awareness, then accountability perceptions will move in the "preventable tragedy" direction for earthquakes. Of course authorities who have shown courage in trying to overcome inertia on seismic safety are apt to gain politically in the aftermath of an earthquake.

4. Hazard mitigation/preparedness measures can be feasible.

When presentations of benefit/price ratios facilitate comparisons, the cost effectiveness of seismic safety investments impresses policymakers--even if officials must recognize the likelihood of serious inaccuracies in the estimates. Cost ambiguities pose greater problems in gaining approval for earthquake management expenditures vis-a-vis competing priorities. Understandably, these problems diminish when seismic safety advocates request modest allocations. Nevertheless, other characteristics of demands for public resources affect political feasibility. Program success varies inversely with the extent to which restrictions on uses of existing property are retroactive. Program success also varies directly with the degree to which incentives--as opposed to penalties--are used to attain program goals.

While the seismic safety community cannot abandon crucial retrofit or design regulation programs, any agenda of policy recommendations must also include more humble fare. If a jurisdiction can only afford measures which make few demands on community resources and relationships, depict this choice as a modest but useful contribution to earthquake safety. Since such precedents often incrementally expand into more substantial programs, comprehensive emergency management proponents would be well advised to avoid forcing "either/or" choices between the "rational" and "nothing."

5. Burdens can be spread across society and over time.

Numerous means exist for distributing pain more broadly and gradually. Direct or indirect subsidies can remove punitive characteristics from retrofit programs. Lengthy, incremental enforcement schedules can displace retroactive elements from many of the same programs. Granting building officials discretion to alter rules slightly with each ownership, occupancy, or use change avoids severe penalties for any one actor. Obviously these illustrations are not exhaustive, but they do suggest ways to diminish politically deleterious equity problems.

An effective approach to the problem of allocation of justice also uses the long time horizon to advantage. Estimate the human, property, and productivity costs of the model earthquake. Specify acceptable risk levels by declaring the reductions in these amounts a decisionmaking body intends to achieve through policy. Estimate the monies required to reach these objectives. Finally, divide these mitigation/preparedness costs by the number of years in the interval constituting a cumulative earthquake probability of 50%. The quotient will probably indicate that small amounts of money need be invested each year. Such a figure will seem outrageously small to those committed to improving seismic safety, yet might appear very reasonable to an official with general responsibilities. Such reasonableness can determine whether earthquakes receive some attention or no attention.

6. Seismic safety solutions can serve multiple social purposes.

Cross fertilization between earthquake and other disaster preparedness planning can benefit both--substantively and politically. At the mitigation level, emergency managers will assuredly acknowledge the compatability between the goals of more stringent lateral force requirements and wind load standards sufficient to protect structures from hurricane force winds. Firemen, too, whose lives often depend on the structural integrity of burning buildings are likely to support programs to retrofit hazardous structures. And administrators of infrastructures which include rusty, leaky lifelines appreciate having additional arguments for accelerating repair and replacement schedules.

More general support can result from identifying seismic safety goals with overall redevelopment purposes. When broad coalitions of interests seek improved safety, efficiency, and beauty in an area, increased earthquake safety should be both an advertised and an actual benefit of the project. In the same vein, neighborhood associations working to decrease crimes, fires, and household emergencies will often express an interest in earthquakes. Not only is seismicity increasingly recognized as a serious (but largely soluable) problem, but because it is also such a fascinating topic, it serves organizational maintenence and enhancement needs.

In these and other cases the consistency between seismic safety goals and others facilitate approval chances. They also make activist friends for seismic safety proponents. Perhaps a parting caution is in order: be sure to distance yourself from single issue advocates who use seismic safety cynically and largely for other purposes. While seismic factors deserve detailed consideration before locating and building critical facilities, the reflexive identification of seismic safety with the underlying issue in the minds of many can discredit seismic safety.

7. Seismic safety solutions can create recognizable beneficiaries.

Rather than wanting to approve general--even symbolic--policies in the "public good," many politicos prefer to indulge specific industries, professions, firms, or individuals. This implies nothing about any party's honesty or ability. Certainly such beneficiaries' commitment and competence usually remain above reproach. This argument depends more on the desire of politicians and bureaucratic entrepreneurs to construct a series of exchange relationships. Relatively tangible media of exchange-contracts, grants, access, publicity, etc.--facilitate clarity--if not necessarily explicitness--in bargaining. The official needs personal or program support in holding or expanding his resources, responsibilities, and constituencies. Those with specific stakes in the transaction are apt to understand and deliver on their end of the agreement. Furthermore, a pro manifests more persistence than a broadly focused amateur, assuring a more stable relationship. The message of this generalization can be stated unambiguously: Do not be reluctant to express your professional judgment and conscience because there is a chance that you might make some money.

8. Seismic safety solutions can generate sufficient coalitions.

Conditions can continue to become more favorable for earthquake safety proponents. A nucleus of long term supporters consists of an expanding array of public and private sector professionals with occupational interests. Middle range supporters include those prominent in organizations whose goals dovetail with seismic safety. People responding to recent media accounts of earthquake phenomena comprise shortrun supporters of such a coalition. While never large except after a community experiences a serious earthquake, the collection can be diverse enough to raise many facets of the problem. In the absence of a concerted opposition, the net effect will be to put the issue on the public agenda. While this represents a moral victory by itself, strong cases and appropriate tactics can yield program victories that begin to institutionalize seismic safety. Of course success in pulling these resources together depends on the quality of leadership and the suitability of its strategy.

SUMMARY

Two themes suffuse the above eight points. First, that aseismic strategies must be based on a consensual politics model under current circumstances. Given the many constraints inherent in that kind of politics, program successes must be small ones. Second, that small seismic safety steps now can establish precedents for larger steps later. This theme is premised on the belief that formal jurisdictional acceptance of "earthquake threat" as a principle is nearly irreversible. Finally, these themes are accompanied by an attitude. While forging a new basis for policy remains a complex and difficult task, the task nevertheless can be accomplished by patiently and persistently communicating with elites and informed publics. Imagination and flexibility remain our most crucial, overlooked resource.

HOW TO GAIN THE ATTENTION AND COMMITMENT OF BUSINESS AND INDUSTRY[1]

by

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INTRODUCTION

There are a number of actions or events which will help to concentrate the minds of business and industry on preparing for earthquakes. Among the most effective ones are the following:

1) The Actual Occurrence of an Earthquake

This is not meant facetiously. Businesses located in earthquake-prone areas of the country are far more sensitive to earthquakes and, undoubtedly, much better prepared for them than are businesses located in areas which rarely experience such phenomena.

If earthquakes do not occur, it may be possible to gain the attention of business and industry by preparing for other kinds of emergencies. Such preparations almost always are a benefit in the event of earthquakes, although they are often inadequate.

2) Publicity

If most people are aware that they live in an area where earthquakes are expected to occur, businesses will respond to their perceived needs for planning and preparedness activities. By the same token,

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[1] in Proceedings of Conference XVIII, a workshop on "Continuing actions to reduce losses from earthquakes in the Mississippi Valley area:" U.S. Geological Survey Open-File Report 83-157, 140 p.

if the public is not aware that severe earthquakes may occur, it is unlikely that many businesses will spend the time, efforts, and resources necessary to develop appropriate preparedness plans.

Members of government, particularly at the State level and, in particular, State governors, can exert considerable influence in convincing companies to make adequate preparations. If a State governor is convinced that an earthquake in his State is likely, he can publicize this fact generally and speak to the business community at large or on an individual basis -- and can exert considerable influence on companies to undertake planning and preparedness activities.

3) <u>Seminars and Conferences</u>

Seminars and conferences are another form of publicity. They bring together knowledgeable people to discuss the likelihood of earthquakes and earthquake damages. They then publicize the results of their deliberations. Special conferences and programs aimed at business and industry can be put together. However, without supporting government publicity and pressure and without general awareness among the public, such conferences, even if specifically designed for business and industry, are not likely to be well attended.

4) <u>Credible Earthquake Predictions</u>

If earthquake predictions are developed for an area and are endorsed by the National Earthquake Prediction Evaluation Council (NEPEC), a flurry of earthquake planning and preparedness activity can be expected. However, the art of earthquake prediction is not sufficiently far advanced to make this a likely prospect.

5) <u>Private Business and Industry Leadership</u>

If some companies, particularly leading ones, are seen to be developing their own plans to deal with earthquakes, it is hard for other companies to dismiss these efforts out of hand. By the same token, if some companies are undertaking preparedness activities, they may be willing to publicize these actions and host seminars and conferences explaining what they are doing and why.

How to Gain the Commitment of Business and Industry

Some achievable actions include:

1) Convince the business community that damaging earthquakes are probable within a reasonable period of time. Unless a company is convinced that a damaging earthquake is likely, it makes no sense for them to expend resources preparing for such an event.

2) Educate companies about earthquake hazards. Demonstrate to companies what kinds of buildings are hazardous during earthquakes and what kinds are considered resistant to earthquakes. Show how building structures and interiors can be strengthened to reduce earthquake damage.

3) Prepare cost/benefit analyses to demonstrate the economic value of being prepared for earthquakes. Show that relatively modest investments of time and money can protect against potentially enormous losses should earthquakes occur. Convince companies that measures taken in anticipation of earthquakes are often very effective in the event of other kinds of emergencies, such as: fires, explosions, and the like. Demonstrate that such preparedness measures do have an economic value to the company.

4) Show how liabilities for injuries and damage can be reduced or contained by adequate preparation for earthquakes. The conventional wisdom in companies is that unless negligence is proved, they are not likely to be held liable for injuries and damage caused by earthquakes; and that if negligence should be proved, their normal liability insurance will cover them. This propostion has not been

adequately tested in the courts and so its validity is not certain. At the same time, many companies will find that their liability insurance is inadequate in the event of an earthquake, where injuries and damage are extensive and can lead to enormous claims.

5) Establish an emergency planning position in the company. Most companies attach the emergency planning function to some other position. This means it represents one more thing to do for someone who is often already fully occupied if not overburdened. As a result, emergency planning tends to get overshadowed by the person's normal duties.

   If emergency planning is set up as a separate function, it will be the primary responsibility of one or more individuals and will not be submerged by other activities. This will ensure that plans are developed and reported and the appropriate issues are raised, even if some company managers are reluctant to commit their limited resources to such projects.

A critical element in all of the above is that the senior management of the company be convinced of the value of emergency planning and support this activity. Without such support, no efforts by subordinates can bear fruit.

GAINING COMMITMENT OF VOLUNTARY AGENCIES[1]

by

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INTRODUCTION

Volunteerism and the agencies formed to provide avenues for voluntary action in the United States have often been cited as unique to American culture. A phenomenon of sharing and concern for others is not seen in other societies of the world, at least not to the degree known here in the United States. Consequently, one would think that how volunteers and their organizations operate and what is entailed in obtaining their interest in community action is well understood by most of us. Unfortunately, this tends not to be the case. We tend to forget that these agencies are composed of people just like us. In fact, the majority of Americans are volunteers in their communities in one way or another. Therefore, the methods necessary to gain voluntary agency commitment to a particular cause is very similar to the methods of gaining our individual commitment to a cause. Gaining voluntary agency commitment has three basic components.

STRATEGIES

Do Your Research

There are two primary types of voluntary agencies, they can be characterized as traditional and non-traditional. Organizations such as the various religous/ church groups, the Red Cross, the Sierra Club, and the Y's fall into

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[1]in Proceedings of Conference XXI, a workshop on "Continuing actions to reduce potential losses from future earthquakes in the Northeastern United States": U.S. Geological Survey Open File Report 83-844, 129 p.

the first group. They share the qualities of being well-known, have clear mandates as legitimate volunteer action groups, are usually multi-faceted in their programs and motivation, and are often able to tap into the financial and people resources of a national organization.

Non-traditional volunteer agencies are harder to "get a handle on." Often single community based and usually known as single cause groups, the non-traditional agency often does not have the advantage of a broad-based national constituency, or relatively secure financial base. They have the advantage of being highly innovative in approaches to problem solving and enjoy extraordinarily high commitment from their adherents.

Resources available from each agency must be identified. Is the group primarily a service agency? An advocacy group? Do they have a highly visible public information component? Do they have an on-going natural disaster program element? By seeking the answers to these and similar questions it becomes possible to come to know the character and philosophy of each agency.

Additionally, it is essential to understand the motivation of their leadership and the members at large. Volunteers are like all of us. The motives for voluntary action do not differ greatly from the motives for success in the workplace. The only major difference is that the altruistic payoff is not in monetary terms; but, the other and perhaps more important benefits of recognition, prestige, and a sense of contribution are just as germaine to the volunteer as it is to the vice-president of General Motors. We cannot expect to gain the commitment of the voluntary sector without addressing and providing these essential benefits.

Know What You Wish The Voluntary Agency To Contribute

Voluntary agencies or groups are again similar to individuals in that ambiguous concepts tend to diminish our understanding which concomitantly diminishes the ability to effectively deal with tasks. Agencies are willing, in most instances, to help formulate the task; however, the need must be clear cut and supported by solid factual data presented in understandable terms.

Nearly as important as presenting a clear concept of what the voluntary agency is asked to do is the requirement to bring them into the project as early as possible. The earlier - the better. Few agencies will appreciate being asked to participate only after other approaches have failed or when they have not had adequate opportunities to contribute to the assessment and planning components of a project.

Sell The Agency On The Need

Voluntary agencies have many activities they wish to accomplish and too few resources to accomplish all of their priorities. In order to sell these groups on earthquake planning, a telling argument must be made in order for them to reorder their priorities and resource allocations. Contact must be made with the senior volunteer and paid leadership of these groups and a convincing presentation provided that clearly demonstrates the need.

Once again, appeals to their altruistic motivations is appropriate. The leadership are also members of their communities, they are legally responsible for planning for safety and security of their volunteer workforce and the physical plants owned by their agencies. The constituency of the dozen or so largest traditional agencies is in excess of 100,000,000 persons - approximately 1/2 the nations population. In addition, the buildings and other physical plant of these agencies are capitalized in the many billions of dollars. Pointing out that a earthquake will threaten their personal and agency's security can go a long way in "selling" the need to participate in a hazards reduction plan. This approach can have a secondary effect. For instance, if a church's parochial school system retrofits it's buildings due to earthquake hazards, can the public school deny the need for retrofitting their building?

When agreement has been reached with agencies for their commitment, it is important that a "contract" be negotiated. This may be either formal or informal; yet, must be precise as to what the group or agency is willing to accomplish. It tends to be another myth that volunteers cannot be held accountable. Nothing can be further from the truth. Effective organizations always welcome accountability, regardless of their basis for being (i.e.

private, non-private, governmental, etc.), since accountability is the "mirror" which reflects their success as an organization.

Yet, like all organizations, leadership turnover is a constant, and a contract in the form of a written agreement of cooperation can often be the difference between a fragmented, stressful involement or a well coordinated and productive collaboration.

SUMMARY

When the three tasks cited above are adequately addressed, the voluntary agencies of this country constitute a formidable and available resource to accomplish many of the objectives of this workshop. Key to activating that resource will always be a good understanding of why these agencies exist, their motivations, and the resources each may bring to bear.

RECOVERY FOLLOWING AN EARTHQUAKE: A PROSPECTIVE ASSESSMENT FOR ARKANSAS FOLLOWING A CENTRAL UNITED STATES EARTHQUAKE[1]

by

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INTRODUCTION

The rational preparation for and recovery from a future earthquake in the Central United States will depend upon developing a proper perspective on the nature and extent of its impacts. This paper explores a sequence of events that could happen following a great earthquake in the region. The purpose of this paper is to present a hypothetical future situation, not to represent that which is specifically expectcd to occur. While the author has attempted to be realistic in forming the estimate of future events, there is no representation that the events portrayed in this paper are expected.

The premise of this paper is that a massive earthquake has occurred with an epicenter near Blytheville, Arkansas. Shortly after the event the Governor of the State of Arkansas appointed an Earthquake Commission to advise him on how to manage the State's emergency policies and programs. The ten Commissioners represent the diverse interests within the State. The Workshop is presumed to take place in preparation for a Commission hearing. The participants were split up into three groups and asked to role-play as if they were members of a particular constituency: the Farm Bureau, the Business Roundtable, and the State Democratic Committee. The role-playing exercise proceeded through the following steps:

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[1] in Proceedings of Conference XXIII, a workshop on "Continuing actions to reduce potential losses from future earthquakes in Arkansas and nearby States:" U.S. Geological Survey Open-File Report 83-846, 234 p.

1. A background briefing on the event by Commission staff followed by questions from the participants;

2. Individual group meetings by the constituency groups to discuss the problems posed to them by the earthquake and the recovery process;

3. testimony before the Commission presenting the group's needs, views, and interests; and,

4. presentation by the Commission of its recommendations.

The Commissioners asked questions as did the audience. The highly interactive aspects of these presentations cannot be captured in a written paper.

ARKANSAS EARTHQUAKE COMMISSION

The Governor's original charge to the Commission was to:

1) Monitor State and Federal emergency programs;
2) Advise on areas where there are problems or inequities;
3) Recommend priority State actions to improve emergency response; and,
4) Act as the people's ombudsman.

Now that the immediate response problems are somewhat under control, the Governor has discovered that there has been little thinking on how to proceed with the recovery of the State. And, he has discovered that the political temperature is heating up as various interests sense their possibilities for gain and loss. He has directed the Commission to report to him on what the State should do to assure its rapid, economic, and equitable recovery. The Commission's preliminary report is to be ready within 2 weeks, and their final recommendations report within 10 weeks.

As the first part of its process, this Commission yesterday heard from a number of experts who have conducted research on the topic. Today they will hear from the organizations listed in Table 1.

The rules of the hearing were very simple. Each group's representative was given 10 minutes to express the group's position. Each speaker was accompanied by two others. The Commissioners asked a few questions on the positions discussed by the speakers as well as those positions taken by others. The presentations were succinct and to the point. Generally, the presentations covered the following items:

1) The special problems that their constituency groups face;

2) Specific policies or programs they advocate; and/or,

3) The criteria the Commission should use to evaluate its overall recommendations.

While written position papers were to be submitted, the oral presentations had the most influence on the Commission's formulation of the recommendations to the Governor.

Table 1 - Organizations testifying before the Arkansas Earthquake Commission on March 30

Citizens Coalition of Little Rock
State Emergency Response Director
Federal Coordinating Officer
Chairman, Memphis City Council
Little Rock Free Press
WXYX-TV News Director
The Southern Christian Leadership Conference
The Arkansas Farm Bureau
State AFL-CIO, Building Trades Council
Chairwoman, City Council of Ellenville
Ozark Tourist Development League
Association of County Executives
Business Roundtable of Arkansas
The Minority Caucus for Quality
Chairman, Arkansas Democratic Party
Chairman, Arkansas Republican Party
The Chairman, Peace and Freedom Party
The Chairwoman's Libertarian Party
Arkansas Poultry Development Council

BACKGROUND BRIEFING ON THE EVENT

On Tuesday, March 10, at 2:07 p.m., 20 days ago, a massive earthquake occurred in Arkansas. It is reported by the National Earthqiake Information Service in Golden, Colorado, to have a magnitude (M_s) of approximately 8.5. The earthquake was centered near Blytheville, Arkansas, just below the boot heel of Missouri. A preliminary analysis of the few strong ground motion recordings taken in the area, coupled with macroseismic observations, indicates that strong shaking lasted over 90 seconds, with a maximum effective acceleration of over 0.7 g.

A major aftershock, approximately 6.7 in magnitude (M_s), occurred on March 14. The event was centered just northeast of Little Rock, Arkansas. This latter event did substantial damage to already weakened structures. There have been numerous additional aftershocks that are continuing to this very moment. The event has caused substantial damage in nine States, with some damage reported in a total of 14 States. The press characterizes it as the most severe natural disaster to have occurred in the United States. There is considerable consternation in political circles because the great earthquake everyone expected in California happened here. Despite the efforts of some emergency response agencies the public was generally unaware of the risk. For all intents and purposes, the public was unprepared.

Earthquake damage in the region can be characterized by four major observations. First, damage to unreinforced brick structures, which have inherently little earthquake resistance, has been extensive; damage occurred as far as 400 miles from the epicenter. Second, there have been large soil failures on a scale not seen before in the United States. Third, the damage to lifelines is unprecedented. Lifelines are the electrical, water, sewer, communications and transportation systems that tie a community together and provide the services on which we all depend. Fourth, there has been extensive damage to flood control works, e.g. levees, locks, and flood control dams.

The Earthquake Engineering Research Institute (EERI) reconnaissance team has made an estimate for the Federal Emergency Management Agency (FEMA) of the extent of damage. Figure 1 shows a highly preliminary distribution of damage

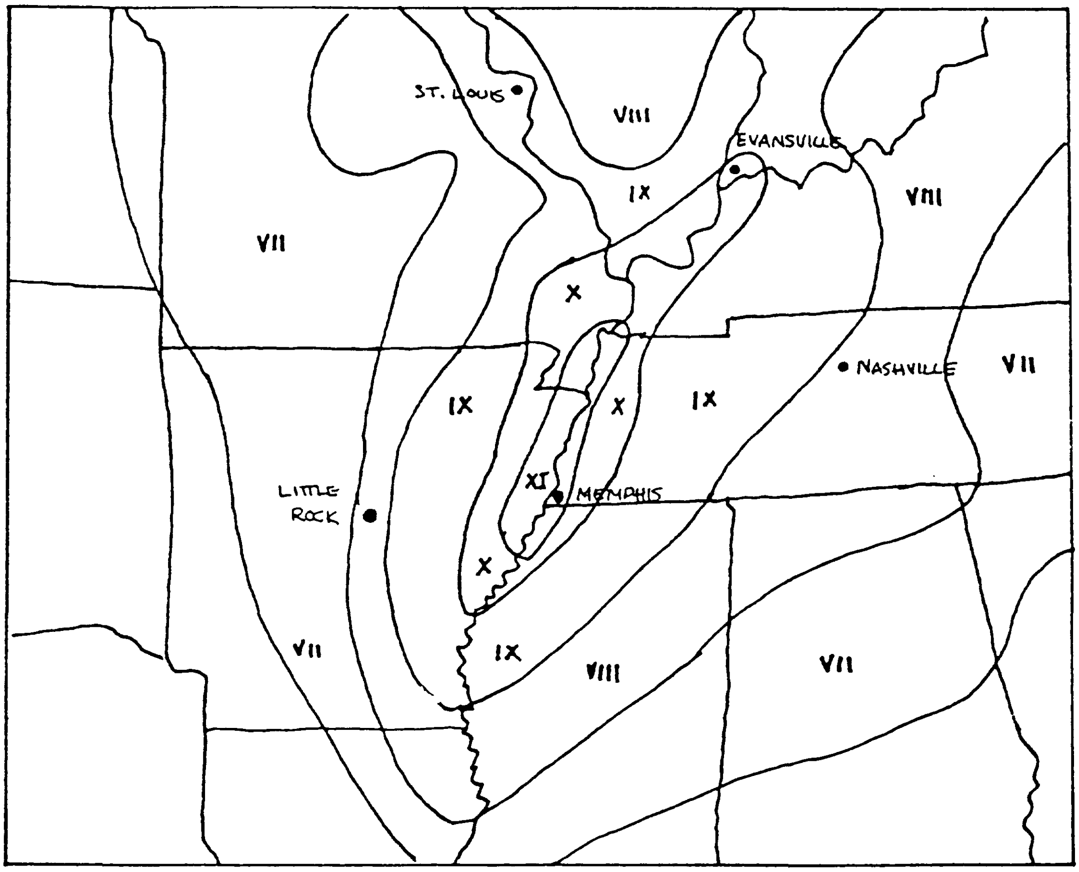

Figure 1.--Preliminary Isoseismals for the earthquake of March 10.

throughout the region for the March 10 event; Figure 2 shows the intensity distribution for the March 14 earthquake. Damage intensities are expressed in the Modified Mercalli Intensity (MMI) scale. Roughly speaking, the MMI can be characterized as given in Table 2. The distribution of damage from the latter event was more severe than might be otherwise expected because many structures damaged in the first event were "finished off" by the aftershock. Figure 3 presents a composite estimate of the damage distribution for the two events. It should be emphasized that more large, damaging aftershocks are expected in the region based upon historical precedents and comparable tectonic settings in other parts of the world.

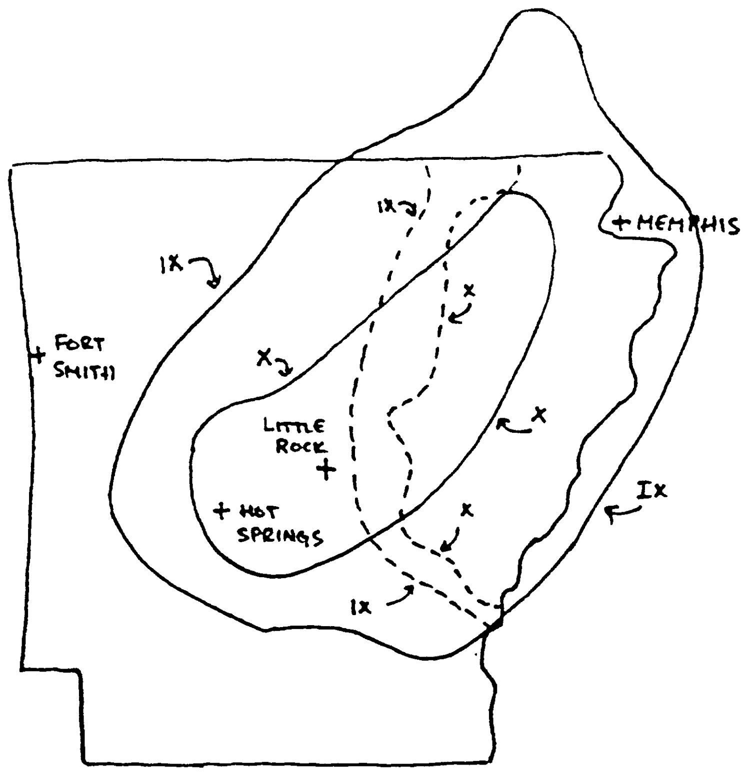

Figure 2.--Preliminary isoseismals for the earthquake of March 14 (solid lines) compared to those of the March 10 earthquake (dotted lines).

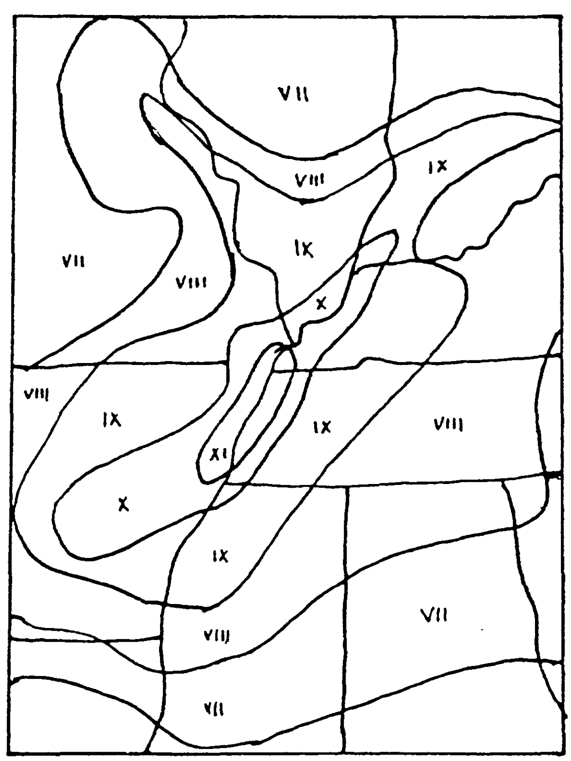

Figure 3.--Preliminary isoseismals for the combined March 10 and 14 earthquakes.

Table 2.--The Modified mercalli Intensity Scale (Abstracted)

MMI	Description
XII	Damage complete.
XI	Few if any masonry structures remain standing. Broad fissures in the ground.
X	Some well-built wooden structures damaged; most masonry and frame structures destroyed along with their foundations; ground badly cracked. Considerable landslides along river banks and steep slopes.
IX	Considerable damage in specially designed structures; well-designed frame structures thrown out of plumb. Buildings thrown off of their foundations. Underground pipes broken.
VIII	Damage slight to specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fallen chimneys, factory stacks, columns, monuments and walls. Heavy furniture overturned.
VII	Everyone runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable to poorly built or badly designed structures.
VI	Felt by all; many frightened and run outdoors. Damage slight.
V	Felt by nearly everyone; many awakened. Unstable objects fall over; some plaster cracking.

Preliminary assessments of the extent of life loss, injury damage, and the extent of housing loss have been assembled from the hit areas. The loss of over 4,500 lives, over 18,000 injuries requiring hospitalization, direct damage in excess of $20 billion, and the loss of over 100,000 housing units are the largest each that peacetime emergency response organizations have had to cope with. Although these figures are huge, they are considerably less than the first reports of $100 billion in losses and 25,000 dead.

The specific impacts on Arkansas indicate over 800 dead, 3,000 injured and requiring hospitalization, approximately 20,000 dwelling units unusable, and about $4 billion in property damage, approximating that to the Nation from Hurricane Agnes.

The President has thus far declared disasters in Arkansas, Missouri, Illinois, Indiana, Kentucky, Tennessee, Mississippi, Louisiana, and Alabama. Several additional requests are still pending. All in all, this is the largest number of States for which declarations have been made for a single disaster. The resources of FEMA, State and local emergency response organizations, and supporting public relief organizations are being severely strained. Without the extensive use of National Guard personnel, it is doubtful that any organized response would have been possible.

Damage has been particularly heavy to commercial and governmental buildings, transportation and utility systems, and flood control works. Approximately two-thirds of the life loss and injury occurred within the MMI X area. Most of the housing loss is concentrated in the MMI IX and X regions. A preliminary assessment of impacts indicates:

1) Interstate highways are in limited service within MMI VIII areas; blockages and bridge collapses have reduce capacity to 33 percent of normal.

2) There has been damage to at least 50 earth dams in the epicentral area and over 500 miles of levees have been destroyed.

3) Over 1000 chemical spills have been reported. Most occurred at agricultural chemical storage facilities. The most serious have occurred at major chemical plants along the principal rivers of the region. The extent of water contamination and resulting health hazards are unclear.

4) No highway or railroad bridges that cross the Mississippi below St. Louis and above Vicksburg are usable.

5) River traffic on the Mississippi, Missouri, Ohio, and Arkansas rivers is limited. A large number of locks have been damaged and the lack of electrical power is preventing others from being used. Since these are linear systems, loss of one lock can shut down the entire river.

6) Airports within the region are closed to commercial traffic because of power outages, damage to control towers, and extensive damage to runways. The FAA has restricted flights within the MMI X area. Fuel and services availability are limited.

7) Rail access to the area is limited; many rail bridges have failed, and numerous embankment failures have closed lines.

8) Water systems in the region are heavily damaged. Public authorities have recommended against use of municipally supplied water within the MMI IX region due to extensive damage to water storage, treatment, and distribution systems. All users of surface water below St. Louis and Louisville on the Mississippi and Ohio rivers have been warned of potential contamination from massive chemical spills. Fishing has been adversely affected in the Mississippi delta.

9) Thirteen interstate natural gas and petroleum pipelines have been closed until they can be repaired and inspected. Natural gas pipelines within MMI XI areas are all closed pending inspection; numerous breaks have been discovered. Local natural gas distribution within MMI VIII areas has been curtailed.

10) Telephone service within the MMI IX region is approximately 20 percent of normal service; many areas are served only by short-wave radios. Amateur and CB radio operators have formed a fairly effective communications network.

11) Electricity production capacity in the region is now at 30 percent of the preearthquake level within the MMI VIII area. It is estimated that 50 percent capacity will be restored within the year; full restoration is at least 5 years away.

12) Electrical service is available to 70 percent of the residential areas within MMI VIII and to 50 percent of business areas. Traffic control and street lights are generally nonfunctioning.

13) Numerous schools suffered substantial damage with much associated life loss.

14) Approximately 50 percent of the preearthquake hospital beds within MMI IX, and 66 percent in MMI VIII are available.

15) The occurrence of large fires was moderated by the unusually heavy rainfall in the previous few days.

16) The impacts on the financial community has been unprecedented. Among the most important are:

  a) The St. Louis Federal Reserve Bank computers have been down since the event, as have their branches at Little Rock, Louisville, and Memphis. While this load has been partially picked up by other reserve banks, the loss of data communications among member banks in the MMI V11 region has severly constrained the Federal Government's ability to perform its commercial and regulatory functions.

  b) Standard and Poors Corporation has suspended the ratings of Missouri, Arkansas, and Tennessee municipal, special district, utility and selected business bonds, as well as those of numerous other communities in the nine State area. These bonds are widely held. Suspension has impaired their value, disrupted the market in tax-exempt bonds and thrown into question the viability of several retirement funds.

c) The financial condition of insurance companies within the region is uncertain. While there was little earthquake insurance written in the region, payments for medical costs, workman's compensation, business interruption, automobile damage, and professional liability are expected to be very large. The theory is already being advanced that earthquake damage should be covered by normal household insurance since the damage resulted from inadequate design and construction practices, not the earthquake itself. While this legal theory may sound farfetched, it has been successfully argued in California for landslides, and was the basis for large payments to householders after the 1983 Coalinga earthquake, even though their policies expressly excluded earthquake damage.

17) There are widespread shortages of construction materials, equipment and skilled personnel. Costs for some materials have been bid out of sight--particularly plywood. A large influx of potential construction workers from other areas is expected, although there is little use for them now except for debris removal and clean up.

18) The snowpack in the upper Mississippi, Missouri, and Ohio Rivers is unusually large. The spring thaw is now underway and the Corps of Engineers expects widespread flooding. They have yet to be able to take into account the impacts of the widespread damage to levees, dams, locks, or flood potential.

19) Cleanup and recovery is well underway at the individual and family level where they do not need externally supplied resources.

The citizens' response in the impacted area has been outstanding. Generally the cleanup and recovery processes at the individual family level are well underway. The outpouring of assistance has been overwhelming. There has been a large inflow of people from unaffected areas offering help. Disrupted roadways have impeded their entry to many areas. Social scientists refer to this as "convergence." Initially, public response organizations were overwhelmed with these offers of aid. The convergence of people at sites of extreme need far exceeded the capacity for utilization; they initially impeded efficient response. This is now under control, in part, due to the imposition of restricted access by the highway patrol in the most severely affected areas.

NATIONAL POLITICAL SITUATION

The political situation 20 days after the earthquake can be encapsulated in the following observations:

1) Approximately 40 Representatives and 16 Senators are demanding regular, personal briefings on the situation. Three Congressional committees have already scheduled hearings, and more are in the offing. There is a regular military shuttle being run to show Congressmen and high Administration officials the damaged area.

2) There are widespread reports that spilled toxic materials are just sitting there with no efforts underway to clean them up.

3) Over 40,000 people are still housed in temporary shelters, and there is no apparent plan on how or when these people will be placed in more permanent housing. The blockage of many roadways is preventing importation of trailers; they are being set up far from those who have need for them.

4) There is confusion on whether there should be an evacuation of the area near the local nuclear power station. There are reports that damage was done to the containment structure. Actions thus far by emergency response officials range from attempted evacuation to assurances that everything is fine. The antinuclear groups are having a field day.

5) Priorities among Federal agencies are unclear; staff and resources are not consistently assigned. A perfunctory review indicated that even with the consolidation of emergency functions under FEMA several years ago, there are still many separate program responses underway.

6) A caucus of eight Senators and 35 Congressmen are publicly calling for the President to exert direct leadership for response and recovery.

Even though the earthquake occurred only 20 days ago, legislation providing additional funds to the depleted disaster response fund has been enacted and signed into law. In addition, the following bills have been introduced:

1) To remove the requirement of 25 percent cost sharing by the State as a condition for Federal assistance.

2) Reduce the SBA interest rate for reconstruction loans to 1 percent.

3) Increase the amount of individual family grants to $10,000.

4) Repeal the Davis-Bacon Act so that artificially high wages need not be paid for cleanup and reconstruction.

5) Eliminate minority contracting requirements for Federal procurement of goods and services.

6) Increase the minority contracting set aside to 45 percent, matching the percentage of minorities in the impacted area.

7) Waive payment of Medicare premiums for everyone in the impacted areas.

8) Provide Federal guarantees, after the fact, for State and local governmental bonds for those areas severely affected.

9) Provide Federal reinsurance for private firms, ex post facto.

10) Provide supplemental unemployment coverage, aid to dependent children, and welfare benefits.

This list is long and growing longer. There appears to be little constituency for restraint, and certainly none yet voiced at the national level.

COMMUNICATIONS PROBLEMS

There is a public information nightmare. The flow of information and misinformation to the public is staggering and continuous. The electronic media preempted their regularly scheduled programming and presented continuous, live broadcasts for the first days. Most of these reports have been pictures of the damage and interviews with either eye witnesses or "experts" from undamaged areas. These "experts" have included some with knowledge or experience directly related to this earthquake; some who have special interests they are trying to advance using this earthquake as a target of opportunity; and some with no knowledge of the area. "Factual" data from the damaged area is incomplete and often contradictory. The range of contradictory reports covers the need for medical transportation, the imminent collapse of dams, the contamination of water supplies, the extent of chemical spills, fire occurrence, public health threats, building safety, and the imminence of large aftershocks, to name but a few.

The disaster intelligence functions of the FEMA and other emergency response agencies have been overwhelmed with the problem of trying to verify rumors and respond to the immediate demands of the press. Among the key problems leading to this condition are:

1) Several key emergency response officials were killed or injured;

2) Many counties have no organized response capability;

3) Radio frequencies used by local fire, police, and emergency response organizations are different among themselves and among adjacent jurisdictions;

4) Unconfirmed reports are receiving widespread media coverage; and,

5) Reports are focused on individual observations.

As the social scientists are quick to point out, the conditions for rumoring are ideal:

1) there are conflicting official reports;

2) formal information channels are disrupted;

3) there are perceived harmful effects; and,

4) informal communications are heightened.

BUSINESS ROUNDTABLE

The Business Roundtable is made up of the chief executives of the 50 largest firms located within the State. They have assessed the situation within the State now that the emergency period is coming to an end and have reached several conclusions discussed below.

As the recovery process is now beginning, it is clear that there is no overall concept for recovery being fostered either by the Federal Government nor the State. What guidance there is seems to hold that the restoration of business and commerce is of the lowest priority, especially when compared to assistance to householders. While there was no objection to this during the lifesaving phase, now that recovery is underway the need is great to provide assistance that allows the economy to be restored. The business community does not want Government to assume a direct role of its activities, but it does want the Government to allocate some of its effort to the restoration of utilities, transportation, and the other intermediary functions that allow the business and commercial sectors to function.

Damage to the banking system has been great and is a matter of great importance and urgency. Most banks are highly dependent upon computer systems for every aspect of their operation. Data processing facilities were particularly hard hit. Such facilities are vulnerable to earthquake destruction and disruption. The Federal Reserve Systems interbank service is partially back in operation; however, there are major problems in restoring individual bank systems. The financial condition of many banks is in question and the ability of these banks to provide the financial resources and services necessary for the restoration of the commercial sector are severely lacking.

Electrical power, communications, transportation, and other utilities are the life blood of business. Currently, the first priority for allocation of these services is to households. Without a change, the business sector could be crippled. It is of the upmost importance that industry be given priority access to these important lifelines.

The distribution system for raw materials, intermediary products, and finished goods has been severely disrupted. Rail, river, and highway transportation is in poor condition and many routes are impassable. Without rapid restoration of a means to move products, the commercial and manufacturing sectors will be crippled.

Business Roundtable Recommendations

The viability of the State of Arkansas is intricately tied to the functioning capability of its industrial and business community. Between them, the manufacturers, processors, and retail distributors of the State have been a source of 80 percent of all the wages earned in Arkansas. Unless business can be back in operation within 6 months, competition from other areas will take over our markets and the entire economy of the state will collapse. With this in mind, the Business Roundtable asserts its need for representation on the Governor's Commission and makes the following recommendations to this body.

1) Banking -- Highest priority must be given to the recovery of the banking system. We recommend that the Governor request Federal assistance and relaxation of stringent interstate banking restrictions so that the cash and financing necessary for all aspects of recovery are available both to business and to the public. Allocation of emergency generators and available electricity to restore data processing facilities for banking is critical and of the highest priority.

2) Electrical Power -- The shortage of electrical power is a hardship for the entire State. For industry, however, it is a critical element--factories cannot function without it. We, therefore, recommend that electricity be brought in from outlying, less-effected areas, that private agencies be permitted to buy electricity from TVA at cost, as

available, and that business and industry be given priority in allocation.

3) Communications -- Of the several State emergency communications networks now operating, we recommend that one be allocated to business and industry as they work to rebuild, repair facilities, reestablish supply relationships among manufacturers and distributors, and restore production.

4) Transportation -- The Governor take a leadership role in directing the restoration of transportation routes important to commerce. Only the Governor has the authority to organize the available equipment and personnel, both military and private, throughout the State so that repairs proceed in a logical and efficient manner. We recommend also that a portion of the helicopters and 4-wheel-drive vehicles, extant and under State control, be allocated to the business community for transportation of needed equipment, raw materials, finished products, and distribution of goods.

5) Labor-Management Cooperation -- Now is the time for labor and management to recognize that they are each vital components in the industrial equation. We urge that labor and management reopen, in good faith, their existing contracts and work rules to assure that the joint objective that each share in continuation of businesses is achieved. In many cases this may require wage and work rule concessions. We urge that these be examined carefully and expeditiously outside the usual confrontation environment. We urge that business assure its employees that they will benefit from concessions in the future, if they are necessary, when the firm returns to a healthy, competitive state.

6) Funding for Reconstruction -- The capital needs of business far exceed that available from within the businesses community. Losses far exceed the amount of insurance coverage. Without access to additional capital, many businesses will be unable to reopen, severely crippling the economy of the State. The following measures are recommended:

a) A national, State-guaranteed industrial bond issue to provide capital for business restoration;

b) A moratorium under the State's Uniform Commercial Code on business debts for a period of 1 year;

c) A moratorium on State taxes for businesses which have suffered greater than 25 percent loss or damage for a period of 5 years, or until recovery of the amount of uncompensated damage; and

d) That the Governor recommend a 35 percent cut in Federal corporate taxes for impacted businesses until full recovery is achieved.

Through these immediate actions, the disastrous effects of the recent earthquake can be moderated. Rebuilding of the State's economy can proceed, taking advantage of improved machinery, processes, and techniques as well as restructuring to make better use of the natural and people resources of the great State of Arkansas.

A final note. It has been proposed that electrical rates be raised to four times their preearthquake level for power use in excess of 150 kwh per month. This will be devastating to industry. While the usage by households may be very elastic, the majority of industries have to use electrical power for production. Production of one unit of output requires a set amount of energy in most cases. We feel that the net effect of such an action will be to negate all the other positive steps recommended above to aid in the recovery of the economy of the State.

ARKANSAS FARM BUREAU

The Arkansas Farm Bureau represents the over 50,000 farms in the State. Agriculture is the largest business in the State. An analysis performed by a damage committee has concluded that the farming community has been severely affected. The public does not seem to be aware of this since the media have not focused on this problem because damage is not concentrated. The

Commission's observations are given below, all focusing on the fact that planting is about to begin.

The high snowpack in the upper Mississippi, Ohio, and Missouri River watersheds portends the potential for large scale flooding. The earthquake damaged many levees and other flood control works principally through embankment failure. While there has been some action on the major levees protecting urban areas, there has been little action on those that protect farms. The ability of farmers to make repairs on their own is limited by their access to machinery and parts. Farm machinery was, in many cases, damaged by the earthquake and the availability of parts to repair or transportation to replace is limited. Unless the flood works are repaired immediately, a year's crop will be lost for about half the State. Compounding this problem is the short supply of fuel. Without fuel, there will be no planting season. Without transportation the seed and fertilizer will not be available.

Lastly, access to loans is disrupted by the problems banks are having. The farm industry is dependent upon loans to finance each year's activity. It is unclear what the full extent of continuing banking problems will be, but it seems clear that without an immediate break in the situation, many farmers will face foreclosure.

Farm Bureau Recommendations

Farming is the backbone of the economy in Arkansas. It is faced with a series of impediments that could seriously impact the ability to recovery. These problems and the Farm Bureau's recommendations for resolution are detailed below.

1) Flood Control -- The damage to levees in key agricultural areas represents a clear threat to farms, especially with the high probability of flooding in the near future. The extent of damage far exceeds the ability of landowners to repair both do to shortages of personnel and equipment. We recommend that the repair of levees and other flood control works be given highest priority for emergency reconstruction. Currently Federal personnel, principally military,

are being used for a variety of tasks in cleanup and initial reconstruction that are of much lower priority. We recommend that the Governor direct that all available Federal personnel and equipment be directed at repair of flood control works. A personal appeal to Governor's of unaffected States for the use of their equipment and National Guard personnel in this emergency reconstruction effort should be made at the earliest possible time.

2) Loans -- Farmers depend on loans as the principal source of capital to purchase seed, fertilizer, and agricultural chemicals for the coming year's crop. The damage done to the banking system, and particularly the impaired financial condition of rural service banks, presents a special hardship to farmers. We recommend several direct actions:

   a) Low-cost loans to farmers for a 3-year period to help them recover. The Governor should make a special effort with the Department of Agriculture to assure that Arkansas gets special treatment under existing programs and that inappropriate regulations are suspended.

   b) Low-cost loans for capital improvements be made available to farmers as they are to small businessmen under Federal and State programs.

3) Transportation -- While urban highways and main transportation routes are being reopened slowly, those of particular importance to transportation of agricultural materials and products seem to be of low relative priority. We recommend that the Arkansas National Guard be assigned responsibility as its principal activity to reopen transportation with first priority given to routes important to agriculture and industry.

4) Markets -- Farmers in other regions are already taking steps to limit the importation of agricultural products from Arkansas (arguing contamination and infestation risks) and to exploit the opportunity to sell they products here. We recommend that the Governor forcefully inform the Governor's of these States that we will not accept such

blatantly discriminatory practices. If they persist, then the State should take whatever steps are necessary to protect the integrity of our basic agricultural industry by protecting future markets.

5) Fuel -- Current fuel allocation programs discriminate against agriculture. We recommend that the Governor give first priority to allocating fuel supplies under his control and authority first to lifesaving functions and second to agriculture. Without adequate fuel all the other actions recommended will have limited effects.

These actions are recommended as a package to assure that the State has the opportunity to prosper in the future and maintains the values that have made our State great.

STATE DEMOCRATIC COMMITTEE

The Democratic State Committee has met several times since the earthquake. During the emergency period, the public had a common goal of protecting life and property. Now that the emergency period is ending, the public is starting to observe their individual losses and sorting out who is gaining and who is losing. Politically, this is a time of ferment. The next statewide election will be held in 8 months. Tt has been observed that the last time there was a situatuation of this magnitude within the State's reconstruction following the War Between the States, the State stayed Democratic for a century. Scapegoating has started, and the Governor is under heavy criticism for the inadequacy of State and Federal response. While this may not be justified, it portends severe political problems as the various impacted groups start to press for advantage. Some have already suggested that the Governor be abandonod by the Party since there is a high likelihood that the public will blame him for everything that goes wrong, is not done, or is inequitable. Running against this situation is a lot easier than defending it.

The appointment of the Commission has deflected some of the political heat but it will not act as a shield for long. The Republican Party is rumored to be preparing an aggressive plan to seize political control of the State. Various minority groups are claiming that the poor and disadvantaged are not receiving equitable treatment and are unlikely to receive their fair share as benefits are channeled to the middle class and business. Regional tensions are starting to be observed as those sections of the State not particularly affected are seeing virtually every resource available to the State channeled to the impacted area.

Democratic Party Recommendations

This is no time for the traditional rivalries among different political interest groups to impede the strong, united effort of the people of this great State to recover from the devastating blow dealt by the recent earthquake. We reaffirm our commitment to the principal that government exists to serve the people. We call upon all interests to join in a truly humanitarian effort of public service that sets aside the petty differences of the past. We pledge that we will not as a party engage in any actions that takes partisan advantage of situations that are attributable to the earthquake and call on others to make the same public pledge.

The Democratic Party hereby makes available to the State and to the several public service associations now serving the State so admirably, the full assistance of its organization. As most will attest, we are well organized to the grass roots level and have the ability to muster great effort for and by the people.

We have three specific recommendations to the Governor for immediate action.

1) All recovery efforts be unified across party lines, and that no one should exploit the situation to advance any political cause or individual interest at the expense of the public. The Governor should appoint a bipartisan Council of citizens to monitor the actions of governmental officials to monitor their actions an recommend actions to assure that they are ethical, non-partisan and in the public interest. The Council should represent all the diverse interests of the State. The Council should have all the authorities and resources needed to assure its success.

2) The restoration of critical facilities should receive the highest priority for competing resources. Hospitals, emergency

communications, hazardous materials containment, and emergency operations centers are at the center of our ability to respond to another earthquake, which the scientists tell us is likely.

3) The Governor requests a clear, concise, and realistic assessment of the total assistance likely to be available under Federal programs, both as a proportional share and absolute amount among the several impacted States. We specifically counsel that the Governor and our Congressional delegation push for aggregation of recovery support into block grants and loans for administration by the State. It is quickly becoming apparent that neither the public nor its elected leadership would allocate resources among competing interests in the way that Federal program officers are indicating they will. We must control our future, not relegate it to others who are not from our State or who will have to live with the results.

4) Considerable personal effort should be exercised by the Governor in consolidating and solidifying the efforts of all cabinet offices and departments of the State to assure consistent and appropriate action during recovery.

5) Now is the time for the public as individuals and families to recognize the extraordinary capacity it has demonstrated to help itself during this stressful time. The future will be a time of great testing of their resolve to prosper. We urge that the Governor give great emphasis to calling upon the people, individually, as family groups and through their churches and community organizations to foster self reliance and initiative. To recognize individual initiatives and efforts we recommend that the Governor establish a recognition program of awards for exemplary accomplishments. Gardens can be planted, community projects for repair and restoration of those less fortunate or unable to help themselves are but a few of the initiative that individuals can take. The creativity, energy, and capacity of the people is unbounded. Sustaining the public's extraordinary effort through the balance of the recovery can and will create a better Arkansas--one for which we can all take pride and credit.

COMMISSION'S INITIAL RECOMMENDATIONS

The Commission has met the Governor's requirement to report with high priority actions within 14 days. Their overwhelming view is the the people of Arkansas have the resolve, the adaptive capacity, and the will to recover and prosper following this massive event.

The first recommendation of the Commission, given 10 days ago, has already been acted upon. The Governor has met with the Governors of other impacted States--Missouri, Kentucky, Tennessee, and Illinois. They have jointly and unanimously agreed:

1) To jointly foster recovery of the impacted areas;

2) To avoid competition among their States for recovery assistance and industrial investment;

3) To cooperate to foster an economic resurgence of the region;

4) To enforce building codes, inspection procedures, and land use requirements that contain appropriate levels of earthquake protection to assure that various interests do not use lesser requirements as a means of attracting capital, jobs, and people to locate in one area versus another; and,

5) Not to sacrifice long-term preparedness for the expected aftershocks to achieve more rapid recovery.

They have agreed to meet regularly and have each assigned a senior advisor to communicate daily with their counterparts.

The Commission has recommended specific actions in four distinct areas--Resources, Finance, Lifelines, and Administration. They are enumerated below.

RESOURCES

1) Establish recovery information clearinghouses in several regions of the State to assure that information is available to everyone on the

same basis. These clearinghouses should be vertically integrated with the central State office providing both information to the regional centers and aggregating needs for communications to the Governor.

2) Request that available Federal military personnel focus their assistance to the State on the restoration of flood control works, particularly levees. The expected flooding poses such a severe threat to the agricultural community and thus to the State as a whole, that this is one of the highest priorities. It is felt that focusing such Federal assistance in one area will improve performance substantially.

3) Undertake the sale of $500 million in State-guaranteed industrial Development Bonds to provide financial assistance to State business. The recommended interest rate is 9 percent with the first year's interest deferred. Equity participation is considered a condition for such loans, since the State should not incur the risk of loss without the potential for gain.

FINANCE

1) Declare a moratorium on financial obligations under the State's Commercial Code until June 10, at which time an extension may be considered. The legal status of many claims is in doubt, and the value of many assets questionable. The delay will afford the community the opportunity to better assess the condition of loans and forestall legal disputes that could be injurious to the financial future of the State.

2) Remove the State's restrictions on interstate banking. The condition of many banks is in question, and there have been several offers from eastern and western banks that if the interstate banking restrictions are lifted, they are prepared to move into the State in a big way. They are prepared to make the appropriate assurances that they will be good and productive additions to the State's economy.

LIFELINES

1) The National Guard should be assigned as its principal task the opening and restoration of transportation routes. Restoration is needed quickly to allow commerce and business to reestablish itself. The primary focus should be on commercial, business, and farm access roadways. Residential restoration is definitely a secondary priority and should only be undertaken where absolutely necessary for life safety.

2) Emergency approval by the State Utilities Commission of a raise in electrical rates to four times their preearthquake level for use in excess of 150 kwh per month. Current capacity and distribution networks are limited, and some mechanism must be found to allocate power among the competing users. The pricing mechanism is judged to be the most equitable one available. The 150 kwh level was selected as the amount needed to operate refrigerators and other essential household appliances. While it will pose some hardships on householders, these are deemed by the Commission to be within an acceptable level.

ADMINISTRATION

1) Call a Constitutional Convention to amend the State's Constitution to allow State debt. Currently the State may not run a deficit. This severely limits the State's ability to meet emergency lifesaving needs or to foster recovery. While there are other mechanisms to accomplish this purpose, they are all deemed too slow.

2) Add 10 people to the staff of State's Liaison Office in Washington, D.C. to assure that the State has access to what is happening in Washington, D.C. and to assure that the State's interests are adequately presented and defended before the Congress and the Administration.

3) Provide an emergency grant to the Arkansas Red Cross and cooperating relief agencies. They have rendered assistance of unquestioned value

to the State's citizens. They have exhausted their meager resources and need aid if they are to continue. It is the Commission s conclusion that they are the lowest cost mechanism for the equitable provision of those in need.

4) Institute wage and price controls for 90 days. There are widespread reports that gouging for services and products is being practiced. Controls are felt by the majority to be the only effective means to put an end to such practices. A minority of the Commission feels that there are already adequate legal means to prosecute flagrant violators and that the price mechanism is the only equitable way to allocate scarce resources.

AFTERWORD

This discussion has been purely hypothetical. Its purpose was solely to stimulate the reader to think about the problems posed by a massive earthquake in terms other than the direct damage or the immediate emergency problems of lifesaving.

It would be impossible to convey in a paper the spontaneity of the discussions that was elicited from the role-playing at the Workshop. As the process proceeded, the participants became more involved and began to understand that the environment in which decisions will be made is one where parochial interests will be aired and political interests not only presented but served. After all, the political process is first and foremost the process wherein differing interests express themselves and work toward resolution of problems that are not well posed and have no optimal solutions. The purpose of the exercise was to illuminate the political nature of reconstruction policy and to initiate a process of accommodation.

Time and time again, we have learned that we cannot effectively respond to problems that have not been thought through prior to the need for immediate action. While emergency life- and property-saving functions are pressing and tax our resources, they are nonetheless straightforward. We know how to respond--only our lack of materials or management skills will prevent satisfactory action. The difficult problems are those where we cannot rely on our instincts or the goodwill of others and the public will not have a consistent view of satisfactory performance. These are problems that have no simple solutions--indeed, they probably have no best solution at all. But our ability to recognize, diagnose, and react to these complex socio-environmental issues is critical. This paper has attempted to start a process of examination that can bring these problems out into the open where they can be calmly and rationally discussed and functional relationships that lead to effective earthquake preparedness can be developed. It continues a process begun by the senior author in his paper "The Charleston Earthquake: A Prospective Assessment." Hopefully it will achieve this purpose.

ACKNOWLEDGEMENT

The senior author sincerely appreciates the contributions of those named for their assistance in conducting the exercise and to the participants in the Workshop for enlivening beyond his grandest expectations both his presentation and his notion of a role playing exercise.

REFERENCE

Thiel, C. C., 1983, "The Charleston Earthquake: A Prospective Assessment" in Conference Proceedings, The 1886 Charleston Earthquake and Its Implications for Today, edited by Walter Hays and Paula Gori, U.S. Geological Survey Open-File Report 83-843, p. 62-83.

THE PUGET SOUND EARTHQUAKE PREPAREDNESS PROJECT[1]

by

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INTRODUCTION

The Puget Sound Earthquake Preparedness Project was the third of four earthquake projects sponsored by the Federal Disaster Assistance Administration (FDAA).[2] I directed the project as a Disaster Programs Officer working out of the Region 10 office of FDAA in Seattle. The hazard analysis performed by the United States Geological Survey (USGS) under an interagency agreement with FDAA was kicked off in April of 1974 and completed in November of 1975. The bulk of activity with users on the hazard analysis occurred during 1976 and the first part of 1977.

INFORMATION PRODUCER/USER COMMUNITY

Objectives of the Hazard Analysis

The purpose of the hazard analysis is succinctly stated in the USGS report:

> This study is intended to inform those agencies serving the region of potential hazard to people, structures, and lifeline functions, in such a way that the administrators of emergency services can proceed with confidence in planning response to earthquake disaster.[3]

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[1] in Proceedings of Conference V, "Communicating earthquake hazards reduction information:" U.S. Geological Survey Open-File Report 78-933, 426 p.

[2] FDAA's functions have been absorbed into the Federal Emergency Management Agency.

[3] United States Geological Survey, A Study of Earthquake Losses in the Puget Sound, Washington Area, Open-File Report 75-375, 1975.

We in FDAA thought the information would serve disaster response activities in two ways: (1) It would sensitize political and administrative leadership (primarily in government) to the hazard and motivate them to devote resources to disaster preparedness programs; and, (2) it would provide enough detailed information on possible problems after an earthquake to indicate where government specifically needs to improve its disaster response capability.

Users of the Hazard Analysis

The purpose can be understood better by looking at the intended users. We felt that the primary users would be local, State, and Federal agencies with disaster responsibilities. The focus of our thinking was about governmental agencies, but it was recognized from the first that the information would be useful to hospitals and hospital associations (or councils), natural gas, electric, and telephone utilities, and the American Red Cross. It was our opinion that the information would be useful, to the public as well, but we made no efforts to aim the study at this group, and had no clear conception of how they might be able to use the information.

Ultimate Objectives

The FDAA regional staff believed that the report should result in an improved ability in the region to respond to a major earthquake. Consciously we steered away from earthquake damage reduction or mitigation for two reasons: (1) The type of report that USGS was prepared to do for us lent itself more to response concerns; and (2) we saw response as the primary function of FDAA. We further believed that it was the responsibility of FDAA to bring the information to the attention of organizations with disaster responsibilities, help interpret the information for them, and encourage them to use the information in improving their disaster response capabilities. The momentum for doing the hazard analysis had not been generated from within the region. It was part of a National program originating with FDAA's predecessor, the Office of Emergency Preparedness, which recognized that the country was ill-prepared to deal with infrequently occuring, but potentially devastating earthquakes. Interest in this program on the part of the Office of Emergency Preparedness and subsequently FDAA was stimulated by a group of professionals in the seismological and earthquake engineering community, especially Karl Steinbrugge who developed a hazard analysis methodology with direct, practical applications. Once the concept of the study was explained to the regional FDAA staff, we were convinced the project was worthwhile. At that time, the Director of the Washington Department of Emergency Services also indicated his support for doing the study.

Constraints

The intention on the part of all parties, producers and users, was that users would contribute to the research design. However, we were restricted in funds - about $180,000 which could be devoted to the Puget Sound project. Also, the methodology had already been developed and used on two other projects, San Francisco and Los Angeles. We consequently restricted our consideration of options in research design to that which was within the existing methodology.

There was a major constraint in how much control FDAA could exert over the use of the hazard analysis once completed. State, local, and private users were totally beyond our directive authority. We had to rely on our ability to present a convincing case. Although we had no sticks, we had one carrot in a matching grant program for State disaster preparedness. Likewise, although FDAA was tasked with coordinating Federal response to disaster by law, our authority over Federal agency disaster preparedness activities was nonexistent.

HOW THE INFORMATION FLOW WORKED

Figure 1 is the model of the anticipated information flow in the Puget Sound project. It is divided into ten steps. I will compare the anticipated flow with what actually occurred in each step.

Step 1

This involved the preliminary determination of what we wanted out of this study. The diagram below illustrates the approach taken:

Figure 1. Information Flow Model

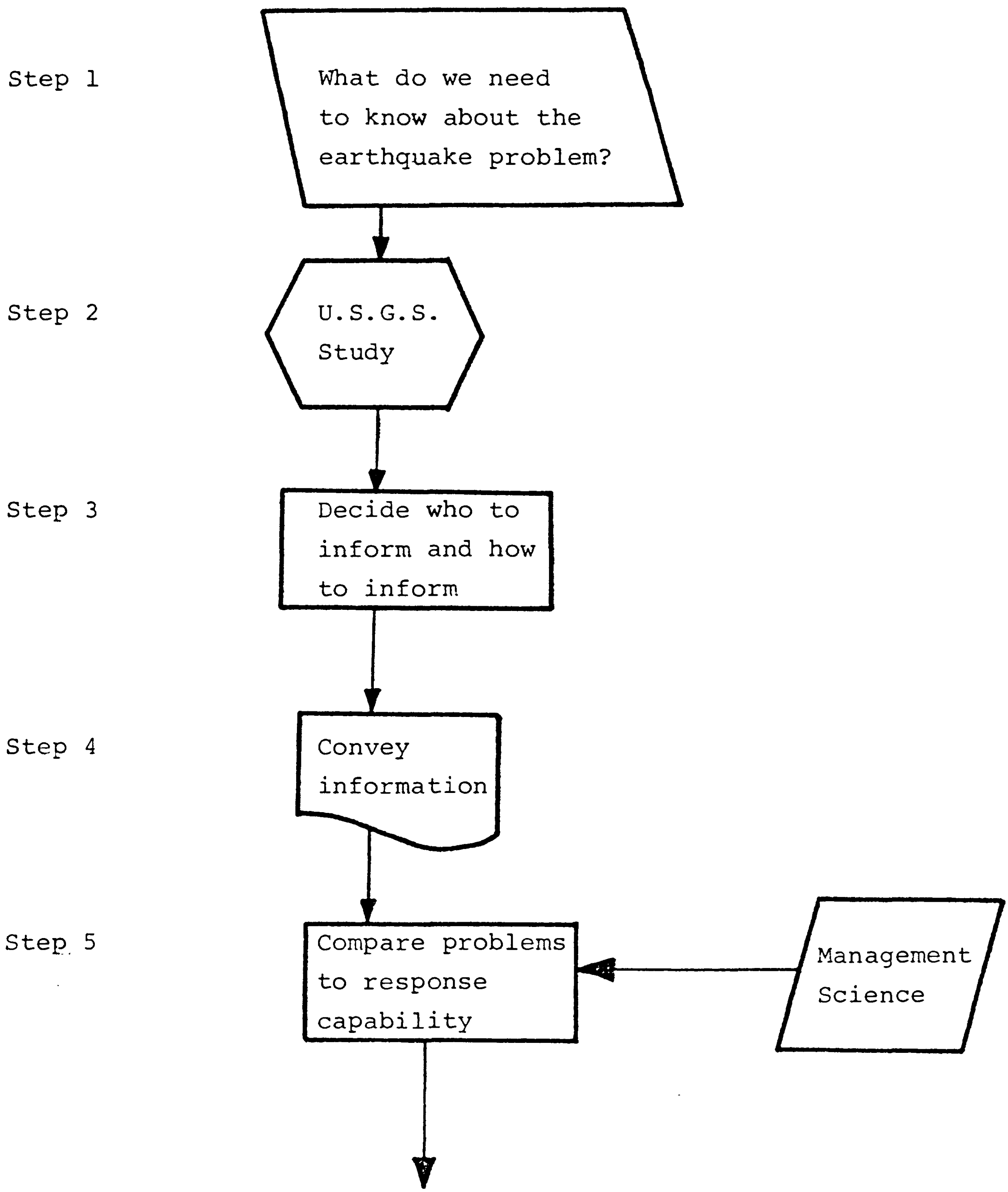
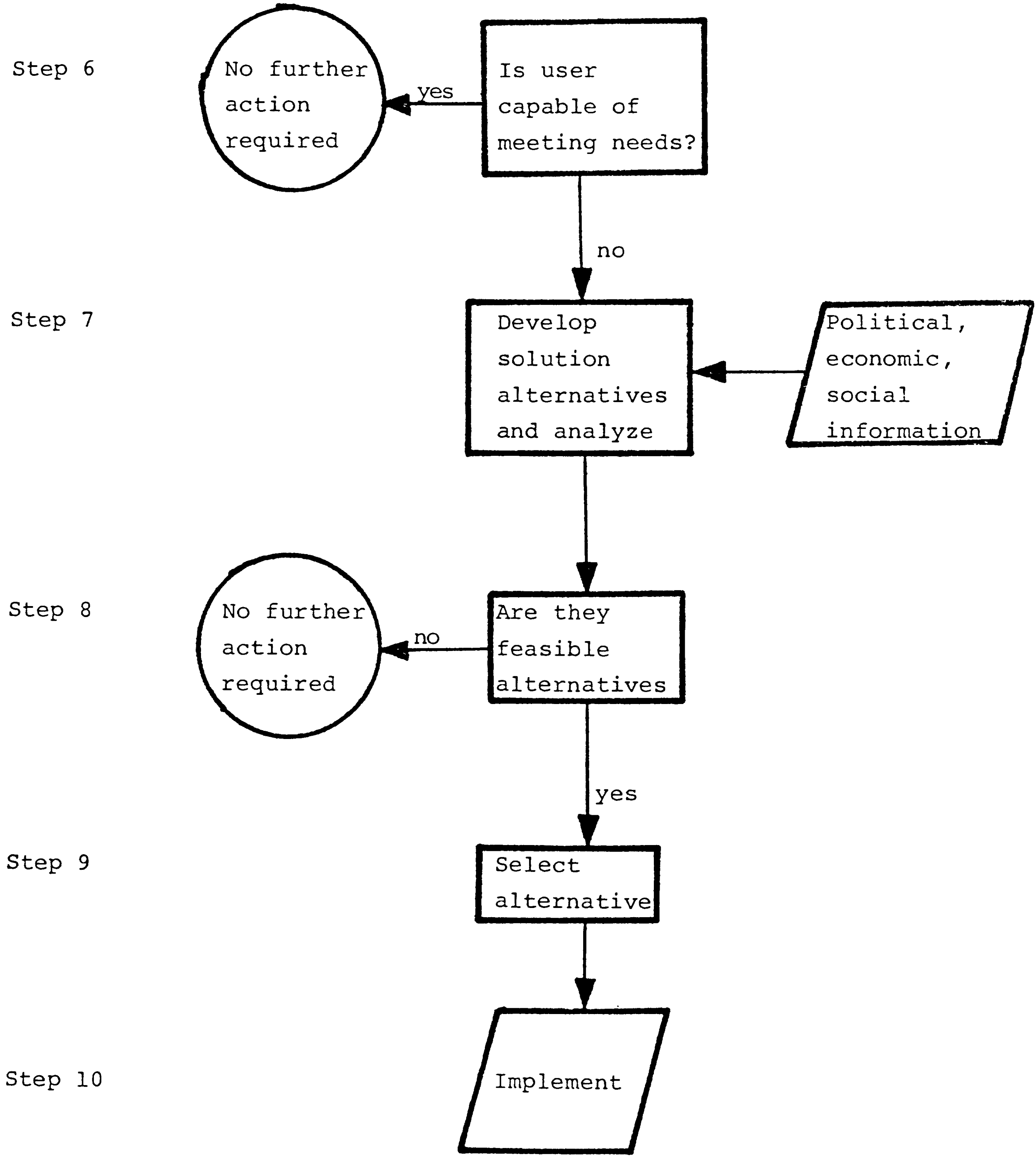
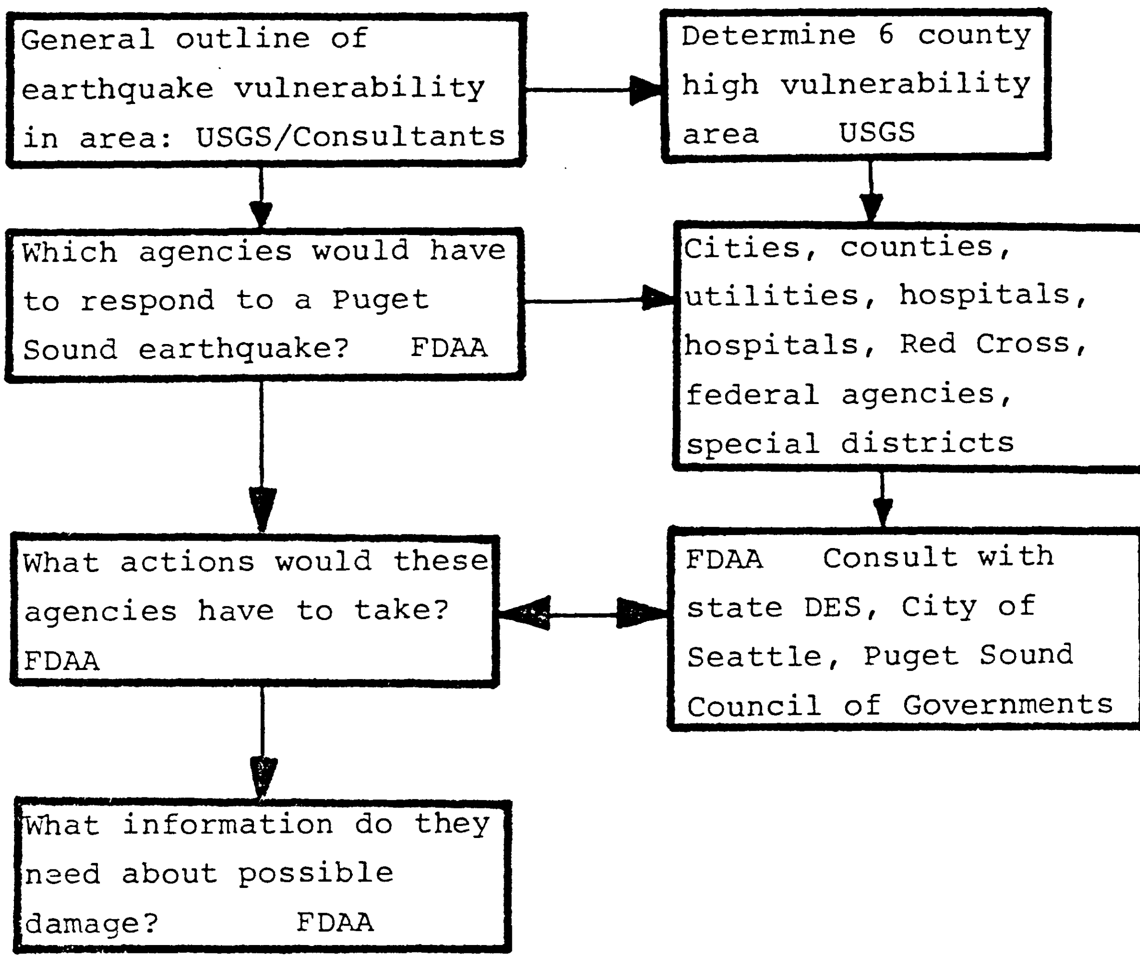


Figure 1. (Continued)



Step 1

Deciding content of hazard analysis

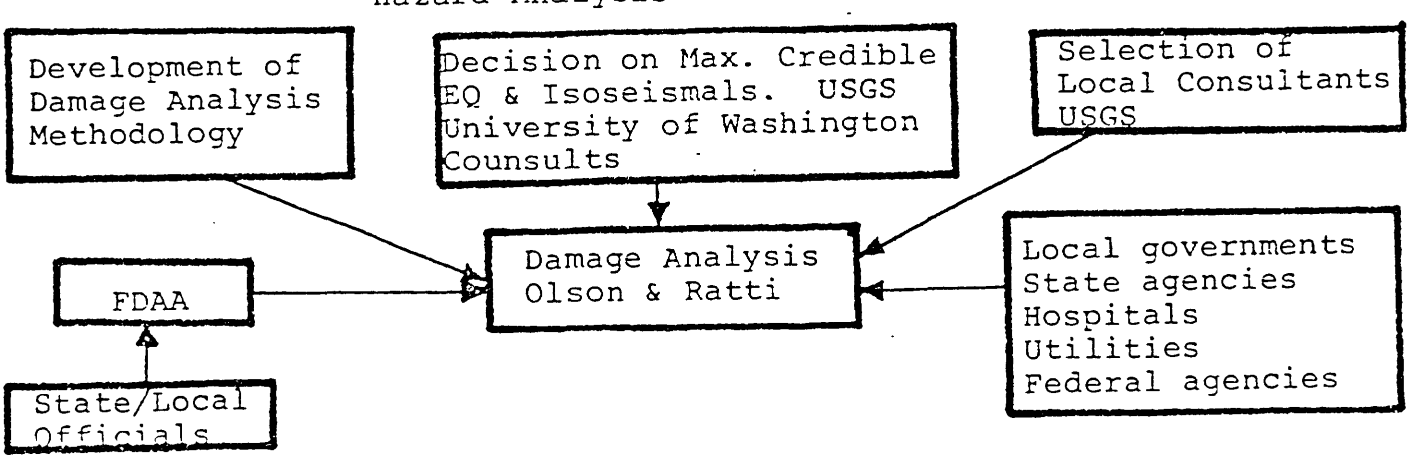


USGS and Consultant Karl Steinbrugge gave us a general idea of what potential problems might be in terms of the probability of a damaging earthquake, the type of damage we might expect, and the area of highest probable impact. The area of highest probable damage roughly fits the six county area at the southern end of the Puget Sound. From this, FDAA developed a user list based on our own knowledge of the agencies and what they do. We brought the State Office of Emergency Services, and the City of Seattle Office of Emergency Services into the discussion to help us establish the type of information needed at the Puget Sound Council of Governments, which represented the cities and counties in the area. We did not recommend major changes in the research design. However, we did recommend more aggregation of the damage estimates by political subdivisons, and by smaller geographical areas in the densely populated metropolitan Seattle area. The intent was to better pinpoint the areas of potential damage for decision-makers.

Step 2

This includes all the activities involved in doing the hazard analysis itself. Below in the diagram of Step 2.

Hazard Analysis Procedure



USGS gave the University of Washington a $5,000 contract to furnish data for the isoseismal study. As well as serving as a source of data, it served the motivational purpose of getting local seismologists involved in the project. I use the term "motivational purpose" because involvement of the local scientific community in the project would make the findings more credible to the ultimate users. This is not irrational; because who should know best about an area but the local scientists who study it every day.

A local engineering firm was selected for the damage analysis because of (1) its knowledge of the local area construction practices and the sources of information, (2) its accessibility to users after the analysis was completed, (3) the need to build a capability in the area for future studies, and (4) credibility.

The first that many of the potential users of the information heard about the project was when they were contacted by the engineering firm to get information about their facilities.

FDAA staff was continually involved with the engineering firm, reviewing findings and the format for presentation of findings. Our major contribution was in the area of getting the damage figures stated in a way most understandable to users, and in establishing the geographical areas for data aggregation. A few local and State officials were consulted about this.

Step 3

This was the decision on how to inform users about the results of the project. Part of this involved revising the list of users--based on the findings of the damage analysis. Table 1 lists classes of users and the means we decided to use to reach each of them. The USGS report was the key vehicle, and we worked with the consultants and USGS to improve its utility as a method of transferring information. We were critical of the San Francisco and Los Angeles report because we felt users would have to dig through a lot of information to get at what was relevant to them. Therefore, the report for Puget Sound started with a three page summary of the results. This was immediately followed by a one page summary of the damage findings for each county, with county isoseismal maps. Table 2 is the summary used for King County.

Table 1

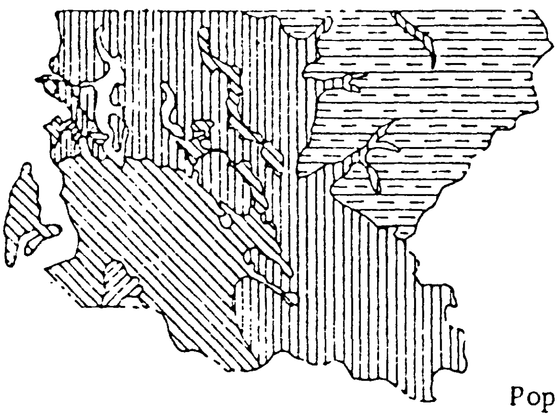
Means for Conveying Information

Informing Responsibility	User	Means
FDAA	Public	Report Summaries Press Releases Interviews Report in Libraries
FDAA	Utilities	Report Briefing
FDAA	Cities	Report & Summaries ES Directors Briefings Briefing department heads Technical Assistance
FDAA	Counties	Report & Summaries Briefing County Commissioners ES Directors briefings Technical Assistance
FDAA	Hospital Councils	Report & medical summary Briefing Technical Assistance
FDAA	Federal Agencies	Report to each agency RD Briefing agencies RDs and key staff Technical assistance Briefing Federal Regional Council and Federal Executive Board
OES/FDAA	State Agencies	Report Briefing selected agencies Brief Governor's EQ Council

Table 2. Anticipated Damage Patterns From Earthquake Disaster

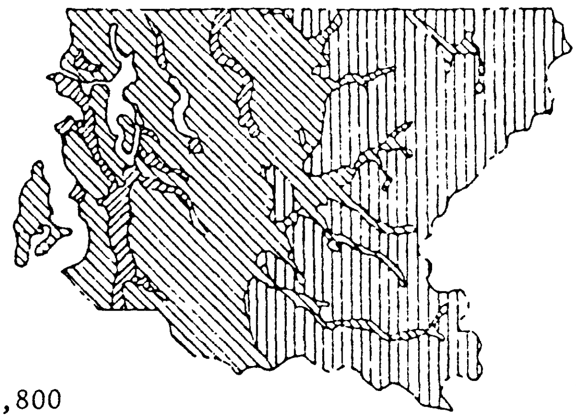
King County

Postulated earthquake "A"		Postulated earthquake "B"



Modified Mercalli Intensity

- IX
- VIII
- VII
- VI
- V



Population 1,143,800
Area in mi^2 2,128

Vital needs	Earthquake "A" Minimal	Earthquake "A" Minor	Earthquake "A" Major	Earthquake "B" Minimal	Earthquake "B" Minor	Earthquake "B" Major
	Degree of impairment					
Communications		●				●
Fire		●				●
Police		●				●
Electric power			●			●
Water		●				●
Access roadways			●			●
Medical:						
Manpower			●			●
Hospitals			●			●
Ambulances		●				●
Blood bank		●				●
Supplies		●			●	
Food supplies	●				●	
Schools (as shelters)		●				●

Estimated losses

	Earthquake "A"	Earthquake "B"
Deaths	1,500	1,650
Serious injuries	6,000	6,600
Homeless	7,130	18,630

For briefings, Stephanie Pulakis of our staff developed an 11 minute sound/slide presentation that gave the summary results of the study and the background on the seismicity of the area. This was used as an introduction. It covered the basic findings. We would then gear the rest of the presentation to the specific needs of the group.

An important objective was to get to the decision-makers in these organizations. To get and keep the attention of these people the presentation had to be short and to the point. Hence, the short sound/slide presentation. We found that even though we provided for overall and county summaries in the report, we needed an additional overall summary written in newspaper style for the media. For the counties, we developed detailed county summaries. We were dealing with a fact of life that people expect instant information. I think we are getting conditioned to this by television news. Most events on television are reported in one minute and 15 seconds; and an indepth story lasts one minute and 45 seconds.

We advertised at our briefings that we had a staff member available to help agencies use the report in evaluating their response capability.

The Governor's Earthquake Engineering Advisory Council was briefed by FDAA, USGS, and OES. This was a council that had met only one time before; but it had the responsibility for advising the Governor on how the State should prepare for earthquakes. It consisted of university people involved in seismology or earthquake engineering, and local engineering and building officials.

FDAA assumed a primary role in informing city and council people because OES decided not to engage in a major earthquake preparedness effort. I will discuss this development later.

<u>Step 4</u>

This is the step where information transfer took place. There was a very intensive effort for four months after the release of the report, and it continues to this day from time to time. So to an extent it overlaps the succeeding steps. There was a kickoff news release; members of the media were invited to come by the office to pick up the report and media summary. The press and electronic media maintained interest for about one week. Almost all newspapers, television stations, and the major radio stations carried the story. A few radio stations asked for interviews. One television station was considering doing an interview, but declined when they found out we had no exciting graphic materials. Most of the county commissions and the city people were receptive to attending a briefing.

Steps 5 and 6

The next step in our model calls for use of the information to analyze emergency response capability; that is, the user was encouraged to compare the damage projections to his capability of responding, and to arrive at a list of response deficiencies. FDAA activities in this area stopped with encouragement to the users and the offer of technical assistance (with the exception of the Federal agencies where we took a more active role). The accomplishment of Step 5 is spotty. Many of the counties and cities used the damage profile in disaster simulations, and arrived at deficiencies in this way. FDAA held a workshop of Federal agencies to arrive at some conclusions regarding Federal deficiencies. The National Guard and Ft. Lewis also used the damage profile as the scenario for disaster simulations. The goal was to have each user analyze capabilities in Step 5, and reach a decision in Step 6 on each response problem about adequacy of agency capability. If the answer in Step 6 is "yes" for a problem, then for that problem nothing further would have to be done. If the answer is no, then the user would move on to Step 7.

The process from Step 5 on was carried to completion only by the Federal Regional agencies. The Federal program was found to be primarily deficient in its ability to communicate and assure itself the support facilities necessary to perform in a coordinated manner after the earthquake. This included the following deficiencies:

1. Assessing needs for Federal assistance;

2. Receiving requests for assistance from State and local agencies;

3. Conveying instructions to Federal agencies in the region and out side;

4. Keeping Washington, D.C. headquarters informed on needs and Federal actions.

Step 7

This involves looking at the alternative solutions to theelimination of the deficiencies, and evaluation of those alternatives. Here information on the political, economic and social level should be fed in.

Step 8

This is a listing of feasible alternatives. The benefits must be greater than the costs in economic terms. The same is true of politics; they must be potentially acceptable to the political decision-makers. They also must not violate social norms.

Step 9

This is selection of the alternatives. In the case of the Federal agencies, Steps 7 to 9 were accomplished through a series of workshops with agencies, and two workshops that included all Federal agencies. The last workshop used simulation to test out some of the alternative solutions. The solution involved the development of a radio procedure, a series of automatic actions for agencies in an earthquake, and the selection of alternate operating sites.

Step 10

Two and one-half years after the USGS report came out, we are still in the implementation stage, but expect completion soon. This involves publishing the plan, and briefing each agency. Yearly, there will be a meeting to discuss plan revisions, and to refresh memories on what is supposed to happen.

EVALUATION OF THE PROCESS

What problems can be found with the process?

We saw the process break down in Step 5, the point where it came time to use the information. Let's ask five questions:

1. Were the damage figures relevant? If so, the problem originated in Step 1. In Step 1 the needs of the users were determined. This was not done systematically. FDAA did this in consultation with DES, and one city OES director. We could have had a series of workshops where the parameters of the information available would be explained, and then the users allowed to suggest what they specifically needed from the hazard study. A questionnaire to all potential users could have been employed. It would have been a good idea to do all of this, but we do not think lack of relevancy was the problem.

2. Did the users understand the information? The end products of the USGS report were statements as simple as the number of people killed or injured, and the number of bridges damaged. This was not the problem. There was difficulty in conveying an understanding of "maximum credible earthquake." As a guide to official action, the concept was not sufficient. The most frequent question asked was "When is the next earthquake?" What officials seemed to be seeking was a risk statement, such asprobability of an earthquake occurring this year, or expected level of earthquake damage over the next 10 years.

3. Was the report credible? Out of the hundreds of contacts we had, I can recall only one where the credibility of the report was questioned. This was from a soils engineer who felt that the liquification problem was not adequately considered.

4. Did the users know how to use the data? No. The cities and counties did perceive its usefulness in developing earthquake simulations. But the users did not have a methodology for discovering response

deficiencies. This is much more difficult than the damage analysis. Damage analysis is dealing with a static situation with few interdependencies. It is an aggregation of what happens to individual structures right after the earthquake. The response environment is dynamic and interdependencies are the rule. Simulation is the easiest way to get at this. But the simulation must include all the relevant variables, and the results must be rigorously analyzed. Table 3 illustrates the problem agencies had in their analysis. Column A is what they got from the USGS report. Column C is what they needed to correct deficiencies. To arrive at C, intermediate result B must be developed. This is a translation of the damage statement to a problem statement; e.g., how many people will need shelter and mass feeding for how long?

5. Were they incapable of moving on to the other steps because of low level of motivation? This is not the motivation of the emergency services people so much as the political and administrative leadership. Even the analysis takes staff time. The leadership must agree that this is important before it is done. One of the FDAA objectives for the hazard report was to provide this motivation. It did not provide enough. The critical lack of commitment to the project was at the State level. The Department of Emergency Services agreed at Step 1 that they would engage in a planning effort based on the report; and they accepted a Federal matching grant to do this. After prolonged negotiation on a work plan for use of the grant money, the State DES relinquished the grant, and decided to make no special efforts at earthquake preparedness. The reason given was that the State's general disaster planning was sufficient. As a consequence of this, there was no one to work with the cities, counties and State agencies. FDAA offered technical assistance (in the form of the time of one staff member); but this did not meet the need. Effort was also needed to encourage the local governments and State agencies--to provide additional motivation; State DES should have assumed this role.

The Need for an Intermediate Level of Analysis

This would be a level of analysis and information production between the physical scientists and the user. This would address the problem in question 4, and provide column B in Table 3. For the Federal efforts, the intermediate analysis was performed through the leadership of FDAA. Here is a place for management science and the use of social scientists. Notice this input is part of our model, although it did not take place to any extent.

The lack of an assessment of deficiencies at the local and State level precluded a complete analysis of Federal capability. The Federal effort lacked knowledge of where the State and local efforts were likely to fail based on systematic analysis. Consequently, the Federal effort could get very little into substantive questions (e.g., how would the Federal agencies provide additional portable toilets), but dealt more with coordinative procedures. The Federal work was based more on the experience with local needs and deficiencies in past disasters.

The Need for Political Support

Even with an intermediate level of analysis, there is nothing to assure that the agency will go on to complete the process; i.e., select alternatives for solving the problems and implementing the solutions. There still must be attained a minimum level of motivation.

LESSONS LEARNED AND IDEAS FOR THE FUTURE

For the future, we should prescribe an information flow model like that shown in Figure 2. This calls for an intermediate level of analysis, and the interjection of social and management science into the flow. It will cost perhaps more money and time. But it might be done for the same amount of money by narrowing the scope. We might have done a damage analysis just for metropolitan Seattle, and spent the savings for the intermediate level of analysis.

Table 3. Levels of Information

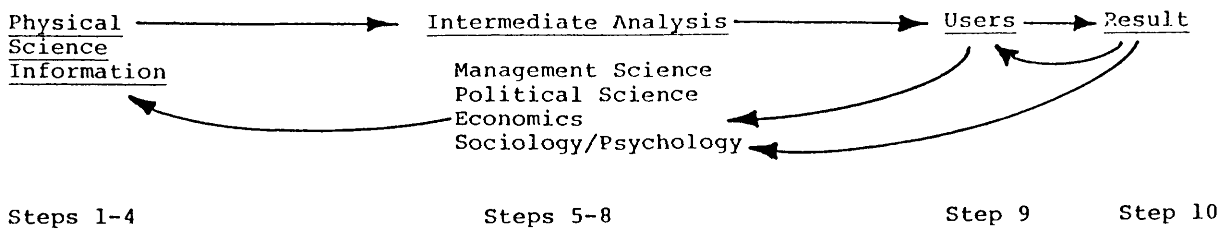
A Direct Damage	B Problems	C Deficiency
Number of Deaths	Need 800 body bags	Need body bag supply
Number of Injuries	Need 400 pints of blood within one hour	Need way of locating more blood outside area
Number of homeless	Number that will require shelter and feeding for 30 days.	Need to identify more shelter space
% impairment of fire stations	Number of unattended fires	Need way of getting X number of fire trucks from outside
% impairment of commo centers	Number of emergency calls not received	Need backup commo system
% impairment of State buildings	Vital State functions not performed	Outside teams of State workers must be identified
% impairment of radio stations	Number of people with no access to emergency information	Emergency information system needed
Number of bridges impaired	Number of families isolated	Need way of transporting panel bridges
Transformers damaged	Number of families without electricity for 15 days	More mass feeding facilities must be identified
Number of sewage line breaks	Number of families without sewers for 15 days	Need way of identifying location & transporting portable toilets
% classroom impairment	Reduction in shelter spaces available	Identify more shelter space
Tons of debris in streets	Vital access route blocked	Need to identify contractors with dozers

The intermediate level of analysis would contribute the following:

Management science	Response deficiencies Statements of risk useful to officials
Economics	Benefit/cost analysis-economic feasibility of alternative solutions
Political science	Political feasibility/ strategies to gain acceptance of the infor mation by users
Sociology/psychology	Translate damage estimates into estimates of people problems. Would be used in response deficiency analysis.

This new information flow model calls for an iterative process. The old model (Figure 1) is unidirectional--scientists to users to result. The Figure 2 model prescribes feedback loops. Although I would expect the feedback between the intermediate analyst and user to be most frequent, there would be requirements to go back to the initial information source--to get more information, to get interpretation of the information, to get qualifications of the information, to request more studies. This would mean a greater time commitment on the part of the physical scientist. He won't be able to simply turn over his report, and wash his hands of the project. He must remain accessible. This may mean that instead of one final report, as in the case of the Puget Sound study, there would be a series of reports; with each we would move closer to meeting the users total information need.

Figure 2. Revised Information Flow Model



Users should be systematically polled on how they will use the information, and what information they need. There is a Catch 22 operating here. The scientists do not know what to study until the user says what information he needs. The user does not know what he needs until the scientist tells him what information he can provide. The iterative process allows for this. There must be dynamic interaction between scientists and users.

Users should be required to commit themselves to the use of the information. USGS could require that users sign a contract to perform Steps 5 through 7. It might also help to have users contribute to the cost of the analysis. Then they would feel under an obligation to make good use of the information.

REDUCING EARTHQUAKE DAMAGE THROUGH LAND-USE PLANNING[1]

by

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STATEMENT OF THE ISSUE

Planning decisions involving the use of land have significant long-term implications for earthquake safety in the Eastern United States. Such decisions can only reduce losses where earthquake hazards, such as ground shaking, ground failure, surface fault rupture, and flooding are known, mapped, and used in development decisions by the private sector and in land-use plans and decisions by the public sector. Because planning is a power granted by the State to local governments, each State can influence the degree to which the planning authority allows, encourages, or requires local application of earthquake safety practices.

INTRODUCTION

Earthquake-hazard reduction can be achieved through two principal measures--avoidance of the hazards and the design and engineering of building sites and structures. Both measures generally are implemented through the planning process which entails: (1) the identification of problems and the definition of goals and objectives to resolve them; (2) the collection and interpretation of data; (3) plan formulation; (4) evaluation of impacts; (5) review and adoption of plans; and (6) plan implementation (Blair and Spangle, 1979). Although the planning process is carried out at all levels of government and the private sector, responsibility and authority for land-use planning resides

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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.

largely at the local governmental level, usually with cities and counties. As practiced in most parts of the United States, land-use planning is part of the political process. Elected public officials make the final decisions on adoption and implementation of proposed plans, which, perhaps more than most other governmental decisions, usually are developed with citizen involvement. As a consequence, earthquake-hazard reduction through land-use planning requires broad community support.

A variety of factors constrain the planning process in achieving earthquake-hazard reduction, particularly in the Eastern United States. These factors include:

1. Generally poor knowledge of the type, location, recurrence, and degree of hazards.

2. Extensive existing development.

3. Infrequency of seismic events to develop and maintain an awareness of the problem.

4. High costs of hazard mapping, and implementation of certain hazard-reduction measures.

5. Social/political resistance to land-use controls in some areas.

Overcoming these constraints to effective earthquake-hazard reduction in the Eastern United States will require concerted and dedicated effort by all concerned professionals--scientists, engineers, planners, sociologists, disaster preparedness and response specialists, communicators, and decisionmakers. Critical to the adoption of land-use measures in the face of the constraints noted above is the integration of seismic safety measures with other natural hazard-reduction programs, such as those for floods, hurricanes, tornadoes, and landslides, and with other community concerns such as open space and urban redevelopment.

APPROACHES TO LAND-USE PLANNING IN OTHER PARTS OF THE UNITED STATES

Although California is regarded as a leader in earthquake-hazard reduction, much of the current progress made there is the result of knowledge gained from the Alaskan earthquake of 1964. That earthquake produced a variety of postearthquake land-use measures, which through immediate adoption, are likely to greatly reduce losses from future earthquakes (Mader and others, 1980). For example, recognition of the vulnerability of the town of Valdez led to its complete relocation. Other measures to preclude redevelopment in high-risk areas, particularly in Anchorage, have gradually been eroded, so that less than 15 years later, high-occupancy, high-rise structures have been built at the head of the L-Street slide, and pressures are mounting for development of single-family residences in "Earthquake Park," the site of the disasterous Turnagain Heights landslides. Many of these measures were adopted as the result of strings attached to Federal disaster assistance and had little local support; the erosion of many of these measures can be attributed to local pressures and to inconsistent and uncoordinated Federal actions.

An unexpected fallout from the Alaskan earthquake experience was not only the spreading of a general awareness of earthquake hazards to California, Washington, and Oregon, but also the specific hazards expected in those States. For example, the severe ground shaking and landslide damage to structures on thick, soft, saturated sediments elicited strong concern by a number of people in the San Francisco Bay area as to the safety of structures built on "bay mud" adjacent to San Francisco Bay. These concerns led to public opposition to several proposed new housing developments on reclaimed bay marshland. The public debate arising from this opposition served to create a local awareness of the problems and focused attention as important land-use issues to deal with them.

That awareness, probably more than any other single factor, brought about the creation of the California Joint Legislative Committee on Seismic Safety, which has spawned many of the earthquake-hazard reduction measures adopted since 1970. Although some of these measures were conceived prior to the February 9, 1971, San Fernando earthquake, it is questionable as to whether they would have been enacted by the California legislature had that earthquake not occurred. Similarly, other advances in earthquake-hazard reduction have usually followed destructive earthquakes, such as the 1933 Long Beach earthquake, which stimulated the California legislature to adopt the Field Act, which sets earthquake-resistant standards for school building construction, and the Riley Act, which regulates unreinforced masonry structures.

Many States authorize local governments to plan and regulate development, but few States mandate local planning. In California, all cities and counties are required to prepare and adopt a general plan that includes certain specified elements. Zoning and subdivision of land also must be consistent with the general plan. Nevertheless, local communities generally have the latitude of tailoring the plan to their needs and to determine which measures to adopt and how to implement them.

So, although local governments have land-use planning responsibilities, their concerns usually are limited to 5-, 10-, or even 20-year plans--far shorter than the recurrence intervals for most large earthquakes. Even after a large earthquake, unless a community has a strong prior commitment to land-use planning and has adopted a postearthquake reconstruction plan it seldom has the financial resource in the midst of devastation to resist the pressures to return to normal, which usually means reconstructing according to existing uses (Mader and others, 1980). As a consequence, most of the land-use examples I will discuss have been the result of State-mandated amendments to land-use authority delegated to communities.

Geologic Hazards Special Studies Zone

One notable exception to local responsibility for planning is the California Geologic Hazards Special Studies Zone Act, which is an example of State-level seismic zoning. Originally known as the Alquist-Priolo Special Study Zone Act, the legislation established a zone one-eighth of a mile beyond the outermost of all known traces of active or potentially active faults. Within this zone no structures for human occupancy are to be built without a geologic study to ensure that the structure is not located on an active fault trace. The Act was later amended to exclude developments of four dwelling units or less. The zone is to be delineated by the State Geologist, but requirements for geologic studies and the approval or denial of siting plans are implemented by local governments from guidelines established by the State Mining and Geology Board; the State Geologist also is responsible for reviewing the geologic reports. Kockelman (1980) discusses and illustrates the provisions and applications of the Act.

Impetus for the act was twofold: (1) it seemed the height of irresponsibility to locate structures for human occupancy on the trace of a fault that could move during the lifetime of the structure when such structures cannot be designed to resist the displacement of the fault; and (2) faults appeared to be one of the easiest of the earthquake hazards to identify and map.

Implementation of the Act has eliminated fairly effectively large new subdivisions in and across active fault zones. This result was achieved without necessarily reducing the number of dwelling units in a subdivision because most jurisdictions have waived density requirements and have permitted clustering of dwelling units to maximize land use. However, the Act has had limited effect in restricting the siting of single, or small numbers of, dwelling units on faults, because the owners presumably are unable to afford the cost of geologic studies. A few communities have undertaken to bear the cost of the geologic investigations to relieve landowners of the financial burden and to encourage safe siting. Interestingly, a study of existing land use in several Special Studies Zone areas by Risa Palm (written commun., 1980) indicates that despite California's real estate disclosure law, prices and sales of homes in such zones have not been affected by the Act. The reasons appear to be varied: (1) real estate personnel are not the most effective communicators of hazard information, especially when it is not in their financial interest; (2) disclosure often is not made until after buyers are committed to the sale; (3) the study was conducted in sought-after residential areas; and (4) other attributes of the property (access to shopping, schools, and transportation) were more important to house buyers than an unknown risk from a fault that may not have moved in 100 years, especially when the buyers might relocate in 5-10 years.

Seismic Safety Element

One of the first pieces of legislation passed after the 1971 San Fernando earthquake became known as the Seismic Safety Element. The legislation was simple, short, and ambiguous. It amended the State Planning Law to include the element as one of the mandated elements of the General Plan (Chapter 150, Section 65302 (f) of the California Government Code) and requires:

> A seismic safety element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to effects of seismically induced waves such as tsunamis and seiches.

The law was later amended, broadening it to include an appraisal of mudslides, landslides, and slope stability.

The initial impetus for the seismic safety element, drafted before the 1971 earthquake, was to at least make planners aware that there were seismic hazards, what they were, and to "consider them" in development of a general plan. With the San Fernando earthquake came a much greater awareness of earthquake-related hazards and pressures to formalize consideration of such hazards in the general plan. For example, the California Council on Intergovernmental Relations (CIR, now consolidated in the State Office of Planning and Research) prepared guidelines (1973) to assist local governments in preparing seismic safety elements. The guidelines provide that the element include:

A. A general policy statement that:

    1. Recognizes seismic hazards and their possible effect on the community.

    2. Identifies general goals for reducing seismic risk.

    3. Specifies the level or nature of acceptable risk to life and property (see Safety Element Guidelines for the concept of "acceptable risk").

4. Specifies seismic safety objectives for land use.

5. Specifies objectives for reducing seismic hazard as related to existing and new structures.

B. Identification, delineation, and evaluation of natural seismic hazards.

C. Consideration of existing structural hazards. Generally, existing substandard structures of all kinds (including substandard dams and public utility facilities) pose the greatest hazard to a community.

D. Evaluation of disaster planning program:

1. For near-term earthquakes, the most immediately useful thing a community can do is to plan and prepare to respond to and recover from an earthquake as quickly and as effectively as possible, given the existing conditions of the area. The seismic safety element can provide guidance in disaster planning.

E. Determination of specific land-use standards related to level of hazard and risk.

These guidelines, prepared long after drafting of the Act and the San Fernando earthquake, went well beyond the thoughts in the minds of the drafters of the legislation (A1, 2, 4, 5, and B), and accomplished much more than was thought possible.

The response by communities to the legislation, guidelines, and outpouring of proposals from consulting firms seeking to prepare the elements, was predictably varied. Few communities had staff members with expertise to provide all the information needed to satisfy the CIR guidelines. A few prepared highly simplified goals and general policies (A1, 2, and 4), using existing planning staff. Many contracted with geotechnical firms for the earth science input which was incorporated into a plan prepared by in-house staff. Others contracted to consortiums of geotechnical, structural engineering, and planning firms. Fees for such seismic safety element plans ranged from $1,000 to $125,000.

Assessing Seismic Risk

Blair and Spangle (1979) expanded considerably on the CIR guidelines, noting that "Evaluating seismic hazards is only part of assessing seismic risk. The other part is assessing the vulnerability of land uses and occupancies to earthquake damage." Such an assessment includes an inventory of 1) current land use (number of dwelling units, rate of occupancy, location of businesses, number of employees, and so forth); 2) structures with high and involuntary occupancy (large apartment buildings, office buildings, major employment and shopping centers, auditoriums, stadiums, hospitals, schools, prisons, and convalescent homes); 3) hazardous structures (older, nonearthquake code buildings, particularly masonry buildings and those with poorly attached parapets, cornices and other appendages); 4) lifelines (water, sewage, gas, electric transmission, telephone, and railway lines and highways, plus related facilities, such as water and gas storage area, telephone exchanges, power stations, airports, harbors, and bridges); 5) facilities for emergency response (command and communication centers, hospitals, medical offices and supply centers, fire and police stations, potential emergency shelters such as schools, churches, and theaters); 6) and other critical facilities (nuclear powerplants, large dams, and storage facilities for toxic materials). Inventories of these land uses should be prepared in map form at scales comparable to those for maps of geologic hazards.

Risk can be expressed in a variety of ways and with varying degrees of precision. Blair and Spangle (1979) describe examples of several such methods, including estimating dollar losses on a statewide basis (Alfors and others, 1973), deaths and injuries on a regional basis (Algermissen, 1972), population at risk on a national basis (Ayre and others, 1975), relative risk on a community basis (Armstrong, 1973), and through scenarios for a given community (San Diego County, 1975). They point out that each of these methods also can be applied as a part of consideration of any proposed land use or occupancy change.

Policies and actions based on hazard and risk assessment inherently involve either an explicit or implicit definition of acceptable risk. Blair and Spangle (1979) define acceptable risk, from the point of view of the public agency, as "that level of risk at which no governmental response is considered necessary." They also consider it "as a measure of willingness to incur costs to reduce risks." Such a determination is commonly made explicitly when a public agency is considering land-use plans and regulations, siting and design of major public facilities, renewal or rehabilitation of existing built-up areas, emergency-preparedness plans, and building code requirements.

PLANS, REGULATIONS, AND ADMINISTRATIVE PROCEDURES TO REDUCE SEISMIC RISK

In the discussion that follows, I have drawn heavily on previously published material, extracting sections from Seismic Safety and Land-Use Planning (Blair and Spangle, 1979) and Seismic Hazards and Land-Use Planning (Nichols and Buchanan-Banks, 1974). Kockelman and Brabb (1978) discuss seismic zonation methods developed in the San Francisco Bay area and present six examples of how local governments have used the methods in their local earthquake hazard reduction programs--assessments, plans, and implementation. Different plans, regulations, and administration procedures may be appropriate for different forms of seismic risk. The forms of seismic risk can be divided into ground shaking, ground failure, surface faulting, and flooding effects.

Ground Shaking

Seldom can a structure, without regard to its height, be declared inappropriate if it is carefully designed for the characteristics of a given site (Nichols and Buchanan-Banks, 1974). Nevertheless, as a broad planning tool, knowledge of expectable ground shaking effects, in combination with other community objectives, could lead to low-density land uses in high-shaking intensity areas. Elsewhere, such knowledge can lead to adoption of building code provisions appropriate to the shaking characteristics of that area. For example, Redwood City, California, adopted special building code requirements for structures to be built on thick saturated sediments that have high (long) fundamental ground periods and that could be subject to differential settlement during an earthquake (Kockelman, 1980).

Ordinances also might require that increasingly detailed geologic, soil engineering, and structural engineering analyses be performed for buildings with high-projected occupancies in areas of greatest expected shaking motion. Blair and Spangle (1979) cite the San Jose seismic safety element and the San Francisco Community Safety Plan as such examples. Because it is difficult to predict strong ground motion characteristics and their effects quantitatively, except for a given structure on a given site, it is desirable to establish a legal and procedural framework that remains flexible enough to accommodate increasingly sophisticated methods of prediction.

Other measures that are critical to a lessening of ground-shaking losses, particularly human life, include the adoption and strict enforcement of a hazardous building abatement ordinance and an ordinance to require removal of dangerous parapets as has been so successfully implemented in Long Beach, Calif. Because of the high potential economic impact, hazardous building abatement regulations might best be imposed gradually on a priority basis, selecting first those structures that are the most dangerous and that have the highest occupancies, followed by buildings that constitute a lesser hazard and that have lower occupancies. Such abatement actions often can coincide with urban renewal objectives. Parapet ordinances, if enforced in urbanized areas, particularly where older high-rise structures may have poorly secured appendages, have the potential for sharply reducing casualties and property damage during earthquakes.

Ground Failure

General land-use policy to limit damage from ground failure might be guided partly by knowledge of broad areas where instability is believed to be so pervasive that, along with other considerations, its preservation as open space or other nonoccupancy, may be indicated. On the other hand, except during earthquakes, such failures generally occur fairly slowly, may be preceded by precursors, and usually do not result in loss of life, even though extensive or complete destruction of property is common. Therefore, the problem might be ignored. Alternatively, because ground failures can be life hazards during earthquakes, areas of known or likely low stability might be designated as geologic hazard zones. In such zones, background studies (geologic and soil engineering reports) should be required to demonstrate that both static and dynamic hazardous conditions either do not exist or can be overcome by site preparation work or engineering design prior to approval of subdivision and site development applications. Although individual structures may be sited safely in such areas, roads, gas, water, and sewerlines seldom can be built without crossing unstable areas. Long-term costs in the form of maintenance of public service facilities may be great and generally must be borne by the entire community.

Blair and Spangle (1979) cite Portola Valley's response to landslide problems as being to avoid hazardous areas--"a response consistent with the town's existing and planned pattern of low-density residential development and policies for preserving the natural environment." They also note that "in jurisdictions fostering urbanization or in already intensively developed areas, special site and building design or engineering to mitigate the risk from slope failure may be emphasized," and refer to the special site investigations proposed in the San Francisco Community Safety Plan and the Santa Clara County Baylands Plan.

Other solutions to instability problems that have been pursued include adoption of a program to allow tax deductions for property owners whose land is particularly susceptible to ground failure. Such a program might be designed to alleviate tax burdens on property where existing structures are being damaged and on unimproved land, as long as it remains unimproved, or until the owner can demonstrate that he has eliminated the hazardous conditions. For those relatively few developed areas where severe instability problems are known to exist and disaster merely awaits the triggering action of an earthquake or an exceptionally wet winter, consideration should be given to the implementation of a hazardous building abatement ordinance or to the initiation of nonconforming use or nuisance procedures.

Surface Faulting

In zones of potential surface faulting and deformation, the consequences of rupture to existing or planned uses should be assessed and alternative uses compatible with fault rupture, and with adjacent and regional land uses, should be considered. Alternatively, controls may be placed on the method of construction and the location of structures so that an undue hazard would not occur. Implementation regulations might call for establishment of a fault hazards easement (Mader and others, 1972) that would require a setback distance from the active fault traces. The amount of setback might differ with the type of faulting and deformation expected. It might also vary with respect to the character of individual faults and even segments of a single fault, as well as with the knowledge, or lack thereof, of the fault zone and the structure or development being considered. Thus, the more critical the structure, the greater should be the setback limit.

In addition to adoption of a fault hazards easement, similar to a scenic easement, jurisdictions might consider adoption of "fault hazard zoning" or the broader "geologic hazard zoning," which would include such hazards as landslides and floods as well as faults. Such zoning might override conventional zoning, prohibit human occupancy, require a land use compatible with both the hazard and adjacent areas, or stipulate minimum site investigation and safety standards. Certainly, any development to be considered within, or immediately adjacent to, an active fault zone should require geologic studies to demonstrate that the proposed construction would conform to standards of community safety and that an undue hazard to life and property would not ensue.

Alternatively, prohibition of all uses other than those essential to the public welfare (utility and transportation facilities) could be considered in areas of extremely high hazard. Certain types of land use are compatible with the high level of hazard attendant even to such areas as the San Andreas fault zone. Some of these uses include open space, recreation areas (including golf courses, nurseries, horseback riding, bike trails, and so on), cemeteries, freeways (but not interchanges), parking lots, and solid-waste disposal sites (under some conditions).

Where development already is present within active fault zones, jurisdictions can adopt policies leading to the removal of critical engineering structures on the most accurately located active fault traces. Nonconforming building ordinances should be considered that could require eventual removal of structures in the greatest danger, starting with those that endanger the greatest number of people--hospitals, auditoriums, office buildings, and apartment houses, followed by commercial buildings, and perhaps eventually by single-family residences. The nonconforming building ordinances could be based on either an arbitrary time schedule or on the depreciated life of the structure involved. Other innovative options for control of development include tax incentives and adoption of urban renewal policies that would encourage removal of hazardous structures and that would prohibit reconstruction in hazardous areas after earthquakes or other natural disasters (Diplock and Nichols, 1972). Another approach might involve the exchange of existing public land dedicated to uses compatible with fault hazards with private land actually subject to those hazards.

Flooding

Although little is known about possible tsunami, seiche, or dam-failure effects in the Eastern United States, a considerable amount of flooding is known to have occurred during the 1811-12 New Madrid earthquakes. A concerted effort should be made in each jurisdiction to assess potential flooding risks and to adopt various methods of reducing them:

1. Restrict land uses to those that are economically essential (docks and warehouses) and warn owners, builders, and occupants of the hazard. Prohibit siting of high-occupancy and critical structures (schools, hospitals, police and fire stations) in potential inundation areas.

2. Place areas of potential inundation under flood-plain zoning, prohibit all new construction, and designate existing occupancies as nonconforming.

3. Where economically feasible and without encouraging a false sense of security, construct restraining or diversion structures to minimize potential inundation.

4. Institute appropriate systems to warn of impending failure or inundation.

5. Adopt and implement evacuation plans.

6. Seek elimination or strengthening of potentially hazardous dams.

Other approaches are discussed by Waananen and others (1977).

From the examples of land-use policies, plans, regulations and procedures discussed earlier, I hope that certain basic approaches to earthquake-damage reduction have become apparent. In the approaches discussed below, there is an implicit understanding that earthquake-hazard reduction is but one aspect of an overall hazard reduction program that must be integrated with other community concerns, such as redevelopment and open-space planning, in order to achieve community goals at the least cost.

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SUGGESTED APPROACHES FOR IMPROVING THE STATE OF EARTHQUAKE PREPAREDNESS IN THE EASTERN UNITED STATES THROUGH LAND-USE PLANNING

A. Establish State hazard mapping programs that provide needed information as to the types, locations, and degree of hazards from ground shaking, surface faulting, landslides, liquefaction, subsidence, and flooding in each local jurisdiction within the next 5-year period.

B. Amend existing State statutes that pertain to the planning authority of cities, towns, and counties to require consideration of safety from natural hazards.

C. Encourage local governments to inventory their current land uses, including the integrity of existing structures, in order to assess the risk to those uses from the hazards mapped. Base future land-use decisions on acceptable risk.

D. Adopt legislation requiring that evaluations of risk be made in advance of permitting and construction of critical facilities, including high-occupancy structures.

E. Prepare model legislation, regulations, and development policies for natural-hazard areas.

F. Prepare model local safety policies, plan criteria, and plan implementation devices consistent with all hazards faced in each State.

G. Prepare postearthquake reconstruction and mitigation plans as a condition for receiving State and Federal assistance following a damaging earthquake.

PRIMACY, DECLINE, AND DECREPITUDE: THE BUILDING LIFE CYCLE, AND ITS RELATIONSHIP TO EARTHQUAKE HAZARD REDUCTION STRATEGIES[1]

by

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The problem of building performance is central to the earthquake issue because by far the greatest death, injury and property loss are caused by the relationship between building performance, ground motion, and people. It has often been observed that the greatest of earthquakes occurring in open country is of interest only to the seismologist.

This paper develops a scenario for dealing with buildings in the Northeastern United States as they relate to the earthquake threat. The term 'scenario' is used to indicate something less, or more schematic, than a plan. In doing this, it is proposed to pull together information from a number of sources, including knowledge of building performance, experience in California in dealing with the regulation of building design and construction, and knowledge of the nature of the threat in the Northeastern United States, which is derived predominantly from papers presented at this workshop. This paper may present a view somewhat different from that normal to this kind of discussion and as such the extent to which it stimulates controversy and interest may serve to throw some of the issues into sharper relief. While specifically responding to the problems of the Northeastern United States, the analysis presented here may also be applicable, in principle, to other areas of the United States

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[1] in Proceedings of Conference XXI, a workshop on "Continuing actions to reduce potential losses from future earthquakes in the Northeastern United States": U.S. Geological Survey Open File Report 83-844, 129 p.

As a beginning, it is suggested that the experience in the small town of Coalinga, California, in May 1983, was a blessing in disguise. A succinct description of what happened is that the extensive damage and destruction of unreinforced masonry buildings accelerated, into the space of about 10 seconds, a natural process of building decay that normally would have taken some 20 years or so.

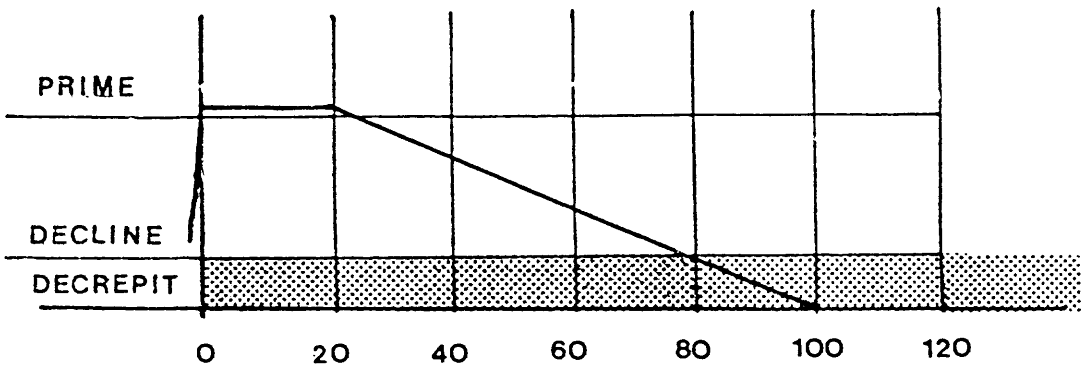
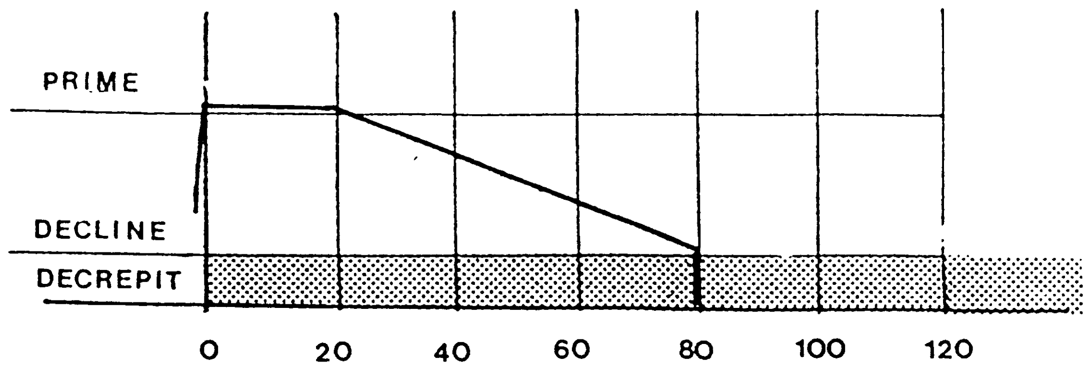


Figure 1. Normal building life (100 year example)

Figure 1 shows three stages of normal building life related to time: these are, the new building in its prime, the building going into decline (though still socially, economically, and environmentally valuable) and the building entering a decrepit state. "Decrepit" we would define as below an acceptable level of thermal environment, health, structure, fire safety, weather proofing and appearance. For the building with a 100 year life shown in Figure 1, it is decrepit for the last 20 years. If the building is removed during its decrepit state, this is economically and environmentally advantageous, and ideally the building would be removed when it enters this state, so that the building stock would not be encumbered with decrepit buildings.* (Figure 2) It can be argued that the Coalinga earthquake removed buildings that were in a

*The argument is often made that old buildings ("decrepit" in our terms) serve a useful social and economic purpose by providing housing for the poor or facilities for marginal commercial enterprises. It is a fine point as to whether social ends are really served by enabling people to live and work in decrepit buildings that are unhealthy and dangerous.



Figrure 2. Building demolish at optimum time, entry into decrepitude

decrepit state: it "pulled the plug," and provided the city with an unexpected opportunity for re-planning and reconstruction with State and Federal economic aid that would otherwise never have been presented, and saved the city from a slow and depressing decay. Replanning does not necessarily imply the replacement of the old downtown, but rather the investigation of new construction strategies that make sense in relation to Coalinga's economic future. Downtown Coalinga at the time of the earthquake, for all its charm, was not exactly a hot investment prospect. This enforced pause provides an opportunity for a thorough investigation of the city's future.

To the argument that perhaps many of the Coalinga buildings had not, in fact, entered the decrepit state and were still in useful decline, it can be countered that the earthquake tested the building structures and they were proved inadequate in no uncertain terms, and hence were ripe for removal. Also, the upper floors of most buildings were unoccupied because of non-adherence to fire codes.

The effect of renovation or remodeling is to prolong the building life. Figure 3 shows normal decline arrested by minor remodeling at the 30th year, and the prime life span renewed by a major renovation after 50 years. Many variations of this pattern are, of course possible. Figure 4 shows the life of a major historical movement, such as a cathedral, which, by continual renovation is kept close to prime condition. This activity is not cost-beneficial and only justified if the building is of great aesthetic or cultural value.

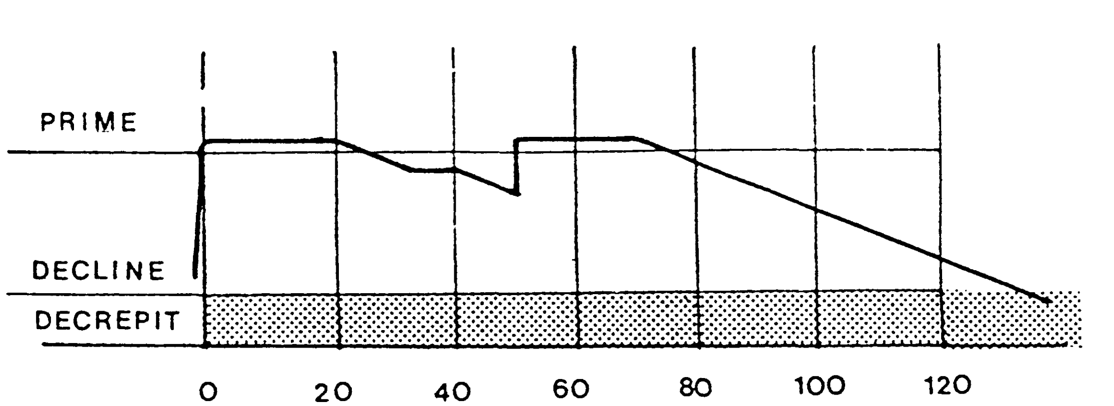


Figure 3. Building life span extended by renovation

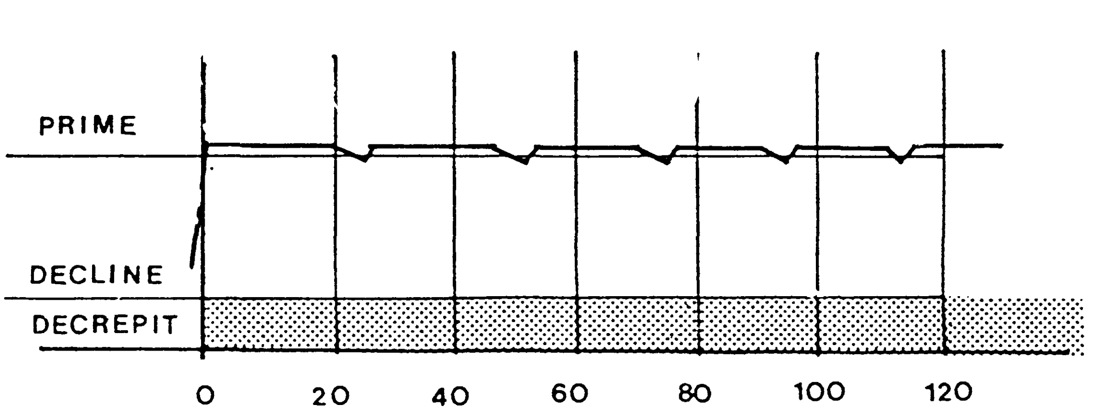


Figure 4. Life span of historic monument

The period of time which a building occupies in these stages may vary considerably. A small store will have a much shorter life than a major institutional building. The observations in this paper are directed to the typical commercial - retail and office buildings, and small industrial facilities that make up much of our downtown building stock.

But even if it was beneficial economically to Coalinga to have its decrepit buildings removed by "radical surgery," were the casualties too high a price to pay for this convenience? It is reasonable to argue that, not withstanding the injuries and one near-death in Coalinga,* the casualties through the earthquake are <u>less</u> than if the buildings had lived out their full life, in the course of which time people would have been injured and even killed by fires, gas explosions, falling down rotten staircases, and the like.

The argument that this earthquake was a good thing for Coalinga can, of course, only be maintained if individuals who lost property are taken care of and made economically secure whether by insurance, State or Federal government means, and that the psychological trauma of the earthquake has not left permanent detrimental effects on Coalinga's citizens.

The important point that this argument introduces is that there is in fact a natural life for buildings and to the extent that one improves the building one is increasing its life; and when earthquake or fire removes the building, they are terminating it. This termination may be premature, but in the case of an old, decrepit building, is often an economic and even social benefit.

The predominant earthquake threat is to existing buildings because every year our construction adds some 2 to 3% to the building stock, so that in a 50-100 year period, depending on the nature and quality of each existing building, our building stock is essentially replaced. At the same time people are living and working in existing buildings and only quite slowly does the effect of new building begin to change the inventory of buildings.

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*at the time of writing, 10 weeks after the earthquake, one casualty is still in hospital, in a coma.

In relation to the issue of whether to retrofit the existing buildings in the Northeast to make them seismically safe, one can see that there is a good match between the natural replacement cycle of 50-100 years by which old and dangerous buildings will be replaced or renovated through the normal market process, and the figures presented by Prof. Toksoz which discussed the probabilities of a Modified Mercalli VII earthquake in this region. Prof. Toksoz gave a minimum figure of 35.7 years, a maximum figure of 219 years and a mean figure of 88 years for the return period of an MM VII earthquake, with a 95% confidence factor. Thus it can be seen that the mean figure is also approximately the mean figure for our normal replacement time. It should also be noted that an MM VII earthquake is one that would damage and destroy only buildings poorly constructed of unreinforced masonry, such as those of Coalinga or many in the Northeastern United States. The probabilities of a great earthquake in the MM IX range, as presented by Prof. Toksoz, seem so remote that using the figures in any way to encourage public action would not make sense. He shows a minimum of 276 years and maximum of 2,770 years with a mean of 876 years, as the return period for this intensity earthquake.

Based on this it is suggested that the correct procedure for dealing with existing unsafe buildings in the Northeastern area is to do nothing about them at all. At the same time, the public should be continually reminded how dangerous these buildings are. An exception would be that any buildings which, through normal market reasons or because of their historic merit, are rehabilitated so that their life is extended, should be subject to seismic requirements. In addition, new buildings should be subject to seismic requirements. With this strategy, then, the existing buildings would be allowed to decay in relation to their natural lifetime, but any new or rehabilitated building will be brought up to a seismic condition that responds to the expected requirements of a Northeastern earthquake. Thus in the period of 50-100 years with no special attention paid to ordinary existing buildings, the building stock of the Northeastern United States would then be seismically resistant. This strategy has the happy effect of making political, economic, and social sense.

This strategy, then, says that no active planning should be done for the retrofit of average existing buildings. At the same time energy and resources should be developed for initiating a realistic seismic code for new and rehabilitated buildings and for improving the design and construction practices in the region. So our strategy has two parts, passive and active, that are precisely related to one another and to the expectations of seismic activity.

In looking at the code issue - what kind of seismic code is appropriate for the Northeastern United States - it is suggested that the traditional code approach as used, for example, in California, is not appropriate. By this is meant a code which is essentially based on developing design force levels to which the entire building must then be designed. There is considerable evidence to show that historically the force to which a building has been designed i.e. the traditional code level, has had much less effect on the performance of the building in earthquakes than issues of general import such as the configuration of the building, the number and type of interior walls and partitions, the quality of its construction, and in particular, the extent to which the walls and floors have been structurally tied together (1). It is suggested then, that a code approach for the Northeast, which essentially is dealing with earthquakes of lesser magnitude than are faced in California, might concentrate on improving general standards of construction, and mandate a few simple construction practices - even of a prescriptive nature - that ensure that the building is well constructed, tied together, and reinforced to a reasonable level. The code should also reflect the different nature of the Northeastern earthquake relative to California, which might be summarized as being of lower magnitude and longer period, which is beneficial in respect to the unreinforced masonry building which is the greatest threat, because these are generally short period buildings, and hence amplification of ground motion is less likely.

If this strategy were to be pursued there are two alternative futures. The first future is that no significant earthquake occurs within the next 50-100 years. If this is so, the building stock is replaced through the normal cyclical process with safe buildings and from that point on the whole aim of any hazard reduction program that relates to buildings has been accomplished on an extremely cost effective basis.

Suppose, however, that a damaging earthquake does occur before a significant amount of the buildings stock has been replaced. Based on our analysis the buildings that will be seriously damaged or destroyed will, for the most part, be those that have entered the decrepit state, so their removal is economically and environmentally beneficial. The major issue then becomes the extent to which there will be deaths and injuries, because these have much more emotional impact than property loss.

It can be argued, that even under these circumstances, casualties in the Northeast would not be very severe.* There are three reasons for this. The first is that experience has shown that death and serious injury are caused by the total collapse of buildings, not simply by severe damage. The Coalinga experience has reinforced this view (2). Analysis of Coalinga damage shows that very few buildings suffered total collapse, and hence there were few casualties. The second part of the argument is that old buildings by their (decrepit) nature tend to be marginal economically and are often of low occupancy. In Coalinga 30-40% of the downtown buildings were empty, partly because the community could not support the rentals and partly because in some instances upper parts of the buildings had been declared unsafe for fire purposes. Moreover, old buildings are often for industrial and storage purposes in which the occupancies at risk are very low relative to the size of the building. The third argument relates to the exception to the above: masonry residential buildings which may in fact have fairly high occupancy. However, research has shown that residential buildings are intrinsically safer than commercial or industrial buildings, and hence the probability of total life threatening collapse is even more remote (3). The reason for this is that residential buildings have short structural spans, a large number of small rooms and relatively small windows. This results in a large number of walls which provide for much more support compared to a wide span commercial or industrial building.

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*This argument holds true in other seismic areas also. In areas of more severe shaking than the Northeast, we can expect the major casualties in large concrete frame buildings, of poor architectural configuration, constructed prior to about 1973, when the impact of new codes following the 1971 San Fernando earthquake began to be felt.

So although there will be some casualties in a Northeastern earthquake, under these circumstances, it is a reasonable speculation that they would not be very great, and the argument presented earlier would hold good: that for these decrepit buildings, casualties occurring through their normal life might equal or exceed those caused by an earthquake that cuts it short. And, of course, to the extent that marginal and decrepit buildings are destroyed without injury the result, as noted earlier, would be a benefit to the environment and economy of the city.

A related response to pursue if the earthquake occurs is then for the authorities to say in effect, "I told you so," and relate the damage to the fact that the public had been told that unstregthened buildings would be subject to damage. At that point, if a real seismic threat is established, there is then ammunition to go into a fully publically supported retrofit program, recognizing the common statement of all who have studied these problems that without a disaster a retrofit program will never fly.

Even in California, where threat of danger is far more intense than in the Northeastern United States, retrofit programs have proven most difficult to get underway and at this time there are only three in existence. The most sophisticated of these is the ordinance adopted by Los Angeles in 1981, after 8 years of study, which is related to the possibility, estimated at something like a 10% probability in the next 30 years, of a great earthquake in the Los Angeles area.

This ordinance provides for a two-stage construction program under which if wall anchoring systems are installed, the time limit to complete the remaining structural strengthening (3 years) is automatically extended from 1 to 7 years, depending on the level of risk in the building. To date the building department has issued 1250 orders to building owners, has checked 750 renovation plans, and issued 500 building permits. One hundred and thirty retrofit projects are under construction, and 140 are finished some of which are first stage construction (4). One of the useful aspects of this program has been to force building owners of marginal buildings to consider the nature of their building and to take action of some sort, thus arresting the natural process of decay, or accelerating it in a beneficial way by demolition. By this process, if a building is renovated, its natural life is extended; and the ordinance requires a seismic retrofit. If it is demolished, then the authorities are initiating a "controlled earthquake," ensuring collapse when the building is uninhabited.

In summary then, the proposed strategy for the Northeastern United States would have the following features:

1) continue a low level public information program on the earthquake hazards,

2) put the major effort into code reform and professional education and development,

3) develop innovative code approaches appropriate to the nature of the Northeastern United States threat, and

4) stress in doing this that it is directed to a general improvement of building construction quality rather than being explicitly oriented towards earthquakes.

The effects of the arguments presented here in relation to other areas of the country would be two. First to relate the probability of earthquakes to the natural life of buildings and if the pattern is similar to that of the Northeast, then to pursue a similar strategy to that proposed. Second, if the earthquake threat is seen as greater, then, instead of efforts to mandate wholesale retrofit of all masonry buildings at great cost and possible little gain, to conduct an analysis aimed at identifying those buildings that have entered the state of decrepitude. These buildings should then not be flagged for renovation but their removal should be encouraged, through tax incentives or other mechanisms, with due respect for individual, social or economic hardship that relates to the building.*

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*present tax structures provide for lower taxes on old buildings. A more logical one would be to increase taxes on decrepit buildings to make it economically beneficial to owners either to renovate or demolish their undesirable structures.

But policies that attempt to insist on prolonging the life of buildings that are better off dead will never make political, social or economic sense.

REFERENCES

1) For example: Henry J. Degenkolb, "Earthquake Performance of Old Buildings," EERI Seminar 'Fix'em,' 1982. to quote, "... a fact that in the design and construction of buildings, the reliance upon and conformance to codes has relatively little to do with the performance of buildings in earthquakes." This paper develops this argument in some detail.

2) Another example is that of the Imperial County Earthquake of 1979. Structural engineers performed emergency inspections of 19 unreinforced masonry buildings, of which 5 were not posted unsafe, 5 had portions roped off or posted unsafe, and 6 were posted unsafe. None suffered total collapse, no one was killed or injured in these buildings.

3) Martel studied masonry buildings in Compton, California after the 1933 Long Beach Earthquake. Out of 122 commercial buildings, 53% were demolished. Out of 21 residential buildings, 0 were demolished. Martel, R.R., "Earthquake Damage to Type III Buildings in Long Beach, 1933," in Earthquake Investigations in the Western United States, 1931-1964: U.S. Coast and Geodetic Survey Publication 41-2 (1966).

4) Information from Earl Schwartz, Chief, Conservation Bureau, Department of Building and Safety, Los Angeles, June 23, 1983.

SEISMICALLY SAFE STRUCTURES AND THEIR COST-EFFECTIVENESS[1]

by

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INTRODUCTION

The total process by which seismic resistance is built into structures and made cost-effective involves a series of interconnected and highly complex professional activities occurring over many years. These activities embrace the contributions of geologists, seismologists, lawmakers, economic managers, planners, architects, engineers and builders.

The contributors have divergent primary professional goals expressed in highly unique languages, but each provides an element of knowledge that ultimately becomes fused into a chain of actions that provides our society an acceptable level of seismic safety.

This paper is designed to explore the role of the engineer as the goals of relative safety and cost-effectiveness are pursued. There is the hope that an improved understanding of this role by other professions will accrue to a safer seismic environment.

The engineer is responsible for the structural design of a building's foundation, columns, walls, girders, beams and floors--those elements of a building that give the building its seismic resistance. In discharging this responsibility, consideration must be given to building codes, cost, architectural design and available builders skills, as well as consideration

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[1] in Proceedings of Conference XXIII, a workshop on "Continuing actions to reduce potential losses from future earthquakes in Arkansas and nearby States:" U.S. Geological Survey Open-File Report 83-846, 234 p.

of geology and seismology. In short, the engineer makes his decisions within a field of constraints that limit his options. It is not the purpose of this paper to comment on these in-place constraints but rather to explore how the engineer makes both seismically safe and cost-effective decisions within their limits.

BUILDING CODES AND BUDGETS

The two major constraints are building codes and budgets stated in a very explicit way: "The minimum acceptable seismic design is to be found in the governing building code and the maximum acceptable seismic design must be within the project budget."

As a practical matter the building code may be regarded by the engineer as unchangeable while the budget may have some flexibility. But it is very difficult to alter a budget and usually very little can be done unless very compelling evidence is discovered and effectively presented to justify spending additional money.

ARCHITECTURE AND PLANNING

The architecture and site planning are the second level of constraints but are nearly as rigid as the first since the design of a building is usually the product of lot shape, zoning ordinances and market demand for space. Thus, the size and height of a building are governed by factors which are to a great extent beyond the engineer's control. Within these constraints of law and budget, size, and height, the engineer can and does design buildings that are seismically resistive and cost-effective and socially acceptable. In the following sections of this paper the process by which this is done is described.

SEISMIC DESIGN

The engineering design of a building is a step by step process which is summarized simplicistically as "trial-test & cost". Each stage is conducted independently of the others and numerous cycles of trial-test & cost are needed before the best solution is found. The dominant variables that must be considered by the engineer involve: 1) materials, 2) column spacing, 3) beam and girder depths, 4) types of bracing, 5) types of connections, and 6) often foundations. Within these six major variables there are countless combinations. As a practical matter the engineer must choose the most effective candidate variables and based upon his professional judgement, create his basic designs.

CODE LEVEL OR PRELIMINARY DESIGN

Having chosen these variables the engineers will next develop preliminary or trial structural schemes that satisfy the building codes, architectural design and budget. It will be assumed for this paper that these schemes include consideration of both steel and concrete frames which are the leading structural materials in common use. Also it will be assumed that consideration is given to both braced and flexible frames. For you who are not engineers, a braced frame is one in which selected vertical elements or bays of a building are made very stiff through the use of "X" type bracing or reinforced concrete walls known as shear walls. On the other hand a flexible frame, as the name implies, is a system of columns, girders and beams that are connected in such a way as to provide adequate strength to resist both vertical loads of gravity and horizontal loads of earthquakes.

Next the engineer will test these schemes for the seismic loading that appears in the building code, which may vary from "no seismic requirement" to something very substantial. If the preliminary design is found lacking, the schemes are revised until solutions conforming to the code are found. These are the minimum acceptable structural solutions for the building frame.

Next the engineer must "cost" the structure. This is done by the engineer usually with the assistance of professional estimators and/or contractors who have a special costing expertise. The end product of this effort is a dollar price tag for each of the minimum schemes previously described.

With the information developed through the "trial-test & cost" process the engineer is now prepared to make a first-order decision among some four or more preliminary structural options. Knowing that each meets the requirement of the building code and the architectural design and knowing their relative costs, the schemes can now be ranked in their most cost-effective order and one of the more cost-effective and seismically resistive structures chosen for final design.

This process of code design by "trial-test and cost" is fairly simple and many successful structural designs have followed this process. For a very large number of structures, especially low risk structures, the code process is appropriate and adequate, but it should be borne in mind that the system has latent shortcomings that may reach serious proportions. These shortcomings arise from the absence of considerations regarding the relative safety of the different schemes when exposed to the full spectrum of seismic motion expected in the region and from the cost-effectiveness of designing for those ground motions in excess of the code minimum. For medium and high risk structures the value of this added information is vital to sound engineering, social and economical decision making. The answer lies in a more elaborate analysis process called "Seismic Spectrum Design".

SEISMICITY SPECTRUM DESIGN

"Seismic Spectrum Design" may be regarded as an extension of, rather than an alternative to, the previously described minimum design. It is based <u>first</u> on recognition of the fact that seismic events vary greatly from microtremors up to some maximum based on the crustal structure of the region. In addition it recognizes the attenuation of energy and alteration of the signal frequency content that are highly influenced by the magnitude of the earthquake, the region in which the earthquake occurs and the wave travel path to the structure. Some source areas are a great deal more active than others as can be readily seen by comparing the two States of Texas and California. These geoseismal variables are accounted for by seismologists and engineers through the establishment of magnitude recurrence or intensity-recurrence curves and attenuation-distance curves and frequency-distance curves unique to the region receiving the structure. These curves describe for the engineer the "best-estimated" range of seismic loads that a structure may possibly experience and they may be used to investigate a structure through rational loading structural analysis and probability procedures.

The engineering procedures by which a trial structure is "tested" against the seismicity spectrum utilizes either structural analysis procedures or the use of life-loss and damage parameters developed from building performances during actual earthquakes. A detailed discussion of these procedures and parameters is beyond the appropriate scope of this paper, but the products of the analysis and their application to balanced decisionmaking will be discussed.

The author has found it most satisfactory to begin a "Seismic Spectrum Design" using those structure schemes previously designed and described that meet the minimum requirements of the building code and project budget. Using these, a simulation is made of those seismic events that have been identified as credible by the regional intensity-recurrences curves.

The results of the simulations indicates both the dollar losses and the life losses to be expected from damages to each minimum scheme when it is exposed to each expected intensity of earthquake. The simulated losses may be evaluated in their absolute sense, i.e., how many dollars worth of damage and how many lives will be lost or they may be viewed in relative terms as is the custom of insurance companies in viewing other type losses.

In analyzing property damages, the author prefers to translate the property dollar damage into a ratio expressing the damages and the cost of the structure. This is done by simply dividing the value of damages by the cost of the structure and thus creating a dimensionless parameter L/C. For example, if a structure is expected to collapse during an intensity 9.0 earthquake it will be a total loss and the L/C ratio will be 1.0 for that structure following an intensity 9 and greater earthquake. The process is repeated for each trial structure and each credible earthquake; thus the process is referred to as the "seismic spectrum" process.

The results of such a process are amenable to graphic presentation and representative plots are given in figure 1 which shows property losses to a stiff, nonductile structure and a flexible structure (See Figure 1). Such an analysis gives the engineer the capability to look at the full range of credible seismic events and the performance of each trial structure . In this way the engineer maximizes the cost-effectiveness and the safety of his design.

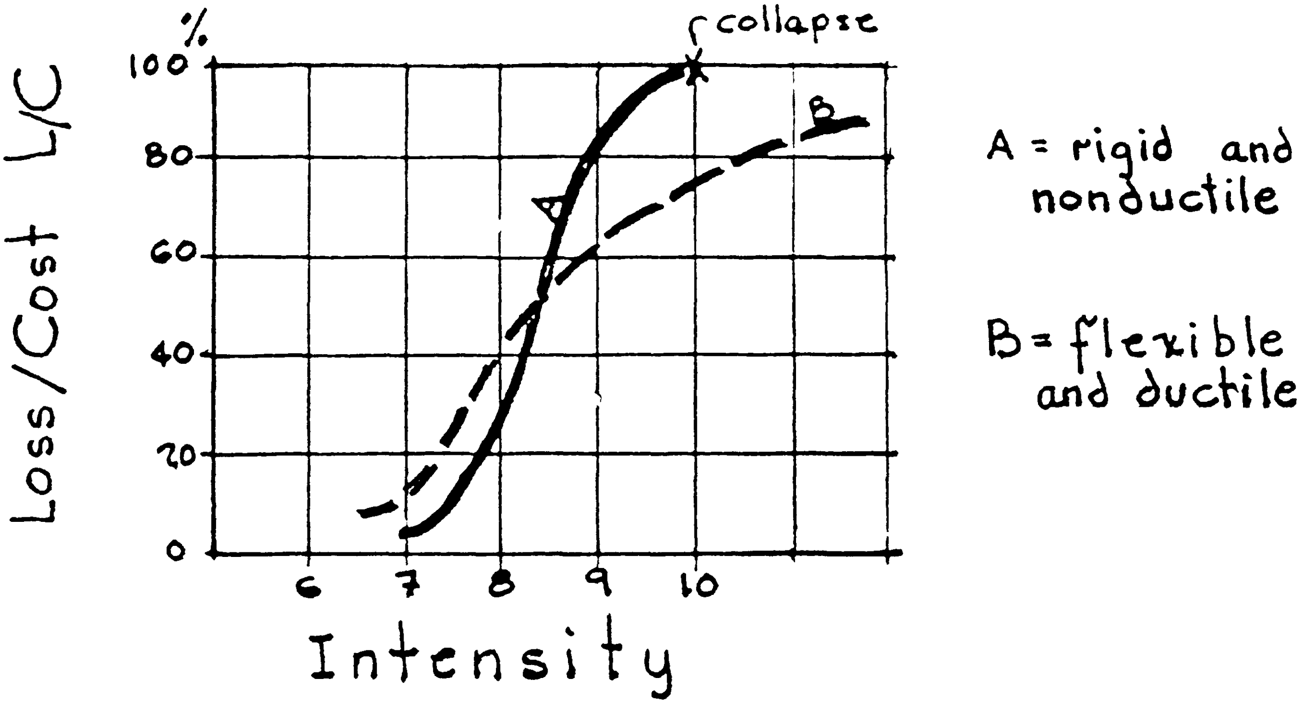

Figure 1--Property Loss Spectrum

Life losses may, like property losses, be analyzed using "seismic spectrum" methods. Each trial structure is exposed to each credible intensity earthquake and the life losses calculated. These losses may be looked at in absolute loss terms or expressed as a mortality ratio similar to insurance statistics or expressed as life loss to dollar-cost of the structure. Different engineers may prefer different terms but regardless of the specific dimensions of comparison there emerges from such an analysis an explicit profile of the seismic safety of each trial structure throughout the range of credible earthquake hazards. Typical results of an analysis of a brittle nonductile structure and a flexible ductile structure (See Figure 2) are shown in terms of the deaths to population ratio D/P of the structure. Here again, the engineer can extend the range of his understanding of the safety and cost-effectiveness of his design to embrace the full spectrum of risk to those who live in the buildings that he designs.

Since there is a unique relationship between expected intensity and time, the "Seismic Spectrum Design" process allows the engineer to extend his analysis to consider the probability of expected seismic events and their expected

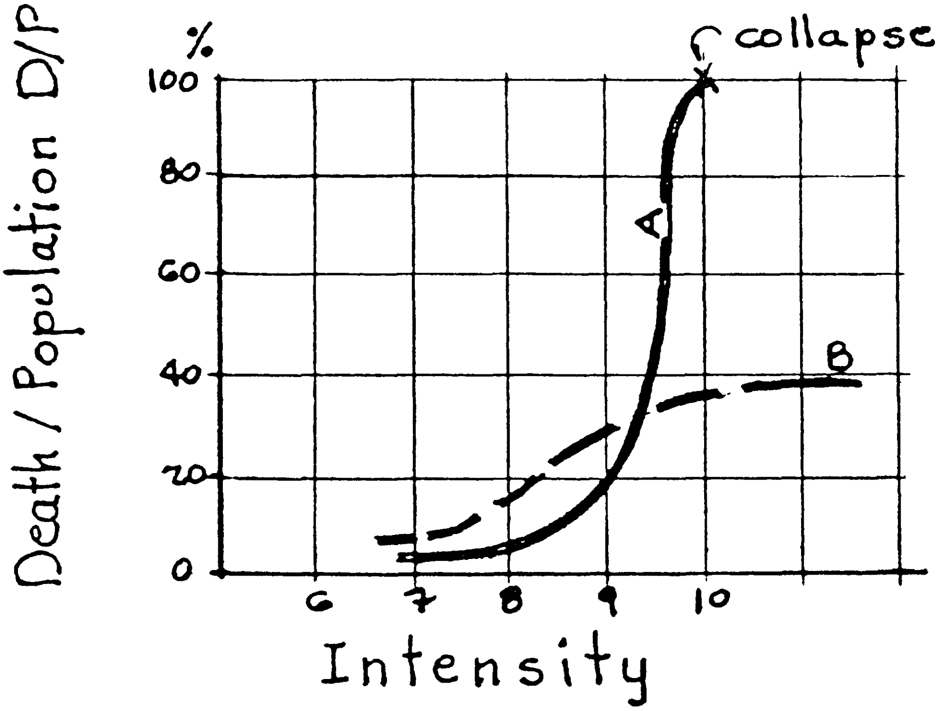

Figure 2--Life Loss Spectrum

losses. In this way the cost-effectiveness of any realistic design option can be investigated probabilistically and related to the risks to which society is exposed such as fire, disease, and auto accidents.

CONCLUSIONS

The role of the engineer in the scenario of seismic safety is played in the company of many other equally dedicated players--seismologists, geologists, lawmakers, architects, planners and builders, all of which are important.

Because the safety and cost requirements of each building are unique, there are no structural solutions that fit all cases. For simple structures and low risk structures, the structural scheme may be selected and the design carried-out using the requirements found in building codes and manuals of practice. For complex structures and structures of high risk or importance to a community, the engineer has at his disposal the "Seismic Spectrum" approach that allows the engineer to minimize the potential losses of property and life and to maximize the cost-effectiveness of his contribution to his client and to the whole of society.

SEISMIC RETROFIT[1]

by

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THE PROBLEM - THE QUESTION

The question was posed, "Is retrofitting of existing buildings a viable option?" I understand the problem as follows: Is it economically possible to protect life and property from earthquakes by retrofitting existing buildings? Must buildings be demolished and reconstructed to modern earthquake resistant provisions to assure life and property safety? Or do we let occupants of our older, built environment remain "at risk" until the building deteriorates and the owner or developer sees an economic incentive, outside of seismic hazards, to replace the structure? The technology of building rehabilitation together with social and political concerns greatly influence the answers to these questions. The National Science Foundation (NSF) over the past few years has begun to fund research to study the technological and social issues connected with building rehabilitation and seismic retrofit.

RETROFIT - ACCOMPLISHMENTS IN RESEARCH AND PRACTICE

Research

The amount of research on repair and strengthening of buildings for seismic resistance has increased significantly in the past few years. The engineering community and NSF became aware of the need to better understand the

[1] in Proceedings of Conference XX, a workshop on "The 1886 Charleston, South Carolina, earthquake and its implications for today:" U.S. Geological Survey Open-File Report 83-843, 502 p.

technologies of structure retrofit and of how repair or strengthening processes actually affected a building's seismic response about 1970. Reinforced concrete and unreinforced masonry structures were the focus of most retrofit research because buildings constructed of those materials generally suffered the worst damage in earthquakes. Experimental research concentrated on building one-third to full-scale models of structural components, loading and falling those models, repairing and/or strengthening them, and retesting. The models were built with new materials but were designed to older, non-earthquake resistant provisions. Comparison of the retest with original response demonstrated the quality and response of the repair/strengthening material and how the retrofit altered the overall response of the structure. Most experiments used static, reversed cycle loading, but a few by Clough, Mayes and Gulkan at the University of California and by Agbabian, Barnes and Kariotis in southern California were either shake-table or real-time dynamic experiments. The overall results of the retrofit tests provide an excellent, though limited, view of retrofit technology and of the response of the repaired/strengthened structure. Most important, the tests have proven that structures may be repaired and strengthened simply and economically to provide greatly improved ductility, strength and earthquake resistance.

Analytical research oriented toward retrofit has been considerably more limited than experimental research. Analysis of reinforced concrete under cracking and yielding deformations and of rocking masonry units is an extremely difficult task. Research on such analysis is ongoing.

Research on retrofit of whole structures has been extremely limited. The Japanese tested a full size seven-story reinforced concrete shear wallframe building structure and retested the repaired structure.

The author knows of no research on the seismic retrofit of "non structural" building elements like exterior cladding or partition walls. Further lacking in analytical and experimental investigations is the study of steel, concrete and masonry materials as they actually occur in existing buildings. The deteriorated condition of masonry built 1840 is much different than masonry constructed in a laboratory in 1980. The behavior of twisted Ransome bars differs from that of new deformed bars in laboratory models of reinforced concrete. And the moment-rotation character of riveted iron frames is not that of welded steel assemblages. Research both in the United States and abroad has lacked understanding of old building materials and of "historic" construction techniques.

Practice

The practice of seismic retrofit and building rehabilitation is far in advance of research. In the United States and particularly in California, architects, engineers and builders have learned the art and craft of retrofit through experience. The 1933 Field Act in California required that all primary and secondary schools built prior to the Act be made as seismically safe as current building code requirements. Over the past 50 years hundreds of California schools have been strengthened for seismic resistance. The collapse of a Veterans Administration Hospital resulting from the 1971 San Fernando Earthquake led to a comprehensive evaluation by the VA of its existing hospital facilities nationwide. VA hospitals in Charleston, South Carolina and in Augusta, Georgia, have been seismically retrofit. Boston has enacted special retrofit provisions for historic buildings. San Francisco enacted a strict parapet ordinance. And the City of Los Angeles recently has required that unreinforced masonry buildings built prior to 1934 be seismically upgraded.

The California Office of the State Architect has helped develop their Title 21 and Title 24 building code provisions oriented toward existing structures and their retrofit. California engineers have learned how to evaluate older reinforced concrete and masonry school structures, to conceive of strengthening procedures and to accomplish both architectural and structural retrofit. The state engineers consistently have taken a very conservative approach in evaluating the strength of the existing building; much of the retrofit has resembled building a new lateral load resistant system within the older gravity load resistant building. Yet some conditions like anchorage capacities, bond of shotcrete-to-brick and attachments for terra-cotta facades had to be estimated or crudely tested on site. Systematic research results were not available. Codes were developed based on experience. With codes in place, research seemed unnecessary.

The Veterans Administration retrofit approach was much the same as for California Schools: match current building codes plus make the facility able to function after an earthquake. Engineers designed new buildings within the old; they used their best judgements to create seismic safety but followed the building code as closely as possible.

San Francisco engineers, with considerable debate, have agreed to securely attach parapets and to structurally connect roof disphrams to load bearing walls. The parapet ordinance in San Francisco was originally conceived to prevent all facia from falling on occupants running from a building and on sidewalk pedestrians. Furthermore, California engineers have been forced to bring existing buildings up to current seismically resistant standards when a structure has been substantially rehabilitated. Rehabilitation of buildings like the State Capitol, Stanford University Quad, the Cannery and many older San Francisco merchantile establishments have forced them to conceive of retrofit schemes.

The City of Los Angeles foresaw substantial risk of collapse of older unreinforced masonry buildings and enacted Division 68 of their building code which establishes criteria for seismic retrofit. These criteria are substantially different and generally less stringent than having a building meet new building code requirements. Much of the technical rationale behind Division 68 was the observed behavior of unreinforced masonry buildings during the 1971 San Francisco Earthquake and the results of NSF sponsored research by Agbabian, Barnes and Kariotis.

The requirement for retrofit in Calfornia has given those engineers a learning-by-doing knowledge of seismic repair/strengthening. Yet the actual adequacy or over-capacity of many of their solutions is yet to be determined. And the retrofit techniques which have been applied to school buildings and hospitals are very expensive, up to 50% to 80% the cost of a new building.

TECHNICAL AND SOCIAL ISSUES

The basic technical issue concerning seismic retrofit is that rehabilitation of an existing structure is a completely different design and construction process than the conceptualization and building of a new structure. The idea that a retrofit for an existing building meet building code provisions for new structures is fallacious because that idea assumes that an existing structure can be evaluated by code provisions. Codes work well on the concept design provisions-construction path, but they cannot work in reverse. The attempt to bring an existing building "up-to-code" results in the California school building technique of constructing a new building within the old.

Economic retrofit depends on the architect's and engineer's art--their judgement of how a system will respond; and it depends on a constructor's craft of matching new structural elements to those existing. Most building codes by their nature as minimum standards, cannot utilize such dependence on art and craft except by such statements as, in the Uniform Building Code, "The provisions of this code are not intended to prevent the use of any material or method of construction... that they are at least the equivalent of that prescribed in this code in suitability, strength, effectiveness, fire resistance, durability, safety and sanitation." New code-like provisions such as Division 68 and Chapters 13 and 14 of ATC-3-06 attempt to utilize an engineer's creative capabilities.

Engineers are reluctant to follow a broad provision like that given above. Without a specific code, an engineer faces liability problems he has avoided by following The Code. An earthquake may prove his art and creative concept lacking; is he then liable for life and property loss?

Economics and the people's desire to preserve historic buildings will force the continued use of existing, currently unsafe structures. The California school building and VA method of retrofit is economically unfeasible for most structures in regions of moderate or even severe seismicity.

The social and political issue becomes do we, the people, want some earthquake safety in our existing structures, or none. Some safety means application of low cost, innovative techniques which may not appear to satisfy new building code criteria.

ACTIONS

Research

Research can do much to clarify and help solve the technical and social issues--the problems. Specific research areas are the following:

1) The current design and construction practice of seismic retrofit must be thoroughly investigated to help establish the art and craft of retrofit.

2) Old metal, reinforced concrete and masonry construction techniques must be evaluated so that modern engineers can better evaluate existing structures.

3) Improved methods of quantifying the quality of existing materials must be developed.

4) Experimental research must be undertaken to examine the response of complete structures and structural and nonstructural elements built using old materials and historic construction techniques.

5) Simple analytical methods to approximate the response of existing buildings must be developed.

6) Code and legal concerns must be examined to determine how retrofit provisions can be applied.

Public policy needs to be developed to demonstrate that earthquake damage is not an "Act of God". The earthquake is the Act; the damage of man-made facilities is preventable.

Retrofit may be economically accomplished in the Southeast as a building is being rehabilitated if architects and engineers are encouraged to artfully construct seismic resistance. The social desire to maintain our historic structures will be achieved as we learn how existing buildings actually behave and how they may be strengthened as opposed to how to meet new building code requirements. A public policy of neglect, let the people remain "at risk" until we build anew, need not be tolerated if thoughtful research and education enlightens designers to economical seismic retrofit procedures.

Finally, in the Southeast the question of earthquake hazard mitigation for existing structures cannot be addressed as a separate technical, social or political issue as it may be in regions of high seismicity like California. Seismic retrofit may reasonably be accomplished as part of a multihazard, strong wind plus earthquake, mitigation scheme. And the mitigation construction will occur during an architectural modernization and rehabilitation of the building.

EVALUATION OF THE EARTHQUAKE GROUND-SHAKING HAZARD

by

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INTRODUCTION

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

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

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

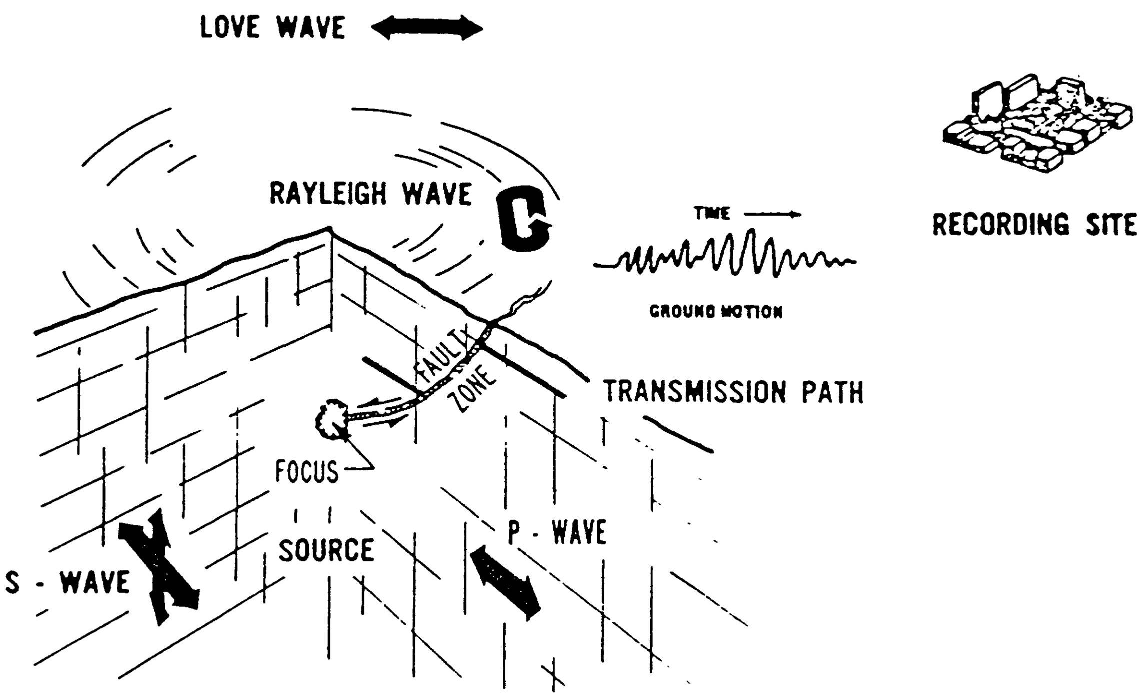

Figure 1.--Schematic illustration of the directions of vibration caused by body and surface seismic waves generated during an earthquake. When a fault ruptures, seismic waves are propagated in all directions, causing the ground to vibrate at frequency ranging from 0.1 to 30 Hertz. Buildings vibrate as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

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

EVALUATION OF THE GROUND-SHAKING HAZARD

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

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

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

1) Resist minor earthquakes without damage,
2) Resist moderate earthquakes without structural damage, but with some non-structural damage, and
3) Resist major earthquakes with structural and non-structural damage but, without collapse.

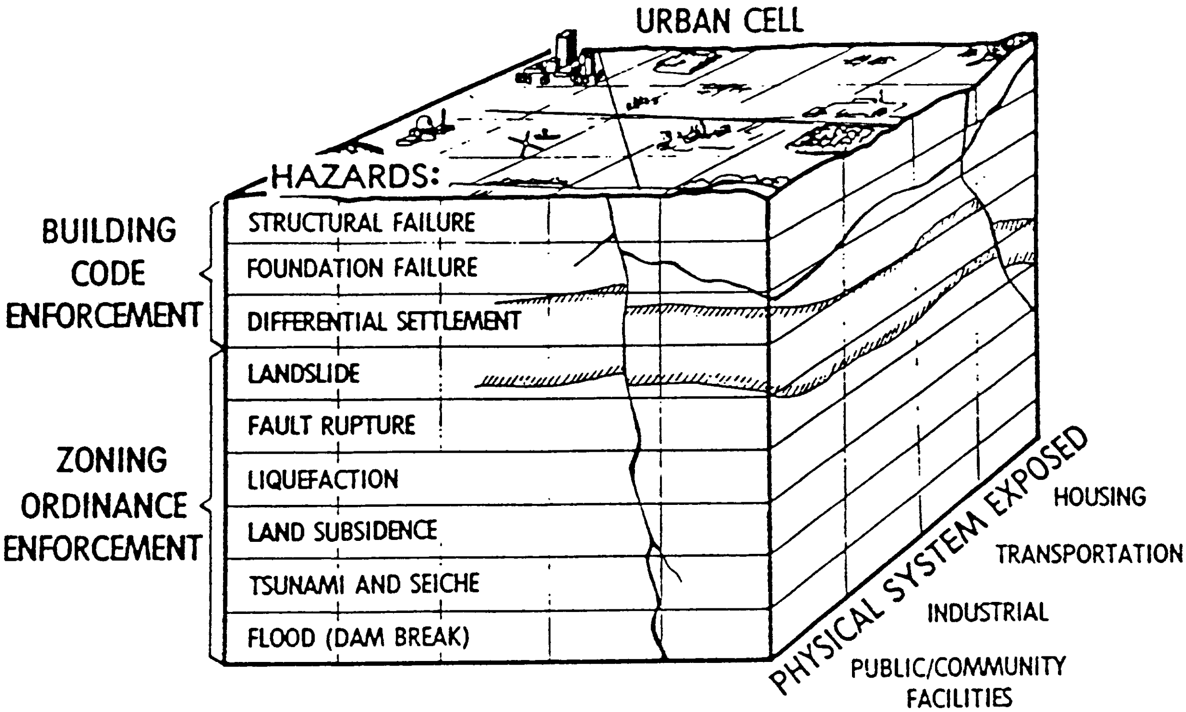

Figure 2.--Schematic illustration of a typical community having physical systems (public/community facilities, industrial, transportation, and housing) exposed to earthquake hazards. Evaluation of the earthquake hazards provides policy makers with a sound physical basis for choosing mitigation stratigies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

HISTORY OF SEISMIC ZONING

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

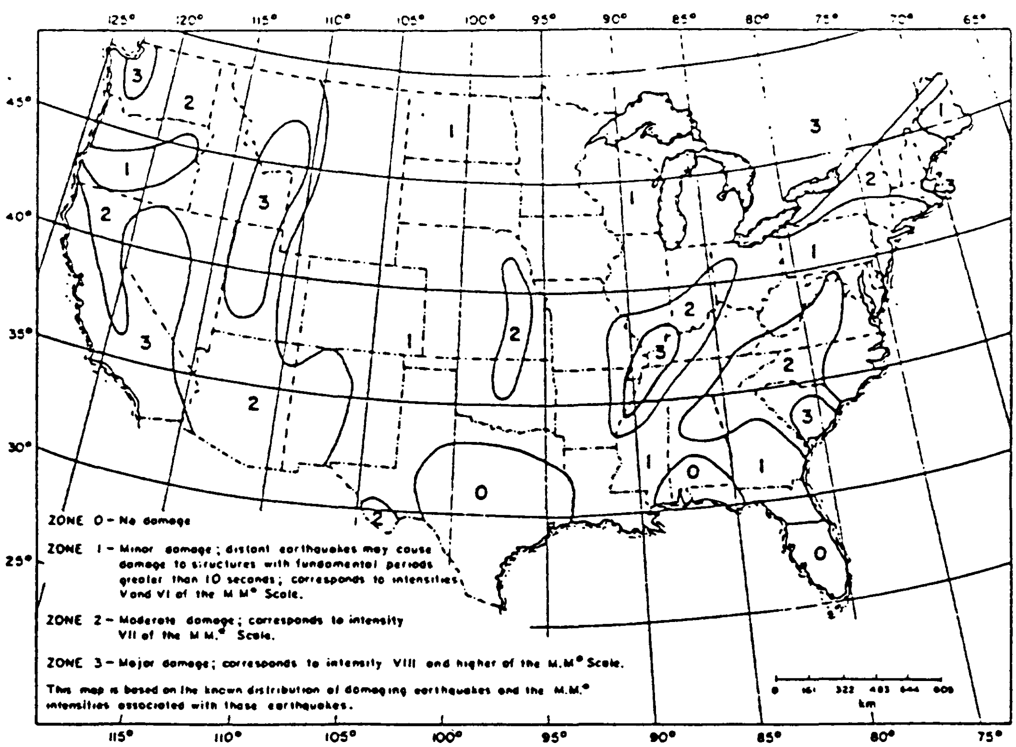

Figure 3.--Seismic hazard zones based on historical Modified Mercalli intensity data and the distribution of damaging earthquakes (Algermissen, 1969). This map was adopted in the 1970 edition of the Uniform Building Code and incorporated, with some modifications, in later editions. Zone 3 depicts the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

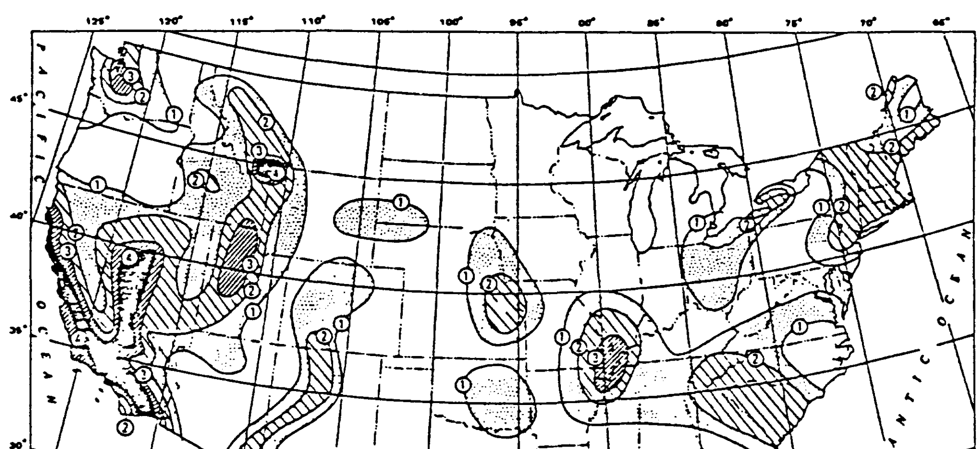

Figure 4.--Map showing preliminary design regionalization zones for the contiguous United States proposed by the Applied Technology Council in 1978 for its model building code. Contours connect areas underlain by rock having equal values of effective peak acceleration. Mapped values have a 90 percent probability of not being exceeded in a 50 year period. Zone 4 depicts the greatest ground-shaking hazard (0.40 g or greater) and Zone 1 represents the lowest hazard (0.06 g). Sites located in Zone 4 require site-specific investigations.

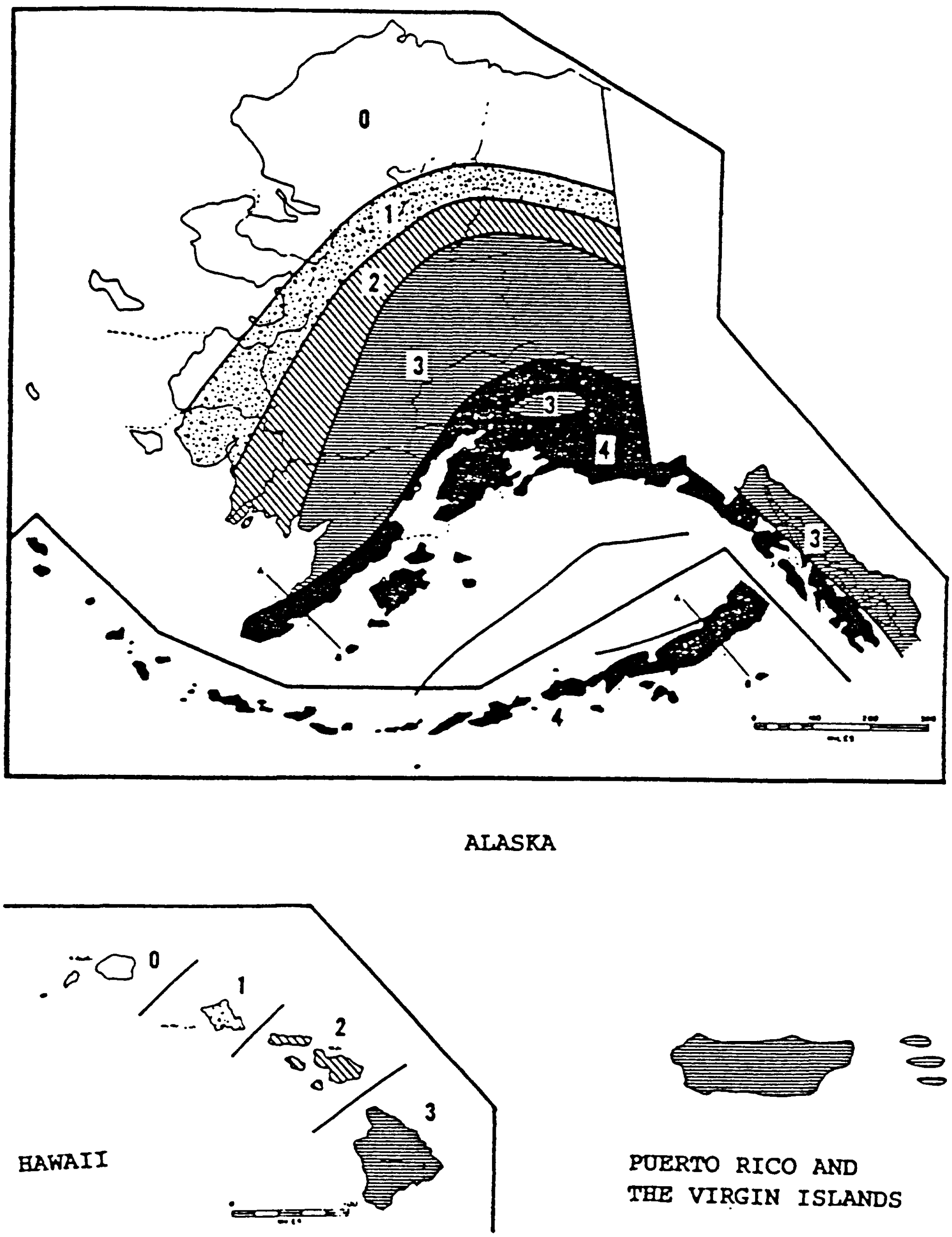

Figure 5.--Map showing preliminary zones of the ground-shaking hazard in Alaska, Hawaii, Puerto Rico, and the Virgin Islands. Puerto Rico and the Virgin Islands lie in zone 3, as denoted in the 1979 edition of the Uniform Building Code. California, in comparison, lies in zones 3 and 4.

PROCEDURE FOR EVALUATING THE GROUND-SHAKING HAZARD

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

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

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

RESEARCH PROBLEMS

A number of complicated research problems are involved in the evaluation of the ground-shaking hazard (Hays, 1980, 1984). These problems must be addressed if more accurate specifications of the ground-shaking hazard are desired. The problems can be catagorized in four general areas, with each area having a wide range of technical issues. The following representative questions, which generally can not be answered with a simple "yes" or "no", illustrate the controversy associated with ground-shaking hazard maps.

Seismicity

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

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

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

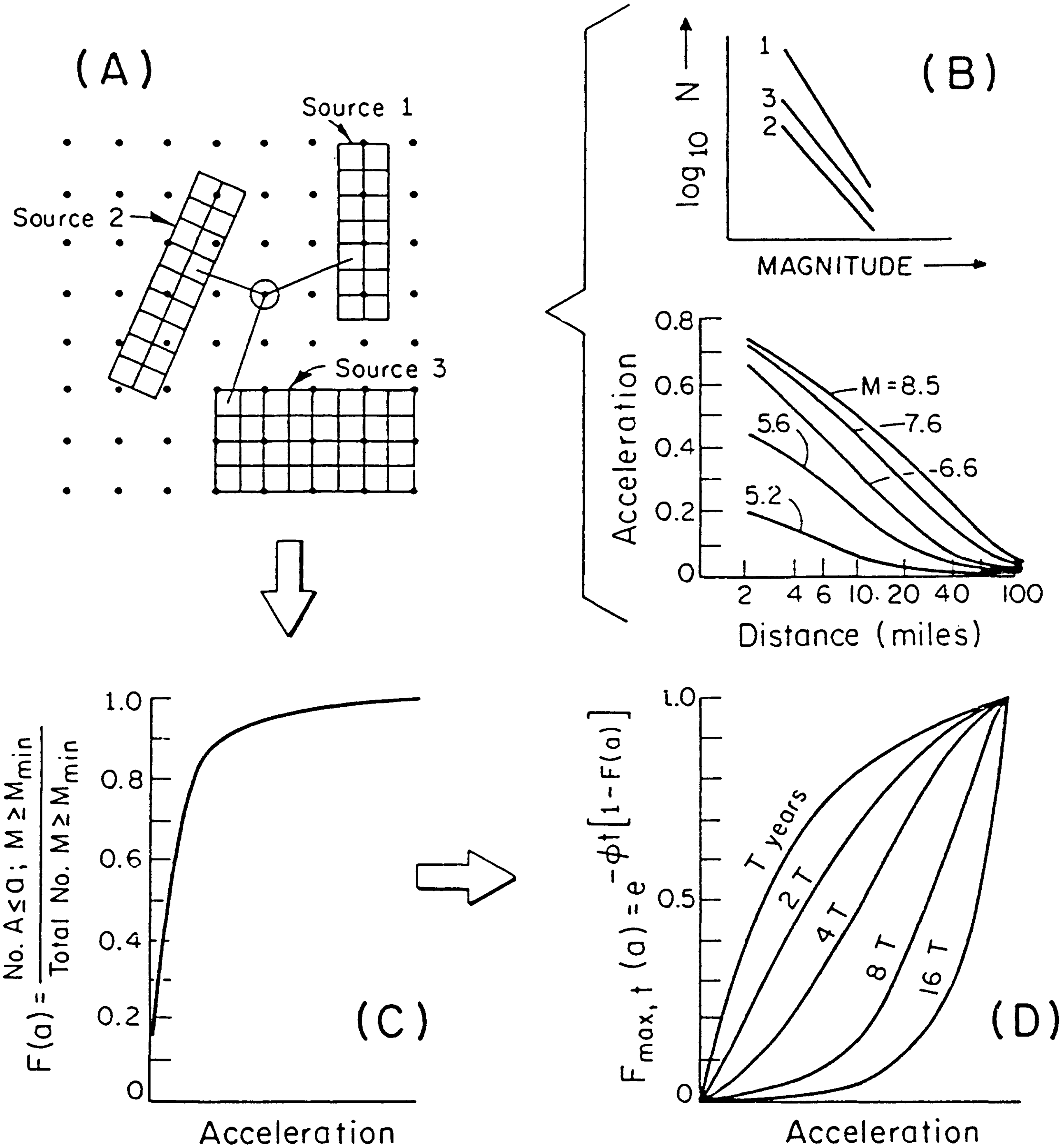

Figure 6.--Schematic illustration of the procedure for constructing a probabilistic ground-shaking hazard map. Inset A shows 3 typical seismic source zones and the grid of points at which the ground-shaking hazard is calculated. Inset B shows typical statistical distributions of historical seismicity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

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

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

The Nature of the Earthquake Source Zone

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

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

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

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

Seismic Wave Attenuation

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

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

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

Local Ground Response

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

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

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

CONCLUSIONS

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

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PROCEDURES AND DATA BASES FOR EARTHQUAKE DAMAGE PREDICTION AND RISK ASSESSMENT[1]

by

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INTRODUCTION

Efforts to assess earthquake losses have likely been made following major earthquakes for the entire history of mankind. The great San Francisco earthquake of 1906, however, is the earliest event for which useful documented quantitative evaluations of losses are available. Loss evaluations have been made with varying degrees of rigor following each of the subsequent major earthquakes in the United States, although loss statistics prior to 1971 have been of limited value because of the substantial effort involved in compiling detailed loss information and the sparsity of available ground motion data.

Efforts to develop quantitative loss prediction procedures have been made only in recent years. Fifteen years ago, predictive estimates of damage that might result from earthquakes were almost nonexistent. The development of various procedures for estimating losses caused by ground motion has been prompted by the increased potential loss resulting from increased population density near active faults, the availability of more complete data from recent earthquakes, and other factors. However, the development of a single, general yet rigorous damage prediction methodology is not presently feasible because of the complexity of the problem and the sparsity of data.

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[1] in Proceedings of Conference XIII, "Evaluation of Regional Seismic Hazards and Risk:" U.S. Geological Survey Open-File Report 81-437, 248 p.

This paper discusses the various factors that must be considered in developing damage prediction procedures and reviews various procedures that are currently available. The paper also provides an example of a theoretically based loss prediction methodology and describes a specific damage factor model. Finally, a summary of research needs in the area of earthquake damage prediction is given.

CONSIDERATIONS FOR DEVELOPING DAMAGE PREDICTION PROCEDURES

Several factors must be considered in making comprehensive damage predictions:

- Reasons for making predictive estimates of earthquake losses
- Types of losses to be estimated
- Causes of earthquake damage
- Structure types and classifications
- Structure elements, materials, and assemblage
- Ground motion and structure response
- Approaches to predicting damage
- Contemporary earthquake-resistant design philosophy
- Risk evaluation and hazard reduction
- Timing

These ten factors are discussed below.

Reasons for Making Predictive Estimates of Earthquake Losses

It is beneficial to identify the various reasons for making predictive estimates of earthquake losses. Although there are a variety of reasons, the most important are:

- Disaster preparedness planning
- Reduction of future losses
- Structure design optimization
- Determination of earthquake insurance needs and rates

Types of Losses to be Estimated

Consideration of the types of losses to be estimated -- or the manner in which the losses are to be identified -- is essential for making comprehensive damage predictions. Although there are many types of losses, the most important, consistent with the above reasons for estimating losses, are:

- Life loss
- Injuries
- Structural damage
- Nonstructural damage, e.g., partitions, glazing
- Mechanical and electrical equipment damage
- Damage to contents, e.g., furniture, merchandise
- Losses due to lost production and lost wages

Causes of Earthquake Damage

Earthquakes cause various types of physical phenomena to occur in the vicinity of a fault rupture -- and sometimes at great distances from the affecting fault. Because the occurrence of these phenomena may lead to earthquake losses, they must be considered in making damage predictions.

The primary physical phenomenon caused by earthquakes is ground shaking; other events are secondary phenomena caused by ground shaking. A list of these various causes of earthquake losses is as follows:

- Primary phenomenon: ground shaking

- Secondary phenomena:
  -- liquefaction
  -- landslide
  -- tsunami
  -- flood
  -- fire
  -- interrupted lifeline services

Structure Types and Classifications

A first step in predicting earthquakes losses is to inventory structures that might be subjected to significant ground motion. For loss prediction purposes, the term structure can be defined as any object of value that can be damaged by ground motion. Typically, most structures will be buildings. Generally, the vast majority of buildings will be low-rise (1- and 2-story) structures; however, most affected areas will also have many other types of structures.

Establishing structure categories is only necessary for damage evaluations of large numbers of structures. For such evaluations, it is appropriate to categorize structures to minimize the overall work involved in making the damage evaluation. A list of typical categories and examples of structure types is given in Table 1. These structure types can be further classified into subcategories according to their physical and mechanical characteristics, such as their vibration properties, structural systems, materials of construction, architectural components, and building configurations. Of course, by creating structure categories and thereby lumping structures into groups, greater variability is introduced into the final damage evaluation because rarely are any two structures identical in all respects.

Structure Elements, Materials, and Assemblage

Because a completed structure consists of an assemblage of many elements, the effect of each element on the response of a structure to dynamic ground motion must be understood if damage prediction procedures are to be developed. A common aspect of the many elements that make up a typical structure is that all can be damaged -- as a result of either a primary or a secondary effect. For dynamic response and damage prediction purposes, the most important properties of the various elements are:

- Mass
- Force-deformation relationship
- Energy absorption (damping)
- Damageability

Table 1

Typical Categories and Examples of Structures

A. Buildings

1. Residential (houses, apartments)
2. Agricultural (farmhouses, barns, outbuildings)
3. Commercial (stores, gasoline stations)
4. Institutional (schools, hospitals, churches)
5. Industrial (refineries, mills)
6. Special (shrines, ruins)

B. Utility and Transportation Structures

1. Electrical power structures (lines, transformers, switch gear converters, beacons)
2. Communication and microwave stations (reflectors, towers, equipment)
3. Roads, railroads, bridges, overpasses, tunnels, retaining walls
4. Air navigational facilities (beacons, marker stations)
5. Airfields and parking areas
6. Marine and waterfront structures (piers, bulkheads)

C. Hydraulic Structures

1. Earth, rock, or concrete dams, outlet works, control structures
2. Reservoirs, lakes, ponds, sumps, forebays, afterbays, and adjacent shores and slopes (for wave generation)
3. Canals, pipelines, siphons, surge tanks, elevated and surface storage tanks, distribution systems
4. Water storage, cisterns, distribution, processing stations
5. Petroleum products (liquid and gas) storage, handling, piping, processing stations

D. Earth Structures

1. Earth and rock slopes (for potential instability determinations and predictions of damage to roads, fields, stream contamination, hazards to persons)
2. Major existing landslides, land creep areas, snow, ice, or earth avalanche areas, subsidence areas
3. Natural or altered sites with scientific, historical, cultural, or ecological significance (pueblo dwellings, scenic rock formations, historical landmarks, archaeological sites)
4. Berms, dikes, banks

E. Special Structures and Items

1. Conveyor systems, tramways, cableways, flumes, ski lifts, trestles, headframes, personnel lifts
2. Ventilation systems, stacks
3. Mobile equipment, rolling stock, vehicles, drillrigs
4. Towers, poles, signs, frames, antennas
5. Material storage, ore heaps, elevated bulk storage, tailings piles, gravel plants, tailings ponds, corrosive fluid storage
6. Agricultural equipment, irrigation lines
7. Furnishings, shelf goods, roof-mounted air conditioners, bric-a-brac, dishes

Mass is important for determining inertial force magnitudes; the force-deformation relationship (stiffness), for determining the rate of element deformation and for determining limits of deformation (damage thresholds); energy absorption, for establishing the rate of decay of vibratory motion; and damageability, for determining the extent of damage for the level of structure response. Mass and force-deformation characteristics are also the principal parameters affecting a building's frequency and mode shape characteristics. Because these properties vary widely from element to element and because there are so many elements involved in structures, it is desirable to categorize and classify them.

For damage prediction purposes, classifying the elements of a structure according to function, i.e., structural or nonstructural, provides useful distinctions. Generally, a structural element is one that is important to the overall survival of a structure. Thus, damage to a nonstructural element would not be nearly as consequential as damage to a structural element. Examples of structural elements are foundations, beams, columns, vertical-load-bearing walls, and shear walls. Nonstructural elements include windows, partition walls, residential chimneys, and hung ceilings. Although damage to a nonstructural element might be hazardous to people, damage to structural elements is potentially much more serious because many more people could be endangered by building collapse.

For damage prediction purposes, materials are distinguished by the manner in which they deform under load. Materials are characterized as brittle or ductile, as flexible or stiff, and as strong or weak. Figure 1 shows schematic force-deformation relationships that define these six characterizations. The common definitions of these terms, except ductile and brittle, also apply in the field of structural dynamics. A ductile material is one that does not fail at the first sign of distress and also absorbs large amounts of energy when it deforms (Blume, 1960). Steel framing is a classic example of a ductile material. Brittle materials, such as glass, are generally understood to fail completely at or near the first sign of distress.

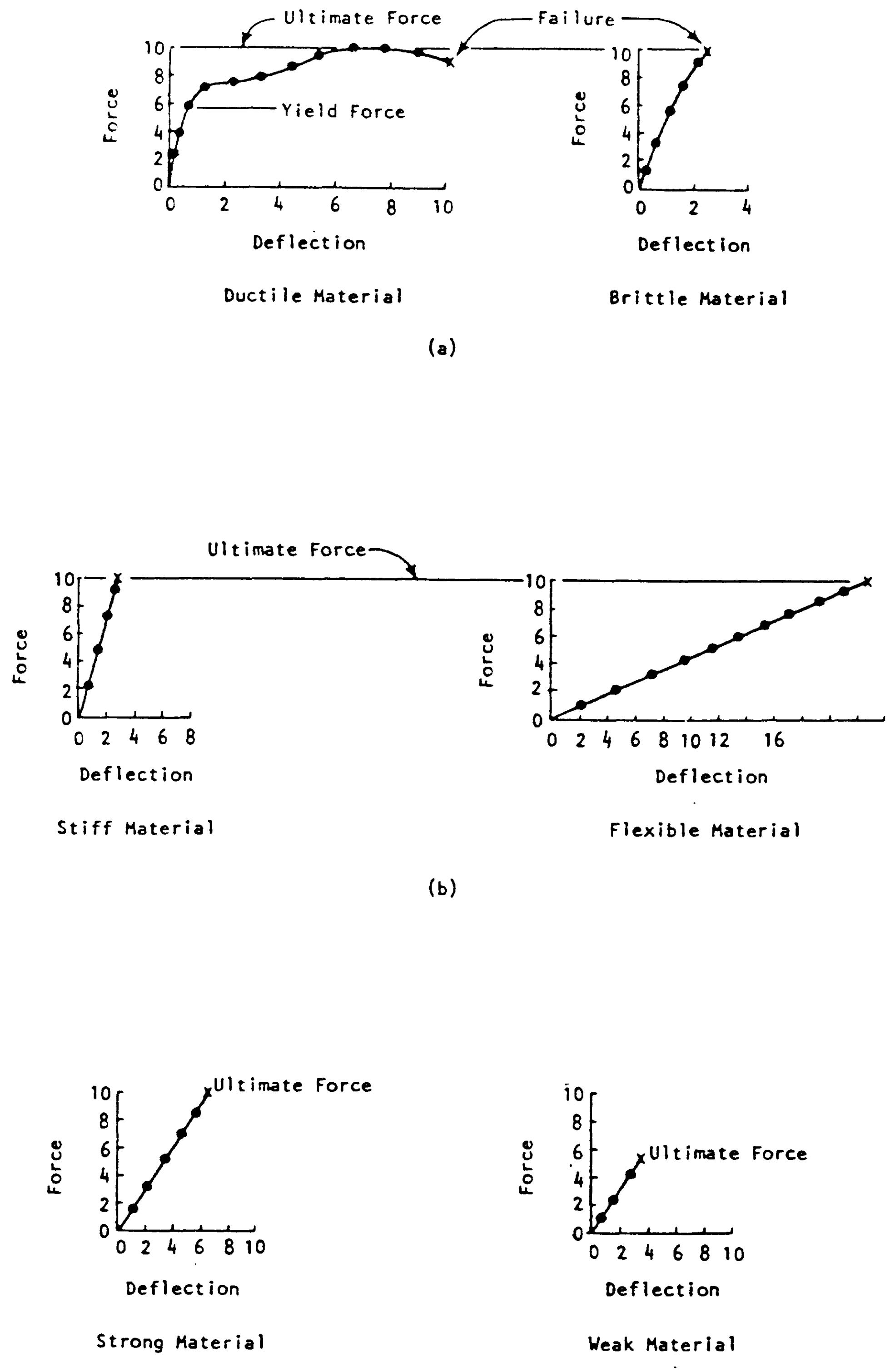

Figure 1--Structure material characteristics (from URS/John A. Blume & Associates, Engineers, 1975)

The assemblage of the elements that make up a structure is important to damage prediction in two respects. First, the manner in which various elements and materials are arranged in a building and their relative stiffnesses determine the order in which members are damaged. Plaster-surfaced, nailed, wood-frame construction provides a classic example of this. Nailed wood framing is generally characterized as a ductile material, while the plaster surface represents a brittle material. Knowing the general force-deformation relationship for the two materials, one can readily predict that the plaster will be severely cracked before any serious damage is done to the wood-frame timbers. Second, the degree of competency of element connections determines the extent to which an element participates in resisting lateral inertial forces caused by dynamic ground motion. Competency also involves the clearances between elements; for example, because of the relatively large tolerances in normal window installation, the RULISON underground nuclear explosion caused very little damage to window glass in low-rise buildings compared with damage to interior wall finish materials (Scholl and Farhoomand, 1973).

Ground Motion and Structure Response

Free-surface ground motions can be completely identified in terms of three independent orthogonal components (ignoring rotations about the three axes). These can be recorded in terms of time-varying acceleration (A), velocity (V), or displacement (D), depending on the type of seismometer used. Example acceleration recordings for the three orthogonal components representing moderate-amplitude earthquake motion are shown in Figure 2.

If the base of a structure is suddenly moved, other parts of the structure will not respond instantaneously but will lag because of inertial forces and structure flexibility, as illustrated in Figures 3 and 4. The concept of inertial forces is not new, of course -- Newton described it in his Second Law of Motion as the product of the mass of the structure (weight) times acceleration, or $F = mA$.

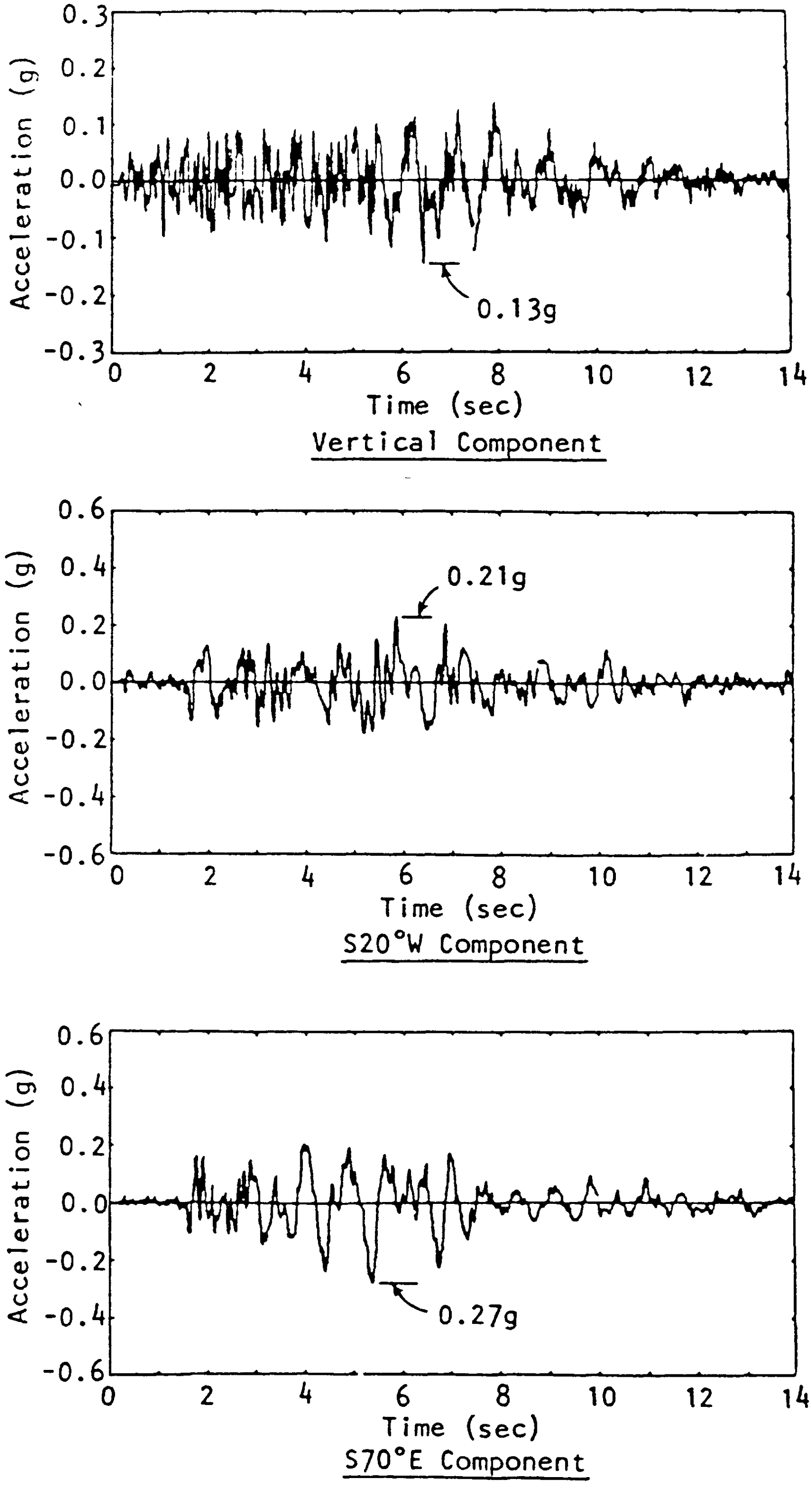

Figure 2--Strong motion recordings for the San Fernando earthquake of February 9, 1971, at Glendale, California, Station 32 (from URS/John A. Blume & Associates, Engineers, 1975)

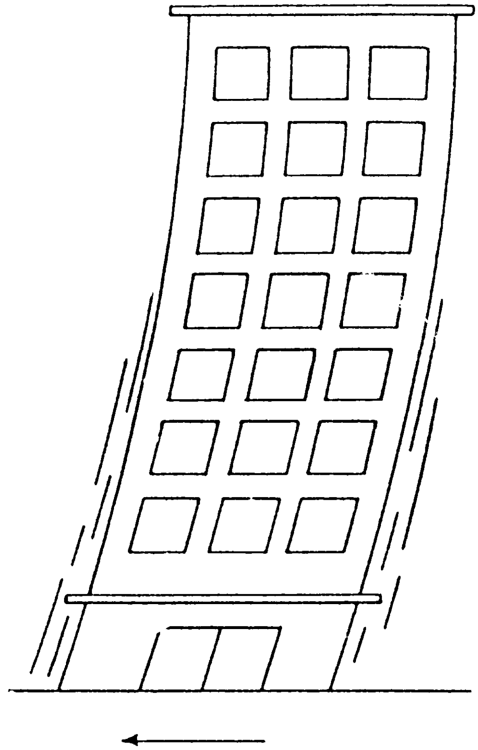

Figure 3--Schematic of high-rise building shear-type instantaneous distortion caused by ground motion (from URS/John A. Blume & Assoicates, Engineers, 1975)

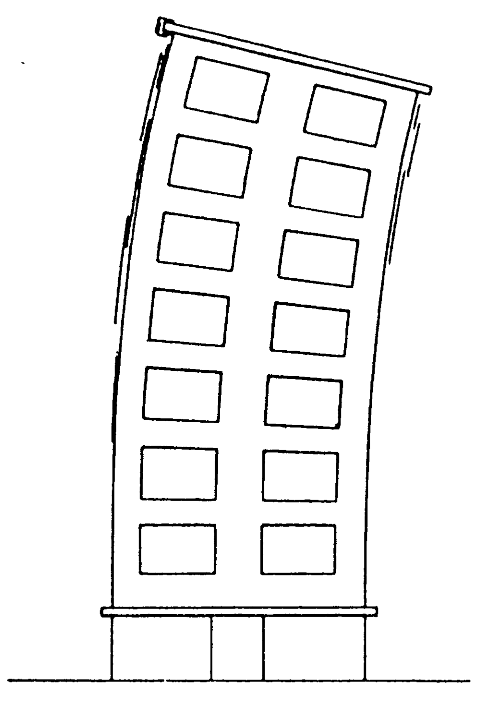

Figure 4--Schematic of high-rise building bending-type instantaneous distortion caused by ground motion (from URS/John A. Blume & Assoicates, Engineers, 1975)

For simplicity, Figures 3 and 4 show motion in only one plane. Because the ground motion at a point on the earth's surface is three-dimensional, as described above, the structures affected will deform in a three-dimensional manner. Practically, however, the inertial forces generated by the horizontal components of ground motion are more important for seismic damage prediction than the vertical components because structures are less rigorously designed for lateral than for vertical forces and because of the factors of safety commonly used in vertical gravity load design.

A fundamental premise in structural dynamics is that structures are flexible or deform under load. Although the stiffness (inverse of flexibility) of different structures varies, depending on the materials and framing configuration involved, virtually all conventional civil engineering structures have some degree of flexibility. The elastic properties of structures and how their variations affect response and damage were discussed above.

The magnitudes of inertial forces induced by ground motion excitation are functions of the masses and accelerations of a structure. Although the masses of a structure can be easily and accurately identified, determining a structure's accelerations is more difficult. If a structure were perfectly rigid, i.e., if its entire mass moved precisely as the ground moves, establishing its acceleration and force distribution during ground motion excitation would be simple. However, because flexible structures deform under load, as Figures 3 and 4 show, the motion in various parts of a structure usually differs from that of the free ground surface. In some cases, a structure's motion amplitudes are greater than the ground motion; in other cases, the reverse is true.

For accurate calculation of a structure's motions, and therefore the acting inertial forces, a dynamic structure response analysis must be performed. At a minimum, the fundamental aspects of dynamic structure response must be included in damage prediction procedures that are to have any general applicability. Quantitative aspects of dynamic structure response are discussed in numerous text books.

The important characteristics of earthquake ground motion, as it affects structure response and damage, are:

- Amplitude
- Frequency content
- Duration
- Periodicity

All these characteristics, except for duration, are reflected in standard response spectrum plots. Duration can be revealed in three-dimensional response spectrum plots (Schopp and School, 1972), but, because of the added complexity of presenting three-dimensional plots and because duration is less important than other ground motion characteristics, it is commonly not explicitly presented. However, for certain damage predictions (e.g., those involving liquefaction and low-cycle fatigue), knowledge of ground motion duration is crucial. In some cases, duration is presented by specifying the number of seconds during which the record shows that ground motion was greater than some given amplitude (e.g., acceleration $\geq$ 0.05g).

Currently, seismological intensity scales (e.g., Modified Mercalli and Rossi-Forel) are used extensively for damage prediction purposes. Although the various ground motion characteristics listed above are reflected in the seismological intensity scales, the scales present two serious limitations. First, the various ground motion characteristics are not independently distinguishable, and, second, the scales are not quantitatively applicable (except in a very approximate sense) to engineering analysis and design. The seismological intensity scales were first developed nearly two centuries ago and have been evolving ever since that time; however, they simply do not possess the quantitative precision compatible with modern seismic analysis and design technology.

Response spectrum plots facilitate distinguishing response amplitude as a function of frequency. This is important in engineering because different structures have different natural vibration frequencies, and thus dynamic amplification of various structures depends on amplitudes of ground motion at various frequencies.

Approaches to Predicting Damage

A comprehensive damage prediction methodology should satisfy the following criteria:

- It should be based on sound theory and engineering principles, and it should relate to and use commonly known engineering analysis and design methods and parameters. This would allow improvements to be made easily in the damage prediction methodology as the state of the art in engineering design and analysis advances. It should also facilitate the use of the methodology by most practicing professionals without requiring extensive experience with damage prediction technology.

- The methodology should be easily adaptable to all engineering structures. This criterion will be satisfied if the methodology is based on engineering principles and uses commonly known design and analysis methods and parameters.

- The methodology should have provisions for using the data from actual earthquakes and from laboratory experiments as they become available.

- The methodology should account for uncertainties in the ground motion demand, the structural capacity, and the analytical methods and assumptions. This requires the methodology to adopt a probabilistic approach.

- The methodology should be able to be conveniently automated for use of computers in real-world applications. This requires a modular structuring of the methodology. Basic modules, for example, can be ground motion prediction, structure response prediction, structure (or component) inventory, basic damage prediction, and economic factors. In addition, a decision analysis module can also be incorporated. The structure response -- damage relationships or data can be stored as a separate module or as a damage data library.

Selection of an approach to predicting damage requires consideration of utilitarian factors, that is, whether damage is being predicted for a single structure, for a group of structures, or for a large urban area. These factors affect the degree of data-base structuring required for the methodology.

For the completely general case, an earthquake damage prediction methodology for structures would include the following steps:

1. Inventory methodology
2. Ground motion prediction methodology
3. Loss prediction methodology (loss algorithm)

Inventory methodology is relatively straightforward, and an example is given later in this paper. Ground motion predictions can be made in many ways. An outline of a general ground motion prediction methodology is also given later in this paper.

Loss algorithms, whether structure specific or for structure groups, can be developed from either empirical or theoretical procedures. The practical limitations of each approach require that information from both sources be used for developing loss prediction procedures involving real structures.

Empirical Procedures. Empirical procedures involve gathering and correlating ground motion information and loss information from past earthquakes or other sources of ground motion. Figure 5 shows an example of this type of information, giving a plot of mean damage factor (ratio of dollar loss to replacement value) versus 5%-damped response spectrum acceleration averaged over the period band of 0.05 to 0.20 sec. While this information is very useful, it has two serious limitations:

- It is almost impossible to gather the necessary volume of information for the wide variety of structures that exist in a large urban area.

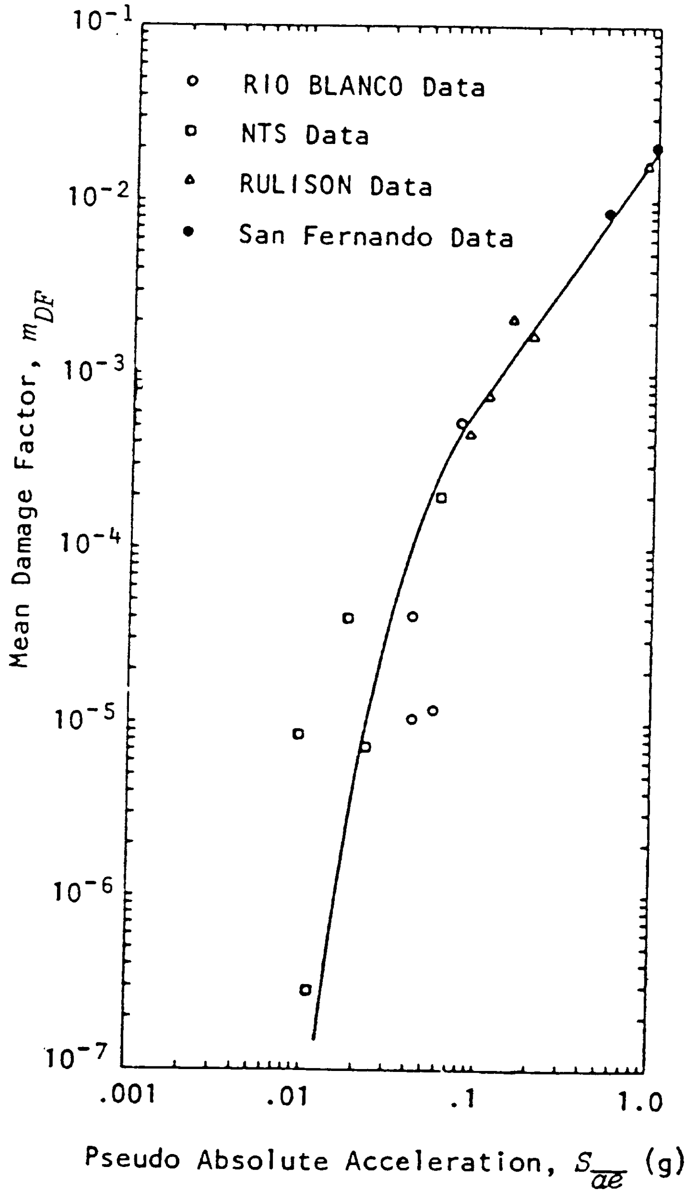

Figure 5--Mean damage factor versus spectral acceleration for low-rise buildings (from URS/John A. Blume & Associates, Engineers, 1980)

- Changes in design and construction practice cause the information to have limited applicability for future events.

Theoretical Procedures. Theoretical procedures involve employing mathematical models, which include consideration of the physical and mechanical properties of a structure, for predicting damage. This approach is the avenue of choice from the perspective of generality and flexibility. If the procedures are based on the fundamental principles of structural engineering and dynamic response, engineers can use these procedures in future designs to reduce future earthquake hazards and can easily modify the methodology to reflect those design changes that would reduce future earthquake damage.

No single methodology will ever suffice for all damage prediction needs. All practicable methodologies are by necessity approximate, and various degrees of precision are required for different prediction needs. In addition, the variations in the many types of structures and structure components virtually dictate that different prediction approaches be used for different situations. For example, interstory drift is an important indicator of damage for structural and nonstructural components of a building, while floor acceleration is an important indicator of damage for equipment.

An example is provided below to illustrate one theoretical approach to predicting damage.

First, various interstory drift limits can be determined from test data or can be estimated for many types of structure configurations. Accordingly, information such as that given in Table 2 can be determined. The interstory drift information can then be used to calculate response spectrum amplitudes for the various drift limits as follows.

From fundamental considerations of dynamic response analysis, and considering only the fundamental mode response:

$$\delta_{roof} = S_d \gamma \qquad (1)$$

Table 2

Interstory Drift Limits for Various Structure Types

Lateral-Force-Resisting System	Interstory Drift (cm)		
	Observable Damage, Δu_1	Yield Capacity, Δu_2	Ultimate Capacity, Δu_3
Wood Frame Unreinforced Masonry Reinforced Masonry Reinforced Concrete Frame Reinforced Concrete Shear Wall Steel Frame Steel Braced Frame Steel Eccentrically Braced Frame	.25*	1.0*	5.0*

*Values assumed for this example. As further data are obtained, appropriate values can be filled in for each structure type.

where:

δ_{roof} = displacement of the roof relative to the ground

S_d = response spectrum displacement

γ = modal participation factor for fundamental mode with roof displacement normalized to unity

Then, assuming both a straight-line fundamental mode shape and that the fundamental building period, T, can be approximated by:

$$T = 0.1N \tag{2}$$

where:

N = the number of stories

it follows that:

$$\Delta u \cong \frac{\delta_{roof}}{N} = \frac{\gamma S_d}{N} \tag{3}$$

where:

Δu = average interstory drift

Finally:

$$S_d = \frac{N\Delta u}{\gamma} \tag{4}$$

Equations (2) and (4) facilitate plotting various interstory drift limits onto a response spectrum plot. In that form, damage can be crudely estimated by comparing a demand ground motion response spectrum with various structure component capacities developed from interstory drift limits. The calculated S_d values for the example assumed drift limits in Table 2 are given in Table 3. These S_d values are plotted in Figure 6, which also shows a plot of the 5%-damped response spectrum for the 1940 El Centro earthquake record.

Contemporary Earthquake-Resistant Design Philosophy

Structural analysis technology for prediction of earthquake response has advanced significantly in the past 15 years. Linear dynamic response analyses are commonplace today, and nonlinear dynamic response analyses are feasible

Table 3

Response Spectrum Displacement For Various Damage Thresholds and Building Heights

Number of Stories, N	T (sec)	γ	$S_d = \frac{N\Delta u}{\gamma}$		
			Observable Damage	Yield Capacity	Ultimate Capacity
1	0.1	1.0	0.25	1.0	5.0
2	0.2	1.2	0.42	1.67	8.3
3	0.3	1.29	0.58	2.33	11.6
4	0.4	1.33	0.75	3.01	15.0
5	0.5	1.36	0.92	3.68	18.4
10	1.0	1.43	1.75	6.99	35.0
20	2.0	1.46	3.42	13.70	68.5
30	3.0	1.48	5.06	20.27	101.4
40	4.0	≈1.5	6.67	26.67	133.3

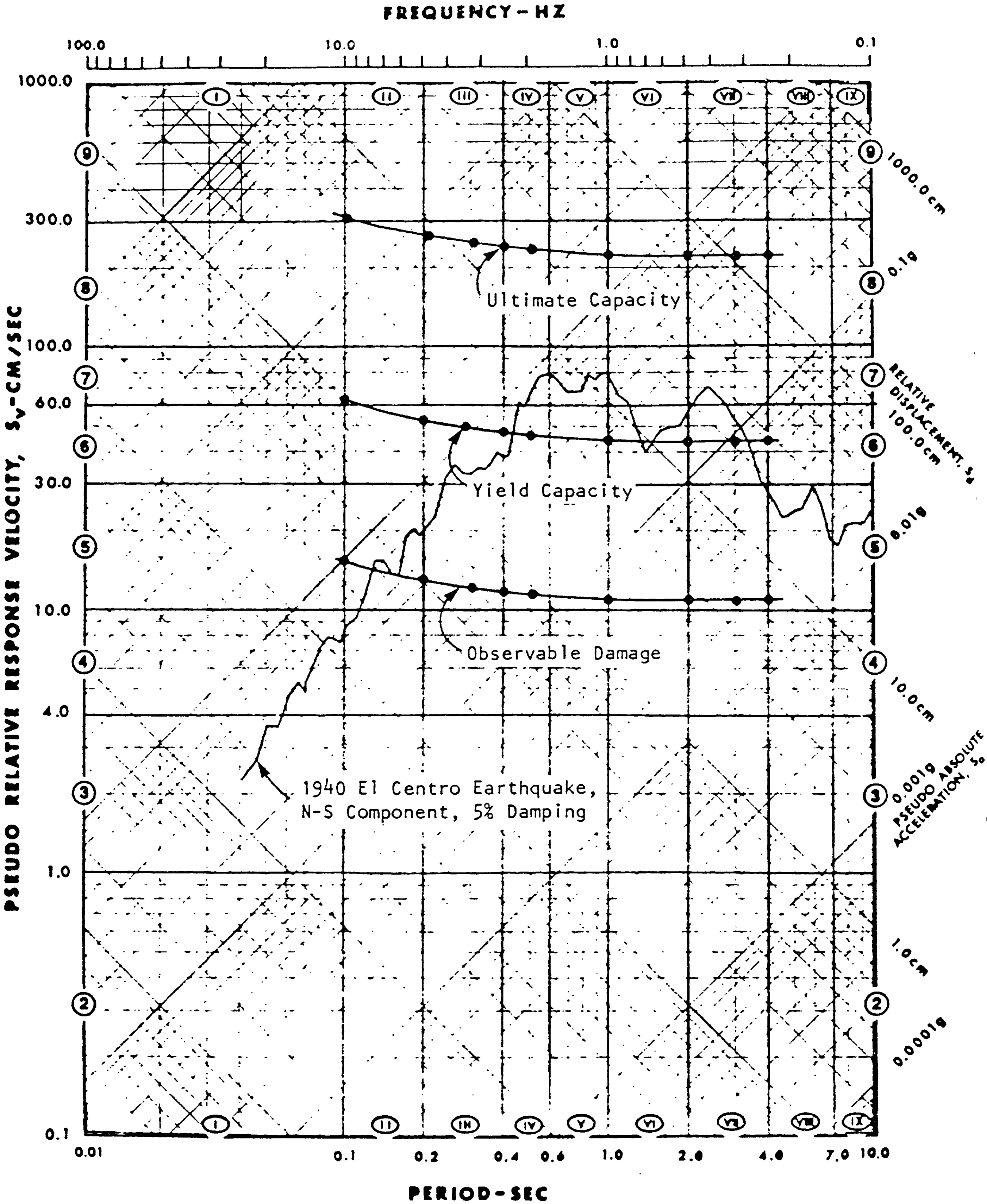

Figure 6--Response spectrum amplitudes for various damage thresholds for reinforced concrete frame structures (from URS/John A. Blume & Associates, Engineers, 1980)

for simple structures. These analyses are used for calculating structure member stresses and strains and are correspondingly used in design (i.e., structure members are sized by comparing calculated stresses and strains with those allowed by various codes and standards).

Unfortunately, the codes do not specify the degree of damage associated with various prescribed stresses and strains. In addition, the stated philosophy of contemporary earthquake design procedures (Structural Engineers Association of California, 1975) is that structures are expected to be damaged during major earthquakes but that collapse is to be precluded by using the recommendations prescribed. Finally, because structures are expected to be damaged during major earthquakes, they will respond nonlinearly.

Figures 7 and 8 illustrate (in an idealized sense) the contemporary code philosophy. Two important observations can be made from these illustrations. First, it is clear that nonlinear response considerations must be included in any attempt to relate response and damage. Second, once damage occurs, the structure behaves nonlinearly, and response is no longer easily tractable through acceleration. Accordingly, ultimate capacity is more appropriately gauged with displacement.

Risk Evaluation and Hazard Reduction

Risk evaluation implies determination of the probability of experiencing loss from some given hazard. Hazard reduction implies establishing ways and means for reducing or mitigating the loss. The processes involved in hazard reduction are, in general, similar to the process of optimization.

Figure 9 is an example of one possible optimization (or hazard reduction) scheme for earthquake-resistant design of structures. In this example, the risk mitigation scheme is to alter the structure capacity. Another risk mitigation scheme is to locate the structure at a site with a lower earthquake hazard.

Hazard reduction is most effectively achieved through the structure design process. The ability to distinguish quantitatively between the effects of one

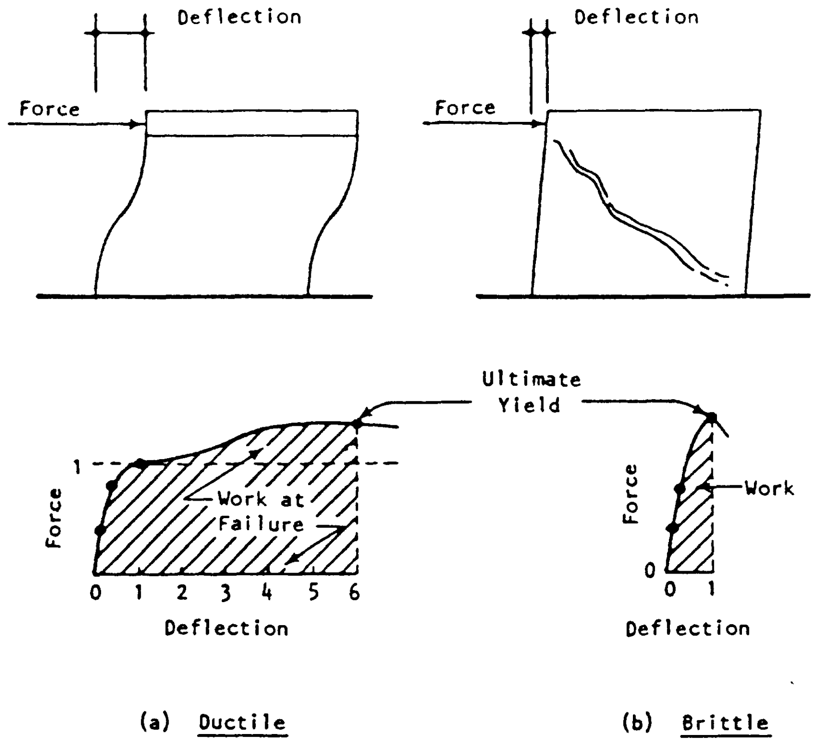

Figure 7--Building material failure characteristics (from URS/John A. Blume & Associates, Engineers, 1975)

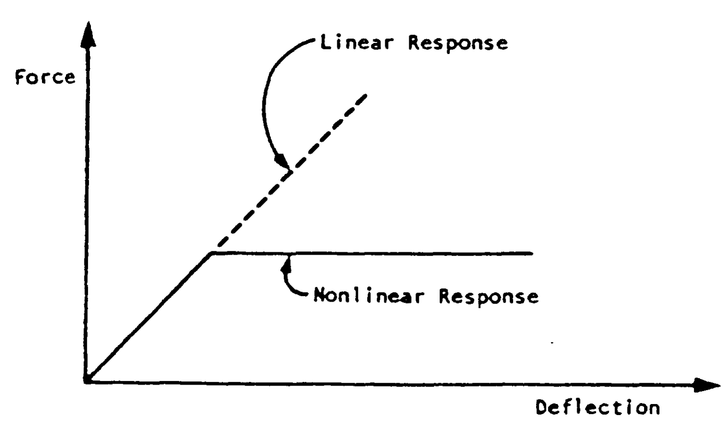

Figure 8--Example bilinear force-deflection curve

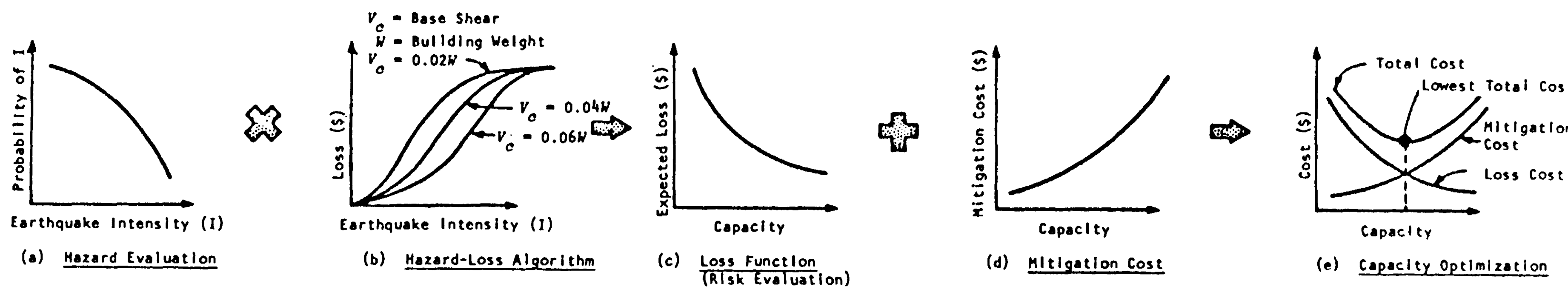

Figure 9-- Earthquake-resistant design optimization

earthquake hazard and another is included in the process. Accordingly, loss evaluations based on the principles of dynamic structure analysis and design are the most expedient means for achieving earthquake hazard reduction.

Timing

The time of day and the time of year an earthquake occurs are significant for earthquake damage prediction. Although the time of day during which a major earthquake strikes has little effect on damage per se, it can affect the number of persons injured or killed. In the western United States, it is generally expected that life loss would be greater for an earthquake that occurs during business hours than for one that occurs during nonbusiness hours. This is simply because during nonbusiness hours a greater percentage of the affected population will be in wood-frame homes, which are generally expected to be more resistant to earthquakes than are typical commercial buildings. Recent earthquakes in other countries have not shown this to be true in all cases, however.

The time of year a major earthquake occurs affects both potential damage and life loss because of changes in climatic conditions. Foundation and soil failures (particularly landslides) are much more likely if an earthquake occurs when the ground is saturated than when the ground is dry.

REVIEW OF AVAILABLE PROCEDURES

Methodologies for predicting damage to structures due to ground vibrations have been developed by various investigators.

A methodology for estimating earthquake-induced economic losses to wood-frame dwellings in California was developed by a team led by Steinbrugge, McClure, and Snow (1969) to aid in analyzing the feasibility and effectiveness of earthquake insurance. This method uses the Modified Mercalli Intensity (MMI) scale to describe the intensity of ground motion. For a given earthquake, such as the maximum credible earthquake, empirical isoseismal maps are developed. These maps consider the rupture of the fault (hence, the ellipticity of the isoseismals) and the empirical relationship between magnitude and MMI. Empirical data are used to determine the area enclosed within a given MMI isoseismal line as a function of magnitude. Because MMI is used to represent the ground motion intensity and because MMI is directly related to damage, no structural response calculation is done.

Damage to wood-frame dwellings is estimated by four components: structure, interior finish, exterior finish, and chimney. These damage components are further subdivided to account for major variations within each component, such as age of dwellings. For each damage component, the degree of damage is described by such terms as slight, moderate, severe, and total loss.

The relationship of MMI to the degree of component damage is estimated by professionals and improved using the available data. These MMI-damage relationships are converted into relationships of MMI to repair cost, also estimated by professionals.

To predict losses to wood-frame dwellings within a region, the region under consideration is divided into standard location areas (SLAs). For a given earthquake, MMI is estimated for each SLA. Then losses for each SLA are calculated by using the MMI-loss relationships. Characteristics of the structure population within each SLA (inventory data) are derived mainly from data from the United States Bureau of the Census.

The method is a good one for the type of buildings for which it is intended. The sources of information identified are of great value for similar future studies. However, the method requires a great deal of expertise that can only be provided by experienced professionals from such diverse fields as engineering, statistics, and insurance. Also, the method cannot be applied to other types of structures without extensive modifications.

Studies have been performed to improve the above method and to apply it to other types of structures. Rinehart et al. (1976) have performed a sensitivity analysis to determine the relative significance of various parameters considered in the method with respect to losses. This analysis has led to improvements in the method.

Algermissen et al. (1978a) extended the previous work to cover buildings other than single-family dwellings. In their study, a building inventory methodology was formally introduced. A building classification, not necessarily related to engineering design parameters, was adopted from the Insurance Services Office (ISO) system and used in the method.

On the basis of their previous work, Algermissen et al. (1978b) developed a technique for rapid estimation of earthquake losses. This method entails development of a series of maps showing contours of the percentage of losses for specific building types at each MMI level. The method could be valuable for quick postearthquake loss estimates; however, the necessary data must be collected and processed before an earthquake occurs, and experts with specific understanding of the method must be available.

Culver et al. (1975) describe another method for surveying and evaluating existing buildings to determine the risk to life and to estimate the amount of expected damage. In their method, damage to both structural and nonstructural building components resulting from extreme natural hazards such as earthquakes, hurricanes, and tornadoes is considered. The method can treat a large class of structural types, including braced and unbraced steel frames, concrete frames with and without shear walls, bearing-wall structures, and long-span roof structues.

Culver et al. include three independent but related sets of procedures for estimating damage for each of the natural hazards. The first set of procedures (the Field Evaluation Method) provides a means for qualitatively determining the damage level on the basis of data collected in field surveys. The second set (the Approximate Analytical Evaluation Method) uses a structural analysis of the building to determine the damage level as a function of the behavior of critical elements. The third set (the Detailed Analytical Evaluation Method) is based on a computer analysis of the entire structure. The procedures are presented in a format that allows updating and refining.

The Field Evaluation Method and the Approximate Analytical Evaluation Method do not estimate the extent of damage quantitatively. In the Detailed

Analytical Evaluation Method, the ground motion at a site is expressed in terms of a site particle-velocity spectrum, which is obtained by multiplying a hard-rock velocity spectrum by an appropriate soil amplification factor. Alternative procedures are described for obtaining the hard-rock velocity spectrum and the soil amplification factor for a given site.

A response spectrum approach with provisions for amplitude-dependent damping and stiffness characteristics is suggested for calculating the structure's response to the prescribed ground motion. The response parameters used in predicting damage are maximum floor accelerations, floor velocities, and interstory displacements. Three types of damage, namely, structural, nonstructural partition, and nonstructural window damage, are related to these parameters. Structural damage and window damage are assumed to be functions of interstory drift, whereas nonstructural partition damage is assumed to be related to the maximum floor velocity and acceleration.

The relationship between the percentage of structural damage at a given story level and the maximum drift at that level is assumed to be a normally distributed curve defined by a mean ductility to failure and an associated coefficient of variation. Ductility to failure is determined empirically, and professional judgement is exercised in selecting the proper coefficient of variation.

Nonstructural damage at a floor level is estimated by treating that level as a site on the ground subjected to an effective floor MMI, I_i, which is empirically related to maximum floor acceleration and velocity. The relationship between I_i and the percentage of nonstructural damage to the floor is also given by an empirical formula, which includes a parameter called *quality factor*, reflecting the damageability of the specific construction type. The relationship of story drift to glass damage is treated much like structural damage, with a defined drift-to-failure value, an associated coefficient of variation, and assumed normal distribution.

The method described by Culver et al. attempts to relate engineering parameters to the extent of damage suffered by the components of a given structure. However, damage is expressed in percentage only and is not related to monetary loss.

An extensive program, led by Whitman, Biggs, Cornell, and Vanmarcke, has been undertaken at Massachusetts Institute of Technology (MIT) to develop a method titled Optimum Seismic Protection and Building Damage Statistics. The title was later changed (Whitman, 1973) to Seismic Design Decision Analysis (SDDA).

To select the level of seismic resistance to be required for an individual structure or a group of structures, the SDDA considers (1) the cost of providing increased seismic resistance, (2) the damage that may occur during future earthquakes, and (3) the human and social consequences of such damage.

Many studies have been performed and reports published as part of the SDDA program. A description of the program as originally conceived is given in Report No. 1 (Whitman et al., 1972). Theoretical structure response studies are described in Reports No. 3 and No. 4 (Anagnostopoulos, 1972; Biggs and Grace, 1973). Damage data and statistics obtained from the 1971 San Fernando, California, earthquake are given in Report No. 7 (Whitman et al., 1973). Report No. 8, by Whitman (1973), gives damage probability matrices for multistory buildings. Two reports attempt to correlate earthquake damage to tall buildings with strong ground motion parameters (Wong, 1975; Whitman et al., 1977). In Report No. 30, Schumacker and Whitman (1977) apply the methods developed to the estimation of losses to cities and regions.

Czarnecki (1973) has developed a damage prediction method, as part of MIT's SDDA program, that is based on engineering principles and is oriented toward high-rise buildings. In this method, the damage is related to the structural response parameters. The building can be analyzed for a given earthquake using any acceptable dynamic analysis technique, such as response spectrum analysis or linear or nonlinear time-history analysis. Total damage to a given building is classified into components. Components suggested for high-rise buildings are structural damage (damage to steel frames, concrete frames, braced frames, shear walls), nonstructural damage (damage to drywall partitions, exterior glazing, brick masonry walls, concrete block walls), and other damage. Structural damage is fully attributed to the vertical structural elements (e.g., columns and shear walls) and is assumed to be proportional to the inelastic energy absorbed by those elements.

Nonstructural damage is associated with maximum interstory drift. Drift-damage curves are developed on the bases of actual data and engineering design practices. No attempt is made to consider the variabilities of the parameters used in the damage prediction or of the final results.

The three distinct methods developed by Blume for predicting damage to structures due to large underground nuclear explosions are equally applicable to predicting damage due to earthquakes. These three methods -- the Engineering Intensity Scale (EIS) method, the Spectral Matrix Method (SMM), and the Threshold Evaluation Method (TEM) -- provide a means for making progressively more detailed predictions of structural effects due to seismic motions.

The EIS method (Blume, 1970) is used to estimate the extent of the area in which structures might be damaged and to make a general evaluation of the incidence and degree of damage to structures within that area. In the formulation of the EIS, ground motion is characterized by 5%-damped spectral velocity (S_v), and structures are characterized by their fundamental-mode vibration properties. Neglecting mode shape considerations, the important correlation variables for relating motion and damage are S_v amplitude and building period. The 5%-damping value is used because damping in many real structures varies from about 2% to 10%, and 5% has been made a standard reference level in the nuclear event structural response program conducted by URS/John A. Blume & Associates, Engineers (URS/Blume), for the Nevada Operations Office of the U.S. Department of Energy.

Engineering intensity (EI) numbers are assigned to various spectral velocity bands. The range of spectral velocities (S_v) and periods (T) applicable to civil engineering structures is divided into a 10 by 9 matrix with ten intensity levels, from 0 through 9, and nine period bands, I through IX, which range from 0.01 sec to 10 sec.

A significant amount of data on ground motion caused by underground nuclear explosions and corresponding damage data have been available for establishing the incidence and degree of damage for various EI ranges for low-rise buildings (Hafen and Kintzer, 1977; URS/Blume, 1975). In addition, motion and damage data from the 1971 San Fernando earthquake for low-rise (Hafen and Kintzer, 1977; Scholl, 1974) and high-rise (Hafen and Kintzer, 1977; Wong, 1975) buildings are available. Motion-damage relationship information for high-rise buildings from Whitman et al. (1977) and the additional correlation work currently in progress at URS/Blume will provide sufficient information for this class of buildings.

The SMM has been in continuous development and use by URS/Blume (or John A. Blume & Associates, Engineers) since 1966. The earliest version was presented in January 1967 (Blume, 1967). The method has subsequently been simplified and further developed (Blume, 1968; Blume and Monroe, 1971; URS/Blume, 1975). The method is based on observed data and theoretical considerations and is applicable to both high-rise and low-rise structures. The SMM uses physical and engineering characteristics of structures and ground motion spectra, including their variabilities, in relating ground motion to structural response and damage. Because of this characteristic, the SMM has potential for further development and application to a variety of structures. A detailed description of the SMM is given in a later section of this paper.

The TEM (Blume, 1969), which is used for predicting the effects of dynamic ground motion on structures, involves a systematic and detailed dynamic structural analysis of individual structures. This method is used to identify both the potential risk from a structure's failure caused by ground motion and modifications that might improve the resistance of that structure to failure. Basically, the TEM is an extension of conventional structural analysis procedures used in design. It requires the identification of various capacity thresholds and the evaluation of the probability of exceeding the thresholds for a given seismic event. It is intended to provide detailed insight into the structural behavior of an individual building under lateral loading and to take advantage of several mitigating factors that are normally ignored in structural design practice in the interest of providing additional, but realistic, margins of safety.

A fundamental step in conducting a threshold evaluation analysis is to develop a mathematical model of the building. Because the TEM considers both elastic and inelastic response, it is usually desirable to develop at least two mathematical models. The frequencies and mode shapes obtained from the mathematical models are used to estimate the response spectrum demand amplitude.

A capacity threshold is defined as the total lateral load that would be required to cause a building to reach a specified level of behavior. For example, a code-required threshold is the base shear coefficient required by an applicable building code. Similarly, a yield limit threshold is the smallest base shear coefficient causing a significant structural member to reach yield stress.

With this information, the probability of exceeding the various capacity thresholds for a particular seismic response spectrum can be evaluated. The significance of a high probability of exceedance depends on the threshold and the severity of the demand spectra being considered. For example, a high probability of exceeding the yield limit or observable damage threshold for a seismic event that is likely to occur several times during the building's useful life may be an unacceptably high risk. However, for the maximum credible seismic event, it may be acceptable to exceed all thresholds except story failure or collapse.

EXAMPLE LOSS EVALUATION METHODOLOGY

General Earthquake Loss Prediction Methodology for an Urban Area

Prediction of losses to an urban area from an earthquake involves a series of complex procedures with many steps requiring extensive computations and data handling. Accordingly, a systematic approach is necessary in which all significant procedures are identified and sequenced and all the necessary information described.

Figure 10 is a flowchart that shows the major procedures requiring well-defined methodologies for systematic prediction of losses to a city or to a designated urban area from an earthquake. These procedures are:

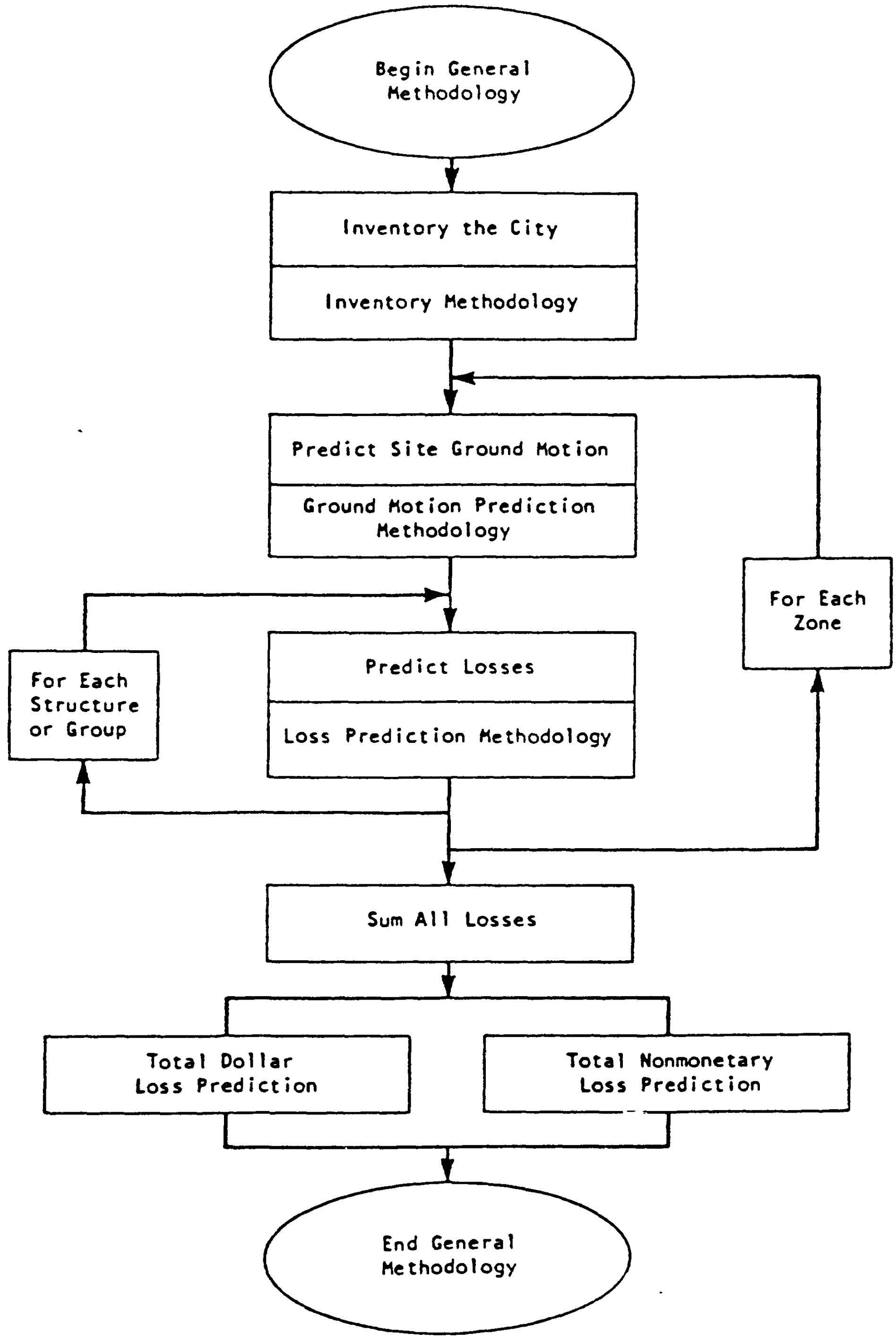

Figure 10--General earthquake loss prediction methodology for a city

1. Zoning the city and classifying and takintg an inventory of structures within each zone (inventory methodology)

2. Predicting the ground motion parameters for each zone (ground motion prediction methodology)

3. Predicting losses for individual structures and groups of structures (loss prediction methodology)

4. Summing losses from all structures and zones for the prediction of losses to the city

The methodologies for accomplishing procedures 1 through 3 are described below. The loss prediction methodology (procedure 3) can be established from empirical or theoretical considerations; the discussion provided below can accommodate either. The development of a theoretically based loss prediction algorithm, the Spectral Matrix Method, is presented in a later section.

Inventory Methodology. Cities are made up of many different types of structures. Even if it were possible to accurately predict losses that might be incurred by each structure, it would be an enormous taks to come up with a citywide prediction. Therefore, the first step in the procedure is to divide the city (if it is so large or if the assumed earthquake is so close that the ground motion would vary substantially within the city) into zones for which the ground motion is defined. Then the structures in each zone can be classified into general groups. An example of extensive classification was given in Table 1. In general, conventional structures, such as low-rise, wood-frame residential houses or high-rise office buildings, can be classified so that, for each class, average structural characteristics can be estimated. Special structures, such as power stations, dams, and lifelines, might have to be studied individually to determine their characteristics. The next step is to inventory each classification to determine the number of structures in each class and their replacement values.

Figure 11 is a schematic description of the inventory methodology.

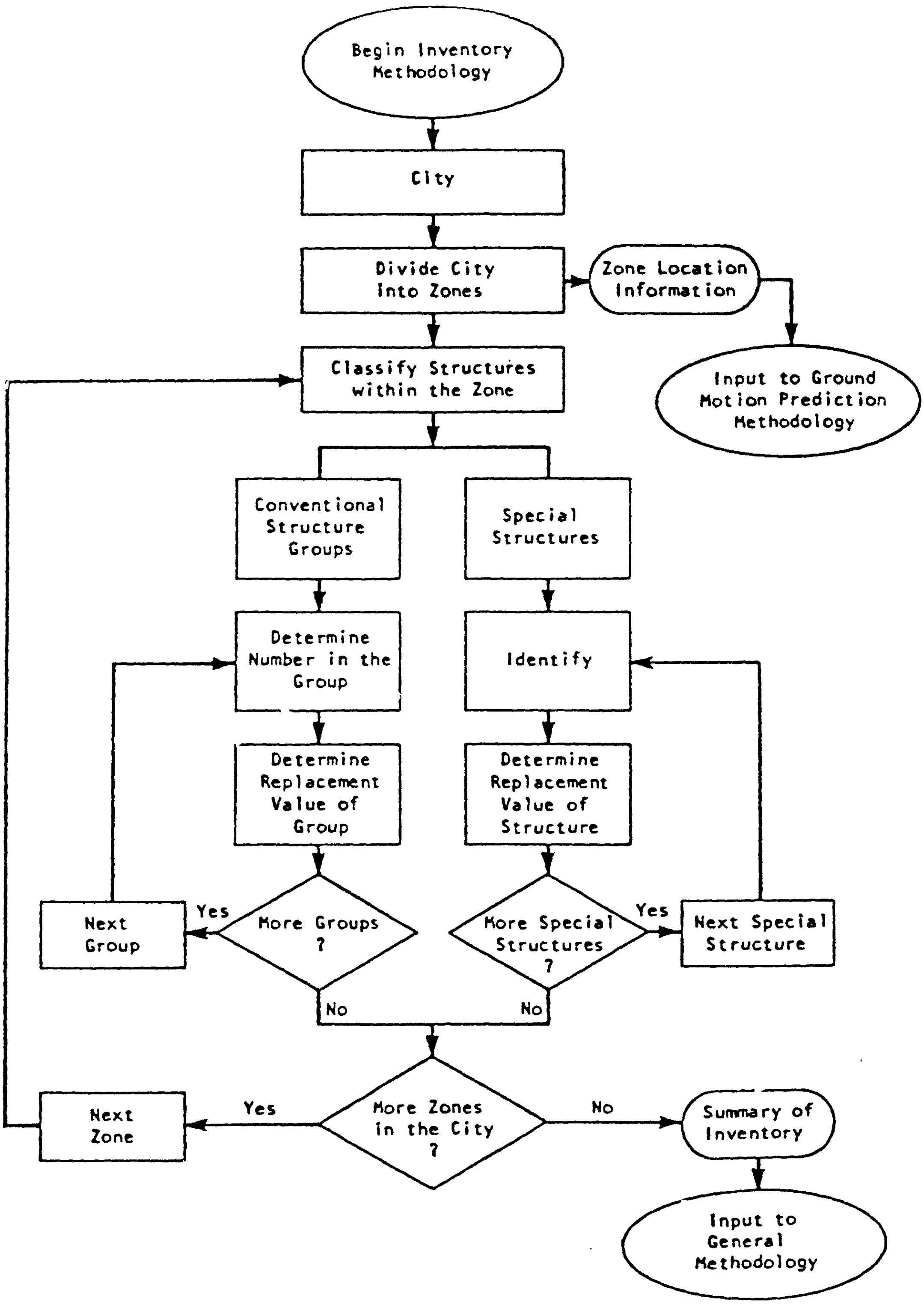

Figure 11--Inventory methodology

Ground Motion Prediction Methodology. Methods exist for estimating the characteristics of a maximum credible earthquake in regions where earthquake sources and mechanisms have been studied and are understood. Methods also exist for estimating the ground motion characteristics at a site due to a given earthquake with defined magnitude and source. Ground motion characteristics at a site can be described in terms of several parameters, such as:

- Peak values of ground accleration, velocity, or displacement
- Response spectra for acceleration, velocity, or displacement
- Intensity scales, such as the MMI scale or the EIS

Therefore, for an earthquake described by its magnitude, epicenter location, and depth, the ground motion parameters at a site some distance away with known local soil conditions can be estimated using state-of-the-art technology.

Figure 12, which presents a method for predicting site ground motion characteristics, shows how ground motion prediction is related to the general loss prediction methodology. The loss prediction procedure is independent of the ground motion prediction procedure; therefore, any of the available ground motion prediction procedures can be used.

Loss Prediction Methodology for a Structure or a Group of Structures. Earthquake losses for a given structure, or for a group of structures with common characteristics, can be estimated by following the procedure shown as a flow-chart in Figure 13.

The characteristics of two elements are needed as input to this process:

- Earthquake ground motion at the site
- Structure, contents, use, and occupancy

Different structures respond to the same ground motion differently. Sometimes, even apparently similar structures may respond to the same ground motion differently. The response of a structure to a given earthquake is a

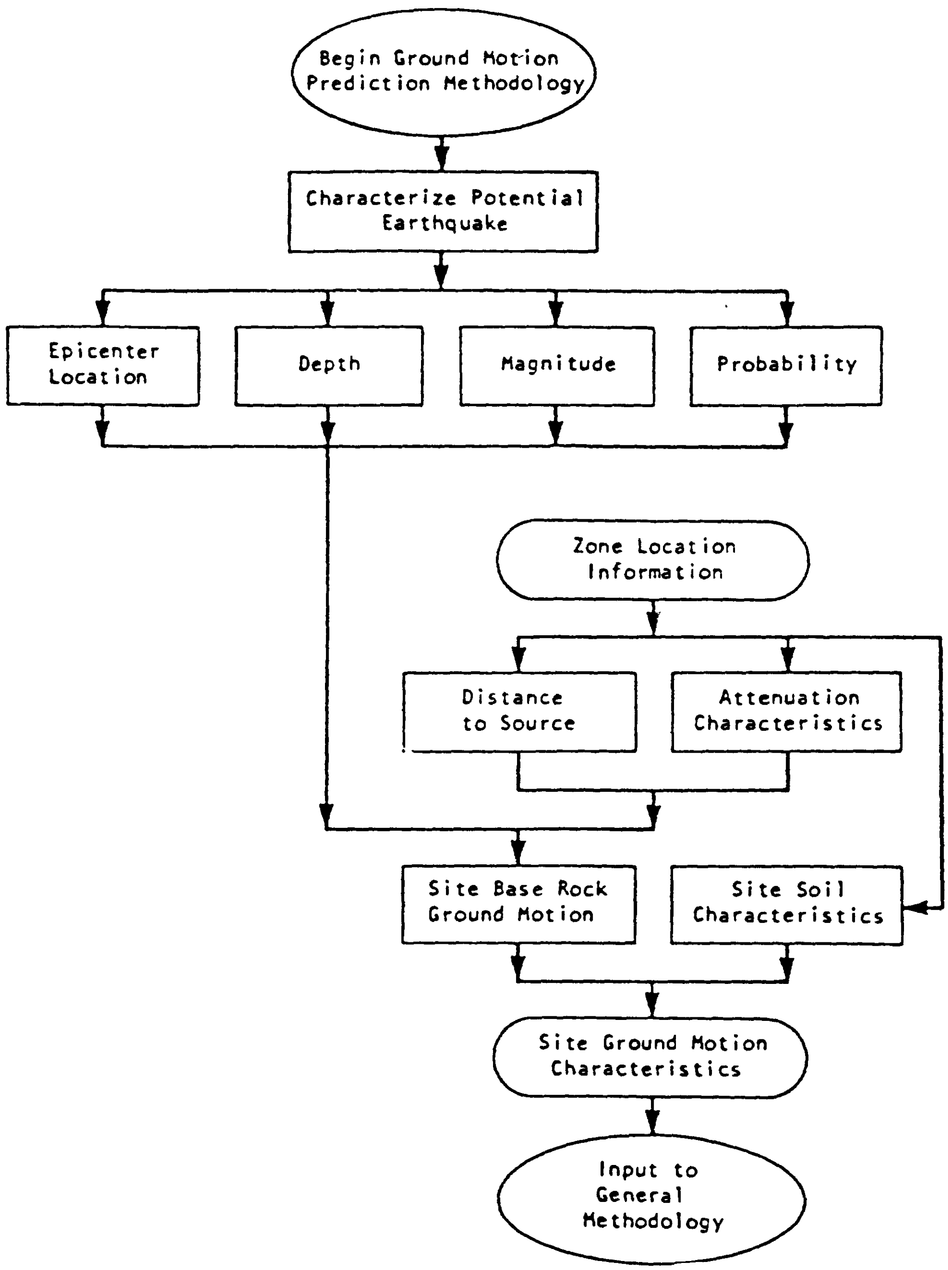

Figure 12--Site ground motion prediction methodology

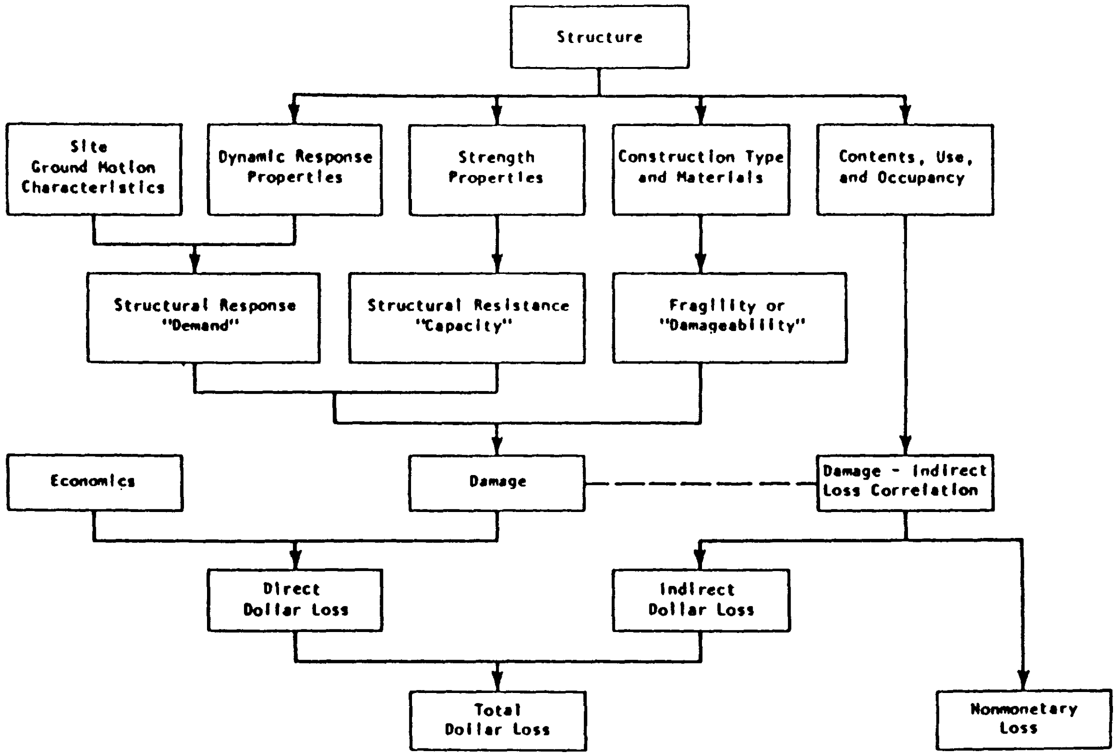

Figure 13--Loss prediction methodology for a structure or group of structures

function of the structure's dynamic response properties as well as the characteristics of the ground motion. The significant parameters that determine the response of a structure to a certain ground motion are:

- Mass of the structure and its distribution
- Stiffness of the structure and its distribution
- Damping capacity of the structure
- Interaction between the structure and the soil at the foundation

The maximum response that a ground motion would generate in a structure is the *demand* on that structure by the earthquake.

Structures are constructed of various materials and are designed to accommodate certain design loads. Each structure has a limit beyond which it cannot resist any higher loads; if forced further, it fails or suffers large deformations. Therefore, the resistance of a structure to earthquake loads it its *capacity*. It is convenient to express capacity and demand in terms of the same parameters and units. This can be done simply and with reasonable accuracy for most structures.

Damage that can be induced in a structure is a function of how large a demand is being made on the structure relative to its capacity. Damage is also a function of the construction type and materials. Some structures are ductile and can deform without suffering much damage, whereas others are brittle and can suffer extensive damage with little deformation. This property of structures can be expressed in terms of a functional relationship that may be called damage funtion, fragility, or *damageability*.

Earthquake demand on the structure, the structure's capacity to resist, and its damageability determine how much physical damage may be incurred by the structure. The next two significant steps are to convert the damage into monetary losses and to determine the other possible effects of the damage.

The dollar value of the damage suffered by the structure can be estimated with relative ease, especially for certain types of structures for which data exist from past earthquake experiences. Damage is usually expressed in terms of a *damage factor*, which is the ratio of the estimated value of repairs to the replacement value of the total structure. Therefore, the direct dollar loss is obtained simply by multiplying the damage factor with the replacement value of the structure.

THE THEORETICAL DAMAGE FACTOR MODEL OF THE SPECTRAL MATRIX METHOD

General Considerations

The SMM was conceived as an orderly, standardized procedure for predicting damage to structures subjected to phenomena such as underground nuclear explosions, air blasts, earthquakes, tornadoes, hurricanes, and floods. While the SMM makes a number of contributions to damage prediction technology, its principal feature is its theoretical damage factor model. Initially proposed by Blume (1967), the model has been under continuous development by URS/Blume since 1966 (e.g., Blume, 1968; Blume and Monroe, 1971; URS/Blume, 1975; and Blume, School, and Lum, 1977).

Fundamental principles of the SMM are that the ground motion demand, D, imposed on a structure and the damage-resisting capacity, C, of that structure can be identified by response spectrum values. These relationships are readily established by identifying demand and capacity in terms of base shear (URS/Blume, 1975).

Experimental observation of both ground motion and structure damage has revealed that both demand and capacity are random variables, and damage prediction therefore becomes a problem of joint probabilities. From observation of ground motion induced by underground nuclear explosions, demand variability appears to be best defined by the lognormal probability density function. From observation of failure testing for individual structure elements (Blume, 1967) and from preliminary correlation of theoretical and experimental motion-damage relationships for structures (URS/Blume, 1975), the Weibull probability density function appears to define the variability of capacity well.

Theoretical Development of the Model

The defining damage factor relationship between demand and capacity equates the energy absorbed by the inelastic capacity with an assumed equivalent elastic model. The basic assumption is that the amount of energy absorbed by an individual structure is independent of whether the building responds elastically or inelastically (Blume, 1960; Blume and Monroe, 1971). This relationship is shown in Figure 14.

For the elastic demand model:

$$E = \frac{1}{2}\frac{V_e^2}{K} \tag{5}$$

For the inelastic capicity model:

$$E = \frac{1}{2}\frac{V_y^2}{K} + \left(\frac{V + V_y}{2}\right)(\Delta - \Delta_y) \tag{6}$$

but

$$V = K\Delta_y + (\Delta - \Delta_y)\xi K$$

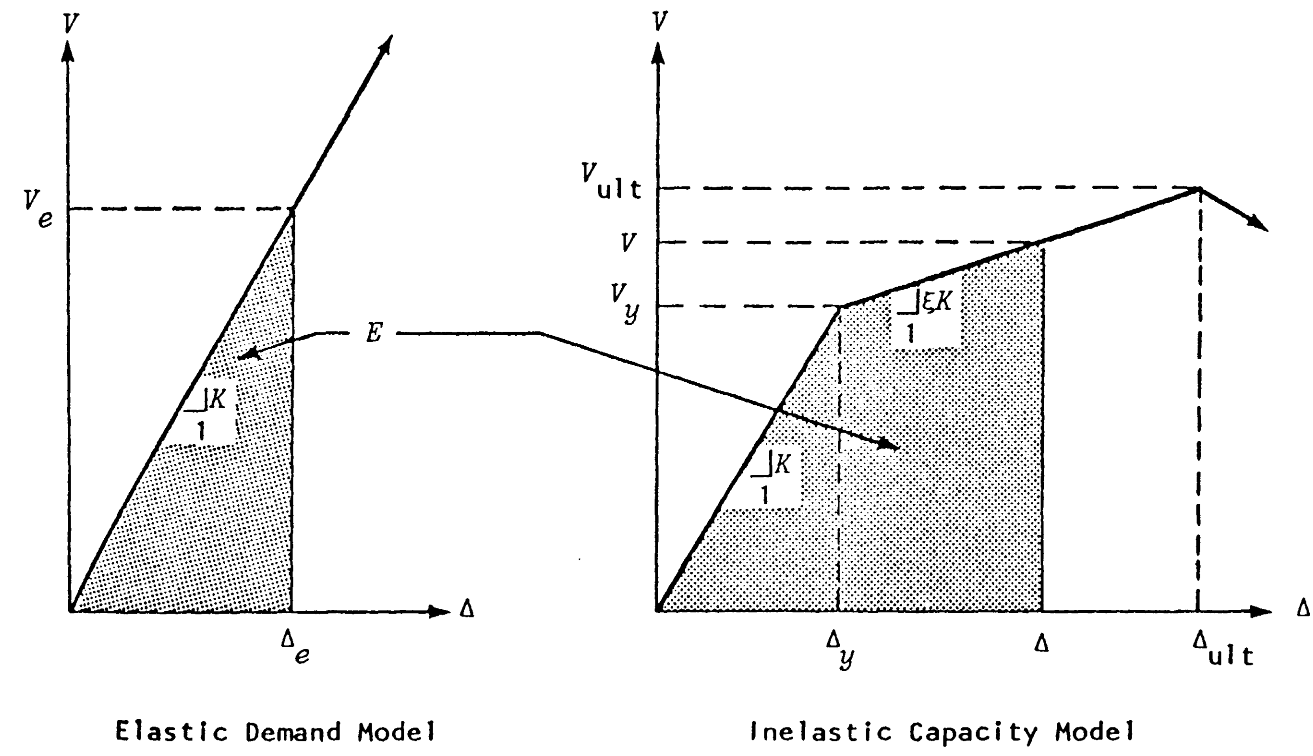

Figure 14--Demand and capacity energy models (from URS/John A. Blume & Associates, Engineers, 1975)

and $$\mu = \Delta/\Delta_y$$

Therefore:

$$E = \frac{1}{2}\frac{V_y^2}{K}\left[2(\mu - 1) + (\mu - 1)^2 \xi + 1\right] \tag{7}$$

By equating Equations (5) and (7), an expression for ductility, μ, can then be obtained:

$$\mu = 1 - \frac{1}{\xi} + \sqrt{\frac{1}{\xi}\left[\frac{1}{\xi} + \left(\frac{V_e}{V_y}\right)^2 - 1\right]} \tag{8}$$

where ξ is the bilinear parameter as shown in Figure 14 and V_e/V_y is the ratio of demand over capacity, D/C.

Note that for the elastoplastic case ξ is equal to 0. If one substitutes $\xi = 0$ into Equation (8), numerical solution problems will be encountered. Therefore, derivation of ductility, μ, for the case of $\xi = 0$ is warranted.

The derivation is presented in Blume, Scholl, and Lum (1977). The result shows that for the elastoplastic case:

$$\mu = \frac{1}{2}\left[\left(\frac{V_e}{V_y}\right)^2 - 1\right] + 1 \tag{9}$$

Damage factor is defined as the ratio of dollar damage for a building to the building's replacement value. In the SMM, it is also defined as a function of ductility:

$$DF = \frac{\text{repair cost}}{\text{replacement cost}} = \left(\frac{\mu - 1}{\mu_{ult} - 1}\right)^{\kappa} \tag{10}$$

where κ is an economic scale factor and μ_{ult} is the ultimate ductility.

Substituting Equation (8) into Equation (10) and substituting D/C for V_e/V_y, the formal definition of damage factor is:

$$DF = 0$$

if $D/C < 1$

$$DF = \left[\frac{\sqrt{1 + \xi\left[\left(\frac{D}{C}\right)^2 - 1\right]} - 1}{\xi(\mu_{ult} - 1)}\right]^{\kappa} \tag{11}$$

if $1 \leq D/C \leq \sqrt{2\mu_{ult} - 1 + \xi(\mu_{ult} - 1)^2}$

$$DF = 1$$

if $D/C > \sqrt{2\mu_{ult} - 1 + \xi(\mu_{ult} - 1)^2}$

For the elastoplastic condition -- a special case -- damage factor is obtained by substituting Equation (9) into Equation (10):

$$\begin{aligned} DF &= 0 && \text{if } D/C < 1 \\ DF &= \left[\frac{\frac{1}{2}\left[\left(\frac{D}{C}\right)^2 - 1\right]}{\mu_{ult} - 1}\right]^{\kappa} && \text{if } 1 \leq D/C \leq \sqrt{2\mu_{ult} - 1} \\ DF &= 1 && \text{if } D/C > \sqrt{2\mu_{ult} - 1} \end{aligned} \tag{12}$$

Demand, D, and capacity, C, are considered to be random variables defined by appropriate probability density functions. The lognormal probability of demand, D, is defined by:

$$p_D(d) = \frac{1}{\sqrt{2\pi}\, d \ln(N)}\, e^{-\frac{1}{2}\left[\frac{1}{\ln(N)} \ln\left(\frac{d}{\check{D}}\right)\right]^2} \qquad d > 0 \tag{13}$$

where:

$\breve{D}$ = median demand value
N = geometric standard deviation
d = known value of demand
D = demand (as a random variable)
ln = log with base e

Figure 15 shows example demand lognormal probability density functions.

The Weibull probability of capacity, C, is defined as:

$$p_C(c) = \frac{k}{u}\left(\frac{c - \varepsilon}{u}\right)^{k-1} e^{-\left(\frac{c-\varepsilon}{u}\right)^k} \qquad c > \varepsilon \tag{14}$$

where:

$$\bar{C} = \varepsilon + u\Gamma\left(1 + \frac{1}{k}\right)$$

$$V_C = \frac{u}{\bar{C}}\sqrt{\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)}$$

$\Gamma(\ )$ = the gamma function
c = known value of capacity
C = capacity (as a random variable)

Figure 16 shows example capacity Weibull probability density functions.

Using the standard procedure for computing the expectation of a function of a random variable (Benjamin and Cornell, 1970), the general expressions for mean, m_{DF}, and mean square, $E(DF^2)$, of the damage factor are:

$$m_{DF} = \int_1^{\lim} p_{D/C}(x)\left[\frac{\sqrt{1 + \xi(x^2 - 1)} - 1}{\xi(\mu_{ult} - 1)}\right]^{\kappa} dx + \int_{\lim}^{\infty} p_{D/C}(x)\,dx \tag{15}$$

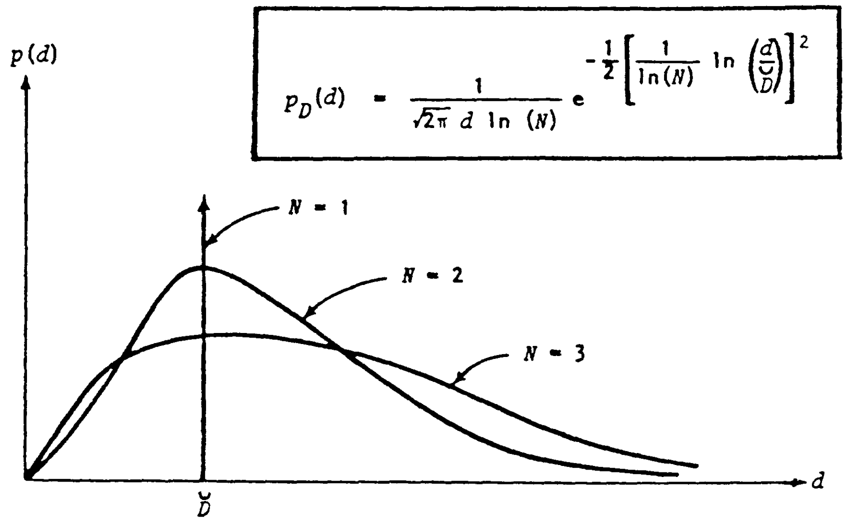

Figure 15--Example demand lognormal probability density functions (from URS/John A. Blume & Associates, Engineers, 1975)

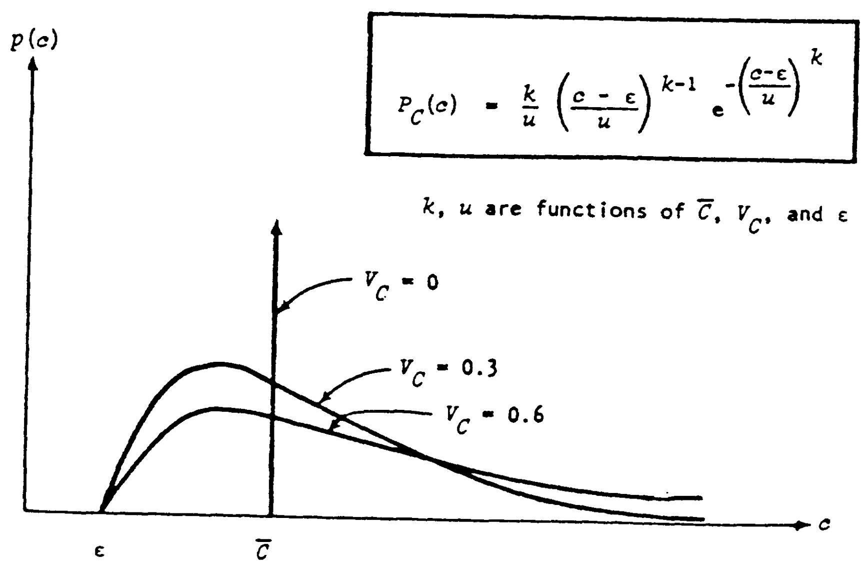

Figure 16--Example capacity Weibull probability density functions (from URS/John A. Blume & Associates, Engineers, 1975)

$$E(DF^2) = \int_1^{\lim} p_{D/C}(x) \left[\frac{\sqrt{1 + \xi(x^2 - 1)} - 1}{\xi(\mu_{ult} - 1)} \right]^{2\kappa} dx + \int_{\lim}^{\infty} p_{D/C}(x)\, dx \qquad (16)$$

where:

$$\lim = \sqrt{2\mu_{ult} - 1 + \xi(\mu_{ult} - 1)^2}$$

$p_{D/C}(x)$ = probability density function of d/c equal to x

These expressions for m_{DF} and $E(DF^2)$ are derived in URS/Blume (1975).

The function $p_{D/C}(x)$ is the probability density functions of the quotient D/C, which is derived to be:

$$p_{D/C}(x) = \int_{-\infty}^{\infty} |c| p_{D,C}(xc,c)\, dc \qquad (17)$$

where:

$p_{D,C}(xc,c)$ = joint probability density for demand and capacity

x = specified value of d/c

It is reasonable to assume that demand and capacity are independent, which allows $p_{D,C}(d,c)$ to be factored as follows:

$$p_{D,C}(d,c) = p_D(d)p_C(c) \qquad (18)$$

Combining Equations (17) and (18), and using the definitions for $p_D(d)$ and $p_C(c)$ given by Equations (13) and (14), $p_{D/C}(x)$ is expressed as follows:

$$p_{D/C}(x) = \frac{k\int_{\varepsilon}^{\infty}\left(\frac{c-\varepsilon}{u}\right)^{k-1} e^{-\left\{\left(\frac{c-\varepsilon}{u}\right)^{k}+\frac{1}{2}\left[\frac{1}{\ln(N)}\ln\left(\frac{xc}{\breve{D}}\right)\right]^{2}\right\}} dc}{\sqrt{2\pi}\, xu \ln(N)} \tag{19}$$

Equation (19) is derived when probabilities of both demand and capacity are uncertain. However, when capacity is certain; that is, when

$$\int_{-\infty}^{\infty} P_c(c)dc = 1$$

then:

$$p_{D/C}(x) = \frac{1}{\sqrt{2\pi}\, x \ln(N)} e^{-\frac{1}{2}\left[\frac{1}{\ln(N)}\ln\left(\frac{x\bar{C}}{\breve{D}}\right)\right]^{2}} \tag{20}$$

and when demand is certain:

$$p_{D/C}(x) = \frac{D}{x^2}\frac{k}{u}\left(\frac{\frac{\breve{D}}{x}-\varepsilon}{u}\right)^{k-1} e^{-\left(\frac{\frac{\breve{D}}{x}-\varepsilon}{u}\right)^{k}} \tag{21}$$

The detailed derivations of Equations (19), (20), and (21) are presented in Blume, Scholl, and Lum (1977).

Values for m_{DF} and $E(DF^2)$ can be obtained by numerical integration using Equations (15) and (16) with the expression for $p_{D/C}(x)$ given above. Finally, the standard deviation of the damage factor, σ_{DF}, is obtained from the standard relationship:

$$\sigma_{DF} = \sqrt{E(DF^2) - m_{DF}^2} \tag{22}$$

From the derivations of mean and standard deviation of damage factors, it can be seen that several parameters have been introduced that distinguish various structure types for predictions. These structure-based parameters are included in the theoretical damage factor model to take best advantage of available structure-element test data and thus to facilitate application of the procedure to predictions involving structures for which no empirical data on motion-damage relationships exist. Specifically, these parameters are: ultimate ductility, μ_{ult}; mean capacity, $\bar{C}$; lower bound on damage, ϵ; coefficient of variation of capacity, V_C; bilinear parameter, ξ; and economic scale factor, κ. A detailed discussion of the ranges of these parameters for three important classes of structures -- high-rise, low-rise, and light industrial buildings -- is given in Blume, Scholl, and Lum (1977).

SMM Calibration for Low-Rise Buildings

Substantial empirical data pertaining to damage to low-rise, wood-frame buildings caused by ground motion have been documented in the past decade. (See, for example, Figure 5.)

Figure 17 shows example mean and standard deviation damage factor curves for low-rise buildings. Rather than plotting the damage statistics as functions of the median demand, $\check{D}$, the normalized variable $D/\bar{C}$ is used. The mean and standard deviation damage factor curves for different values of the demand geometric standard deviation are plotted. The curves for N equal to 1 correspond to the situation where demand is known with certainty. Also shown are empirically derived data points. These points confirm the reasonableness of the N-equal-to-1 curve. The curves for values of N greater than 1 are for the more typical situation in which the ground motion demand is uncertain.

SUMMARY OF RESEARCH NEEDS

Methodologies proposed by various investigators for estimating earthquake losses have been briefly described in this paper. These methodologies have contributed significantly to earthquake loss prediction technology; however, none can be regarded as comprehensive because none provide sufficient detail to facilitate making changes to important structures based on engineering characteristics of ground motion that affect damage and because none can be used in comparing and selecting design strategies. Loss prediction procedures

Factor, σ_{DF}

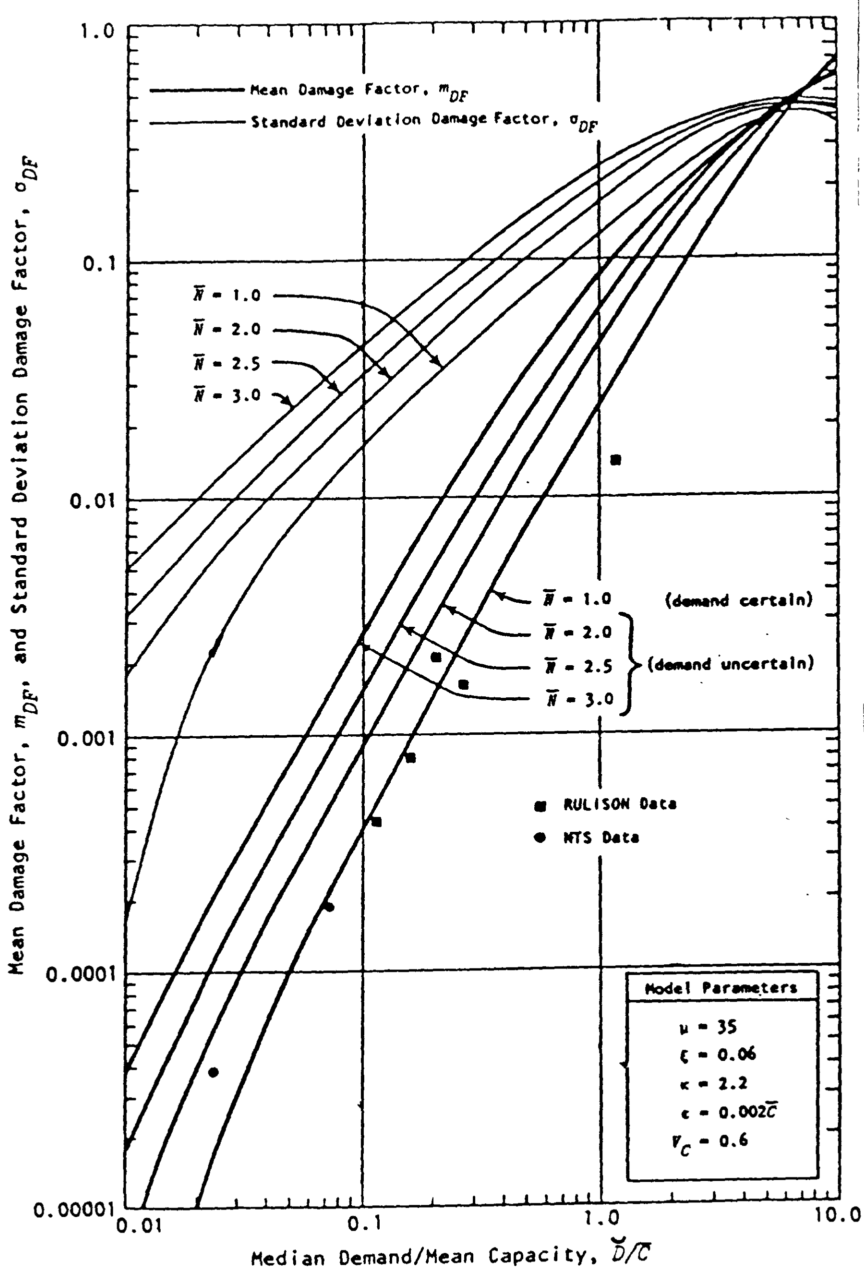

Figure 17--Mean and standard deviation damage factor relationships for individual low-rise buildings (from URS/John A. Blume & Associates, Engineers, 1975)

must be comprehensible and useful to the structure designer to facilitate earthquake hazard reduction.

Loss prediction procedures proposed to date that do consider all structures are so general that it is difficult, if not impossible, for all but their authors to make the changes necessary to account for updated seismic design criteria and industry technology developments. For example, new freeway bridges built according to updated seismic design criteria will likely not experience as much damage as the older bridges that were affected by the 1971 San Fernando earthquakes. Therefore, a need exists for comprehensive loss prediction methodologies that are based on engineering analysis and design principles and that incorporate structure and ground motion parameters commonly used in design. These methodologies should be applicable to all types of structures and should have provisions for evaluating potential life loss or injury and for evaluating secondary economic losses on the basis of structure usage.

The Spectral Matrix Method developed by Blume appears to be the most highly developed of the general, theoretically based damage prediction methods. The SMM warrants further development and practical use because it considers, on a rational and realistic basis, most of the significant engineering parameters affecting damage. However, the ranges of these parameters for various types of structures need to be verified with actual data from past earthquakes, engineering analysis, and laboratory experiments.

Several reports of significant postearthquake damage investigations provide insight concerning earthquake losses: Lawson (1908), Freeman (1932), Martel (1936), Steinbrugge and Moran (1954), Steinbrugge et al. (1971), Scholl (1974), Whitman et al. (1977), and Hafen and Kintzer (1977). Most of the specific loss-ratio information available pertains only to low-rise and high-rise buildings -- yet these two classes of structures constituted only about one-half the total damage caused by the 1971 San Fernando earthquake (Steinbrugge et al., 1971). A significant need exists for earthquake damage data for all other types of structures, in addition to low-rise and high-rise buildings.

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FORMS AND FUNCTIONS OF SEISMIC SAFETY ORGANIZATIONS[1]

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INTRODUCTION

Many States in the Mississippi Valley and in other seismically active areas recognize the need for a seismic safety organization to implement the action plans developed at this workshop and an earlier workshop held in Knoxville, Tennessee. This paper addresses the possible functions seismic safety organizations can perform and the orgnizational forms they can take. As an example, the Utah Seismic Safety Advisory Council's form and functions will be explored.

Most seismic safety organizations perform one or more of these types of functions:

Information Services

1) Collect and share information (e.g., secretariat) including:

a) Specialized library of books, roster of names,
b) Inquiry and research (e.g., reference service).

[1] in Proceedings of Conference XVIII, a workshop on "Continuing actions to reduce losses from earthquakes in the Mississippi Valley area:" U.S. Geological Survey Open-File Report 83-157, 140 p.

2) Prepare information pieces including:

   a) Specialized newsletter,
   b) Research briefs, maps, and analyses,
   c) Monographs, and professional papers.

3) Perform or manage research (seek State and Federal grants).

Educational, Training, and Assistance Services

1) Offer courses, other training.

2) Take lead role in bring new information to attention of members

3) Provide indirect (direct) technical assistance to localities.

Advocacy Activities--pushing for advances in earthquake plans preparedness.

1) Advocate State actions including:

   a) inclusion of seismic resistant element in local general plans,
   b) inclusion of seismic element in State building codes.

2) Advocate local actions (e.g., land use controls).

Review and Regulatory Activities

1) Review on a State-by-State basis seismic safety code revisions in order to draft provisions applicable to the region.

2) Review designs and construction standards for public buildings.

3) Set standards for public buildings as example for private sector.

Regional and National Representation

1) Advocacy functions may be pursued at a multi-State level or national level.

2) The organization may serve as a focal point or present a presence, for national attention, publicity, inquiries, etc.

A graphic description of these categories of functions, which may be achieved incrementally, follows.

POSSIBLE FUNCTIONS FOR A SEISMIC ORGANIZATION

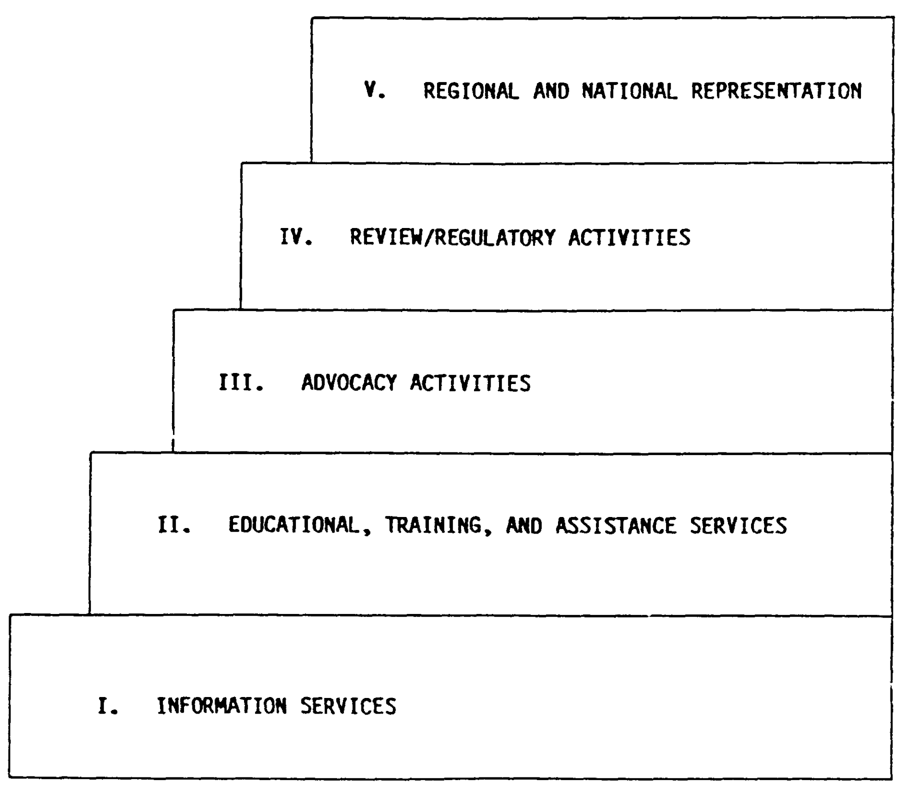

Figure 1.--Functions of an organization represented as steps with information services as the first step and regional and national representation as the fifth step.

THE UTAH SEISMIC SAFETY ADVISORY COUNCIL

The Utah Legislature created the Utah Seismic Safety Advisory Council in 1977 to develop public policy recommendations and programs leading to earthquake hazard reduction activities. The council, which finished its work in 1981, was charged with providing many of the functions identified earlier. Below is a categorization of the services the council provided:

1) Educational, training, and assistance services

   a) Educate the public and private sectors on earthquake safety.
   b) Recommend training for specialized enforcement and technical personnel which may have responsibilities relating to earthquake hazards.

2) Advocacy activities

   a) Recommend a consistent policy framework for seismic safety in Utah.
   b) Suggest goals and priorities for earthquake hazard reduction.
   c) Recommend Statewide and local programs to reduce earthquake hazards.
   d) Request that State agencies devise criteria to provide seismic safety.

3) Review and regulatory activities

   a) Review proposed earthquake-related legislation and propose needed legislation.
   b) Advise the Governor and Utah Legislature on matters relating to seismic safety.
   c) Recommend the addition, deletion, or changing of State and Federal standards as deemed desirable to promote seismic safety.
   d) Recommend methods for:

      - improving building standards and construction compliance with the standards.

- siting and designing of critical facilities, hospitals, and schools.

- delineating fault zones which require special investigation, regulation, and reporting procedures.

The Utah Seismic Safety Advisory Council performed many advocacy and regulatory functions due to its establishment by the State Legislature to "advise the governor, legislature, State, and local governments, and the private sector on possible ways of reducing earthquake hazards." Other seismic safety organizations may emphasize different functions, depending on nature of the seismic hazards and risk in their State or region, the task that the organization is set up to perform, and the experience and interests of the membership of the organization. Over time, organizations may also change, expand, or reduce the services they provide.

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