UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROCEEDINGS OF CONFERENCE XXXII

WORKSHOP ON

FUTURE DIRECTIONS IN EVALUATING EARTHQUAKE HAZARDS OF SOUTHERN CALIFORNIA

NOVEMBER 12 - 13, 1985
LOS ANGELES, CALIFORNIA

OPEN-FILE REPORT 86-401

MENLO PARK, CALIFORNIA

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DAVIDSON CONFERENCE CENTER
UNIVERSITY OF SOUTHERN CALIFORNIA
LOS ANGELES, CALIFORNIA

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NATIONAL EARTHQUAKE HAZARDS REDUCTION PROGRAM

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SOUTHERN CALIFORNIA EARTHQUAKE PREPAREDNESS PROJECT

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PREFACE

Southern California faces the greatest seismic risk of all the regions of the United States. The region is inhabited by more than 12 million people and is one of the Nation's key commercial and industrial centers. It lies astride a web of potentially active faults, including that segment of the San Andreas fault that has the highest probability of generating a great earthquake during the next 30 years. Damaging earthquakes occur every four years, on the average, within the region.

The unique setting of southern California has made the region a prime focus for earthquake research and hazard-reduction efforts. USGS Professional Paper 1360, which highlights the marked advances in methods for evaluating earthquake hazards influenced by geologic conditions, is a recent example of such efforts. Moreover, southern California contains the largest and most experienced groups of scientists, engineers, planners, and emergency managers concerned with earthquake problems. This community has assumed leadership roles nationally and internationally in identifying hazards and in developing innovative land-use, engineering, and emergency preparedness solutions.

This workshop was organized so that representatives of the community of scientists, engineers, planners, and emergency managers of southern California could examine progress to date and suggest what might be the most appropriate next steps to take in reducing the earthquake threat. The goal of this publication, which is the fourth in a series on knowledge utilization, is to help define the paths along which future earthquake-hazards-reduction actions in southern California might proceed. In addition, we believe that the insights recorded herein are transferable to scientists, engineers, planners, and emergency managers in other earthquake-prone regions of the Nation.

Walter W. Hays
Office of Earthquakes,
Volcanoes, and Engineering
United States Geological Survey

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INTRODUCTION

Joseph I. Ziony and William J. Kockelman
United States Geological Survey

The workshop, "Future Directions in Evaluating Earthquake Hazards of Southern California," was held in Los Angeles at the University of Southern California on November 12 and 13, 1985. The United States Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the National Science Foundation (NSF), the California Governor's Office of Emergency Services, the California Department of Conservation/Division of Mines and Geology, the California Seismic Safety Commission, the Southern California Earthquake Preparedness Project, and the Southern California Association of Governments jointly sponsored the workshop.

SOUTHERN CALIFORNIA'S EARTHQUAKE THREAT

Southern California, which contains more than 12 million people and the important metropolitan centers of Los Angeles and San Diego, straddles a broad boundary between two horizontally moving crustal plates and contains more than 100 potentially active faults that can generate destructive earthquakes. More than 40 damaging earthquakes have occurred in the region since 1812, and future major earthquakes are inevitable.

The probability that a large earthquake (exceeding magnitude 7) will occur within the next 30 years along the San Andreas fault northwest of Los Angeles is currently estimated to be 40 percent or greater (Lindh, 1983; Wesson and Wallace, 1985). Projected losses of $25 billion and estimated casualties of tens of thousands (FEMA, 1980) would surpass the effects of any previous natural disaster in the United States.

Moreover, many potentially active faults that can generate moderate-sized earthquakes lie within or adjacent to the metropolitan areas. Although scientists cannot yet assign probabilities for future events on these lesser faults, the faults pose a significant hazard. For example, a magnitude 6.5 event within the Los Angeles basin could result in losses exceeding those from a great earthquake on the more distant San Andreas fault. The 1971 San Fernando earthquake, whose epicenter was on the margins of the metropolitan area, demonstrated how vulnerable a complex urban society can be to the damaging effects of moderate earthquakes nearby.

Many parts of metropolitan Los Angeles and San Diego, as well as Long Beach, San Bernardino, and Ventura, are built on alluvial deposits that can amplify earthquake ground shaking or can fail due to liquefaction. In some sectors, urbanization is spreading to upland areas where earthquake-triggered landsliding can be a significant threat. Although the ability of scientists to predict the occurrence of a specific earthquake is still evolving, the distribution and severity of many geologic and seismologic effects of future earthquakes can be predicted with reasonable certainty by using recently developed or improved evaluation methods. This information can be used for planning and engineering actions that may substantially reduce future losses.

REASONS FOR THE WORKSHOP

Several reasons prompted us to convene the workshop:

First, the past two decades have seen remarkable progress in earthquake hazard reduction for southern California.

- o Considerable geologic and seismologic information useful for hazard-reduction purposes has been assembled. These data include detailed geologic maps of the principal fault zones, geotechnical data on the bedrock and alluvial deposits of the region, and geophysical information that helps explain where and why earthquakes occur in southern California.

- o New or improved methods for predicting the location and severity of hazardous geologic effects of future earthquakes have been developed. USGS Professional Paper 1360, which was distributed for the first time at this workshop, is an example of the progress being made in evaluating the potential for earthquake generation, surface faulting, strong ground shaking, ground failure, and tsunamis in the Los Angeles region.

- o Innovative hazard-reduction techniques have been devised, including planning actions to avoid hazardous conditions and engineering methods to accommodate them. California, and especially southern California, has led the nation in legislating and implementing improved building codes, land-use regulations, and emergency-preparedness and response planning to cope with future major earthquakes.

Secondly, the financial resources of both the public and private sectors are limited. It is important, therefore, to take stock of currrent efforts and to develop priorities for the next stage of earthquake hazards research and reduction in southern California. Decisions must be made concerning which scientific research topics are most critical and which hazard-reduction techniques are most effective.

Finally, earthquake hazards reduction is a complex task that requires an integrated and multidisciplinary approach. More interaction must be encouraged between the producers of earth-science information and those who use it for hazard reduction. This workshop was intended to contribute to that interaction. The September 19, 1985 earthquake that had a tragic impact on Mexico City proved once again that scientists, engineers, planners, and decisionmakers have much to learn and much to do if a similar disaster in southern California is to be averted.

WORKSHOP OBJECTIVES AND FOCUS

The workshop had three objectives: (1) to summarize results of recent earth-science research on evaluating earthquake hazards, (2) to present examples of ongoing earthquake hazards reduction efforts, and (3) to discuss what additional scientific and technical information is needed and which hazard-reduction techniques are most effective.

The program was multi-disciplinary and was intended for the presentation both of key results of recent scientific research and of examples of earthquake hazards reduction efforts. The workshop was not a scientific forum for discussing the development of such research, but rather a focus for discussing two important questions: (1) what additional scientific and technical information is needed for reducing earthquake hazards; and (2) which hazard-reduction strategies are most effective and how can they be improved?

WORKSHOP PARTICIPANTS

About 330 people participated in the workshop; a roster of registrants is included in these proceedings (Appendix A). The attendees represented diverse backgrounds including earth science, social science, land-use planning, engineering, emergency management, public adminstration, law, public health, insurance, and real estate. Numerous private firms, universities, public utilities, and Federal, state, and local units of government were represented.

WORKSHOP ORGANIZATION, PROCEDURES, AND PROCEEDINGS

We organized the workshop to achieve an effective exchange between producers and users of earthquake hazards information. Selected speakers and panelists, plenary session and working group discussions, and a pointed dialogue (produce-user debate) in the evening of the first day, were used to ensure this exchange.

The workshop summarized key results of recent earth-science research on evaluating earthquake hazards; examined current activities where hazard information is being used to reduce potential losses; and promoted discussion of possible future directions in both earth-science research and in hazard-reduction efforts. The chief topics explored were:

- evaluating earthquake and surface-faulting potential for hazard-reduction actions,

- predicting seismic intensities for response planning and loss estimation,
- predicting ground motion for earthquake-resistant design,
- predicting major earthquakes for preparedness planning,
- evaluating earthquake ground-failure potential for development decisions, and
- evaluating the shaking hazard for redevelopment decisions.

The first day began with a plenary session where three scientists summarized current research trends and opportunities in the first three topics above. This session was followed by three concurrent working groups, one for each topic. The working group speakers focused primarily on new methods for evaluating earthquake hazards, on how the scientific information is being used to reduce earthquake hazards, and on the effectiveness of specific hazard-reduction efforts. After a luncheon break, concurrent working groups began with panel discussions and closed with comments from the audience. The plenary session was then reconvened, and the moderators and commentators for each working group presented their group's conclusions or recommendations. The second day was similarly organized and addressed the last three topics.

Papers, expanded abstracts, and statements were solicited from cosponsors, plenary speakers, working group speakers, and panelists. Copies were made available to the audience immediately after each plenary and working group session. In addition, the USGS Professional Paper 1360, "Evaluating Earthquake Hazards in the Los Angeles Region--An Earth-Science Perspective," was presented to each registrant.

Workshop proceedings are presented here in order of the working group sessions for each of the 6 topics; the plenary session papers have been placed under the appropriate working group topic, for example:

Topic 1: Plenary Session paper
Working Group papers
Panel and audience discussions

These published workshop proceedings will aid in transferring southern California's successful hazard-reduction efforts to other regions.

Where indicated, certain statements and commentary have been transcribed and edited from audiotape recordings made during the conference. Significant effort has been made to ensure accuracy and thoroughness in reporting such material. Errors and omissions in transcribed materials should be called to the attention of the editors.

PROFESSIONAL PAPER 1360

The earthquake hazards of the Los Angeles region, improved methods for evaluating the distribution and severity of the hazards, and opportunities for reducing the hazards are described in a recently published USGS book (Ziony, ed., 1985). The report presents the latest research evaluating surface faulting, strong ground motion, ground failure, and tsunamis (seismic sea waves) that are expected from future earthquakes. The report contains 16 chapters by 22 experts on the geologic and seismologic effects of earthquakes. Among the significant findings of the report are:

- There are at least 95 fault segments in the Los Angeles region capable of generating damaging earthquakes and rupturing the land surface. The San Andreas and San Jacinto faults are the most active in terms of their rate of slip during the recent geologic past, averaging about 25 mm/yr (millimeters per year) and about 10 mm/yr, respectively. Most other faults have geological slip rates of about 1 mm/yr, except for a belt of faults between Santa Barbara and San Bernardino that have slip rates as great as 6 mm/yr.

- Future earthquakes as large as the following should be anticipated in planning for and designing ordinary structures: magnitude 8+ on the San Andreas fault, magnitude 7 on the San Jacinto fault, and magnitude 6.5 on other active faults. Major earthquakes are repeated at points along the San Andreas and San Jacinto faults approximately every several tens to a few hundred years. In contrast, recurrence intervals for other faults in the region apparently are many hundreds to several thousands of years.

- Geographic variations in the severity of ground motion can be estimated for future earthquakes in the Los Angeles region by taking into account geologic characteristics near the Earth's surface and by applying various predictive methods. Two examples of the four techniques described in this report are:

  -- A computer program that maps, for any postulated earthquake, predicted values of seismic intensity (a qualitative measure of shaking strength useful for planning emergency response and for estimating future losses) across the region. Comparison of predicted intensities and estimated percent damage for various possible earthquakes indicates that a moderate-sized (magnitude 6.5) earthquake within or near the Los Angeles basin would cause a higher dollar loss to structures in the region that a great (magnitude 8+) earthquake on the more distant San Andreas fault.

  -- Newly devised equations that link expected ground motion with earthquake magnitude, distance, site geology, and the slip rates of nearby faults. Predictive maps can be made showing quantitative measures of shaking strength (for example, ground velocity) directly applicable to the seismic design of structures. A sample map for the Pomona-San Bernardino area indicates that ground velocities as high as 400 cm/s and 200 cm/s, respectively, can be expected near the San Andreas and San Jacinto faults in the San Bernardino Valley.

- Areas vulnerable to liquefaction (the sudden loss of ground strength that can cause rupture or tilting of structures) can be identified from the physical and hydrologic characteristics of the sediments within the alluvial valleys. Liquefaction during future earthquakes is most likely on the flood plains of the principal rivers; parts of the San Bernardino, Oxnard, and San Fernando valleys; and coastal and harbor areas of Long Beach and Marina Del Rey. Shaking strong enough to cause liquefaction at a susceptible site is estimated to recur about every 30 to 50 years.

- Earthquake-triggered landslides, particularly rockfalls, are a significant hazard in the populated upland areas. A new method for predicting the areal limits for landslides of various types from different-sized earthquakes has been developed. A magnitude 6.5 earthquake, for example, could cause rockfalls on particularly unstable slopes at distances as far as 69 miles from an earthquake.

- Tsunamis are rare in southern California coastal areas. Wave run-up heights as great as 6 to 10 feet, however, can be expected from distantly generated tsunamis such as might occur during a major earthquake in the Gulf of Alaska. Moreover, locally generated tsunamis triggered by sea floor faulting in the Santa Barbara Channel could cause wave run-up heights as great as 13 to 20 feet at some nearby shorelines.

- Numerous opportunities for reducing earthquake hazards are available. Examples of successful programs and regulations are discussed and illustrated.

To demonstrate the earthquake hazards-evaluation methods described in the report, the geologic and seismologic effects of a hypothetical magnitude 6.5 earthquake on the Newport-Inglewood fault zone in the Los Angeles basin are predicted.

Copies of Professional paper 1360 can be purchased over-the-counter at the USGS Public Inquiries Office, 7638 Federal Building, 300 N. Los Angeles Street in Los Angeles. They also can be ordered by mail from U.S. Geological Survey, Books and Open-File Reports, Federal Center, Box 25425, Denver, CO 80225. A check for $24 payable to "Department of the Interior--USGS" should be enclosed.

OTHER WORKSHOPS OF THE EARTHQUAKE HAZARDS REDUCTION PROGRAM

The workshop is the thirty-second in a series of workshops and conferences convened by the U.S. Geological Survey on earthquake issues and is the twentieth in a series coordinated by Walter W. Hays, Deputy for Research Applications, USGS

Office of Earthquakes, Volcanoes, and Engineering and specifically directed at the use of scientific information for reducing hazards. A list of earlier workshops is in Appendix B at the end of the report. Proceedings of these earlier workshops are available from the Open-File Services Section, USGS, Branch of Distribution, Box 25425, Federal Center, Denver, CO 80225.

Primary stimulus for the workshops is the Earthquake Hazards Reduction Act (U.S. Congress, 1977), which created the National Earthquake Hazards Reduction Program (NEHRP) and directed the Federal government to lead, coordinate, and conduct earthquake research, hazard mitigation, and disaster preparedness. In 1978, the President established the Federal program and specified the roles for Federal agencies and recommended appropriate roles for state and local units of government, individuals, and private organizations.

The USGS has various responsibilities regarding research, hazard identification, hazard reduction, prediction, assistance to state and local governments and the private sector, information dissemination, and public awareness (Schnell and Herd, 1984). The National Bureau of Standards, FEMA, and NSF also have some of these responsibilities, as well as others including leadership, coordination, insurance, land-use guidance, preparedness, and response. A recent report by the Federal Emergency Management Agency (1985) highlights the actions taken by Federal agencies including coordination with and financial support of scientific and technical projects being conducted by non-federal agencies.

ACKNOWLEDGMENTS

We acknowledge the enthusiastic support and advice of the Federal, state, and regional sponsoring agencies. They helped identify speakers and panelists, contributed funds, provided mailing lists, and encouraged their staffs to play key roles in the workshop.

We especially thank the speakers and panelists; their excellent presentations and papers provided the stimulus for candid exchanges of views on the six topics by the registrants.

Special thanks are also due the staff of the University of Southern California Davidson Conference Center; the agencies that exhibited their research, mapping, and hazard-reduction products at the workshop; William M. Brown III, who so ably coordinated the workshop; and Cynthia Ramseyer, for her adept secretarial support and assistance in compiling and editing these proceedings.

REFERENCES

Federal Emergency Management Agency, 1980, An assessment of the consequences and preparations for a catastrophic California earthquake--Findings and actions taken: Washington, D.C., 59 p.

Federal Emergency Management Agency, 1985, National earthquake hazards reduction program--fiscal year 1984 activities--Report to the United States Congress, 192 p.

Lindh, A.G., 1983, Preliminary assessment of long-term probabilities for large earthquakes along selected fault segments of the San Andreas fault system in California: U.S. Geological Survey Open-File Report 83-63, 15 p.

Schnell, M.L., and Herd, D.G., eds., 1984, National earthquake hazards reduction program--Report to the United States Congress--fiscal year 1983 activities: U.S. Geological Survey Circular 919, 148 p.

U.S. Congress, 1977, Earthquake hazards reduction act, as amended: Public Law 95-124, 42 U.S. Code 7701, 91 Stats. 1098.

Wesson, R.L., and Wallace, R.E., 1985, Predicting the next great earthquake in California: Scientific American, v. 252, no. 2, p. 35-43.

Ziony, J.I., ed., 1985, Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, 505 p.

EXECUTIVE SUMMARY

INTRODUCTION

About 330 scientists, engineers, and planners met in Los Angeles on November 12-13, 1985 to discuss what additional earth science and technical information is needed for reducing earthquake hazards in southern California and to identify which hazard-reduction techniques are most effective. Their key observations are summarized here according to the six topics addressed at the workshop.

I. EVALUATING EARTHQUAKE AND SURFACE-FAULTING POTENTIAL FOR HAZARD-REDUCTION ACTIONS

EARTH SCIENCE AND TECHNICAL INFORMATION

Current Status -- Assessment of the earthquake and surface-faulting potential in southern California is well advanced compared to many other regions of the United States. Significant gaps exist, however, in the geologic and seismologic data base available for evaluating many of the potentially active faults, particularly those within or adjacent to the major population centers.

- The general aspects of southern California's seismotectonic framework are reasonably well understood. Most of the likely sources of future major earthquakes onshore have been identified and their seismological character and late Quaternary activity are being assessed.

- Reliable estimates of geologically determined slip rates for late Quaternary time are available only for a few major faults. Rates for the onshore northwest-trending faults west of the San Jacinto fault are poorly constrained, and slip-rates for most offshore faults are undetermined because reliable geologic data have not yet been acquired.

- Direct geologic evidence for earthquake recurrence intervals is limited to single localities on the San Andreas, Elsinore, and a few other faults. For most other faults, recurrence intervals have been estimated only indirectly by using slip-rate data.

- The sizes of future earthquakes can be estimated from assumptions about the dimensions of the late Quaternary faults (particularly the lengths of their known Holocene strands). The potential for large (magnitude 7.5 or greater) earthquakes beneath the Transverse Ranges is an unresolved issue.

- Recently active traces of the principal fault zones have been mapped in detail by the California Division of Mines and Geology under the Alquist-Priolo Special Studies Zones Act. Methods exist for estimating the type and amount of future surface displacement for postulated earthquakes. The geologic data base, however, varies in quality and completeness for southern California.

Future Directions and Needs -- Future research will emphasize improving slip-rate and recurrence-interval estimates of individual faults, and investigating those geologic and seismologic characteristics that influence earthquake potential. Specific needs identified were:

- Continuing search for and documentation of Holocene offsets along all potentially active faults in the region.

- Determining the segmentation characteristics of faults to provide constraints on estimating the likely sizes of future earthquakes.

- Improving networks of seismographic stations to permit more accurate three-dimensional mapping of fault zones to identify continuous fault segments that break in characteristic earthquakes and barriers that may influence variations in fault displacement.

- Additional testing of lithospheric models proposed for the Transverse Ranges to establish whether or not low-angle faults of large dimensions exist within brittle crust.

HAZARD-REDUCTION TECHNIQUES

Current Status -- Fault-rupture zones have been mapped for the entire State under the Alquist-Priolo Special Studies Zones (APSSZ) Act. Cities and counties must regulate development within these zones and real-estate sellers must disclose to buyers if the property being sold is in a zone. Some cities and counties have greater requirements than that of the State law. Specific comments concerning the implications of the APSSZ Act were:

- Avoiding construction astride known active faults is the most effective method of reducing the fault-rupture hazard.

- Location of properties in an APSSZ has reduced the availability of and increased the cost of earthquake insurance.

- Effective disclosure does not always occur; for example, real-estate sellers are uncomfortable commenting on fault-rupture hazards and developers are reluctant to evaluate some sites because of uncertainties about the activity of certain faults.

- As experience in fault evaluation is gained by consulting geologists and local reviewers, the effectiveness of site investigations improves.

- The Act is not retroactive, and the extent to which existing structures lie astride active faults is unknown.

- Cities and counties frequently lack the resources to develop and enforce appropriate ordinances regulating development in these zones; there is no State agency charged with overseeing local implementation of the Act; and there is no penalty for not complying with the Act.

Future Directions and Needs -- The general trend in society is to hold developers, contractors, and regulators more liable when natural hazards occur, even when a property owner signs a waiver absolving local government from responsibility. Local geotechnical staffs hired to review and advise on the APSSZ are advising on other geologic hazards and on improving local regulations. Specific needs identified were:

- Identifying and reducing hazards for existing buildings astride active faults.

- Evaluating the effectiveness of local enforcement of the APSSZ Act and performing cost/benefit analysis of existing hazard-reduction techniques.

- Providing a State or regional depository for earthquake-hazard information and a program to systematically categorize, review, and use such information.

- Creating regional redevelopment agencies with land-use planning, development, and financing powers prior to earthquakes.

- Revising the procedures of lending and insuring institutions so that they complement local development regulations.

- Extending the APSSZ Act to other earthquake hazards such as liquefaction and landsliding.

II. PREDICTING SEISMIC INTENSITIES FOR RESPONSE PLANNING AND LOSS ESTIMATION

EARTH SCIENCE AND TECHNICAL INFORMATION

Current Status -- A computer-based method predicts seismic intensities for specified earthquakes by applying numerical models of the earthquake source, crustal attenuation characteristics, and empirically derived relative intensity increments for different geologic units. It has been used to map predicted intensity patterns for various potential California earthquakes and to estimate earthquake losses.

- Recent studies demonstrate that intensity can be correlated directly with strong-motion parameters for frequency bands applicable to ordinary structures. Current predicted-intensity maps, however, do not account for longer period effects or resonance effects.

- The predictive model assigns intensity increments based upon geologic ground conditions obtained from 1:250,000-scale State geologic maps. The model is strongly sensitive to assumptions about the water-table depth in alluvial sediments.

- o Losses are estimated by incorporating empirical correlations between observed historical intensities and percentage damage experienced by various types of structures. However, marked differences with other loss-estimation methods in predicted losses from equivalent postulated earthquakes are common.

- o Building inventory data bases are inadequate for many metropolitan areas in southern California.

Future Directions and Needs -- Continued research into the effects of various local geologic factors on shaking intensities is needed. Substantial improvements in estimating damage factors at different intensity levels are critical for reliable loss estimates. Specific needs identified included:

- o Testing the assumption that shallow ground water in alluvial sediments increases seismic shaking. Possible effect of variations in sediment thickness on shaking response also needs clarification.

- o Characterizing geologic ground conditions for the metropolitan areas at scales substantially more detailed than 1:250,000.

- o Redefining intensity scales to account for upgraded building codes and improved construction practices. Additional sensitivity studies on all elements of the predicted-intensity and loss-estimation models would improve estimates.

- o Upgrading structural inventories for all major metropolitan areas and entering these into a computerized data base.

HAZARD-REDUCTION TECHNIQUES

Current Status -- Preparedness and response planning are underway based on scenarios using seismic intensities predicted for a major earthquake on the San Andreas fault. Scenario methods provide a framework for incorporating local variations in ground shaking due to geologic and soil conditions. Although scenarios cannot identify where specific damage will occur, they provide a reasonable basis for preparedness, response, and recovery plans and can be used to estimate the emergency response needed. Scenarios have been used for estimating:

- o Damage to critical facilities, specifically lifelines such as highways, airports, railroads, marine facilities, communication lines, water supply and waste disposal facilities, and electrical power, natural gas, and petroleum lines.

- o Number of deaths, number of injured requiring hospitalization, and economic losses.

- o Number of homeless and the need for emergency housing.

Future Directions and Needs -- Earthquake scenarios are needed for potential major earthquakes along other southern California faults. The insurance industry requires more reliable estimates of future losses from earthquakes because of legal requirements to offer residential earthquake insurance and because of the large potential losses on commercial buildings. Specific needs identified were:

- o Revising the Modified Mercalli Intensity Scale to better account for the complexity of modern construction types, and to include long-period shaking effects.

- o Improving inventories of the number and type of structures and methods to predict damage or loss.

- o Developing scenarios at larger scales for selected communities.

- o Clearly defining local earthquake-hazards reduction programs, reconstruction plans, recovery team needs, recovery operations, and reconstruction activities.

III. PREDICTING GROUND MOTION FOR EARTHQUAKE-RESISTANT DESIGN

EARTH SCIENCE AND TECHNICAL INFORMATION

Current Status -- The ability to quantitatively predict ground motion has advanced markedly in the past decade. Empirical estimation techniques permit reliable specification of design motions for nearby moderate earthquakes and for distant large earthquakes.

- o Mean values of peak ground acceleration and velocity can be predicted from curves based chiefly on California data. Response spectral values also can be calculated for a range of earthquake magnitudes and local geology.

- o A new method for predictively mapping ground motion accounts for site effects by using shear-wave velocity estimates and by representing earthquake potential by fault slip rate. A demonstration map has been published for part of the Los Angeles region.

Future Directions and Needs -- Collection and analysis of strong-motion data, especially near the source of large earthquakes, should continue. Fundamental studies into the physics of earthquake sources, wave propagation, and effects of differing geologic site conditions on ground motion are essential. Specific needs include:

- o Recording of near-source strong motion from shallow large earthquakes to improve predictive capabilities. Because large California events occur rarely, strong-motion instrumentation must also be placed in other parts of the world with comparable tectonic settings.

- o Determining scaling of earthquake ground motion with source size, effects of directivity, and contribution of nonlinear soil response in reducing ground motion.

- o Improving fault slip-rate estimates for southern California faults as a basis for probabilistic predictions of ground motion.

HAZARD-REDUCTION TECHNIQUES

Current Status -- Engineering design of new structures, and retrofitting of existing structures, is influenced by estimates of future ground motion. For example, strengthening projects for highway bridges were given priorities based in part upon the level of expected ground motion. In 1983, the Applied Technology Council developed retrofit guidelines for highway bridges. The scope of the project was to provide:

- o Preliminary screening process for the initial selection of bridges to be retrofitted.
- o Methodology to evaluate the seismic capacity of existing bridges.
- o Subjective criteria for the determination of retrofit details for existing bridges.
- o Examples of various retrofit measures.

Future Directions and Needs -- Time and resources are needed in developing useful building codes, educating the industry, and creating a mechanism to evaluate the efficiacy of new or unusual innovations such as base isolation and epoxy/polyester strengthening. Codes can only be effective if they are understood by the design practioner and enforced by the regulatory agency. The National Institute of Building Standards' "recommended provisions for the development of seismic regulations for new buildings" will serve as a source document for use by the building community. Specific needs identified were:

- o Expanding the knowledge and the understanding of the behavior of buildings and nonstructural components during earthquake-induced motions, and incorporating research products into improved codes.
- o Compiling case histories of the strengthening of structures, including information on testing and costs.
- o Developing methods to evaluate seismic resistance of existing structures in seismically active areas, and developing a full-scale testing capability which can test to destruction.
- o Continuing studies on the likely location, magnitude, and recurrence of earthquakes to improve reliability of ground-motion hazard assessments.
- o Ensuring that understandable building codes are prepared and that enforcement officials are trained.

IV. PREDICTING MAJOR EARTHQUAKES FOR PREPAREDNESS PLANNING

EARTH SCIENCE AND TECHNICAL INFORMATION

Current Status -- Long-term (several years to several decades) earthquake predictions stated in probabilistic terms have been made for segments of the San Andreas fault system on the basis of seismic gap theory and geologic evidence of recurrence. A short-term prediction stated in probabilistic terms was made on the basis of seismic activity in the City of San Diego. However, well-established relations linking observed geophysical phenomena with earthquake occurrence for a specified magnitude, place, and time window have not been recognized. Earthquake prediction remains in a research phase, although some perceive that it already is in operation.

- Location and magnitude of major earthquakes can be reliably specified for many major fault segments only on very long time scales (decades or longer). Fundamental research into short- and intermediate-term (days to months) must advance significantly before reliable warnings will become practical.

- The Parkfield (central California) prediction experiment is attempting to monitor and identify possible precursors for an impending magnitude 6 or larger event and to understand the rupture process.

- Very short time span (tens of seconds) warnings of imminent strong shaking in southern California from a large earthquake propagating along the San Andreas fault in central California is theoretically feasible using existing technology.

- Validation systems for earthquake predictions exist through operation of the National Earthquake Prediction Evaluation Council and the California Earthquake Prediction Evaluation Council. However, it is difficult to mobilize these groups to assess potential precursors having time spans of hours or a few days.

Future Directions and Needs -- Progress toward reliable prediction requires sustained research into basic physical principles controlling the earthquake process. Sites in southern California with known high-potential for imminent earthquakes should be moniored for possible precursors. Specific needs identified were:

- Improving the ability to make long-term earthquake predictions (forecasts). Probabilistic approaches to expressing the potential for future earthquakes can be refined and extended to possible precursory phenomena.

- Deploying dense clusters of geophysical instruments for focused experiments along high-probability seismic gaps of the San Andreas fault system in southern California.

- Conducting earthquake prediction experiments in other parts of the world, especially in tectonic environments comparable to California.

- Conducting periodic scenario exercises with hypothetical short-term precursors with the prediction-evaluation groups in order to examine the range of assumptions and hypothesis held by experts.

HAZARD-REDUCTION TECHNIQUES

Current Status -- The perceptions of local decisionmakers on the status of earthquake forecasting greatly influences their willingness to deal with prediction issues. Some jurisdictions are organizing to act upon a validated prediction. For example, the City of Los Angeles has a written emergency plan, a full-time staff, an emergency operations organization, and an annual earthquake response exercise.

- Experience shows that the public can react to a prediction without panic or counterproductive actions.

- Rapidly providing full and accurate information to the public, and updating it frequently to control rumors, is the wisest course of action based on extensive experience with predicting hurricane, flood, and tornado events.

- Although it is the scientist's job to recognize earthquake precursory information and to explain its significance, the job of nonscientists is to educate themselves about what the scientist is saying and then make an intelligent response.

Future Directions and Needs -- Because of the intensive scientific research underway in the Parkfield area, it is quite possible that indications of an imminent earthquake will be detected and that this will lead to the issuance of a short-term prediction. Effective systems to manage that prediction are being established. However, for southern California, neither the instrumentation nor the scientific understanding are sufficiently advanced. Thus, local officials may have to base their actions on less rigorous earthquake predictions or forecasts. Given a valid prediction, local government will face difficult decisions about post-earthquake land-use planning and reconstruction. Specific needs identified were:

- Resolving problems in the areas of: issuing warnings to the public, alerting and mobilizing response groups, vacating hazardous structures, posting warnings, evacuating threatened areas, providing mass care and shelter, and determining public liability.

- Educating government officials and the public on the differences between types of predictions -- short-term, intermediate-term, and long-term (forecasts); standardizing terminology and seeking consistent usage among official predictors.

- Developing procedures for rapidly disseminating warnings for a short-term prediction, educating the public in advance as to the type of protective actions that they should take, and knowing how to communicate contradictory information. Because contradictory information leads to inaction, there is also a need to know how to deal with the public's suspicion that "scientists know more than they are telling us."

- Continually assessing the political, economic, social, other secondary effects of predictions.

V. EVALUATING EARTHQUAKE GROUND-FAILURE POTENTIAL FOR DEVELOPMENT DECISIONS

EARTH SCIENCE AND TECHNICAL INFORMATION

Current Status -- Liquefaction potential of geologic materials within many alluvial basins of southern California has been mapped at regional scales using well-established methods. The areal limits for various landslide types triggered in upland areas by specific earthquakes also can be predicted using new hazard-analysis procedures.

- Geologic and hydrologic criteria exist for identifying liquefiable sediments; the limiting distances for liquefaction from different sized earthquakes are established; and the return periods for shaking strong enough to induce liquefaction has been calculated for southern California.

- Liquefaction potential maps at 1:250,000 scale are published for parts of the Los Angeles region, but are not sufficiently detailed for site-specific evaluations.

- Theoretical and empirical studies of earthquake-induced landsliding world-wide permit mapping zones with differing levels of probability of slope failure based on distance from the postulated earthquake source. Determination of the stability of specific slopes, however, requires detailed information on the geotechnical character of specific slopes; this type of data is not yet available for most of southern California.

Future Directions and Needs -- More complete geotechnical and hydrologic data are needed for southern California. Methodologies should be further quantified to permit estimation of the severity of predicted ground-failure effects. Post-earthquake studies of ground failures are essential for refining predictive techniques. Specific needs identified included:

- Conducting long-term monitoring of shallow (especially perched) ground water. More precise characterizations of the abundance, distribution, and relative density of saturated cohesionless sediments could be obtained from closely spaced core penetrometer measurements or possibly from ground-penetrating radar.

- Increasing studies of the seismic stability of man-made cuts and fills in hillside areas, and fills and dikes along major waterways and around harbor areas.

- Improving methods of predicting seismically induced landslides using field experiments with potential slide masses to analyze the roles of cohesion, hydrologic attributes, and changes in pore-pressure on slope stability.

HAZARD-REDUCTION TECHNIQUES

Current Status -- Seismic safety elements, which have been adopted by virtually every California city and county over the past 10 years, provide a useful legal framework for making decisions to avoid or accommodate potential ground-failure hazards. Engineering solutions for reducing liquefaction and landslide hazards are well known, but may be costly for ordinary types of development.

- o Political variables are of greater importance to the initiation and success of earthquake-hazard reduction than are the the current state of scientific knowledge or the availability of technological remedies.

- o Impediments to earthquake-hazard reduction include decisionmakers' priorities other than seismic safety, lack of earthquake-oriented political constituencies, lack of inside advocates, lack of professional review of geotechnical reports within many jurisdictions, and the complexity and uncertainty of ground-failure processes.

Future Directions and Needs -- To improve the quality of seismic safety elements, consideration should be given to improving guidelines and models to assist local governments in preparing the elements. Some seismic safety elements could be improved by adding larger-scale, more detailed hazard maps, simplifying the geologic problems rating system, providing for the addition of new information, and including other local government policies related to geologic processes. The technical community has a responsibility to more actively assist local government in understanding technical information. The following needs were identified:

- o Writing seismic safety elements so that any interested person could understand the technical issues.

- o Reviewing and updating seismic safety elements at least every five years and adding plans and procedures for post-earthquake reconstruction to them.

- o Providing more maps delineating areas of potential ground failure in urbanized areas and transmitting new ground-failure information to geotechnical professionals more quickly.

- o Presenting information in a form more usable to planners and regulators, and upgrading the inspection staffs of medium-sized communities.

- o Requiring local emergency response procedures as part of the seismic safety element, and requiring that the emergency response plans reflect the hazards identified in the seismic safety elements.

- o Making grading ordinances more effective regarding quality control in constructing and inspecting artificial cuts and fills.

VI. EVALUATING THE SHAKING HAZARD FOR REDEVELOPMENT DECISIONS

EARTH SCIENCE AND TECHNICAL INFORMATION

Current Status -- A wide range of approaches, some quantitative and others qualitative, exist for zoning urban areas for shaking hazards. A new technique recently applied to part of the Los Angeles basin yields maps of relative ground response for period bands applicable to buildings of different heights.

- o Engineers desire quantification of ground motion estimates, ideally expressed in probabilistic terms. Financial constraints in evaluating existing structures, however, commonly result in use of simple, "off the shelf" analyses of the shaking hazard.

- o The major geologic characteristics that influence ground amplification in the Los Angeles region have been identified from comparative measurements of ground motions at different sites. Amplification factors relative to shaking on basement rocks can be assigned to distinctive types of local geology.

- o Predictive maps of relative ground response in southern California are possible using the amplification factors and regional geologic and geotechnical data.

- o Certain modern structures such as "tilt-up" buildings, buildings with "soft" first stories, and long-span bridges may pose significant threats to life safety.

- o Unreinforced masonry bearing-wall buildings are the chief threat to life safety. Various engineering techniques to strengthen such buildings to resist shaking have been developed.

Future Directions and Needs -- Testing and comparison of methods to predict relative ground response will continue. Predictive maps should be made for other parts of southern California. Continued structural and safety engineering research is essential. Specific needs identified included:

- o Comparing the different shaking-hazard methodologies by application in the same demonstration area. Research to determine possible correlations between Modified Mercalli intensities and various instrumentally recorded parameters (for example, velocity) should be pursued.

- o Evaluating site response relative to peak acceleration, velocity, and displacement to help translate relative ground response factors into terms more useful to engineers.

- o Developing improved techniques for evaluating and strengthening existing structures, including building types other than unreinforced masonry. Hazards of nonstructural components of buildings should be investigated to a greater degree.

- o Improving methods for predicting damage and degradation of buildings and for developing building and lifeline inventories in southern California.

- Developing methods of incorporating all significant functional, economic, and loss-of-life parameters in a shaking-hazard model.

HAZARD-REDUCTION TECHNIQUES

Current Status -- More than 50,000 unsafe masonry buildings exist in California. California Senate Bill 547, signed into law in July 1986, requires local governments to prepare an inventory of unsafe buildings. Several cities have adopted or are considering the adoption of strengthening or removal ordinances to reduce hazards from unsafe masonry-bearing-wall buildings.

- In response to the 1985 Mexico earthquake, the City of Los Angeles has accelerated its existing program to strengthen or remove unsafe masonry buildings by 1992. A key factor has been the public's recognition of the hazards to life associated with unsafe masonry buildings.

- Although insurance companies may consider differences in shaking hazards, their decisions about coverage and price are affected by many other factors such as market penetration strategy, growth to obtain funds for investments, client accommodation, and competition.

Future Directions and Needs -- The huge inventory of potentially unsafe buildings will continue to be a significant problem for earthquake-hazard reduction. Research is needed in identifying buildings other than unreinforced masonry-bearing-wall buildings that may be unsafe; and in identifying hazards created by nonstructural elements. Other needs identified were:

- A better understanding of the relationship between the stiffness of horizontal and vertical elements, overturning action of walls, rotational/cantilever action of diaphragms, cord stresses of diaphragms, strength and ductility of existing structural elements, and isolation techniques.

- Better understanding of how people actually respond in earthquakes and how to lessen nonstructural and building content hazards.

- Developing more appropriate preparedness and response plans to facilitate recovery and reconstruction.

- Communicating hazard-reduction techniques to tenants and other building occupants as well as the building owners, and providing the public with information on preparedness, strengthening of buildings, and preventing of injuries inflicted by nonstructural components.

- Developing insurance- and lending-agency actions to aid in recognition and strengthening of unsafe structures.

WORKSHOP GOALS OF COSPONSORS

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WORKSHOP GOALS OF THE CALIFORNIA GOVERNOR'S OFFICE OF EMERGENCY SERVICES

William M. Medigovich

This workshop provides an opportunity for representatives from many disciplines, jurisdictions, and public agencies to review the most recent developments in the effort to understand southern California's seismic environment.

California's earthquake safety programs require cooperation among many disciplines and areas of expertise. Emergency management professionals must work together with colleagues in the earth sciences, engineering, architecture, planning, and building safety to understand as much as possible about our earthquake hazards.

Within the past twelve months, several events occurred that necessitated close dialogue, mutual understanding, and coordinated decisionmaking between the technical community and public safety officials.

First, reviews by the National and California Earthquake Prediction Evaluation Councils of research efforts in the Parkfield region resulted in the first validated earthquake prediction to be announced in the United States. Second, in June 1985, the Governor's Office of Emergency Services, the San Diego Office of Disaster Preparedness, and the U. S. Geological Survey reviewed assessments made after three magnitude 4.0 earthquakes occurred in the San Diego area, and issued a public earthquake advisory of possible additional seismic activity over the subsequent five-day period. Most recently, emergency officials have worked with professionals from many disciplines in evaluating the recent earthquakes that damaged Mexico City and the concomitant lessons for our own earthquake safety programs.

Each of these instances required a close working dialogue and mutual respect and understanding among disciplines. In many ways, the success of our future earthquake safety efforts depends upon ongoing exchanges among the groups of people assembled for this workshop.

The Governor's Office of Emergency Services is pleased to participate in this important workshop, and honored to serve as a cosponsor. We look forward to the presentations to be made at this workshop, and to the continuing of our mutual efforts to enhance the public safety of the residents of California.

WORKSHOP GOALS OF THE CALIFORNIA SEISMIC SAFETY COMMISSION

Wilfred Iwan

The California Sesimic Safety Commission is responsible for advising the state administration and legislature on matters of seismic safety policy. In that role, the Commission is vitally concerned about reducing the hazards associated with California earthquakes. We view this conference as a very important step in the formulating of seismic safety policy. We are particularly pleased to see the very broad spectrum of backgrounds of the individuals involved in this conference. We believe that it is only as seismologists, engineers, architects, social scientists, and those in government come together to discuss these matters that truly effective policy can be formulated. We also appreciate the fact that this is not just another technical conference where we will be presenting technical papers and telling each other about our latest equations. The focus of this conference is to determine what additional scientific and technical information is needed, and how that information will be applied to the earthquake problem. We are very pleased to cosponsor this workshop, and I am pleased to introduce the chairman of the Commission, Dr. Bruce Bolt.

Bruce A. Bolt

Thank you, Dr. Iwan. It is a pleasure to see such a large gathering interested in the reduction of earthquake hazards in California. Stimulated by the experience of the 1971 San Fernando earthquake, the California State Legislature and the Governor established the Seismic Safety Commission in 1975 to develop and guide State policy on all aspects of earthquake hazard mitigation in California. To further these goals, The Seismic Safety Commission holds hearings, issues reports, and drafts legislation. The Commission also has provided oversight for the critically important Strong Motion Instrumentation Project Program managed the trail-blazing Southern California Earthquake Preparedness Project (SCEPP) and San Francisco Bay Area Regional Earthquake Preparedness Project (BAREPP). I would like to mention two key new developments.

THE CALIFORNIA EARTHQUAKE HAZARDS REDUCTION ACT OF 1986

Senate Bill No. 548, approved by the Governor on October 2, 1985, establishes the California Earthquake Hazard Reduction Program, which is to be prepared and administered by the Seismic Safety Commission pursuant to its existing authority. The program will consist of a series of five-year plans revised annually, with the first to be submitted to the Governor and Legislature by September 1, 1986.

The establishment of this coordinated program is a step of major historical importance in the struggle to minimize the danger from earthquakes to California's population and economy. The program will specify priorities, funding sources, and resources needed to significantly reduce earthquake hazards statewide by January 1, 2000. This definite goal puts all parties in California on notice that serious steps towards earthquake hazard reduction must be completed in a finite time.

The bill addresses specifically, but not exclusively, the following:

- mitigation, including expansion of scientific and engineering studies (see below),
- preparedness, including critical facilities, disaster preparedness education, and prediction,
- response, including integration of Federal, State, and local plans, and improvements in the statewide communication system, and
- recovery, including military and financial issues for restoration of California's economy.

CALIFORNIA EARTHQUAKE ENGINEERING RESEARCH CENTER

The California Earthquake Hazards Reduction Act specifically gives priority to the improvement of design, and construction methods and practices for rehabilitation of hazardous buildings; to basic research of physical earthquake phenomena; and to expansion of scientific and engineering studies. At the same time, the National Science Foundation (NSF) has called for proposals for "A Research Center for Earthquake Engineering."

In response, a consortium of California universities, including the California Institute of Technology, University of Southern California (USC), Stanford University, and University of California at Berkeley, has proposed a California Earthquake Engineering Research Center. NSF funds, up to $5 million per year for five years, are available for a center, with the proviso that matching funds can be found from the state and elsewhere. At a presentation before the Seismic Safety Commission, Professor J. Penzien, University of California at Berkeley, defined the major objectives of the California Center as "the increased effectiveness of the overall seismic hazards mitigation program." In supporting remarks, Professor G. Housner, California Institute of Technology, stressed how the center would focus the efforts of a large number of researchers on essential problems and significantly upgrade the experimental equipment. He stated that "the center would mark a new era in earthquake engineering research."

I take the opportunity to ask for strong and universal support for both the California Earthquake Hazard Reduction Program and the California Earthquake Engineering Research Center. It is clear that the Seismic Safety Commission, and all others participating in this conference, are going to have a very busy time ahead, but at last we can break the back of the earthquake specter.

WORKSHOP GOALS OF THE CALIFORNIA DIVISION OF MINES AND GEOLOGY

James F. Davis

The California Division of Mines and Geology (CDMG) is a part of the California Department of Conservation which has had the opportunity to participate in the organization of this conference. My remarks will supplement what William M. Medigovich, of the Governor's Office of Emergency Services (OES), told you about state roles in terms of emergency response. As the earth-science organization of California government, we view the staff of OES, in a sense, as our clients. In other words, the CDMG feels that we have the responsibility to interpret the best scientific information we can obtain in the most meaningful way in order for the wisest decisions to be made by emergency response groups that are coordinated by OES. I think this is a tremendous responsibility, and the opportunity which comes from participating in a meeting such as this is truly unique.

- First, we have the background of the September 1985 Mexico earthquake. For those of us who sometimes become preoccupied with the aesthetic side of our activities, that event was a reminder of the tragic side of our work, as well as a clear message that some of the tragedy is certainly preventable. The challenge facing us is to try to mitigate similar tragic circumstances as much as possible.

- Second, we have a high-water mark of technical work --USGS Professional Paper 1360--that has produced the major publication that serves as a background for this conference.

- Third, we are looking forward--rather than back--on those technical accomplishments in the context of assembling a group made up of both users of scientific and engineering information, and the people who have the responsibility to produce it. I think that is the right combination, and the stage should be set for some new insights to be developed by consensus.

WORKSHOP GOALS OF THE SOUTHERN CALIFORNIA EARTHQUAKE PREPAREDNESS PROJECT

Anthony Prud'homme

The Southern California Earthquake Preparedness Project's (SCEPP) goal in co-sponsoring this workshop is to promote the utilization of earthquake hazards information. It is not enough for government to fund studies that identify the earthquake hazards in southern California and stop there. It is equally important that we know how to utilize such information for the purpose of reducing risks and probable injuries and damage.

With specific reference to the program of this conference, once we have evaluated the earthquake, surface faulting, and ground-failure potential of the region from a scientific point of view, we need to be sure that appropriate land-use regulations are actually applied to limit the potential for damage within the hazard zones identified. Otherwise, we will have gained little or nothing of tangible value from our scientific research and endeavors.

By the same token, successfully predicting seismic intensities for an area should provide a framework not only for estimating probable losses, but also, and more importantly, for estimating the type and quantities of resources likely to be required to ameliorate the effects of the earthquake on people and structures in those areas.

If an area's ground motion and shaking potential can likewise be predicted, building codes and retrofit regulations can be much more finely tuned than at present. This affords us the possibility of selective, and overall much less costly, hazard mitigation than the blanket codes and regulations we deal with today.

In actually reducing earthquake hazards, the element of time is just as important as knowledge of the terrain. If we know when an earthquake will strike, we can be far better prepared, and we can save far more lives, than is the case if we are caught totally by surprise.

The information on earthquake hazards and techniques for integrating scientific knowledge into specific preparedness plans to be presented at this workshop will make a major contribution toward SCEPP's goal of actual, practical hazard mitigation. We are, therefore, fully behind the objectives of this workshop. We look forward to your discussion. We have high expectations of applying in practice many of the ideas you will present.

As a member of the business and industry sector of southern California, I might add that the implications of having this information are as important to the business community as to government. In fact, I believe that the risk of potential damage and disruption to business and industry from a catastrophic earthquake is as great or greater than to any other sector of the community. I look forward to a productive two days resulting in advances in our earthquake hazard-reduction efforts.

WORKSHOP GOALS OF THE SOUTHERN CALIFORNIA ASSOCIATION OF GOVERNMENTS

Mark Pisano

On behalf of the executive committee and current president, Kay Ceniceros, of the Southern California Association of Governments (SCAG), I am pleased to extend both our appreciation and full cooperation in preparing and participating in this conference.

As one looks at the issue of earthquakes and catastrophic events, one begins to appreciate more fully man's relationship to the environment. That relationship is the key not only to self-reliance as an individual, but also to survival. Furthermore, it is the potential magnitude of a major earthquake in this region that really confronts that relationship. With this in mind, I recalled a discussion that I had several years ago with SCAG's then president Pat Russell, who is now the president of the City Council of Los Angeles. She told me that during an earthquake test at one of the national centers in which the City Council had participated, she arrived at the realization that an earthquake responder is the quintessential role for a local elected official. It is where men and women really to come to grips with this threat to their survival. Why did Pat Russell say that it is the quintessential role? How is that built into the response, and what is the role of local government?

Essentially, it is through the local community, cities, and neighborhoods, that we begin to understand the geology with which we're living, and that we can relate it to our own existence. If individuals are to respond to their environment, then they must be able to relate it to their day-to-day lives, and not as some abstract planning exercise or threat. What is needed is an actual internalization of "this is the environment I'm living in, and this is how I am going to cope with it under all circumstances." To that extent, the activities of local government, whether by the community plans that they prepare, or through community organizations that develop an understanding of the surrounding environment, will build into the public consciousness and subconsciousness what is going to be necessary in times of emergency.

Local governments are increasing their preparedness activities, and it is through the relationship with scientific, technical, and other communities that local governments, neighborhoods, and individuals are going to develop all the tools necessary to respond to a damaging earthquake event. Another observation is that in a region the size and complexity of southern California, we must clearly understand the faults and their relationships to our cities. Another factor that will be critical in our response is the fact that local governments are becoming

Transcribed and edited from audiotape.

interdependent. For that reason, SCAG has become increasingly active at a policy level and at a staff level. At a policy and staff level, that relationship is becoming crystallized with the Southern California Earthquake Preparedness Project (SCEPP) and the California Office of Emergency Services. We can in fact take the information that Tony Prud'homme of SCEPP mentioned in his opening remarks and implement it into the policy structure of SCAG as we prepare a regional development guide (an overall regional growth plan). These environmental plans and hazard information will help local governments and individuals come to a necessary understanding of what will be needed during the response period after a major earthquake.

I want to congratulate those who have organized this conference, and I want to underscore the one element that I think is critical in the deliberations of this conference: that the technical/scientific community is interacting with the policy-making and political leadership. It is absolutely critical; I laud the conference organizers; and SCAG wholeheartedly supports the conference.

WORKSHOP GOALS OF THE FEDERAL EMERGENCY MANAGEMENT AGENCY

Richard W. Krimm

I am pleased to be here and to participate in what promises to be a challenging and productive workshop.

I would like to take a few moments to describe briefly the National Earthquake Hazards Reduction Program (NEHRP) and the Federal Emergency Management Agency's (FEMA) role in this program in order to establish the context for a discussion of research that is being conducted, as well as research needs in the NEHRP.

Congress enacted the Earthquake Hazards Reduction Act in 1977, its purpose being the reduction of the risks to life and property in the United States from future earthquakes through the establishment and maintenance of an effective national program. The NEHRP brought together the earthquake-hazard related research programs, already well underway, of the U.S. Geological Survey (USGS), National Science Foundation (NSF), and the National Bureau of Standards (NBS) with the activities of FEMA to form an integrated and comprehensive Federal program. These agencies constitute the four principal agencies of NEHRP. Congress has designated FEMA as the lead agency for the NEHRP, with responsibility for developing, leading, and coordinating the program.

The five-year plan for the NEHRP, which was transmitted to Congress in January 1985, translates the purpose and objectives of the Earthquake Hazards Reduction Act into a program consisting of five major elements, and outlines specific goals and objectives for each element. These elements are the following:

1) Hazard Delineation and Assessment

2) Earthquake Prediction Research

3) Seismic Design and Engineering Research

4) Preparedness Planning and Hazard Awareness

5) Fundamental Seismological Studies

It is clear, as one considers the activities which make up these elements, that the NEHRP is heavily weighted towards research. In fact, of the program's $70 million budget in fiscal year 1985, approximately 74 percent, or about $52 million, is allocated to research and related studies. This statistic concerns me, as it suggests an imbalance of resources and priorities in a program Congress intended to implement activities to reduce the earthquake risk to life and property. I am equally concerned with the type of research being supported by the program -- is it relevant for the implementation of hazard reduction activities and how can it be made more so? If research is not thoughtfully and effectively translated into results which can be implemented by municipal, state and Federal government agencies, and the private sector, then it does not serve the goal of the Earthquake Hazards Reduction Act, which is the enhanced safety and welfare of the American people.

FEMA is acutely aware of the need for research to be readily applicable by those elements of society with the authority, responsibility, roles, and resources to carry out earthquake-hazards-reduction activities. FEMA's principal clients under NEHRP are state and local governments, which have the primary and ultimate responsibility for implementing (in terms of hazard reduction) the results of research performed by the other principal agencies of the NEHRP. For this reason, FEMA's earthquake program is designed to utilize these research results by supplying state and local governments with the tools and technical and financial assistance needed for them to plan for, mitigate against, respond to, and recover from earthquakes.

I suggest that the NEHRP may be undertaking too much basic research, and that research which is being conducted may not be as relevant as it should be to support implementation activities. It is my sincere hope that this workshop will be able to address and focus on at least my second point, and to use it as a theme throughout the discussion and deliberations of this workshop.

EARTHQUAKE RESEARCH SUPPORTED AT THE NATIONAL SCIENCE FOUNDATION

William A. Anderson
National Science Foundation

INTRODUCTION

The National Science Foundation (NSF)is one of the major participants in the National Earthquake Hazards Reduction Program (NEHRP) along with the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS), and the National Bureau of Standards (NBS). I was asked to provide a brief overview of NSF's earthquake research program. Our research program is divided into five categories in two different directorates.

ENGINEERING DIRECTORATE

Siting and Geotechnical Systems

This research addresses the fundamental engineering issues related to earthquake ground shaking and describes earthquake interactions on geologic structures including surface and subsurface soil and rock systems. The primary research areas are strong ground motion, stability of geotechnical systems, tsunami systems engineering, and lifeline systems.

Structural Systems

The purpose of this research is to develop the capabilities to predict the behavior of structures during earthquakes, establish practical guidelines and methods for engineering design against earthquake loading, and provide economically feasible methods to strengthen existing hazardous structures. Some specific research areas are dynamic non-linear systems, new and reliable design methodologies, computer simulation, knowledge-based computer systems, damage-assessment methodologies, and lifeline systems.

Architectural and Mechanical Systems

Research is conducted on architectural and mechanical components and systems whose failure during an earthquake could result in serious loss of life, damage, economic losses, and disruption. Examples are architectural and mechanical components in buildings such as glass and exterior cladding, elevators, building mechanical systems, power generation and transmission facilities, building contents, communication systems, and masonry structures in which architectural and structural systems may be integral. Motion mitigation systems such as dampers, active control systems, and base isolation devices are also considered.

Earthquake Systems Integration

This category of research supports research and related activities for the integration of knowledge-producing and knowledge-using systems. Key areas of research include: earthquake mitigation planning; earthquake preparedness planning; impacts, recovery and reconstruction; and technology delivery.

ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES DIRECTORATE

Fundamental Earth Sciences

This research develops the fundamental understanding of the tectonic conditions necessary for earthquake occurrences and provides a framework for earthquake prediction and hazard evaluation. Areas of research include plate tectonics, crustal structure, seismology, crustal deformation, and volcanism and landslides related to earthquakes.

EARTHQUAKE PREDICTION AND HAZARDS EVALUATION IN THE YEAR 2000

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EARTHQUAKE PREDICTION AND HAZARDS EVALUATION IN THE YEAR 2000 -- A DIALOGUE [1]

Clarence R. Allen, California Institute of Technology
and
Richard A. Andrews, California Governor's Office of Emergency Services

INTRODUCTION by Walter W. Hays, United States Geological Survey

Decisionmakers have different perspectives about geologic hazards than scientists and engineers. These differences, which have been summarized by Szanton (1981, table 3-1)[2], are the reasons that implementation of loss reduction measures are difficult. The differences are:

- The ultimate objective of the decisionmaker is the approval of the electorate; it is the respect of peers for the scientist/engineer,
- The time horizon for the decisionmaker is short; it is long for the scientist/engineer,
- The focus of the decisionmaker is on the external logic of the problem; it is on the internal logic for the scientist/engineer,
- The mode of thought for the decisionmaker is deductive and particular; it is inductive and generic for the scientist/engineer,
- The most valued outcome for the decisionmaker is a reliable solution; it is original insight for the scientist/engineer,
- The mode of expression is simple and absolute for the decisionmaker; it is abstruse and qualified for the scientist/engineer, and
- The preferred form of conclusion for the decisionmaker is one of "best solution" with uncertainties submerged; it is multiple possibilities with uncertainties emphasized for the scientist/engineer.

With these principles in mind, let us now turn the clock forward to the year 2000 and a discussion between a decisionmaker and a scientist as they seek to resolve their philosophical differences and reach solutions to problems of earthquake-hazards reduction.

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1 Transcribed, condensed, and edited from audiotapes.

2 Szanton, Peter, 1981, Not well advised: Russell Sage Foundation and The Ford Foundation, New York, 173 p.

Richard Andrews: I became involved in the earthquake business about four-and-one-half years ago. Literally the first day I worked in this business after 14 years as a professor of history, I attended a cocktail party that was held in West Los Angeles where a number of people were gathered to inaugurate the beginning of an earthquake task force in the state of California. A comely young lady came up to me and said, "You realize, of course, that earthquakes are Mother Nature's way of crying out for love." Having dismissed that comment, I thought we had made considerable progress in earthquake-hazards reduction efforts here in California during the past four-and-one-half years. However, in the aftermath of the 1985 Mexico earthquake, many emergency services workers here became subjects of great media attention. One Friday afternoon, a colleague and I had the pleasure of appearing on a mid-afternoon television talk show before a live audience. We were last on the program, following Prince and Michael Jackson look-alikes, Melissa Manchester, Redd Foxx, and a break-dancing act. We then had the pleasure of telling the audience about all the death and destruction facing southern California in a major earthquake. It was then that I thought back to the young woman's comment at the cocktail party, and wondered if we truly had made any progress in the past four-and-one-half years.

What I would like to do very briefly is to provide an overview of where we are and where we might be going in this business that we're collectively involved with. I returned recently from Mexico City. One of the major lessons I came away with from that experience was that the problems the Mexican government and people encountered in that tragic series of events were compounded by the difficulty of various systems of government and various disciplines knowing how to talk to one another. In some cases it was literally the problem of physically not being able to talk to each other, but more importantly it was a problem of really not knowing what the other one was saying. I think conferences like this workshop are very important to bridge that gap so that we do learn to talk to one another. As Bill Medigovich, the director of California Office of Emergency Services, said this morning in his opening comments, we need mutual respect among the disciplines. There is need for an early dialogue in which the users of geotechnical information help define what the information needs to be.

In California, the fundamental problem we face is simply the issue of time. All of the discussions that we've had today could be much more informed if we knew what time frame we were talking about. How quickly do we need to apply the information that we have? Do we have five years, five days, or five hours before an event occurs here that is on the scale we have talked about. In the absence of that basic knowledge, we are left with a high degree of uncertainty that causes much impatience. Those of use who are involved in the policy side or the emergency response side of earthquake hazards reduction get very impatient with some of the debates that go on. In part that impatience is the consequence of two different systems -- the academic research system colliding with people who are involved in emergency response and in direct life-saving activities.

It's important to recognize that we have made great advances, particularly in awareness. If the big earthquake happens tommorrow, there will be fewer people in southern California surprised that it happened than would have been surprised four-and-one-half years ago. I think we have convinced people that this is inevitable in our future, but beyond that again the question is time.

Unquestionably, the research that has been carried on over the last decade has helped narrow that focus of time, but we are still left with a high degree of uncertainty. In California there have been unprecedented levels of commitment to the earthquake program. Just in the last 15 months, Governor Deukmejian has signed legislation appropriating over 2.5 million dollars for previously non-existent programs in the area of seismic safety. It's clear that there is a commitment by both the Governor and the Legislature to seismic safety. If I was asked what would have the greatest impact in the short run for managing an earthquake disaster in California, I think it is the emergency response phase. After reviewing the events in Mexico City, I don't care how good a communications system we have or how rapidly we respond. If we have thousands of people trapped in large buildings, no matter how effective our search and rescue efforts are, we are not going to save a lot of those people. In the long run, the way we're going to save people is through building safe structures. We know how to build earthquake-resistant buildings. The question is simply: who should do it and who should pay for it? Once we resolve these problems, we'll be along the way towards creating an earthquake-resistant environment.

A little bit about earthquake prediction. The only way we're going to make advances in earthquake prediction is to continue the dialogue we're undertaking here today. We must learn how to understand and to have mutual respect for one another. I think for the scientific community there is a tremendous challenge in learning how to deal in the public arena, and learning how to deal with real-time geology and real-time seismology. It's a very different situation than dealing with the research laboratory or dealing with scientific exchanges with colleagues. We've made some progress in that area, but we need to learn from every experience that comes along, from things like the Parkfield prediction and from the San Diego earthquake-warning experience we had in June, 1985. In spite of all the denials by scientists that we can predict earthquakes, I walk in on a Tuesday and someone hands me a paper and says, "Guess what, the USGS thinks there's an increased probability that over the next five days there may be an earthquake of damaging potential in the San Diego area." At that point, all the probabilistic statements go out the window and you're forced to deal with a real situation. It was in part only because of the relationship that had been established between the emergency managers in California and the scientific community that we were able to work our way through.

I think we need to continue to talk to each other, I think, though, we do need to change the order. It's not simply that we are the users of the this information, I think we are also the ones who need to define the direction to go. After all, the name of the program is "The Earthquake Hazards Reduction Program" not the earthquake research program. The name of the game is saving lives, not simply doing eloquent papers.

Clarence Allen: I am going to try to hit two topics in the next few minutes. First of all, where are we likely to be in the year 2000 in terms of the scientific effort in earthquake hazards reduction, and secondly, what are the difficulties and the frustrations that we have as scientists in our interactions with users? One thing that impresses me is that the year 2000 is not very far away. It's only 15 years; I might still be here. If we had asked, "What might be the status of hazard reduction in 100 years?" it would be much easier to answer. I could then wave my arms about prevention and control and all sorts of intriguing possibilities, but for the next 15 years, I think we're forced to be somewhat more realistic and more practical in what we think might actually happen in that relatively short time period.

Let's look back 15 years and see what the next 15 might hold in store. Where were we in 1970? Well, partly because of the fact that the 1971 San Fernando earthquake hadn't yet happened, I think there was far less general concern among the populace in the United States than there is today about earthquake hazards. The 1964 Alaskan earthquake had indeed been a major disaster, but somehow that didn't come as close to home as an earthquake in a metropolitan area such as Los Angeles.

In 1970, interest in this country was increasing in the field of earthquake prediction. Some very intriguing results had come out of Russia that were well known at that time. Many of you will remember the Vp/Vs controversy. I think it's safe to say that we were just beginning to get a real interest in earthquake prediction, but that it wasn't yet a major scientific effort. The USGS professional paper on the 1968 Borrego Mountain earthquake was in preparation in 1970, and one very significant chapter by Malcolm Clark and others described a trench excavation across the Coyote Creek fault that was used to infer slip rates and, under certain assumptions, recurrence intervals of earthquakes.

In 1970 the communication between scientists and engineers, and with the user groups, was minimal as compared to what we have today. A meeting such as this workshop was almost unheard of at that time. A lot has happened in the 15 years since 1970, and I see no particular reason why the next 15 years should not be equally productive. A lot more people are working on the problem than there were 15 years ago, including many from industry. Indeed many of the most significant fundamental contributions to our scientific understanding of earthquakes and hazard evaluation have come from people in the consulting geotechnical and engineering communities. Moreover, earth scientists are working together with the engineers far better today than we were at that time.

Where are we going to be in the year 2000, only 15 years down the line? I think that we're going to find that earthquake prediction in the medium- or short-term sense -- which is really what the term "prediction" means to the public -- will not be a routine procedure by the year 2000. We hope we will have made major progress, but I simply don't visualize that we will be routinely predicting damaging earthquakes by that time.

By the year 2000, another Parkfield earthquake should have occurred. I think the whole future of the prediction research program is going to depend to a significant degree on what happens at Parkfield. A very major effort is being made there. We will have very good instrumentation in that area and I think that the experiment is going to be critical. If the earthquake is really preceded by precursors -- even if they're recognized only in retrospect -- a very significant boost to the earthquake prediction program will occur. However, if the earthquake is not preceded by physical precursors, which is certainly a real possibility, we may instead be turning a greater proportion of our effort toward hazard evaluation. So, I would emphasize that the Parkfield experiment is very critical, and we must be very honest in our evaluation of it. If the earthquake occurs, and we in fact see no physical precursors, I think we will have to reconsider the possibilities of realistic predictions in other earthquake-prone areas during the coming years.

I think we're going to find by the year 2000 that geodetic measurements are of greatly increased importance, not only in terms of possible prediction, but in terms of hazard evaluation. The implementation of new systems such as the Global Positioning Satellite (GPS) is going to revolutionize geodesy. We'll have a much better idea 15 years from now of what kinds of deformation are taking place within the State, not only short-term deformations that might be precursory to individual earthquakes, but long-term deformations that might be telling us what parts of the State are the most dangerous in terms of strain that is slowly building up. I think we are going to find that geodetic measurements will be a more important part of our scientific program than they are now, largely because of improvements in instrumentation.

Furthermore, I think we're going to find, as we've already seen in the last two or three years, an increased reliance on probabilistic approaches, and not just those that depend on a and b values from historic earthquakes. These probabilistic approaches will depend very heavily on other kinds of relevant data such as geologic deformation rates and paleoseismicity. Paleoseismicity studies will have multiplied manyfold, and maybe by that time we'll even understand why the 1886 Charleston, South Carolina, earthquake occurred. By the year 2000, further disastrous earthquakes will have hit the United States. Although probably the "biggie" on the San Andreas will not have occurred yet, we can say that two or three magnitude 6 or 6-plus earthquakes will probably have occurred in the southern California region, and one or two of those probably will have occurred in the metropolitan areas of Los Angeles, San Bernardino, or San Diego. I also predict that at least one or two of these earthquakes will come as a complete surprise to the geologists and the geophysicists and will have occurred in an unexpected place, at an unexpected time, and in an unexpected way -- in somewhat the same manner as the 1984 Coalinga earthquake surprised us.

Let me turn now to some of the problems that we as scientists face in interacting with the users. One of these is the rather surprising speed with which the disaster preparation people have leapt upon the possibility of earthquake prediction, even though the scientists are still far away from that ultimate objective. Now I appreciate that we as scientists have to bear some of the guilt. Perhaps we oversold the program to you people. Yet, we are surprised that people are gearing up to respond to an earthquake prediction when we're really not very close to making realistic scientific earthquake predictions in most areas. Secondly, I think we're a bit frustrated at the willingness and even the eagerness of the public, the press, and even some government agencies to accept alleged earthquake predictions from some questionable sources. Again, we're not without guilt in our dealings with the news media and with the public, but this is an area where we feel very uneasy and a have certain sense of frustration. Thirdly, I think we're a bit unhappy with the lack of understanding or even sympathy towards probabilistic kinds of statements. I remember several years ago a dam owner telling me: "Don't give me all this nonsense about 'probabilities and acceptable risk', just tell me whether the dam is safe or not." Well, I wish that the world were that simple. I think the increasing trend towards probabilistic approaches is indeed very valuable, although Dick Andrews might disagree with this.

Another area of frustration for us, to be very blunt, is the absence of stability in the disaster preparation agencies, which seem to be political footballs whose ranking people come and go with the tides of political change. I'm not sure any of us know the answer to that problem, but trying to deal with the rapid turnover in governmental agencies certainly has been an area of some frustration.

Fifthly, and I suspect Dick Andrews would agree with this, is the lack of response from the community despite our repeated warnings. Just how many times do we have to repeat that the San Andreas is capable of a large earthquake? I've lived here since 1930, and I've heard this statement repeatedly since that time, yet we still have people saying, "Oh, the San Andreas is a dangerous fault? Why didn't you tell us?"

Finally, I'd like to close with a question for Dick Andrews. For those of us in the scientific community, it's really not completely clear what type of scientific information on earthquake hazards is of the greatest use to the public. Let me just ask this question. The newly published USGS Professional Paper 1360 speaks of a magnitude 6.5 earthquake on the Newport-Inglewood fault as being of serious concern to the Los Angeles area. Dick, which would be more valuable to the user community: a valid prediction of a magnitude 6.5 earthquake on the Newport-Inglewood fault at a specific place next week, or a valid probabilistic statement of its likely occurrence during the next 50 years? Those two scenarios aren't necessarily mutually exclusive, but to some degree they represent different avenues of our research.

Andrews: Being one of those short-time political people from a disaster preparedness agency, I'll ask for the short-term prediction!

I think that Clarence has raised many good points. The year 2000 is not very far away and to acomplish anything in the way of significant hazard reduction in southern California, or in the state of California, or even across the United States we're going to have to inaugurate additional programs now. I think the whole issue of probabilistic statements for expressing earthquake potential to the public is one that we need to approach through trial and error. In the San Diego experience, the final public announcement said that one in 20 sequences like the one that occurred the night before have resulted in a damaging earthquake. We thought this was a marvelous way of getting around the uncertainty of saying 5 percent -- 5 percent of what? Then we had a session in San Diego with the various people there who were involved with the issuance of the prediction and one man from the media said "Who ever came up with that stupid idea saying one in 20 historical incidences? Why didn't you say 5 percent? Everybody understands that." The whole issue of how the statements that we make to the public are expressed is one we really need to approach carefully.

One of the things I think is most frustrating for people involved in public agencies at any level is the difficulty of having to choose among the experts at a time when the decision needs to be made. It is frustrating to poll seven or eight seismologists and to get different opinions about what may be going on. I think the scientists need to recognize that they are dealing in a public arena with something that is of much greater consequence than simply the respect of their colleagues: namely the life and safety of the people of California. We need to be closely coordinated on any kind of future predictions that are made. It's just not good to have one group of scientists saying that "Yes, it is going to happen with this kind of probability" and to have three or four other scientists quoted the same day in the paper disputing this conclusion. I think that undermines the entire effort that we're involved in.

Over the next 15 years I think the major thing we need to pay attention to, in addition to improving our response capability, is dealing with the thousands of hazardous structures we have in California. We need to develop a cost effective way to begin to retrofit these and we need to begin to recognize that it is fundamentally a political problem, not a technical problem, that we are dealing with. We clearly have enough information to significantly reduce the earthquake hazard here in California. Scientists need to recognize that their responsibility doesn't simply end with doing research, but that they need to participate in providing testimony to legislatures and they need to speak with a clear voice. I know that this goes against the grain in many ways of what the academic and research community is all about, but for too long some members of the earthquake research community have enjoyed being prophets without honor. They enjoy sitting in their rooms and saying, "Nobody pays attention to us and we really know what to do." Instead they need to be exposed to the light of day or to the glare of television cameras. I would emphasize that we need to go forward together in this enterprise. Clarence Allen pointed to the frustrations with regard to disaster preparedness and the fact that emergency managers have grabbed onto earthquake prediction. We're guilty of some of that, but from the public safety standpoint, earthquake prediction is not a research activity but an operational reality. We need to approach it from that standpoint and go forward together.

Allen: Dick, one of your charges is that the scientists don't have their act together and that various people are saying different things to the detriment of the rest of the community; certainly this has sometimes been true. I might point out that the people in academia have an advantage over those in government. Whenever somebody in government speaks at almost any level, the public somehow assumes that that person is speaking for the government. Everyone knows, however, that when a professor speaks, he's not representing anybody, and this has led to a certain amount of irresponsibility on the part of people in academia making statements, as I emphasized in my presidential address to the Seismological Society of America in 1975. Earthquake prediction represents a very special area, and if one wants to stick his or her neck out, then he or she then has an obligation to defend himself or herself in public. It's quite different from other scientific endeavors. Nevertheless, earthquake prediction is still in a research phase. No one in the world claims to have an earthquake prediction scheme that's operational and reliable. Thus, it's inevitable that scientists are going to have different opinions and, in our society, we think that's good. That's the way progress is made: by competing opinions, theories, and hypotheses.

Let me ask you this, do you think the Japanese have their act together better in the Tokai prediction than we do, and should we try to emulate them?

Andrews: Yes, I think they do. In the Tokai area they have a special situation in some ways comparable to Parkfield. They have identified what they think will be the site of a large earthquake and precursors that will only be manifested in the short term before the event. Whether in fact that will happen or not, we don't know yet. But in terms of organizing and managing the earthquake prediction effort, I think they do have their act together. It is impressive to travel around Japan and talk to people who are involved in the prediction program. They all seem to understand how it is supposed to work if they begin to get anomalous behavior indicated on the instruments. In contrast, I think that if we went around this room and asked people to explain the functions of the National and the California Earthquake Prediction Evaluation Councils, fewer than 50 percent of the people could provide a very clear answer as to what their roles should be.

Allen: Let me give a somewhat less optimistic point of view on the Japanese effort. In the first place, we have to recognize that the Japanese are putting much more money into earthquake problems than we are. Clearly, the problem is more important in Japan than in the United States. But I think the Japanese scientists may be sticking their necks out a bit too far in the case of the Tokai prediction. They've identified only one area for an impending earthquake, and this is where virtually all the effort is going. I would be willing to predict, on the other hand, that the next major earthquake in Japan is not going to be in the Tokai area. I think that their scientific community and their political leaders are likely to find themselves in some trouble as a result. Although scientists in Japan may appear unified, I'm not sure that's entirely desirable. I would argue that the various voices we are hearing in this country on the prediction problem, as well as on other aspects of hazard reduction, are in fact beneficial to the long-term solution of the earthquake problem.

Andrews: Let me ask you a question, Clarence. What would you say is the responsibility of an individual scientist in the event that there is a statement from the California Earthquake Prediction Evaluation Council regarding a consensus that's been reached about an event that's expected within 10 days? What is the responsibility of other members of the scientific community. Should they comment on that publicly? And what role do you think they should play?

Allen: Well, I agree that they have to be very careful. The memberships of both the State and the National councils have been chosen to represent a wide spectrum of scientific opinion. If those councils come out with a judgement that represents a relatively unanimous opinion, then I think scientists have to be very careful in the statements they make. On the other hand, I see no reason for not offering criticism. I don't think it's necessarily irresponsible to offer criticism providing one does it in a way that allows one's opinions to be tested publicly. But I would certainly agree with you that once there seems to be a consensus, then one has to be careful as to what one says.

I'm intrigued by your response that the magnitude 6.5 prediction will be better than the probabilistic statement. I'm not really sure I agree with you. I think that from the point of view of building codes and land-use planning over the next 50 years along the Newport-Inglewood fault and the adjacent parts of Los Angeles, a correct probabilistic assessment of what's going to happen on that fault in the next 50 years might be more beneficial to the citizens of this city than the prediction of an event two weeks from now, which is going to be hard to prepare for anyway.

Andrews: Again, I think we come down to a basic conflict of responsibilities to the many thousands of people that may be killed in that magnitude 6.5 event on the Newport-Inglewood fault. I think that the only thing they would be reminded of is the economist's statement that in the long run we are all dead anyway. In the short run, it is the problem that we would need to focus on and if we're talking about an event that could result in 35 or 40 billion dollars in property losses and tens of thousands of people being killed I think that, again, I would bet on the short-term prediction even recognizing that it would create tremendous problems.

Allen: How is the prediction going to save that 35 billion dollars?

Andrews: It's probably not.

Allen: What is the value of two week's lead notice?

Andrews: It will save lives; it has the potential of saving lives.

Allen: On the other hand, the long-term prediction might well save a large part of that 35 billion dollars, as well as many lives in the future.

Andrews: I hope that those aren't the type of binary choices that we're facing in all of this. Again I would say a 50-year probabilistic statement in some ways begs the fundamental question.

Allen: It's not really a choice of one to the exclusion of the other. The scientific efforts we're making towards trying to predict earthquakes are based upon identifying physical precursors for short- and medium-term predictions. In terms of hazard evaluation, we're looking at sequences of past earthquakes and probabilistic approaches. So to some degree the choice we have to make is about where to spend our money: how much should be put into earthquake prediction versus hazard evaluation? I think this is a serious and difficult question.

Andrews: If I had to make the choice it would be on the development of those kind of data that can help us in the long run reduce the overall seismic hazard. Earthquake prediction alone is not going to help solve the complex problems that are involved in seismic safety in California or elsewhere. I don't think our debate should be over how we divide up what is already a very small pie. We ought to be making a case of why we need to increase the overall level of effort and resources that are devoted to this problem. Many resources have to come from here in California because the problem is both a State problem and a local government problem. I think we have taken steps in the last few years to provide a certain kind of independence in California for the programs that we're involved with. And we need to continue that because I don't think the earthquake solution can be driven solely by Federal priorities and Federal funding.

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EARTHQUAKE PREDICTION AND HAZARDS EVALUATION IN THE YEAR 2000 — DISCUSSION

This session was moderated by Walter W. Hays. Those commenting were Clarence R. Allen, Richard A. Andrews, Valerie R. Kockelman, Anthony Prud'homme, James E. Slosson, James J. Watkins, Edward M. O'Connor, Rachel M. Gulliver, Gary C. Hart, and others who were not identified. The following was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Valerie Kockelman thought that the public should be made aware of any earthquake prediction, thereby being given a choice about what actions to take. Allen agreed, suggesting that scientific predictors take a realistic point of view: if they tried to keep a prediction secret, that would almost guarantee that it would not be a secret.

Prud'homme expressed concern that the dialogue had focused almost exclusively on earthquake prediction, and called for more attention to preparedness planning. Given that there will be a major earthquake in southern California, concerted efforts should be made throughout the community to deal with hazardous buildings, nonstructural hazards, and emergency planning. Prud'homme felt that earthquake prediction was almost irrelevant, and that the focus should be on retrofitting buildings and educating the public about the inevitable earthquake.

Andrews noted that the focus on prediction arose from the topic he was asked to address, but in general agreed with Prud'homme about a comprehensive, balanced approach to the earthquake problem. Andrews felt that the basic issue is the question of time, and quoted Paul Flores: "Quite simply, in Mexico City, the preparedness time ran out." Andrews described the phased approach to earthquake preparedness, noting that constructing earthquake-resistant buildings is a long-term solution. In the interim, however, cost-effective ways must be found to reduce the loss of life and property. Perhaps earthquake prediction fits into the interim strategy of preparedness.

Allen argued that recognizing the earthquake threat and preparing for it is not the whole answer. Engineers need to know which earthquake (magnitude, intensity, and local geology) to incorporate into their designs. For example, in the cases of the Diablo Canyon and San Onofre nuclear power plants, strong earthquake shaking has been designed for. The problem becomes one of designing those plants for appropriate levels of public safety. The appropriate level of shaking for that particular design is determined by geotechnical investigation.

Slosson noted that political perceptions about earthquake prediction were used to resist the implementation of a building strengthening ordinance for the City of Los Angeles. Because earthquake prediction technology seemed imminent, politicians argued against moving rapidly on the proposed ordinance on the basis that evacuation was less costly than strengthening. Slosson saw reliance on prediction technology by politicians as an excuse for not making unpopular decisions.

Watkins noted scientists have forecast a probable catastrophic earthquake in southern California within the next 20 to 30 years, yet public officials are not taking appropriate action. Therefore, neither earthquake predictions nor probabilistic statements seem to be the proper motivators for comprehensive preparedness.

Allen suggested that the 1985 Mexico earthquake did motivate action in southern California. It was no accident that the Huntington-Sheraton Hotel in Pasadena, California was declared unsafe shortly after the Mexico earthquake. Also, a report on hazardous buildings on the University of California at Los Angeles campus was released, and the building strengthening program of the City of Los Angeles was accelerated immediately after the Mexico earthquake.

Andrews also expressed optimism about the political process with respect to earthquake safety. Although not all earthquake-safety-related bills presented by the California Legislature have been signed into law, none have been dismissed out of hand, and most of the unsuccessful bills were not signed for very good reasons. Andrews felt inactivity on the part of local government in earthquake preparedness was abetted by difficult political and economic issues. Andrews thought that programs to strengthen buildings would be more successful if there were a clearer indication of the time available before the next potentially catastrophic earthquake. A high degree of uncertainty about the time of its occurrence, with some projections placing it as far in the future as year 2225, obviates political or economic reasons to take rapid action on strengthening or rebuilding programs.

Allen, referring to Slosson's comments, agreed that politicians might rely on earthquake prediction as an easy solution to their preparedness problems. To some degree, however, scientists are responsible for that attitude because they were unduly optimistic a decade ago about predicting earthquakes. Currently, if scientists were to go before governmental bodies and say earthquakes cannot be predicted, it would be difficult to get those officials to believe them.

An unidentified participant expressed great concern about the consequences of predicting an earthquake that does not occur. Politicians do not look forward to being involved in the disruptions resulting from an earthquake prediction for a populated area. The consequences of possible evacuation, suspended economic activity, and similar problems may prevent politicians from taking strong, concerted action.

O'Connor speaking from his experience as a pioneer in prompting the strengthening of existing buildings, urged the scientific community to press for strengthening programs. Otherwise, decisions about strengthening are commonly left to the building official, who might not be willing to take the pressure of forcing owners to strengthen or rebuild their properties.

Gulliver asked about the prospects for dealing with hazardous structures other than unreinforced masonry buildings. These include tilt-up buildings, mid-rise reinforced concrete structures, structures with "soft" first stories, and certain single-column bridges.

Hart replied by referring to improperly framed 6- and 12-story buildings. In practice, Hart found that building owners generally will not review the earthquake safety of their buildings unless forced to do so by law. Hart recommended that the law require building owners to have earthquake-hazards reports prepared for their buildings, and that these reports be made public. If a report is prepared, and is not made public, then the effectiveness of that report is lost. The procedure is mainly a political one, and it should somehow be applied to all major construction types mentioned by Gulliver.

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I. EVALUATING EARTHQUAKE AND SURFACE-FAULTING POTENTIAL FOR HAZARD-REDUCTION ACTIONS

I. EVALUATING EARTHQUAKE AND SURFACE-FAULTING POTENTIAL FOR HAZARD-REDUCTION ACTIONS [1/]

Working Group Moderator:	Bruce A. Bolt
Plenary Presenter:	Joseph I. Ziony
Working Group Presenters:	Lucile M. Jones Kerry E. Sieh Earl W. Hart Robert B. Rigney
Working Group Panelists:	Arthur C. Darrow Steven Sokol James E. Slosson Egill Hauksson
Working Group Commentator:	Cliffton H. Gray, Jr.
Audience Participants:	George Stolt Gary S. Rasmussen Jeffrey A. Johnson Gilbert Dewart

[1/] Names and affiliations of all participants are listed alphabetically in Appendix A.

EARTHQUAKE AND SURFACE-FAULTING POTENTIAL IN SOUTHERN CALIFORNIA— CURRENT KNOWLEDGE AND MAJOR UNRESOLVED QUESTIONS

Joseph I. Ziony
United States Geological Survey

INTRODUCTION

To avoid or to accommodate the destructive effects of earthquakes in the metropolitan areas of southern California, planners and engineers must know which faults are likely to slip suddenly and what the results of such movement will be. Information needed includes estimates of the location of potentially active faults, their relative activity, the size and frequency of damaging earthquakes expected along them, and their potential for rupture at the Earth's surface.

Considerable progress has been made since the late 1960's in developing methods for estimating earthquake and surface-faulting potential from studies worldwide of major historical earthquakes and of the recent geologic histories of active faults. Concurrently, intensive efforts by geologists and seismologists to map and evaluate the earthquake-generating structures in southern California have created a substantial data base that can be used to relate earthquake occurrence to the geologic framework. As a result, our abilities to evaluate the earthquake and surface-faulting potential for southern California are much better developed than for most other earthquake-prone regions of the United States. Many significant scientific questions, however, remain to be answered before more accurate assessments can be made for the region.

SEISMOTECTONIC FRAMEWORK

Knowledge of the relation between earthquake generation and the geologic framework is fundamental to understanding the potential for future earthquakes. Several seismotectonic models have been proposed for southern California, that are in general agreement about the basic plate-tectonic mechanism operating in the region. Yerkes (1985), for example, provides a recent synthesis that places earthquake generation in southern California within the context of a broad boundary between the Pacific and North America crustal plates. Continuing deformation along that boundary, caused by north-south compression derived from relative motion of the plates, is expressed by right-lateral strike slip on the vertical faults of the northwest-trending San Andreas fault system and by reverse or reverse-oblique slip along the east-trending inclined faults principally within the Transverse Ranges. Current earthquake activity is associated with both systems of faults.

Earthquakes in southern California generally occur within the upper 10 to 15 km of the crust, but there are some significant exceptions. Corbett and Hearn (1984), among others, have shown that the base of the seismogenic layer may be as deep as 22 km along parts of the south front of the Transverse Ranges. Earthquake epicenters north and south of the Transverse Ranges commonly form dense alinements coincident with many of the faults of the San Andreas system. The alinements are most pronounced for the San Jacinto fault, and, to a lesser degree, the Whittier-Elsinore and Newport-Inglewood zones. The pattern of epicenters indicates the distribution of slip on the vertical faults that compose the active plate boundary; this boundary zone is about twice as wide south of the Transverse Ranges as it is to the north, possibly because of some east-west extension south of those ranges (Yerkes, 1985). Within the Transverse Ranges, in contrast, the pattern of seismicity is much more diffuse and complex and can only locally be clearly associated with mapped surface faults. Earthquake fault-plane solutions, from which the sense and orientation of seismogenic fault slip can be derived, generally agree with what is known about the Quaternary slip histories of the major faults in the southern California region; fault-plane solutions and geologic data, however, are discordant for the eastern Transverse Ranges (Webb and Kanamori, 1985).

Several major issues that are important for better understanding of the regional seismotectonic framework need resolution: (1) The location, nature, and kinematics of the boundary between the Pacific and North America plates below the seismogenic layer. Is the plate boundary offset northeastward from the trace of the San Andreas fault in the western Mojave Desert? How are the deformations transmitted to the seismogenic layer? (2) The configuration and thickness of the crustal and lithospheric plates beneath the Transverse Ranges. Is there large-scale detachment faulting beneath the ranges? Is there subduction (downwelling) of the Pacific mantle lithosphere as proposed by Bird and Rosenstock (1984)? (3) The detailed interaction between Transverse Ranges and San Andreas system faults. For example, how are the Newport-Inglewood zone and the Santa Monica fault mechanically coupled? Is segmentation of the Transverse Ranges frontal fault system controlled by spacing of the San Andreas system faults to the south? Answers to these questions will require thoughtful synthesis of available geologic, geophysical, and seismologic data sets and application of new geophysical research methods (for example, high-energy reflection and refraction seismic profiling, or tomographic inversion of teleseismic data). Continued geologic mapping to provide additional insight into the evolution of the regional structural framework is a necessity.

LOCATION OF POTENTIALLY ACTIVE FAULTS

The geologic and seismologic character of southern California faults has been intensively studied during the past two decades. As a result, most of the likely sources of future major earthquakes and surface faulting have been identified and delineated for the onshore region. In the Los Angeles region alone, 95 faults active in the late Quaternary time have been identified and their general characteristics are reasonably well known (Ziony and Yerkes, 1985, fig. 11 and table 5). Geologic strip maps at scales of 1:24,000 to 1:12,000 have been published by the California Division of Mines and Geology (CDMG) and the United States Geological Survey

(USGS) for nearly all the principal Quaternary fault zones. Regional earthquake catalogues, epicenter maps at various scales, and summaries of fault-plane solutions associated with specific faults are available (see Yerkes, 1985, for the principal sources of seismologic data for the region).

The distribution of Quaternary faults onshore is known reasonably well, but continued field studies are necessary to refine estimates of the ages of the most recent surface rupture along the different strands of each fault zone. Careful documentation of the location and distribution of Holocene strands are especially important in evaluating earthquake potential. Recent discovery of Holocene faulting in downtown San Diego (Testing Engineers--San Diego, and others, 1985, unpublished report)--the first in more than a decade of detailed mapping and trenching of Quaternary faults in the San Diego area--demonstrates that the search for and documentation of Holocene activity along suspect fault zones should be an ongoing effort. The potential activity of many fault strands exposed solely in Tertiary or pre-Tertiary bedrock remains to be assessed.

The 1983 Coalinga earthquake demonstrated that seismogenic slip can occur along faults that do not completely penetrate the sedimentary rock cover. Undiscovered potentially active faults, without obvious surface offsets, may occur beneath the Los Angeles basin or other large alluvial basins of southern California. Identification of such structures will be possible only from improved locations of microearthquake activity, from well-constrained fault-plane solutions, and from documentation of late Quaternary folding or warping.

Information on potentially active faults offshore of southern California is much less complete and reliable than for faults onshore. Offshore counterparts to the Transverse Ranges and San Andreas fault systems have been mapped and evaluated using acoustic-reflection profiling techniques (Clarke and others, 1985); however, evaluating the activity of offshore faults is particulary difficult because of uncertainties in determing the ages of offset rock and sediment at the sea floor, in detecting the presence of faults in sediments having similar acoustic characteristics on opposing blocks, and in interpreting the relatively incomplete and less reliably located earthquake record offshore.

FAULT SLIP RATES

Geologically determined fault slip rates can be used to characterize the relative activity of different potentially seismogenic faults in a region. Slip-rate estimates are especially important because several new methods of seismic-hazard analysis (for example, Anderson, 1979; Wesnousky, 1984 and 1986; Joyner and Fumal, 1985) use slip rates to compute the average rate of seismic-moment release on faults.

Reliable estimates of slip rates are known only for a few southern California faults. Even data for either the horizontal, vertical, or dip component are sparse, with component rates determined so far for less than 25% of the known active or potentially active faults. Clark and others (1984) and Ziony and Yerkes (1985) have summarized the available late Quaternary information, which vary greatly in reliability. A provisional slip-rate map of the Los Angeles region (Ziony and

Yerkes, 1985, fig. 21) assigns faults to one of four categories representing estimated ranges in true slip-rate by taking into account available slip-rate data, probable styles of fault displacement, and possible connections with other faults of known rates.

The San Andreas and San Jacinto faults have late Quaternary slip rates of about 25 mm/yr and about 10 mm/yr, respectively. The next most active system is the belt of faults that extends diagonally across the Transverse Ranges from near Santa Barbara to near San Bernardino; individual faults in this system have rates that range from 1 to 6 mm/yr, the higher rates occurring where the belt is narrow and composed of only a few faults (for example, along the south boundary of the Transverse Ranges eastward from Pasadena). In contrast, rates for the southern boundary faults of the Transverse Ranges west from Pasadena appear to be no more than 1 mm/yr.

Closely constrained late Quaternary slip rates have not yet been determined for the northwest-trending fault systems that lie west of the San Jacinto fault, although Ziony and Yerkes (1985) have provisionally assigned rates of about 1 mm/yr to each of these zones. Estimated rates for the Elsinore fault zone range widely, from 1 mm/yr to 7 mm/yr. Investigations currently underway by T.K. Rockwell (personal communication, 1985) suggest a rate of about 4 mm/yr. Vertical component rates of 0.3-0.6 mm/yr, which probably are a fraction of the actual slip rate, have been calculated for the Newport-Inglewood zone and the Palos Verdes Hills fault; a slip rate of about 1.3 mm/yr can be calculated for the Rose Canyon fault, a possible southern extension of the Newport-Inglewood zone.

The greatest deficiency in knowledge regarding southern California slip rates is for the major northwest-trending fault systems that lie offshore--including the San Pedro Basin, Santa Cruz-Santa Catalina Island, Coronado Banks, and San Clemente Island faults. Late Quaternary slip rates for these systems presently are unconstrained by reliable geologic data. Significant slip, however, could be accumulating along them. A recently developed kinematic model (Humphreys and Weldon, 1984; Weldon and Humphreys, in press) proposes that about one-third of the total North America-Pacific plate motion (about 56 mm/yr) must be accounted for by slip on offshore faults. If this model is correct, nearly 20 mm/yr slip would have to occur across these fault systems, a level of activity that would have major implications for earthquake potential and hazard in coastal southern California. Studies now being conducted (T.K. Rockwell, USGS Contract No. 14-08-0001-22012) on the Agua Blanca fault in Baja California, with which several of the offshore systems appear to converge, offer hope for testing the model and providing slip-rate constraints on the youthful faults offshore the San Diego and Los Angeles metropolitan areas. Another test of the model would be to conduct repeat geodetic surveys (using highly precise Very Long Baseline Interferometry methods) between the offshore islands and the mainland to determine the amount of slip currently accumulating across the inner part of the Continental Borderland.

Further detailed geologic studies are also needed to improve slip-rate estimates for faults of the western Transverse Ranges. Better data might test the validity of Yeats' (1981) model of 23 mm/yr convergence across the Ventura Basin, resolve whether it is accomplished primarily by folding or faulting, and determine how the slip is partitioned among the various exposed geologic structures.

EARTHQUAKE POTENTIAL

Deciding whether a fault is capable of generating earthquakes and estimating the magnitude of future events is a markedly qualitative judgmental process. The judgments must take into account the fault's historical seismicity (if any), its dimensions, geologic evidence of past slip events, relations with regional structure and nearby seismogenic faults, and whether it extends to sufficient depth to store and suddenly release large amounts of strain energy. Potentially seismogenic faults in southern California include nearly all faults that have been active in late Quaternary time and which are large and deep enough to penetrate high-shear-strength basement rocks; important exceptions are several young faults in the Ventura Basin possibly resulting from flexural-slip folding of the Tertiary and Quaternary section. Judgments on size of future earthquakes commonly are based on evaluative methods that use empirical relations between earthquake magnitude and the dimensions of activated fault surfaces as determined from studies of historical large earthquakes worldwide (see, for example, Bonilla and others, 1984). Methods for estimating the magnitude of future earthquakes on the basis of the slip rate of a fault (for example, Joyner and Fumal, 1985) are beginning to be applied.

Ziony and Yerkes (1985) evaluated potential magnitudes of earthquakes for faults of the Los Angeles region by taking into account the historical record of large earthquakes, the 15-to-20-km limiting depth for instrumentally recorded seismicity in the region, and the range in dimensions of the late Quaternary faults (particularly the lengths of their known Holocene strands). They concluded that credible earthquake magnitudes for ordinary planning and design purposes are: moment magnifude (M) 8 for the San Andreas; M7 for the San Jacinto fault zone; M6.5 for the other northwest-trending faults lying west of the San Jacinto; and M6.5-7.0 for the late Quaternary reverse faults of the Transverse Ranges. When considering the design of critical facilities, however, they suggest larger events for the latter two fault systems (M7 and M7.5, respectively) because of the possibility that two or more overlapping or adjoining fault segments might rupture simultaneously.

The major unresolved issue with respect to the size of future earthquakes in southern California is whether a very large (≥M7.5) earthquake can occur within or beneath the Transverse Ranges. Many of the late Quaternary faults exposed in the ranges appear to link into systems 100 km or more long; the segments having demonstrated Holocene offset, however, are discontinuous and range from a few kilometers to a few tens of kilometers in length (Ziony and Yerkes, 1985). Several researchers (Hadley and Kanamori, 1977; Yeats, 1981; Webb and Kanamori, 1985) have speculated that a regional-scale low-angle detachment fault occurs beneath the Transverse Ranges. Some models propose aseismic subduction of the lithosphere beneath the ranges, whereas other models would permit a large, low-angle fault surface within the brittle crust. Investigations that could firmly establish whether faults of large dimensions exist at depth within brittle crust could have great significance for the evaluation of earthquake potential in that part of southern California.

The potential sizes of future major earthquakes along the San Andreas fault zone between the Salton Sea and Cajon Creek, just east of the southern end of the 1857 rupture, also must be addressed. We need to determine if the southern San

Andreas fault can generate a great (M8) earthquake or whether the Banning fault, with which the Holocene trace of the San Andreas merges, acts as an impediment to through-going rupture and thus limits the likely earthquake magnitude.

Research on the segmentation characteristics of southern California fault zones would help answer these questions. Large historical earthquakes in many parts of the world appear to have been controlled or spatially limited by physical discontinuities (for example, echelon steps across zones of strike-slip faulting) along the strike of a fault. Studies such as that of Schwartz and Coppersmith (1984) have shown that different segments of the same fault zone have distinctive earthquake recurrence intervals and rupture repeatedly with characteristic earthquakes. Detailed analysis of fault-scarp morphology and of the spatial character of late Quaternary fault segments in southern California thus could significantly improve estimates of the sizes of future earthquakes.

RECURRENCE INTERVALS

Our understanding of earthquake recurrence for individual southern California faults is quite limited. The historical seismic record of the region is too short to reliably estimate the recurrence of potentially damaging earthquakes for particular faults or fault zones (a possible exception is the record for the San Jacinto fault zone, which has generated at least 10 major earthquakes since 1890). Evidence of ancient earthquakes in the geologic record along some of the faults can be used to estimate intervals between discrete episodes of surface faulting or liquefaction; however, repeat times of major earthquakes have been estimated directly from geologic information to date only for a handful of faults in the region because of the rarity of suitable study sites and the time-consuming, detailed stratigraphic analysis required. Because of these difficulties, recurrence-interval estimates commonly have been based solely on assumptions about the geologic slip rate and the average slip (or seismic moment release) per event for individual fault segments. Wesnousky (1986), for example, has estimated earthquake repeat times for Quaternary faults in California by dividing the seismic moment for an assumed fault-rupture length by a seismic moment release rate determined from available slip-rate information. Whether his method, which is based on statistically determined generalizations from major historical earthquakes in different tectonic settings worldwide, is validly applied to individual California faults has not yet been established.

The few geologically constrained data for faults of the Los Angeles region, summarized by Ziony and Yerkes (1985, table 11), indicate that segments of the San Andreas and San Jacinto fault zones have generated major earthquakes in intervals of several tens to a few hundred years. In contrast, the other potentially active faults in the region have estimated recurrence intervals of many hundreds to several thousands of years. By far the most complete record of prehistoric earthquakes is for the San Andreas fault at Pallett Creek, where 12 events in the past 1,700 years indicate repeat times ranging from 65 to 270 years.

Geologic information that would provide reliable estimates for earthquake repeat times along most of the faults within or adjacent to the Santa Barbara, Ventura, Los Angeles, or San Diego metropolitan areas has not yet been obtained.

Recurrence intervals for these faults are particularly difficult to determine because: (1) urban development has destroyed or masked late Quaternary geologic features or deposits containing evidence of ancient earthquakes; and (2) the chances for encountering paleoseismic evidence within a deposit representing a given time span apparently are less because the few data that do exist suggest that slip rates are much lower and recurrence intervals are much longer than for the San Andreas and San Jacinto faults.

Moreover, geologic information on earthquake repeat times at localities along the San Andreas fault in addition to Pallett Creek is needed. Estimates of recurrence intervals should be obtained at various points along the fault in southern California in order to test whether the Mojave and Cajon Creek-Salton Sea segments are characterized by marked differences in repeat times as suggested by some researchers.

The date of the latest major earthquake along a specified fault segment is a critical parameter for a time-dependent assessment of a fault's earthquake potential. This information is known for approximately 25 different fault segments that have experienced historical damaging earthquakes (Yerkes, 1985, table 3). The occurrence time of the last significant earthquake is presently unknown, however, for most of the potential seismic sources in southern California. Before the short-term seismic hazard of the region can be adequately evaluated, numerous detailed trenching studies of Holocene deposits along these faults will be necessary to search for and document stratigraphic data that might bracket the latest earthquake occurrences. Dendrochronologic analysis of trees along youthful fault traces is a potentially useful technique.

SURFACE-RUPTURE POTENTIAL

Methods for evaluating surface-rupture potential have evolved rapidly during the past two decades and now are well developed. The likely location and type (strike slip, dip slip, or oblique slip) of future ground offset can be predicted with relative confidence where geologic relations are observable along late Quaternary fault traces or where reliable fault-plane solutions are available. The amount of surface displacement during a particular future earthquake can be predicted by using empirical relations that link surface faulting with other factors (earthquake magnitude, rupture length, etc.) determined from analysis of historical earthquake observations worldwide (Bonilla and others, 1984). For example, by assuming that surface rupturing will not exceed the mapped lengths of late Quaternary fault traces in the Los Angeles region, maximum limits on surface displacements can be predicted (Ziony and Yerkes, 1985): 10 m along the San Andreas fault; 4 m along the San Jacinto and similar fault zones having segments as long as 85 km; and 2 to 3 m along most of the other late Quaternary faults of that region.

Locations of recently active fault traces onshore that might rupture the ground surface during future southern California earthquakes have been well documented as compared with other earthquake-prone regions of the United States. The principal data sets that can be used for evaluating surface-rupture potential are:

(1) Maps of Special Studies Zones for fault-rupture hazard as designated by the California Division of Mines and Geology (CDMG) under the Alquist-Priolo Special Studies Zones Act (Hart, 1985) show most of the known Holocene faults. These 1:24,000-scale maps, which are updated periodically, delineate youthful fault traces inferred from stratigraphic offsets, landforms, or geophysical evidence.

(2) USGS geologic strip maps at 1:24,000 scale covering the entire San Andreas and San Jacinto fault zones (see Ziony and Yerkes, 1985, table 5 for listing of references). Late Quaternary fault traces identified from reconnaissance field studies and from analysis of aerial photographs are delineated. Recently published maps by Clark (1982; 1984) delineate the southern San Andreas and southern Elsinore fault zones.

(3) Special mapping studies of fault zones by the CDMG and by university and consulting geologists at scales ranging from 1:24,000 to 1:6,000. Faults investigated include the San Andreas fault zone within Los Angeles County; the northern Elsinore fault zone; and the San Gabriel, San Fernanado, Santa Monica-Hollywood and Raymond-Sierra Madre faults. Detailed geologic mapping by the CDMG also has been published for the metropolitan San Diego area and covers the Rose Canyon and La Nacion fault zones.

The geologic data for evaluating surface-rupture potential, however, vary in completeness and quality across the region. Detailed systematic mapping and documentation of recently active fault traces is lacking for most late Quaternary faults in the western Transverse Ranges, for the Whittier fault, and for the offshore region. Moreover, continued detailed geologic studies (including careful logging of trenches and dating of offset deposits) will be necessary along all the potentially active faults of southern California before the occurrence and extent of Holocene surface faulting is fully documented.

CONCLUSIONS

Understanding of the earthquake and surface-faulting potential in southern California is well advanced compared to many other regions of the United States. Significant gaps exist, however, in the geologic and seismologic data base available for evaluating many of the potentially active faults, particularly those within or adjacent to the major population centers. The greatest needs are reliable estimates of late Quaternary slip rates and recurrence intervals for the faults framing the Los Angeles basin and lying immediately offshore. Continued improvements in mapping and evaluating the surface traces of recently active faults in all parts of southern California are desirable for more accurately delineating future sites of ground displacement and for estimating the sizes of characteristic earthquakes. Fundamental questions about the nature of the crustal structure beneath the Transverse Ranges, and the dimensions of potentially seismogenic fault surfaces beneath them, also will need to be resolved before significant improvements in estimating the regional seismic hazard are possible.

REFERENCES CITED

Anderson, J.G., 1979, Estimating the seismicity from geological structure for seismic-risk studies: Bulletin of the Seismological Society of America, v. 69, no. 1, p. 135-158.

Bird, P., and Rosenstock, R.W., 1984, Kinematics of present crust and mantle flow in southern California: Geological Society of America Bulletin, v. 95, no. 8, p. 946-957.

Bonilla, M.G., Mark, R.K., and Lienkaemper, J.J., 1984, Statistical relations among earthquake magnitude, surface rupture length, and surface fault displacement: Bulletin of the Seismological Society of America, v. 74, no. 6, p. 2379-2411.

Clark, M.M., 1982, Map showing recently active breaks along the Elsinore and associated faults, California, between Lake Henshaw and Mexico: U.S. Geological Survey Miscellaneous Investigations Series Map I-1329, scale 1:24,000.

---1984, Map showing recently active breaks along the San Andreas fault and associated faults between Salton Sea and Whitewater River--Mission Creek, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1483, scale 1,24:000.

Clark, M.M., Lienkaemper, J.J., Harwood, D.S., Lajoie, K.R., Matti, J.C., Perkins, J.A., Rymer, M.J., Sarna-Wojcicki, A.M., Sharp, R.V., Sims, J.D., Tinsley, J.C., III, and Ziony, J.I., 1984, Preliminary slip-rate table and map of late Quaternary faults in California: U.S. Geological Survey Open-File Report 84-106.

Clarke, S.H., Jr., Greene, H.G., and Kennedy, M.P., 1985, Identifying potentially active faults and unstable slopes offshore, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 347-373.

Corbett, E.J., and Hearn, T.M., 1984, The depth of the seismic zone in the Transverse Ranges of southern California (abs.): Seismologcal Society of America, Eastern Section, Earthquake Notes, v. 55, no. 1, p. 23.

Hadley, D., and Kanamori, H., 1977, Seismic structure of the Transverse Ranges, California: Geological Society of America Bulletin, v. 88, no. 10, p. 1469-1478.

Hart, E.W., 1985, Fault-rupture hazard zones in California: California Division of Mines and Geology Special Publication 42 (revised), 24 p.

Humphreys, E.D., and Weldon, R., 1984, A kinematic model of southern California (abs.): EOS, Transactions of the American Geophysical Union, v. 65, no. 45, p. 992.

Joyner, W.B., and Fumal, T.E., 1985, Predictive mapping of earthquake ground motion, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 203-220.

Schwartz, D.P., and Coppersmith, K.J., 1984, Fault behavior and characteristic earthquakes: examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, p. 5681-5698.

Webb, T.H., and Kanamori, H., 1985, Earthquake focal mechanism in the eastern Transverse Ranges and San Emigido Mountains, southern California and evidence for a regional decollement: Bulletin of Seismological Society of America, v. 75, no. 3, p. 737-757.

Weldon, R., and Humphreys, E.D., in press, A kinematic model of southern California: Tectonics (in press).

Wesnousky, S.G., 1984, Seismic hazard in southern California due to earthquakes on mapped Quaternary faults (abs.): EOS, Transactions of the American Geophysical Union, v. 45, p. 988.

_____, 1986, Earthquakes, Quaternary faults, and seismic hazard in California: Journal of Geophysical Research (in press).

Yeats, R.S., 1981, Quaternary flake tectonics of the California Transverse Ranges: Geology, v. 9, no. 1, p. 16-20.

Yerkes, R.F., 1985, Geologic and seismologic setting, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 23-41.

Ziony, J.I., and Yerkes, R.F., 1985, Evaluating earthquake and surface-faulting potential, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 43-91.

EVALUATION OF EARTHQUAKE POTENTIAL IN SOUTHERN CALIFORNIA

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INTRODUCTION

To mitigate earthquake hazards in southern California, earth scientists need to determine where large earthquakes are likely to occur and what the resulting ground motion from those earthquakes can be. Since most damaging earthquakes in southern California produce surface faulting, the best estimate of where an earthquake will occur is often made by geologists who evaluate the seismogenic potential of capable faults (Ziony and Yerkes, 1985; Wesnousky, 1986). Estimating the earthquake size at that site and what the resulting ground motion will be is often the province of seismologists.

Analysis of world-wide earthquake data has led to greater understanding of the process by which earthquakes are generated on faults. This allows seismologists to estimate more accurately the various factors controlling the magnitude of an earthquake on a given fault. Such factors are, for example, the segmentation of faults into individual rupture zones and the maximum depth of rupture. In addition, recent refinements in the interpretation of tectonic deformation along the plate boundary of the Pacific and North American plates provide a framework for investigating the earthquake potential in southern California (Humphreys, 1985). The results of these studies provide a basis for quantifying the rate of strain accumulation along faults in southern California and its release in large damaging earthquakes.

Many unresolved questions remain, however, concerning both the characteristics of potential earthquakes on southern California faults as well as the seismotectonic framework that drives the seismic cycle. Answers from continuing research efforts could greatly improve our ability to estimate the seismic hazard in southern California.

ACTIVE FAULTS

The San Andres fault is the only fault near the greater Los Angeles area that is considered capable of generating a $M \geq 8$ earthquake. However, several major faults subparallel to the San Andreas, such as the San Jacinto, Elsinore, Newport-Inglewood, and Palos Verdes faults, and several offshore structures are also capable of generating damaging earthquakes. Similarly, east-west trending faults in the Transverse Ranges such as the Santa Monica, Raymond Hill, and Sierra Madre faults also represent significant earthquake hazards to the Los Angeles metropolitan area. Quantitative evaluation of the relative earthquake potential of these faults is a major goal for both geological and seismological research efforts in the next decade.

Geological investigations have already shown that the long-term geologic slip rates range from 10 mm/yr for the San Jacinto fault, to 1 - 6 mm/yr, for faults in the Transverse Ranges to 0.3 - 4 mm/yr for faults in the Los Angeles basin (Ziony and Yerkes, 1985). Both geologic and seismic data show that Los Angels basin faults are mainly characterized by right-lateral strike-slip motion while the northernmost parts of the Los Angeles basin faults and faults in the Transverse Ranges are characterized by reverse motion (Ziony and Yerkes, 1985; Hauksson and Saldivar, 1984). To further our understanding of the future earthquake potential, the actual geophysical properties of the fault zones need to be determined. Such research efforts will consist of mapping the three-dimensional velocity and attenuation structure of capable fault zones. The goal is to identify continuous fault segments that break in characteristic earthquakes as well as high strength barriers that may influence the seismogenic displacement on a fault.

EARTHQUAKE MAGNITUDE

The magnitude of an earthquake is proportional to its seismic moment (M_o) which can be expressed as; $M_o = \mu L W u$ where μ is an elastic modulus, L is the length of the rupture surface, W is the width of the rupture surface and u is the amount of displacement during the earthquake. An increase in any of these quantities will increase the magnitude of the earthquake. Refinements in the estimates of seismic potential can be obtained by improving our understanding of the factors that control these parameters.

Width of the Fault

In large earthquakes the width of the fault is determined by the maximum depth in the earth at which brittle faulting can occur. Recent work (Sibson, 1982) has suggested that the maximum depth of faulting in large earthquakes is usually equivalent to the maximum depth at which microearthquakes occur in that region. This maximum depth of faulting in southern California averages 12 to 15 km and extends down to 18 to 22 km in a few limited regions. Thus an average approximation of the width of the rupture surface for most large earthquakes in the region is 15 km. However, the relationship between variation in the depth of microearthquakes along the strike of a fault and the width of the fault surface that will fail in a large earthquake on that fault is not well understood. For instance, the maximum depth of faulting near the San Andreas fault itself ranges from 10 km Palmdale to 22 km near Banning. Which depth will control the maximum width of the rupture surface in a great earthquake on the fault and whether the width of the rupture surface could vary along strike is not known. High quality recordings of more large earthquakes and further studies of the relation of large earthquakes to background earthquake activity are needed to resolve these questions. A more dense distribution of seismographic stations and a more detailed crustal velocity model would also improve our estimates of these depths.

Length of the Fault

The San Andreas fault is over 1500 km long but the total length of it has not ruptured in one earthquake. Two of the largest earthquakes on that fault, the 1857 Fort Tejon and 1906 San Francisco events ruptured 360 and 440 km of the fault, respectively (Bonilla and others, 1984). The factors that control the segmentation of the fault and the starting and stopping of rupture on individual fault segments are being researched through the study of world-wide earthquake data. Inhomogeneities in faults strength or structure (asperities or barriers) are considered to be likely sites for initiation and termination of rupture on faults (Aki, 1979; Kanamori and Stewart, 1978; Jones and Molnar, 1979). Geometrical offsets in faults visible on the earth's surface have been shown to extend to seismogenic depths (2 - 12 km) in northern California and China and to be crucial in controlling the initiation and stopping of rupture during moderate and large ($M \geq 6$) earthquakes (Reasenberg and Ellsworth, 1982; Lindh and Boore, 1979; Jones and others, 1982). The 1979 Imperial Valley and 1980 Cierro Prieto earthquakes near the Mexico-California border both initiated at the intersection of the causative fault with another seismogenic structure (Silver and Masuda, 1985). Since such asperities or barriers on the faults are relatively permanent features by human time scales, the same features could control the extent of rupture on a given fault section in several consecutive earthquakes (for example, Bakun, 1980; Schwartz and Coppersmith, 1984).

The segmentation of faults is crucial in estimating their seismic potential. For instance, on the San Andreas fault, because the 1857 rupture zone terminated in Cajon Pass, it is commonly considered to be a likely site for the initiation or stopping of a future large event (Raleigh and others, 1982). However, geologic evidence (Weldon and Sieh, 1985) suggests that an earthquake in the eighteenth century ruptured through Cajon Pass with extensive displacement both north and south of that site. One earthquake has also been proposed for the section of the San Andreas from Cajon Pass to the Salton Sea through the complex San Gorgonio Pass region. However, the San Andreas fault does not form a single coherent structure through the San Gorgonio Pass (Allen, 1981), suggesting difficulties in propogating a large earthquake through the region. The different segmentation scenarios possible from considering all of the proposed sites for ending a rupture surface produce rupture surfaces from 150 to 500 km length which would generate earthquakes ranging from M7 to M8. To determine the most likely scenario, the processes of rupture initiation and termination and the role of asperities in rupture propogation are needed to unravel the details of the rupture process. For these research needs, high quality recordings of earthquake seismograms are needed. A few high-dynamic-range, broad-band seismographs in southern California could provide important data for such studies.

Fault Displacement

The amount of displacement on a fault during an earthquake is approximately proportional to the fault length (Kanamori and Anderson, 1975; Scholz, 1982; Molnar and Deng, 1984). The proportionality arises when the stress drops during the earthquakes do not vary much. Because of this proportionality, the fault length alone can be used to estimate the size of an earthquake expected on a given section of fault (Wesnousky and others, 1984; Wesnousky, 1986). However, large variations in displacement and stress drop have been reported for some earthquakes (Frankel and Kanamori, 1983). Scholz and others (1986) and Kanamori and Allen (1985) have correlated the changes in the displacement-length ratios with variations in slip rates on faults such that faults with low slip rates will have more displacement (and thus larger earthquakes) for a given length of fault. Recent detailed studies using data from state of the art instrumentation have also shown that the amount of displacement during an earthquake can vary significantly along the fault plane (Hartzell and Heaton, 1983 and 1986). Many more earthquakes need to be studied using high quality recordings to better understand these variations in fault displacement and their relation to the structure of a fault. Such studies could lead to site-specific scaling laws for the fault-displacement distribution on a given fault.

TECTONICS AND EARTHQUAKES

The recording of earthquakes in southern California during the last 50 years shows that small earthquakes (magnitude less than 5.0), while concentrated to some extent along the San Jacinto and Elsinore faults, generally show little correlation with the geologic features of southern California (figure 1; for example, Allen and others, 1965; Yerkes, 1985). In contrast, the moderate and large earthquakes (magnitude greater than 5.5) are well correlated with the major mapped faults of the region (figure 2). This pattern differs from that of central California where earthquakes of all sizes are strongly concentrated along the mapped faults. The more random spatial distributions of small earthquakes in southern California could reflect a broad regional strain accumulation which is caused by the complex interaction of the Pacific and North American plates around the Big Bend of the San Andreas fault.

While the smaller earthquakes do not show the same spatial distribution as the larger events, they result from the same causative stress field. Focal mechanisms of the smaller earthquakes can be used to determine this stress state. The work of Pechmann (1983); Webb and Kanamori (1985), Corbett (1982), Hauksson and Saldivar (1984) and Jones (1985) has shown that the maximum principal stress in southern California is horizontal, striking approximately north-south but that its strike may vary locally by several tens of degrees over the region. This consistency of maximum principal stress direction extends over both the San Andreas fault system and the Transverse Ranges in spite of their geologically diverse styles of deformation. The minor local variations in stress direction across the region and their relation to the active faults could provide important information for estimating seismic potential and is being studied in more detail.

Analysis of the discrepancies between the spatial distribution of small and large earthquakes is needed to understand how source parameters determined from the more frequently occurring small earthquakes could be scaled to the larger, damaging events. Techniques are now available that sum the ground motion of many small earthquakes to simulate the potentially destructive ground motion of a large earthquake (Hartzell, 1978; Irikura, 1983). Such simulations of large earthquakes coupled with detailed knowledge of the fault zone structure will make future estimates of earthquake hazards more accurate.

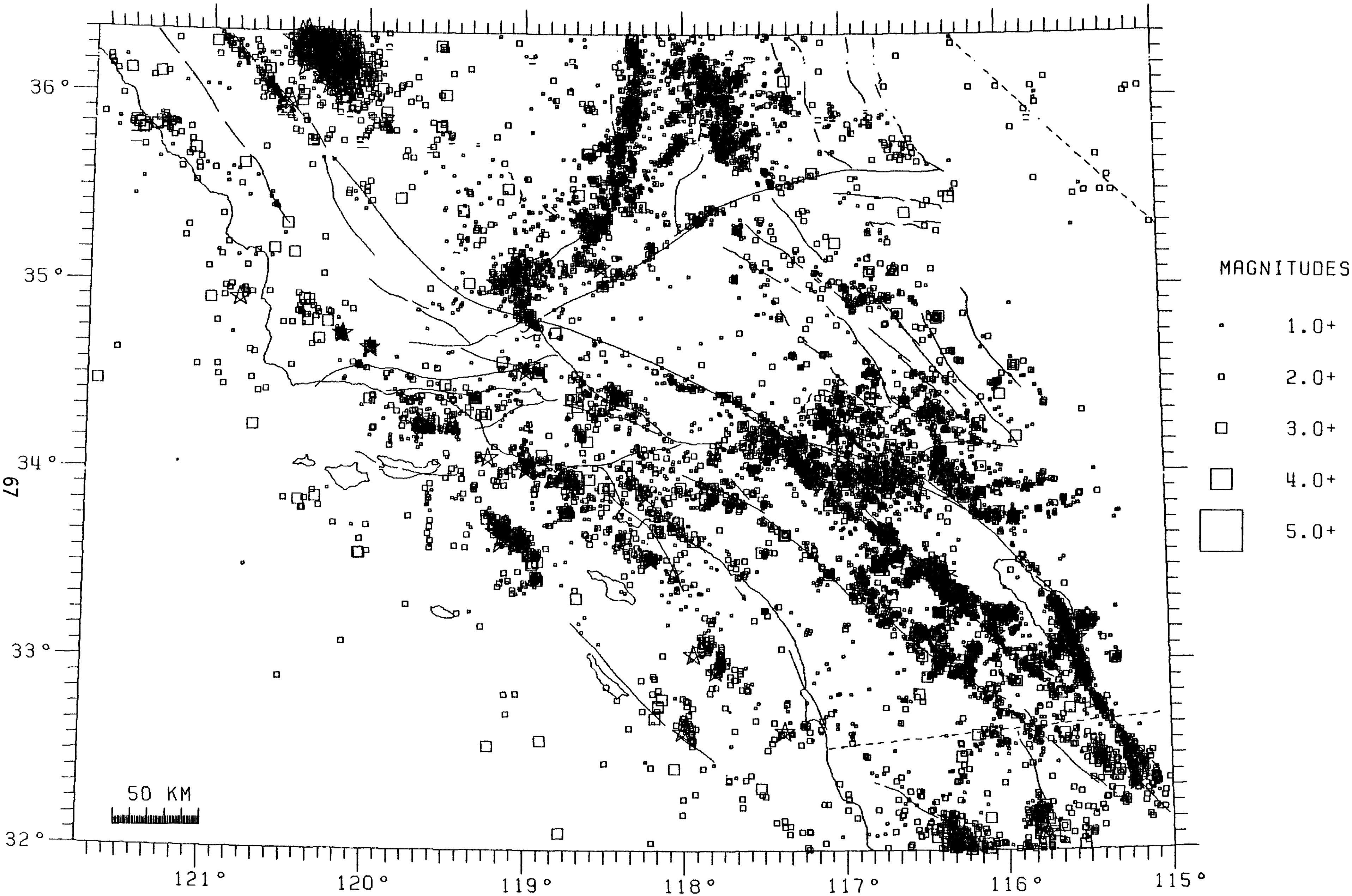

Figure 1. A map of all M $\geq$ 1.0 earthquakes recorded in southern California from 1981 to 1984. Earthquakes of $\geq$ 4.0 are shown by stars.

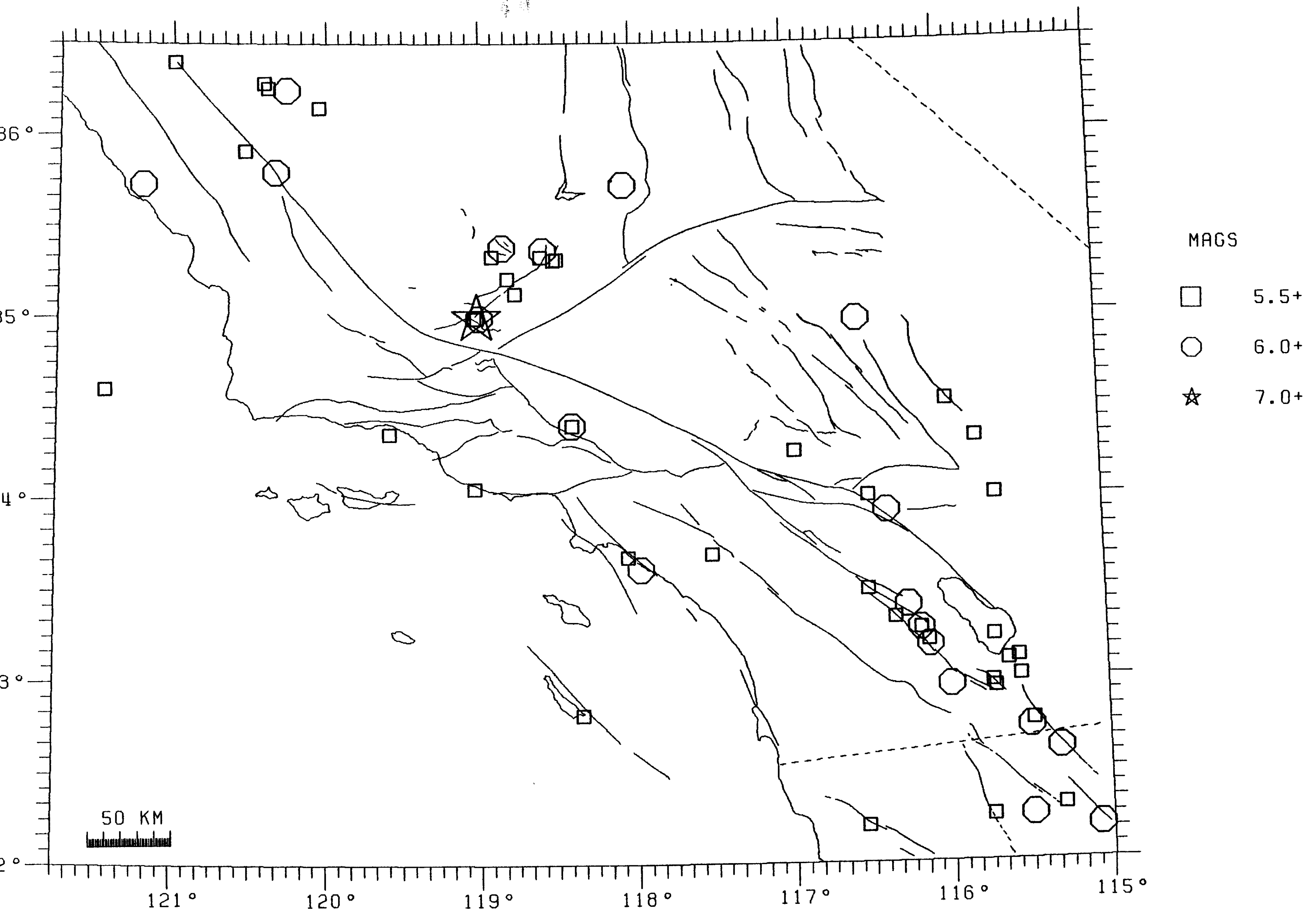

Figure 2. A map of all M $\geq$ 5.5 earthquakes recorded in southern California from 1932 to 1984.

CONCLUSIONS

Major advances in seismology in the last fifteen years have greatly increased our abilities to estimate the seismic potential in southern California. Physical asperities on fault planes are now recognized as important features in controlling the rupture process during earthquakes. The presence of such features has been used to characterize the rupture initiation and termination processes in some earthquakes. Segmentation of major faults is recognized as crucial in estimating the size of potential earthquakes and the factors controlling segmentation are being actively studied. The maximum depth of faulting has been estimated in southern California and scaling laws for relating fault displacement, length, and seismic moment are being developed. The average maximum stress direction in southern California has been established.

Improving our understanding of the structure of fault zones in general and specifically the structure of the large faults in southern California is needed to improve current estimates of the earthquake potential. Questions that need to be addressed are: What are asperities on faults? How do asperities and other fault zone structures affect rupture propogation on that fault? Specifically, what features on the San Andreas fault control the segmentation of the fault into individual rupture zones? How does earthquake rupture start and stop on large faults?

The relationship of smaller earthquakes and the regional strain field to displacement on major faults needs to be better understood. What is different about southern California that causes the correlation between small earthquakes and active faults that is observed in central California to be absent in the south? Further, variations in the stress field and its relation to displacement on major faults needs to be researched in more detail.

To accomplish these tasks, improved networks of seismographic stations are needed, especially stations with high-dynamic-range, broad-band frequency response seisometers that will allow on scale recording of earthquakes over a wide range of magnitudes. In addition, the long term monitoring of earthquakes should be supplemented with large-scale active geophysical experiments such as reflection and refraction profiling of the fault zones.

REFERENCES

Aki, K., 1979, Characteristics of barriers on an earthquake fault: Journal of Geophysical Research, v. 84, p. 6140-6148.

Allen, C.R., St. Amand, P., Richter, C.F., and Nordquist, J.M., 1965, Relationship between seismicity and geologic structure in the southern California region: Bulletin of the Seismological Society of America, v. 55, p. 753-797.

Allen, C.R., 1981, The modern San Andreas fault, in Ernst, W.G., (ed.), The Geotectonic Development of California, Rubey Volume 1, Prentice-Hall, Inc. Englewood Cliffs, NJ, p. 511-534.

Bakun, W.H., 1980, Seismic activity of the southern Calaveras fault in central California: Bulletin of the Seismological Society of America, v. 74, p. 2379-2411.

Bonilla, M.G., Mark, R.K., and Leinkaemper, J.J., 1984, Statistical relations among earthquake magnitude, surface rupture, and surface fault displacement: Bulletin of the Seismological Society of America, v. 74, p. 2379-2411.

Corbett, E.J., 1984, Seismicity and crustal structure studies of southern California: tectonic implications from improved earthquake locations: Ph.D. Dissertation, California Institute of Technology, Pasadena, Calif., 231 p.

Frankel, A. and Kanamori, H., 1983, Determination of rupture duration and stress drop for earthquakes in southern California: Bulletin of the Seismological Society of America, v. 73, p. 1527-1551.

Hartzell, S.H., 1978, Earthquake aftershocks as Green's functions: Geophysical Research Letters, v. 5, p. 1-4.

Hartzell, S.H. and Heaton, T.H., in press, 1986, Rupture history of the Morgan Hill, California, earthquake from the inversion of strong motion records: Bulletin of the Seismological Society of America.

Hartzell, S.H. and Heaton, T.H., 1983, Inversion of strong ground motion and teleseismic waveform data for the fault rupture history of the 1979 Imperial Valley, California, earthquake: Bulletin of the Seismological Society of America, v. 73, p. 1553 -1584.

Hauksson, E., and Saldivar, G., 1984, Recent seismicity (1970-1984) along the Newport-Inglewood fault, Los Angeles basin, southern California: Transactions of the American Geophysical Union, v. 45, 996 p.

Humphreys, E.D., 1985, Studies of the crust-mantle system beneath southern California: Ph.D. Dissertation, California Institute of Technology, Pasadena, Calif., 189 p.

Irikura, K., 1983, Semi-empirical estimation of strong ground motions during large earthquakes: Bulletin of the Disaster Prevention Institute, Kyoto University, Japan, p. 63-104.

Jones, L.M., 1985, Seismotectonics of the Cajon Pass region of southern San Andreas fault: Transactions of the American Geophysical Union, 66, 383.

Jones, L. M., and P. Molnar, 1979, Some characteristics of foreshocks and their relationship to earthquake prediction and premonitory slip on faults: Journal of Geophysical Research, v. 87, p. 3596-3608.

Jones, L. M., B. Q. Wang, S. X. Xu, and T. J. Fitch, 1982, The foreshock: Journal of Geophysical Research, v. 87, p. 4574-4584.

Kanamori, H., and Stewart, G.S., 1978, Seismological aspects of the Guatemala earthquake of February 21, 1976: Journal of Geophysical Research, v. 83, p. 3427-3434.

Kanamori, H., and Anderson, D.L., 1975, Theoretical basis of some empirical relations in seismology: Bulletin of the Seismological Society of America, v. 65, p. 1073-1095.

Kanamori, H., and Allen, C.R., 1985, Earthquake repeat time and average stress drop, in Das, S., (ed.), Fault Mechanics: American Geophysical Union Maurice Ewing Series 6, Washington, D. C., submitted 1985.

Lindh, A.G., and Boore, D.M., 1981, Control of rupture by fault geometry in the 1966 Parkfield earthquake: Bulletin of the Seismological Society of America, v. 71, p. 95-116.

Molnar, P., and Deng, Q.D., 1984, Faulting associated with large earthquakes and the average rate of deformation in central and eastern Asia: Journal of Geophysical Research, v. 89, p. 6203-6228.

Pechmann, J.C., 1983, The relationship of small earthquakes to strain accumulation along major faults in southern California: Ph.D. Dissertation, California Institute of Technology, Pasadena, Calif., 175 p.

Raleigh, C.B., Sieh, K., Sykes, L.R., and Anderson, D.L., 1982, Forecasting southern California earthquakes: Science, v. 217, p. 1097-1104.

Reasenberg, P., and Ellsworth, W.L., 1982, Aftershocks of the Coyote Lake, California, earthquake of August 6, 1979; A detailed study: Journal of Geophysical Research, v. 87, p. 10637-10655.

Scholz, C.H., 1982, Scaling laws for large earthquakes: Consequences for physical models: Bulletin of the Seismological Society of America, v. 72, p. 1-14.

Scholz, C.H., Aviles, C.A., and Wesnousky, S.G., 1985, Scaling differences between large intraplate and interplate earthquakes: Bulletin of the Seismological Society of America, v. 76, p. 65-70.

Schwartz, D.P., and Coppersmith, K.P., 1984, Fault behavior and characteristic earthquakes: examples from the Wasatch and San Andreas fault zones: Journal of Geophysical Research, v. 89, p. 5681-5698.

Sibson, R.B., 1982, Fault zone models, heat flow, and the depth distribution of earthquakes in the continental crust of the United States: Bulletin of the Seismological Society of America, v. 72, p. 151-173.

Silver, P., and Masuda, T., 1985, A source extent analysis of the Imperial Valley earthquake of October 15, 1979 and the Victoria earthquake of June 9, 1980: Journal of Geophysical Research, v. 90, p. 7639-7652.

Webb. T.H., and Kanamori, H., 1985, Earthquake focal mechanisms in the eastern Transverse Ranges and San Emigdio Mountains, southern California and evidence for a regional decollement: Bulletin of the Seismological Society of America, v. 75, p. 737-758.

Weldon, R.J., and Sieh, K.E., 1985, Holocene rate of slip and tentative recurrence interval for large earthquakes on the San Andreas fault, Cajon Pass, southern California: Geological Society of America Bulletin, v. 96, p. 793-812.

Wesnousky, S.G., 1986, Earthquakes, Quaternary faults and seismic hazard in California: Journal of Geophysical Research, (in press).

Wesnousky, S.G., Jones, L.M., Deng, Q.D., and Scholz, S.H., 1984, Historical seismicity and rates of crustal deformation along the margins of the Ordos block, north China: Bulletin of the Seismological Society of America, v. 79, p. 1767-1784.

Yerkes, R.F., 1985, Geologic and seismologic setting, in Ziony J. I., (ed.), Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 25-42.

Ziony, J. I., and Yerkes, R. F., 1985, Evaluating earthquake and surface faulting potential, in Ziony J. I., (ed.), Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 43-92.

ADVANCES IN GEOLOGICAL ASSESSMENT OF EARTHQUAKE POTENTIAL IN SOUTHERN CALIFORNIA

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Within the past decade, geological studies have contributed significantly to our understanding of earthquake potential. Studies of deformed young sediments and landforms along the San Andreas fault are yielding information that is allowing us to identify those segments of the fault most likely to rupture in the near future. These findings are helping to focus prediction studies and hazard mitigation efforts. At this time, the southernmost 300 km of the San Andreas fault appears to be the most likely source of the next great earthquake in California. Furthermore, geologic studies along the Elsinore, San Jacinto, and other secondary faults in southern California are beginning to reveal the recent history of those faults as well. Recurrence intervals, fault slip rates, and other data are now being utilized to issue probabilistic hazard maps for southern California.

In spite of these advances, we have only begun to tap the young geological record for important information bearing on earthquake forecasting. In order to improve our probabilistic forecasts, we need advances in several areas, including the following:

- The seismic potential of offshore active faults is virtually unknown. Techniques need to be devised that will allow retrieval of trench-sized box cores from across these potentially dangerous offshore faults. The seismic history and potential of the Newport-Inglewood zone and other particularly dangerous urban faults must be better known in order to assess accurately the likelihood of their rupture in the near future.

- Radiocarbon analyses of samples which constrain the dates of prehistoric earthquakes need to be more precise and better documented. At the present time, conventional and other radiocarbon dating techniques do not produce dates precise enough to enable correlation of slip events from site to site. Neither do they allow for recognition of temporal patterns in earthquake occurrence. More precise radiocarbon dating as well as dendrochronologic dating of prehistoric earthquakes is now in progress along the San Andreas fault.

ZONING FOR SURFACE-FAULTING HAZARDS IN CALIFORNIA

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INTRODUCTION

Surface faulting is one of several phenomena that can cause damage during an earthquake. It is the sudden displacement along faults that cause earthquakes. When coseismic fault rupture propagates upward to the ground surface, it can be very damaging to man's structures. Surface faulting also can occur in small, incremental steps as a result of tectonic strain after an earthquake (afterslip) or between earthquakes (creep). Man can induce similar fault displacements, and even earthquakes, by withdrawing fluids, reservoir loading, and mining. All of these types of surface faulting can damage structures. Historic fault-rupture has occurred many times in California and has been summarized by Bonilla (1970), Jennings (1975), Grantz and Bartow (1977), Hart (1985), and Ziony and Yerkes (1985).

Because fault rupture tends to be confined to relatively narrow zones and to recur along pre-existing recent faults, the most effective method of mitigating the hazard of fault rupture to buildings and other structures is by avoidance of building astride recently active faults. With these concepts in mind, the California Legislature enacted the Alquist-Priolo Special Studies Zones (APSSZ) Act in 1972 (Public Resources Code, Div. 2, Ch. 7.5). The Act has been amended five times, the last in 1979.

The purpose of the APSSZ Act is to mitigate the hazard of surface fault-rupture by prohibiting the location of structures for human occupancy across the traces of active faults. The Act does not address other seismic hazards. Responsibilities for carrying out this Act are shared by state agencies and local government. Specifically, the State Geologist (Chief of the Division of Mines and Geology) is responsible for delineating regulatory zones--known as Special Studies Zones (SSZ's)--that encompass hazardous faults. The zones are delineated by the California Department of Conservation, Division of Mines and Geology (CDMG) on topographic base maps at a scale of one inch equals 2000 feet (1:24,000). Cities and counties affected by the zones must regulate development "projects" where structures for human occupancy are planned within the SSZ's. Regulation is accomplished by requiring geologic investigations of individual sites in order to avoid siting proposed structures astride active faults. The State Mining and Geology Board has established regulations, known as Policies and Criteria, to guide local jurisdictions in implementing the law (California Administrative Code, Title 14, Division 2, Chapter 8, Subchapter 1, Article III). Additional information on CDMG's zoning program and texts of the law and regulations are contained in Hart (1985).

Under the APSSZ Act, CDMG established numerous SSZ's along the San Andreas, Hayward, Calaveras, and other historically active or major faults in 1974 and 1976. Although most of the faults zoned in those years are clearly hazardous in terms of surface faulting, some of the zones were wider than necessary or encompassed secondary faults that have a low potential for surface rupture. In addition, many potentially active faults had not yet been evaluated for zoning purposes. Consequently, a comprehensive Fault Evaluation and Zoning Program was implemented in early 1976 to cope with these problems (California Division of Mines and Geology, 1976).

FAULT EVALUATION AND ZONING PROGRAM

The objectives of this program are to: (1) evaluate the numerous potentially active faults not previously zoned in California, and (2) re-evaluate many of the faults already zoned with respect to the hazard of surface faulting. Because of the large number of potentially active faults that exist, however, a decision was made to zone only those faults considered to have a relatively high potential for future activity and to have reasonably well-defined surface traces.

The terms "sufficiently active" and "well-defined", taken from the Act (PRC Section 2622), were adopted by CDMG as the criteria that must be met before a Special Studies Zone is established. These terms are defined as follows (Hart, 1985, p. 5):

> "Sufficiently active. A fault is deemed sufficiently active if there is evidence of Holocene (the last 10,000-12,000 years) surface displacement along one or more of its segments or branches. Holocene surface displacement may be directly observable or inferred; it need not be present everywhere along a fault to qualify that fault for zoning."

> "Well-defined. A fault is considered well-defined if its trace is clearly detectable by a trained geologist as a physical feature at or just below the ground surface. The fault may be identified by direct observation or by indirect methods, for example, geomorphic evidence. The critical consideration is that the fault, or some part of it, can be located in the field with sufficient precision and confidence to indicate that the required site-specific investigations would meet with some success."

The Fault Evaluation Program is a long-range program to evaluate the faults in ten separate regions of the State (figure 1). Faults lying outside a given study region also are evaluated when the need exists. Fault evaluations are based largely on the following methods: (1) compilation and evaluation of data of other workers; (2) interpretation of aerial photographs; and (3) field reconnaissance, with local detailed mapping. Because of the lack of resources available for trenching and other subsurface techniques, a great deal of reliance must be placed on existing surface exposures and geomorphic features. Three geologists, including the program manager, are assigned to carry out these Statewide evaluations.

For each fault evaluated, an in-house Fault Evaluation Report (FER) is prepared, summarizing the data and specific zoning recommendations. These

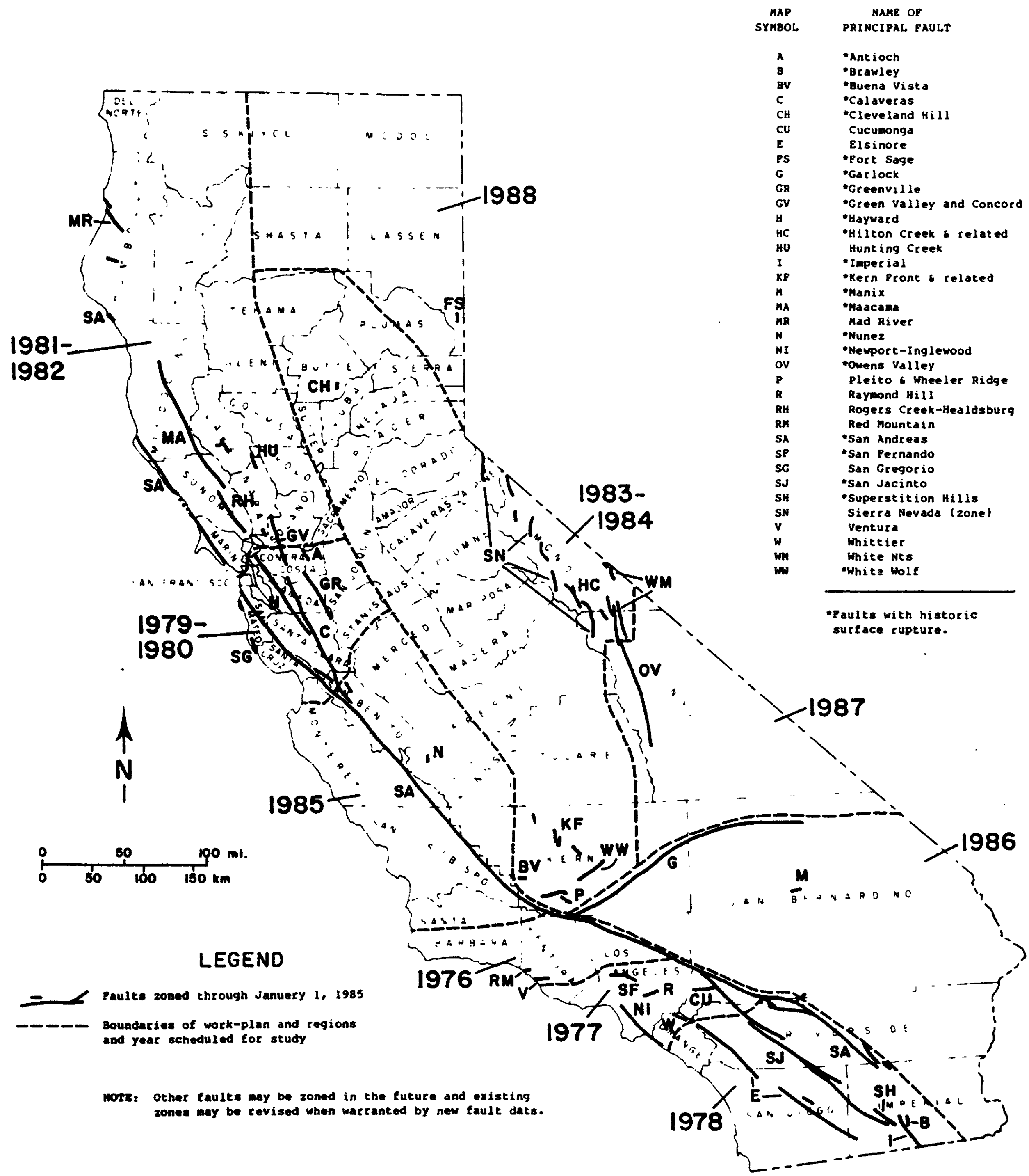

Figure 1. Principal faults in California zoned for special studies under the Alquist-Priolo Special Studies Zones Act of 1972. Dashed lines and dates identify work-plan priorities for studying areas under the Fault Evaluation and Zoning Program, 1976 to 1987.

unpublished FER's are available for reference at the CDMG's San Francisco Bay Regional Office in Pleasant Hill. Upon completion of studies in each region the results of that work are summarized. Summary reports have been released as Open-File Reports for the first six regions evaluated (Hart and others, 1977, 1978, 1979, 1981, 1983, and 1985). One to one-and-one-half years are generally allotted to evaluate each region. Work in the seventh region has just been completed (figure 1) and SSZ maps will be issued for preliminary review on January 1, 1986. Official maps of SSZ's will be issued six months later. Preliminary review and official maps of SSZ's were issued previously for each of the six regions previously studied.

HOW WELL IS THE ALQUIST-PRIOLO SPECIAL STUDIES ZONES ACT WORKING?

This is a reasonable question, although the answer to the question is necessarily somewhat subjective. Perhaps the question is best addressed by examining various aspects of the law and its functions. The question can be viewed in terms of zoning, implementation by local government, site investigations, and the law itself.

Zoning

Since 1974, regulatory zones have been established for the San Andreas, Calaveras, Hayward, San Jacinto, and most other faults in California that are considered to be a threat in terms of surface faulting. A number of other faults known to be active historically or in Holocene time have not yet been zoned because they exist in undeveloped areas of the State. Other potentially active faults also need to be evaluated to determine if they meet our zoning criteria.

When CDMG completes its ten-region evaluation of faults in 1989, there will undoubtedly be a number of active faults that will not have been zoned. This belief is supported by the record of fault rupture that has occurred during the past ten years. As can be seen from table 1, fault rupture associated with earthquakes has occurred mainly along faults that were not known to be active at the time of the event. Some of these faults were not considered to be active and some were not even known to exist prior to the event. Fortunately, most of the faulting was relatively minor in terms of amount of displacement and length of rupture, and occurred in undeveloped areas. From this relatively short period of experience, it is believed that there may be hundreds of active faults in California. Although we cannot hope to identify all of these faults in advance with our small staff, we can recognize most of the more active faults that would cause the greatest damage to the structures of man. We also can record the historic ruptures of active faults when they occur for long-range planning purposes.

Whatever the merits or shortcomings of CDMG's fault zoning efforts, it is important to recognize that zoning by itself does not mitigate the hazard of surface fault rupture to structures. Zoning is only the first step needed to mitigate this hazard.

An increased effort on the part of the U.S. Geological Survey (USGS) and other geologists to map recently active faults would be very helpful to CDMG in its fault and zoning effort. Too many geologists appear to be preoccupied with the

Table 1. Known surface faulting associated with earthquakes in California, 1975-1984[1]. Faults 1, 3, 6, 7, 8, 9, 13 and 14 are zoned and mostly identified on Figure 1. See Bonilla (1970), Jennings (1975), and Grantz and Bartow (1977) for earlier faulting events.

Fault (County where located)	Year of rupture	Magnitude (Richter) of associated earthquake	Surface rupture[2] Maximum displacement (cm)	Total length (km)	Main sense of displacement[3]	Comments
1. Brawley (Imperial)	1975	4.7	20	10.4	N	Also ruptured in 1940 and 1979; fault creep.
2. Galway Lake (Kern)	1975	5.2	1.5	6.8	RL	Fault unknown until 1975; remote area, not yet zoned.
3. Cleveland Hill (Butte)	1975	5.7	5	5.7	N	Fault not previously known to be Holocene-active.
4. Stephens Pass (Siskiyou)	1978	4.6	30	2+	N	Fault not known previously; remote area; not yet zoned.
5. Homestead Valley and Johnson Valley (San Bernardino)	1979	5.2	8 1	3.3 1.5	RL RL	Not yet zoned, area undeveloped.
6. Calaveras (San Benito, Santa Clara)	1979	5.9	1	39(?)	RL	Minor, discontinuous rupture mostly in creep-active segment.
7. Imperial, Brawley, Rico } (Imperial)	1979	6.6	55 15 10	30 13 1	RL N N	Creep triggered on San Andreas and Superstition Hills fault; also ruptured in 1940.
8. Greenville (Alameda)	1980	5.6	3	6.5	RL	Minor left-lateral slip also occurred on Las Positas fault.
9. Hilton Creek-Mammoth Lakes (Mono)	1980	6.0-6.5	30	20	N	Rupture on many minor faults; may relate to volcanic activity.
10. "Lompoc quarry" (Santa Barbara)	1981	2.5	25	0.6	R	Flexural slip on flank of syncline triggered by quarrying; do not plan to zone.
11. Little Lake (Kern)	1982	5.3	0+	10	RL/N	Not yet zoned.
12. "Coalinga Nose" (Fresno)	1983	6.7	5	.005	R	Secondary fault(?) associated with 43cm of anticlinal uplift; too minor to zone.
13. Nunez (Fresno)	1983	5.2-5.9	60	3.3	R	Aftershocks associated with (12) above.
14. Calaveras (Santa Clara)	1984	6.1	20 (?)	1.2 (15?)	RL	Questionable faulting followed by afterslip in 15-km long creep zone to south.

[1] Tectonic (aseismic) fault-creep has been reported since 1975 along various segments of about 16 faults, including the San Andreas, Hayward, Calaveras, Concord, San Jacinto, Maacama, and Garlock faults. Man-induced fault-creep has been reported on 9 or 10 other faults due to withdrawal of groundwater or oilfield fluids.
[2] Includes some afterslip. Rupture length measured from distal ends of rupture, which often is discontinuous.
[3] N= normal displacement; R= reverse displacement; RL= right-lateral displacement.

task of determining the recurrence interval of earthquakes on the San Andreas fault and other sophisticated studies. Even when active faults are mapped, it often takes years for the documenting maps to become available.

Local Implementation

As of January 1, 1985, the state had issued 352 official maps of Special Studies Zones, of which 73 were revised and two were withdrawn. These zones affect 74 cities and 30 counties, each of which must regulate most development "projects" within the zones. To implement the law, a local jurisdiction must determine if a proposed "project" lies within an SSZ and require the developer to hire a registered geologist to make a site investigation prior to issuing permits for subdivisions and for most structures for human occupancy. The resulting geologic report must then be reviewed for adequacy by a registered geologist on behalf of the local jurisdiction.

If active faults are identified, appropriate building restriction zones (setbacks) are established. Following local approval, a copy of the geologic report is submitted to CDMG where it is placed in the open file. Cities and counties are also required to develop appropriate ordinances, regulations, and policies to carry out the State law.

All of this sounds very simple, but local jurisdictions frequently lack adequate staff and funding. They also are encumbered with a host of Federal, State and local laws that demand attention.

It is difficult to measure the effectiveness of implementation and enforcement of the APSSZ Act at the local level. For one thing, there is no single State agency assigned to oversee regulation of the Act, although the State Mining and Geology Board and CDMG have responsibilities to implement specific aspects of the law. Also, there is no penalty for not complying with the Act.

So why should cities and counties bother to enforce the Act? The answer is probably simple. First, city and county officials presumably would not knowingly permit structures to be built at a hazardous site. However, the perception of hazards varies among individuals. Second, liability plays an important role in enforcement. If a city or county permits a project to develop in an SSZ without requiring proper site investigation, it leaves itself open to a lawsuit--with or without fault rupture.

Judging from the 1,820 geologic reports submitted to CDMG since 1974 by 51 cities and 16 counties, it is apparent that at least 69 percent of the cities and 53 percent of the counties are complying with the Act to some degree. The compliance rate is probably much higher, considering that development has not yet been proposed within zones in some jurisdictions. Also, much of the development in SSZ's is concentrated in cities and counties known to be complying. Nonetheless, one or more instances of noncompliance is known or believed to have occurred in at least 15 or 20 cities and counties. This noncompliance ranges from issuing development permits without the requisite site investigations to not submitting geologic reports to CDMG.

Site Investigations

After the issue of the first SSZ maps in 1974, it quickly became clear that most of the consulting geologists hired by developers to investigate development sites under the APSSZ Act were inexperienced in evaluating active faults. Problems related to the identification and location of faults, methods used to locate and evaluate faults, building setbacks, and report documentation. CDMG's response to this was to issue a set of guidelines for evaluating the hazard of fault rupture in 1975 (CDMG Note 49; also published as Appendix C in Hart, 1985) and otherwise attempt to educate the geological profession and others by identifying some of the problems (Hart, 1978). The CDMG also advised geological reviewers regarding specific site issues and encouraged the local reviewers to establish workable standards. These efforts, along with the expanding literature on faults and methods of investigation (Bonilla, 1982), helped to increase the quality of fault investigations and reports.

Another problem that existed, and still persists to some degree, is that of professional attitude. A few geologists simply refused to believe that certain faults (for example, the Newport-Inglewood and Ventura faults) posed a serious hazard in terms of the fault rupture. As a consequence, many of the investigations required under the APSSZ Act were half-hearted and fundamentally inadequate. This attitude was (and still is) nurtured by developers who desire to keep consulting fees as low as possible and the inability of local governments to insist on adequate geologic reports.

In contrast, some consulting geologists have identified apparently inactive fault traces as active or treated landslide features as faults. The CDMG has reacted to these approaches by delineating narrower zones than previously.

As experience in fault evaluation is gained by consulting geologists and local reviewers, the effectiveness of site investigations continues to improve. However, because active faults are very difficult to evaluate at many sites, it is doubtful that site investigations will ever become routine.

The Law

Considering the technical nature of the APSSZ Act and the scientific judgements that are needed to delineate zones and evaluate sites, the Act appears to be working quite well. This assessment is based largely on the intent of the Legislature, which is to prevent new structures for human occupancy from being built astride the traces of active faults. The law does not address the problem of existing structures that are already located on active faults, except where an addition or remodeling is planned or when a property is sold (disclosure). The law also does not address structures <u>not</u> for human occupancy, although part of this problem is dealt with in other ways.

The effectiveness of the APSSZ Act is somewhat variable at the State and regional agency level. Unlike cities and counties, the responsibilities of State agencies are addressed only generally by the Act (PRC, Section 2621.5); regional agencies are not even mentioned. Except for schools covered by the Field Act and hospitals by the Hospital Act (Meehan, 1982), structures built or permitted by State and regional agencies may not have a geologic investigation prior to development. Moreover, geologic reviews to assure adequacy of the reports are not required. In practice, only hospital-site reports are reviewed routinely.

One special aspect of the law (PRC, Section 2621.9) deals with disclosure, which requires that sellers of real property within SSZ's notify prospective buyers of that fact. However, the ramifications and effectiveness of disclosure are too complex to discuss here, and the reader is referred to others who have studied it (Palm, 1985).

Several side effects are created by the APSSZ Act, which are both surprising and interesting. For example, the mere fact that property lies in an SSZ often has a significant effect on insurance rates. Because of this, some insurers charge higher rates within SSZ's. In other cases, some insurance firms reportedly have refused to insure property in SSZ's. Similar effects have been reported by loan companies. The extent of these effects are not well-known and some of the effects may be good or bad, depending on one's point of view.

Perhaps the best side effects relate to the implementation of the Act at the local level. Although all cities and counties are required to have seismic and public safety elements, few of them had the necessary capability (staff, zoning ordinances, policies) needed to deal with the various seismic and other geologic hazards effectively. The APSSZ Act has enabled many cities to develop this capability for one hazard that can be applied to other hazards. For example, many cities and counties have hired geologists or contracted for their services in order to provide reviews and advice regarding the fault-rupture hazard. Most of these geologists eventually provide reviews and services concerning other geologic and seismic hazards. More important, many cities and counties have gained knowledge and developed procedures directed at one geologic hazard that have prepared them to cope with other hazards. They also have developed better regulations, including Seismic Safety Elements, as a result of their efforts to enforce the APSSZ Act. State government likewise has learned how to develop zones and regulations that may provide insight for regulating other hazards. Indeed, the APSSZ Act has attracted attention at the Federal level and has been cited as an appropriate method of controlling development near active faults (Brown and Kockelman, 1983).

Whether or not the APSSZ Act has been cost-effective cannot be answered at this time, because of the many years between fault-rupture events. But the Act will no doubt save lives and reduce unnecessary property damage in the long term. In that respect the APSSZ Act is judged to be successful.

CONCLUSIONS

Although the APSSZ Act addresses only a small part of the seismic hazards in California, it is believed to be effective at both the zoning and implementation levels. Just how effective is judgemental, but most structures built in the SSZ's are believed to be safely located away from active faults. Of course, the problem of old structures that lie astride known active faults remains a serious hazard.

In terms of fault-rupture hazard in California, the following possible actions are suggested:

- A study needs to be made to determine the extent to which existing structures lie astride active faults. Because the APSSZ Act is not retroactive, methods need to be devised to mitigate the rupture hazard to these older structures.

- More effort should be made by the USGS, CDMG, and other geologists to map recently active faults, particularly in developing areas. Detailed maps with supportive data would be very useful to CDMG in carrying out its zoning mandate.

- Consideration should be made to amend the APSSZ Act to require implementation at the State and regional levels, similar to that of cities and counties.

- A study under the auspices of the State Mining and Geology Board would be useful to determine the effectiveness of local enforcement of the APSSZ Act.

REFERENCES

Bonilla, M.G., 1970, Surface faulting and related effects in R.L. Wiegel, editor, Earthquake Engineering: Prentice-Hall, Inc., Englewood Cliffs, NJ, p. 47-74.

_____, 1982, Evaluation of potential surface faulting and other tectonic deformation: U.S. Geological Survey Open-file Report 82-732, 58 p.

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

California Division of Mines and Geology, 1976, Active fault mapping and evaluation program--10 year program to implement Alquist-Priolo Special Studies Zones Act: California Division of Mines and Geology Special Publication 47, 42 p.

Grantz, A., and Bartow, A., 1977, Active faults in California: U.S. Geological Survey pamphlet, 15 p.

Hart, E.W., 1978, Zoning for the hazard of surface fault-rupture in California in Proceedings of the Second International Conference on Microzonation, v. 2, p. 635-646.

_____, 1985, Fault-rupture hazard zones in California: California Division of Mines and Geology, Special Publication 42 (revised), 24 p.

Hart, E.W., Bortugno, E.J., and Smith, T.C., 1977, Summary report--Fault Evaluation Program, 1976 area (Western Transverse Ranges): California Division of Mines and Geology Open File Report 77-9 SF, 13 p., 2 plates.

Hart, E.W., Bryant, W.A., and Smith, T.C., 1983, Summary report--Fault Evaluation Program, 1981-1982 area (Northern Coast Ranges region): California Division of Mines and Geology Open File Report 83-10 SF, 16 p., 1 plate.

Hart, E.W., Bryant, W.A., and Smith, T.C., 1985, Summary report--Fault evaluation program, 1983 area (Sierra Nevada): California Division of Mines and Geology Open File Report 84-52 SF, 24 p., 2 plates.

Hart, E.W., Bryant, W.A., Smith, T.C., Bedrossian, T.L., and Smith, D.P., 1981, Summary report--Fault evaluation program, 1979-1980 area (southern San Francisco Bay region): California Division of Mines and Geology Open File Report 81-3 SF, 23 p., 1 plate.

Hart, E.W., Smith, D.P., and Saul, R.B., 1979, Summary report--Fault evaluation program, 1978 area (Peninsular Ranges-Salton Trough region): California Division of Mines and Geology Open File Report 79-10 SF, 17 p., 1 plate.

Hart, E.W., Smith, D.P., and Smith, T.C., 1978, Summary report--Fault evaluation program, 1977 area (Los Angeles basin region): California Division of Mines and Geology Open File Report 78-10 SF, 16 p., 1 plate.

Jennings, C.W., 1975, Fault map of California, showing volcanoes, thermal springs and thermal wells: California Division of Mines and Geology Geologic Data Map No. 1.

Meehan, J.F., 1982, Public schools and hospital building geologic hazards considerations in E.W. Hart, S.E. Hirshfeld, and S.S. Schultz, editors, Proceedings--Conference on earthquake hazards in eastern San Francisco Bay area: California Division of Mines and Geology Special Publication 62, p. 387-394.

Palm, R., 1985, Geography and consumer protection--housing market response to earthquake hazards disclosure: Southeastern Geographer, v. 25, no. 1, p. 63-73.

Ziony, J.I., and Yerkes, R.F., 1985, Evaluating earthquake and surface-faulting potential in J.I. Ziony, editor, Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 43-91.

REGULATING USES WITHIN THE HAZARD ZONES

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To speak of regulations in an era of deregulation is to fly in the face of current political prudence. But in the case of earthquakes, a regulation to save property and people from this terror brings us back to some of the basic, familiar governmental philosophies regarding the protection of property and the pursuit of happiness discussed and argued when the United States was built in the last half of the 18th century. And if we continue with the spirit of the Great American Compromises of 1776 and 1788, perhaps we can trade regulations for greater seismic safety for those regulations which currently may be considered of lesser importance, such as regulations for scenic highways, curbs and gutters, sideyards, and minimum-square-footage residential requirements.

Five hundred or more cities and counties of California have already authored many ordinances, rules, regulations, and laws which affect seismic safety. In the few minutes we have today to discuss regulations, we will not concentrate on the wide variety of them in the field of land-use planning, structural engineering, architecture (nonstructural features), and geotechnical engineering, but will simply concentrate on areas which need further review and research. Lists of the general topics of ordinances in these fields are in table 1. The list is important because it illustrates programs which are often used, and local governments are proud of their use of these tools. However, no one has really discussed their effectiveness or importance in the field of seismic safety. It would be a fertile field to research or review and prioritize typical seismic-safety ordinance recommendations, and determine their effectiveness in the protection of life and property.

WHAT ARE ACCEPTABLE EARTHQUAKE RISK STANDARDS?

At first glance, it would appear that we are more accustomed to piling regulation upon regulation rather than trading one for the other. Yet, in the field of seismic safety and disaster preparedness, responsibility for ordinances to enforce such safety is firmly fixed by State law and policy on local government, which is accustomed to making trade-off decisions of great potential magnitude on issues of life and death. This is usually done without fanfare in the budget process when injuries and death to people and damage to property are balanced as to nature and type of loss. This occurs when choices are made to fund or not fund a heart team for the hospital, a design team or maintenance group for highways, building and safety inspectors, land-use planners, mental-health technicians, flood-control channels, a fire truck, or additional Sheriff's manpower.

The extent of life- and property-saving capacity of each of these budget packages is not precisely known, but there are enough practical experiences, crude statistics, insurance advantages, or other criteria to make choices. Whether they are accurate or not, the choice is made; issues are put to rest, and records may be kept as to the value of that choice.

However, seismic safety does not have generalized life or death statistics, or a generally known field of knowledge regarding mitigation of risks, that helps it take its place among the safety packages for eventual choice. Sometimes this is an advantage, as the terror of the unknown is a strong force for acceptance of expenditures of unknown benefit; but lack of such information can only hurt the program in the long run. Therefore, before we add regulations or exchange regulations, the value or cost benefit of these regulations should be known through a type of risk analysis or anti-risk regulation analysis. Cost-benefit analysis would be a more positive approach to reviewing alternatives, rather than the often used legal liability approach favored by many political jurisdictions. Does the requirement for a 50-foot setback from a fault line generally save lives and property? Would we get more value if we went 100 feet, or is 10 feet enough? Does anyone know why we generally use 50 feet as a safe and economical approach to set back from fault lines? Maybe it is just an acceptable unit of measure based on old-fashioned lot designs or based on conditions of economics rather than seismic safety.

In the areas of many fault lines and heavy potential shaking, should the decisionmakers believe some building and safety officials who argue that a small increase in standards of the Uniform Building Code (required for all structures) would save the most lives and property at the least cost, and that we could forget geological and engineering studies? After all, the likelihood of some building actually being on a fault line is rather small considered with the total number of houses. Those unlucky, expendable houses on the fault lines would be balanced by those elsewhere with higher uniform standards of safety. Or as an alternative, should we believe some geologists and land-use planners, who hold that if the fault lines and other soil problems are known by our cities, land-use design can effectively minimize seismic risk? In this case, special reinforced structures could be eliminated in exchange for the costs of the special geological and land-use studies? Or as a third alternative, should we believe the geologists and engineers who maintain that with sufficient engineering studies, we can design precisely to resolve the problem for efficiency and economy? Or is it necessary to do all three programs? Or do they overlap each other with unneeded redundancy and expenditure of money?

Alternatively, instead of all the additions to construction standards, we could, with appropriate analysis, determine that controlling the use of the building in relationship to its construction is a more effective way of saving lives and property. To some extent we do this now through the Field Act for schools, the Hospitals Act for hospitals, Essential Service Building program, special construction standards, or rehabilitation programs which give a different priority, standards, or time for compliance to buildings of different uses. Most experts in the field concentrate on their own specialty, and it is only the decisionmakers which should have to choose among these specialties. But for rational decisionmaking, someone needs to set the standards which regulations will then try to implement.

Should our buildings and people be as safe or safer than our highways, safer than the chances of mugging or robbery, fire, and other losses? What continuing standards of safety should be provided for specified periods of time?

To draft reasonable regulations, someone must give us some reasonable choice of risk, and some improbable combination of scientists, sociologists, engineers, and statisticians should focus on this research problem.

WHAT ARE THE HAZARDOUS AREAS?

If we are to focus on regulations within hazardous zones, there needs to be a recognized definition of a hazardous zone. Certainly the Alquist-Priolo Special Studies Zones Act is one source of information for the private sector, as well as the public sector, informing the public of potential hazards and directing the placement of buildings and land-use patterns in California.

The regional threat scenarios produced by the California Division of Mines and Geology (CDMG) for northern California and southern California is a valuable tool for studying seismic safety, hazards, and responses. Whether or not it is a complete, accurate map of hazards is immaterial. It does focus people's attention on certain areas with certain problems which may arise during times of earthquakes. It is a teaching tool which can be generalized for use in many suspected hazardous zones.

The CDMG has produced landslide maps which are based on landslide sensitivity of the terrain and are divided into four categories of hazards. They do not, however, say what the hazard means in determining how to deal with the category shown on the map. Equal attention should be given to the uses of the four categories.

The counties' and cities' general plans, community plans, and seismic safety elements outline specific problem areas which can be used for local planning, although there is not necessarily uniformity of standards among the various plans. Redevelopment areas are sometimes looked at as logical planning units, but their boundaries are generally for economic and blight considerations within political boundaries, rather than geological considerations. They do, however, provide a handy legal tool to accomplish and implement new land-use planning of an area and should be looked at in conjunction with land-use planning based on land-hazard problems.

In reviewing hazardous areas and regulations attached to them, it appears that there needs to be research in the following fields:

1) Private and public studies flowing out of compliance with the Alquist-Priolo Special Studies Zones Act are filed as specified. However, they are not reviewed systematically and no common knowledge is emerging from them to be used by local governments. Other types of studies not related to the Act may or may not be shared with State or local government. To not have this valuable information used in

conjunction with the total picture of seismic safety is a waste of resources and a duplication of effort.

2) There needs to be a State or regional depository for collecting all seismic information and a systematic program to review, categorize, and use it.

3) Seismic-safety planning may have to move from a local base to a regional base, as fault lines and land hazards do not necessarily coincide with city and county boundary lines. Each entity uses its own geologists, experts, criteria, and level of detail, and plans are not necessarily compatible. Proper research could determine how best to accomplish this. The responsibility for such consolidation itself could lie at the State, regional, or local level, with regulations to ensure the government uses those regionally approved plans. To some extent, the consolidation of seismic and other hazard information is being kept by local government. San Bernardino County and the private sector are producing geo-based maps on computers for keeping updated geological and other information showing hazardous areas. This is done by political boundary level rather than a regional geological level, and it may be that some State or regional body should keep this information up-to-date.

4) A redevelopment agency (RDA) generally used in cities could be used as a planning organization because of its powers to accumulate money, consolidate properties into more logical parcels, and set land-use planning standards. The major concern involved in this kind of program is that an RDA's opportunities for collecting overlapping jurisdictions' tax increments do not overwhelm seismic safety policies. The RDA's power to siphon money from fire districts, water districts, and other life-saving organizations might decrease the very powers that must be used in times of earthquake. The advantages and procedures for putting a type of RDA quickly in place after an earthquake, complete with land-use plans, powers, and financing developed prior to an earthquake, should be reviewed. Perhaps a pre-programmed RDA could be set up prior to an earthquake to be utilized immediately after an earthquake.

5) Although local government is primarily responsible for local problems caused by earthquakes, reality says there should be an alternative organization. Local government seems to break down during earthquakes. In the Coalinga earthquake, the city apparently gave way to the county's superior manpower and equipment. The larger organization seems to take over much of the work immediately after the earthquake as a matter of course. Regional joint powers authorities (JPA), the State, or other organization may be the necessary organization in time of major disaster.

WHAT TYPES OF REGULATIONS ARE NEEDED?

There are certain situations which require new regulations and new laws to change human behavior. Adopting regulations is a familiar process to work with, and there are set procedures and skilled personnel to use these procedures, overlayed by the excitement of diplomatic maneuvering for favorable votes. However, laws and regulations are not the only actions that are effective in changing human behavior. In fact, many regulations are in effect and unused as there are hundreds of local government policies made to solve one-time problems and priorities which are no longer valid or are used only on special occasions.

People interested in seismic safety, however, generally want the regulations to be used on a consistent basis as routinely as the Uniform Building Code, Vehicle Code, or other programs accepted by the general public. It would generally be uncomfortable for all if each jurisdiction issued its own version of the Uniform Building Code, even by making it more restrictive, as both scientists and developers are used to moving from political area to political area with certain basic understandings of codes, building techniques, and acceptable solutions to problems.

One type of regulation to change human behavior involves the use of education and training. Education can be for children, involving the school system. It can be at night school involving adults, as was done during the atomic-bomb scare in years past. There is also use of the general media and drills for school children, the communities, and the work places which are part of the educational process.

A second type of regulation could be used to encourage decisionmakers to take appropriate action. These can be in the form of grants for specific programs such as disaster planning, grants for building programs that include seismic safety elements, water and sewer construction grants, all of which are major points in this program, as are tax credits and other inducements for seismic safety. For example, the National Science Foundation (NSF) grant to the County of San Bernardino stimulated an interest in base isolation in the construction of an experimental building, which normally would not be in the purview and interest of local government.

A third type of regulation which is commonly used attempts to control by acting as a punishment or deterrent, such as higher insurance rates, types of use of the building, misdemeanor charges, or the slowing down or halting of a project for failing to act within seismic safety guidelines. The building and safety department generally uses the Uniform Building Code, and the land-use planning organizations use their regulations and authority for controlling and directing land development in the interests of seismic safety through punitive action. Occasionally programs such as transfer of development rights indicate a more positive note in the maze of regulations, which are generally based on misdemeanor charges.

A fourth type of regulation is in the field of management and organization of government. This does not directly impact people, but it affects the governmental private organizations which do impact the population and seismic safety. The placement of the disaster preparedness program in an organization can affect its whole tone and direction. It can be in the sheriff's department, county or city manager's department, decisionmaker's office, or in an office of its own. These typical arguments are time-honored discussions, but there has yet to be a final decision on the best organization to handle disaster preparedness.

There are counterforces to regulations which are sometimes equal to or superior than the regulations themselves. Even though regulations prevent certain types of construction in unsuitable areas, the possibility for the financing of a structure by a specific bank, in turn reinforced by its insurance coverage requirements, makes it almost impossible for local governments to stop construction in hazardous areas. In fact, there are examples of banks deliberately putting their own facilities in hazardous areas to show confidence in the community. There needs to be research in the field of insurance programs and bank lending procedures that would avoid the accusations of red-lining an area and at the same time reinforce good building and land-use-planning programs.

WHAT PROGRAMS COULD BE IMPLEMENTED THROUGH REGULATIONS?

Each of the 500 cities and counties in California has different implementation priorities and procedures for seismic safety. There needs to be research on how to implement programs, evaluate them, and make them effective. At the present time, there are major programs to fund reserach and various Federal and State organizations continuously evaluate research programs and advocate new or different ones or different priorities. Perhaps there needs to be research in the field of implementation of research which is complete and separate from the research organizations themselves. This could be an organization to systematically review research and the impact of regulations and determine which ones should be implemented. Perhaps there could be set aside a fund to implement certain types of programs and to fund certain cities and counties that wish to try innovative regulations in the field of education, regulations, organization, or management. There needs to be some way to systematically transfer knowledge from the researchers to those who use the research.

If implementation is not done by the experts, it will be done by laypersons, and often with good results. There are also various "how to" books and pamphlets being produced to guide the home and property owner towards additional safety for his family and property. However, there is no alternative for a systematic approach to the applied-research programs that can implement what basic research has so laboriously produced for our use and review.

IMPLICATIONS FOR RESEARCH

Some areas of research in the field of regulations and hazard areas are summarized below:

- Analysis of the value (cost/benefit) of existing ordinances and techniques used for the reduction of property loss and loss of life.

- Review of requirements for the determination of hazardous areas in relationship to the scope of detail necessary to harmonize these hazardous areas with the effective improvement of seismic safety.

- Analysis of various "carrots" or benefits to be incorporated in regulations to induce compliance.

- Analysis of various "sticks" or punishments to be incorporated in regulations to induce compliance.

- Analysis to determine whether the "carrot" approach, "sticks" approach, or the educational approach is the best for changing human behavior in relation to the proposed regulations.

- Analysis of the role of banks and insurance companies and their related regulations that encourage seismic safety by their policies of loans and insurance.

- Review procedures for collecting and systematically evaluating geologic information collected through the Alquist-Priolo Special Studies Zones Act, and other acts, and related programs for their impact on regulation of hazardous areas for seismic safety.

- Determine whether seismic safety planning regulations should move from a local base to a regional base for consistency in accumulating information, using it, and applying it for seismic hazard reduction.

- Review the RDA concept and its related regulations and regulatory powers to determine whether all or parts of it could be adapted to reconstruction after an earthquake to consolidate properties into more logical parcels, set land-use planning standards, and finance the program. There may have to be modified programs for putting such an agency in place without lengthy hearings or studies, or the establishment of such standby hearings and studies in advance of the earthquake for use after the earthquake. There would have to be a review of the agency's power to siphon money from fire districts, water districts, and other life-saving organizations so that they do not inadvertently decrease those same powers which are needed in times of earthquake.

- Review the assumption that local government is the best agency for coping with a major earthquake. There may need to be an overlapping joint-powers authority, regional organization, or other entity with regional regulatory authority in a limited field of action. That entity could then be in charge of coordinating problems on a regional basis and aiding local entities that are nonoperational during a pre-specified or pre-determined period of time after an earthquake.

- Review and analyze programs that will implement seismic safety programs and their regulations or make them more effective. This may be an applied research program similar to the National Science Foundation's programs for basic research, or could be a quasi-public organization that would systematically review and research the impact of regulations of basic research.

- Include local governments as partners in the research program, rather than merely subjects of the research program, to produce research that will be used in the future.

The use of regulations and the use of money are popular American responses to the resolution of problems in government, and they are applied daily. If we get less and less money and more and more regulations, someone has to review the regulations and the use of money as to their balance, effectiveness, and priorities for seismic safety. Face validity is not enough to be the basis for creating programs that affect the lives of people and the protection of property amid the horrors of an earthquake. The research community and those that use and implement the results of that research need to join hands for the protection of our society and the safety of our people through appropriate regulations.

TABLE I

LAND USE PLANNING (To avoid and/or reduce the impact of hazards)

Land use plans
Seismic safety elements of general plans
Zoning (density and type of development, hazard setbacks, open space zones)
Subdivision regulations (information requirements, standards, review)
Grading regulations (information requirements, standards, review)
Special development regulations (planned unit development, clustering, transfer of development rights, slope/density)
Project review procedures (administration of development regulations, availability and and use of geotechnical expertise, geologic/seismic report requirements)
Public records of property conditions
Capital improvement programs, budgets
Environmental impact analysis
Redevelopment of hazardous areas
Programs to finance rehabilitation, historic preservation (taxation, property tax, income tax credits, etc.)
Standards in Federal and State programs to assist local governments (cdmg, etc.)
Federal reconstruction assistance (Federal Disaster Assistance Act, Section 406 Procedures, etc.)
Relocation programs and funds

STRUCTURAL ENGINEERING (To reduce risk associated with structural failure)

Inventories of hazardous buildings
Structural design, building code provisions for new construction
Seismic code development, adoption and enforcement--old and new buildings
Methods to strengthen old buildings
Seismic safety in historic buildings
Design of critical facilities (hospitals, fire stations, schools)
Building plan review, building inspection, code enforcement
Posting of hazardous buildings
Redevlopment of areas with concentrations of hazardous buildings
Construction standards for lifelines
Standards and review for major projects (high-rise, high occupancy, involuntary occupancy, critical facilities, etc.)
Standards for the safety of dams
Mobile home anchorage systems

ARCHITECTURE (To reduce risk associated with non-structural features and use of structures)

Site and design review
Non-structural building elements (lighting, ceilings, windows, elevators)
Building configuration

Architectural embellishments (parapets, balconies, chimneys)
Fire safety
Rehabilitation/retrofit assistance

GEOTECHNICAL ENGINEERING (To recognize, avoid, or mitigate hazards)

Identification of seismic hazards (faulting, ground shaking intensity, liquefaction potential, landsliding, other forms of ground failure)
Site selection and preparation, foundation design
Lifeline location, design
Critical facilities location
Dam inundation mapping
Review of projects for public agencies
Recording of geologic information on subdivision maps
Standards for geologic studies and reports

CREDIT: William Spangle and Associates, Inc., 1985, Unpublished memorandum: William Spangle and Associates, Inc., Portola Valley, California.

MODIFYING THE ALQUIST-PRIOLO SPECIAL STUDIES ZONES ACT

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The Alquist-Priolo Special Studies Zones Act has caused an awareness of the location of active fault zones and some awareness of the earthquake hazard. Detailed on-site analyses related to the determination of the existence or non-existence of active faults as prescribed by the Act have greatly increased our knowledge about:

- the location of active faults
- recency of fault movement
- recurrence interval of faulting
- length of displacement per interval and/or with time
- direction of motion
- mechanics of faulting
- general relation of earthquake magnitude to length of fault displacemnent and the mechanics of faulting
- width of the fault zone and/or fault-affected materials

Unfortunately, the Act is specific in intent and wording to the potential for fault rupture and thus overlooks the great multitude of earthquake-related problems and hazards. Earthquake hazard (or seismic safety) analyses that the author has been involved in suggest that fault rupture and/or fault creep may account for only about one-half of one percent of the earthquake damages and losses. Some have unsuccessfully argued that the Act should be expanded to an Earthquake Hazards Reduction Act and address all geologic and seismic hazards. One might argue that the Act as it now exists, is not cost effective. Estimates by the author suggest that the benefit/cost factor related to the Alquist-Priolo Special Studies Zones Act may be negative, whereas other geologic-hazard related studies such as those required for landslides can have a positive benefit/cost factor ranging from 10:1 to 1000:1. The author concurs with the opinion that the Act should be amended to address earthquake hazards such as groundshaking, landslides, and other factors that cause at least 99 percent of the damage, rather than being limited to fault rupture analyses. Those items that should be included in the Act, if amended, can easily be addressed by available technology and professional expertise, such as:

- o time interval (length of time) of strong motion shaking
- o maximum probable magnitude and maximum credible magnitude
- o effect of earth material at site on type of shaking
  -- amplitude
  -- acceleration
  -- intensity of shaking
- o types of ground failure that should be anticipated
  -- liquefaction
  -- settlement and consolidation
  -- landslide, rockfall, etc.
  -- lurching
- o water related problems
  -- tsunamis
  -- seiche
- o effect of groundwater on shaking and other related earthquake hazards.

If the Act remains as originally and currently stated, it should, at least, be expanded to include the analysis of effects of fault rupture and fault creep on lifelines. The most disruptive and costly damage caused by fault rupture appears to be the destruction and/or severance of lifelines. Fault rupture or displacement along faults have caused serious and costly damage to:

- o vital roadways, such as the Interstate highways 5, 210, and 450
- o telephone lines
- o water lines, wells, and storage tanks
- o gas lines
- o sewers
- o other critical service lifelines

Future displacement on faults can sever or damage:

- o the California Aqueduct system
- o major dams
- o freeway interchanges, such as the Interstate highways 10/15 interchange near San Bernardino
- o the Bay Area Rapid Transit system

- interstate gas and oil pipelines
- hazardous and/or toxic waste storage facilities
- pipelines and/or facilities for petroleum or other chemicals which may be toxic or subject to explosion and fire.

IMPLEMENTING LAND-DEVELOPMENT REGULATIONS FOR SURFACE-FAULTING HAZARDS IN LOS ANGELES COUNTY

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INTRODUCTION

This paper is not meant to be a contribution to the science of fault-hazard prediction, but rather a narrative summary of what one local agency has accomplished in the 20-year period between 1965 and 1985. This is followed by recommendations for further studies of potentially active faults shown in the Seismic Safety Element of the State-mandated General Plan adopted by Los Angeles County.

A BRIEF HISTORY OF LOS ANGELES COUNTY'S CODE REGULATIONS

Prior to the San Fernando earthquake, the County of Los Angeles had enforced the intent of the Building Code through the Engineering Geology Section of the Department of County Engineer and the application of Ordinance No. 2225, Geologic Hazards. By bending the interpretation of the code, active faulting was considered a geologic safety hazard, and rightly so. The particular section of the code which was liberally interpreted (Section 309. Geological Engineering Reports) reads:

> The report shall contain a finding regarding the safety of the building site for the proposed structure against hazard from landslide, settlement, or slippage and a finding regarding the effect of the proposed building or grading construction will have on the geologic stability of property outside the building site.

The first clause of this quote has direct application to an active fault, though the original authors of Section 309 did not necessarily have active faulting along the San Andreas fault in mind. The conclusion of the Geology Section was that the term "slippage" had no real meaning since "landsliding" covered all forms of land movement at the ground surface. It was therefore convenient to use the term "slippage" as support for requiring geologic reports over known active faults by liberally interpreting "slippage" as faulting. Of course, this is a weak and euphomous analogy, but lacking a specific earthquake fault ordinance, it was heavily borrowed for ordinance support based upon the very real fact that an active fault is truly a geologic hazard.

Needless to say, much resistance was encountered from realty interests in the stretch of the San Andreas fault undergoing urbanization in Los Angeles County. This resistance was felt through the ranks of the Department, emanating from the County Board of Supervisors. Reason subsequently dictated the need for a specific earthquake fault ordinance. The Board of Supervisors did ordain such an Earthquake Fault Ordinance (No. 10,037) as an amendment to the Building Code, Ordinance No. 2225, effective July 17, 1970. But, it must also be noted that this ordinance lasted a mere two weeks or so before being rescinded by the Board.

Shortly thereafter, the San Fernando earthquake occurred (February 9, 1971) and a reconsideration of the earthquake fault hazard by the Board of Supervisors ensued, culminating in the present earthquake fault ordinance, referred to as Section 311 of the Building Code, effective October 29, 1971.

The rest is history. Section 311, Los Angeles County's Earthquake Fault Ordinance, is the only ordinance to this author's knowledge that is incorporated directly into a building code. It lends support to the County's General Plan, and provides direct support for seismic evaluation of critical structures and large land divisions. It also goes one step further than the Alquist-Priolo Special Studies Zones (APSSZ) Act (Hart, 1985) in that even single-family homes are also evaluated for seismic safety. Los Angeles County, thanks to the action of its far-sighted Board of Supervisors, has set an example for the rest of the nation.

Though one of a kind, Los Angeles County's Earthquake Fault Ordinance is limited in that it pertains only to known active causative faults. For single-family dwellings, it requires as geologic evidence for fault activity only a 5-foot deep trench across an active fault trace as shown in the APSSZ maps, supplied by the State Mining and Geology Board. Admittedly, it is only a minimal code; greater exploratory effort can be applied at the option of the developer and his consulting geologist.

SUMMARY STATEMENT ON CODE REGULATIONS

The California Division of Mines and Geology (1975), states:

> The importance of the review process is emphasized (here) because it is the reviewer who must evaluate the adequacy of reports, interpret or set standards where they are unclear, and advise the governing agency as to their acceptability.

The tone of this message implies that the local reviewer has ultimate authority in what is acceptable. Other than the City of Los Angeles, Los Angeles County probably represents one of the largest local agencies showing real concern for active faults relative to the location of critical facilities, proposed subdivisions, and single-family dwellings. The inclusion of single-family dwellings makes the County ordinance (Title 26, Section 311) even more restrictive than the State's regulations, but Section 311 is in itself inadequate to truly evaluate the location of a known active causative fault, and actually excludes subsidiary active tangential faults (termed cognate or secondary faults by others).

We are reminded by the Joint Committee on Seismic Safety (1974) that "the scope of (an) investigation is dependent not only on complexity and economics of a project, but also on the level of risk acceptable for the proposed structure or development." According to the CDMG (1975) it is obvious that a more detailed investigation should be made for hospitals, high-rise buildings, and other critical or sensitive structures than for low-density structures, such as wood-frame dwellings which are comparatively safe. Therefore, if this risk is acceptable, and presumptions are acceptable, then Section 311 may not be so bad after all. If it is clearly understood that it is only a minimal code requirement, and does not constitute a thorough investigation, it at least discloses the existence of an active fault in proximity to the development, and therefore serves as a public caveat emptor.

If an active fault is not encountered in a 5-foot deep trench, the fault is presumed absent. This is an engineering/administrative decision incorporated into the ordinance. Thus, as the result of influential interests pressing upon the Board of Supervisors, staff geologists capable of advising the agency are effectively prohibited from doing so by the agency's own ordinance. How can this situation be logically resolved? Perhaps by cleaning up the State's regulations, beginning with the State Board of Registration for Geologists, which allows registered engineers to submit geologic reports for local agency review. Engineering staffs may dictate criteria for the reviewer of such reports. This influence is not felt just locally, but in Sacramento as well.

FUTURE PROSPECTS FOR SEISMIC EVALUATION

The above narrative shows what Los Angeles County has accomplished toward ongoing earthquake-hazard reduction through code regulations. Other communities have done as well by using different approaches. This workshop also asks what additional scientific and technical information is needed, and which hazard-reduction techniques are most effective. Since Los Angeles County's approach is pretty well set, it now remains to be seen how that approach can best be improved without returning to former ordinance Section 310, which was much more strict than the subsequent Section 311.

The County's effort currently emphasizes control only around active causative faults, without inclusion of potentially active subsidiary, secondary, or cognate faults which, were they well documented, could be equally active. These subsidiary faults might perhaps be less damaging relative to magnitude of shaking, periodicity, and duration, though they could be just as disruptive as a landslide from the standpoint of surface rupture. There is currently no restriction against placing structures directly over these subsidiary or secondary faults, even if their location is known, unless it can be shown they are indeed active. To this end, there is an ongoing effort to establish the relative activity of the San Gabriel fault, as one example. Indeed, the San Fernando earthquake of 1971 clearly shows how seismically active the Transverse Ranges can be. And the most effective technique for establishing the active parameters of any fault is the state-of-the-art trenching technique which allows trenching as deep as necessary within economic reasonableness.

POTENTIALLY ACTIVE FAULT PROBLEM IN LOS ANGELES COUNTY

Nichols and Buchanan-Banks (1974) state:

> Commonly, faults are regarded as active and of concern to land-use planning when there is evidence that they have moved during historic time or, through geologic evidence, there is a significant likelihood that they will move during the projected use of a particular structure or piece of land. Because geologic evidence may be lacking, obscure, or ambiguous as to specific times of past movement, geologists may be able to estimate relative degree of activity only after a regional analysis that may extend far beyond the locality under consideration. Such analysis may be based on historic evidence of fault movement, seismic activity (occurrence of small to moderate earthquakes along the fault trace even though not accompanied by obvious fault movement), displacement of recent earth layers (those deposited during the past 10,000 years), and presence of geomorphically young, fault-produced features (scarps, sag ponds, offset stream courses, and disruption of manmade features such as fences and curbs).
>
> Knowing that a particular fault is active, however, is only part of the problem. The other part is predicting the likely location of fault ruptures during the next significant earthquake. Geologists generally accept the premise that the next rupture will probably occur along the fault trace that ruptured last, especially if there is evidence of repeated earlier movements on the same fault trace (Wallace, 1968, p. 17). However, movement seldom is limited to a single fault surface throughout the lifetime of a fault system such as the San Andreas. In many places tens or even hundreds or thousands of individual fault surfaces make up the San Andreas in a zone varying in width from a few hundred to many thousands of feet....
>
> Faults that commonly produce significant displacement (more than several inches at a time) often have related branches that diverge from the main fault but usually have less movement along them. They may also have secondary faults that are not directly or obviously connected physically tc the main fault trace. Secondary faults are usually nearby (within hundreds of feet of the main rupture), but they may extend as much as several miles away. As with branch faults, displacement along secondary faults is usually only a fraction of that along a main fault.

In Los Angeles County, various faults, both active and potentially active, though known through the literature and mapped by several agencies, such as the United States Geological Survey, the California Division of Mines and Geology, and local universities and institutes, are insufficiently well defined both on the surface and with respect to their relative degree of geologic activity (recency of movement) to facilitate the most equitable and accurate enforcement of existing code requirements and land-use policies. These requirements were originated to control construction over the traces of faults which are demonstrably active; that is, faults that moved in historic time. Historic time at present only applies to three faults in Los Angeles County: 1) The San Andreas from Fort Tejon to Cajon Pass; 2) the Newport-Inglewood fault zone (uplift); and 3) the San Fernando fault.

Many faults in Los Angeles County are designated as potentially active by California Division of Mines and Geology criteria, whereas their real state of activity may be such that they should be classified as active. One such fault or fault system is referred to as the Malibu Coastal fault. Others are the Whittier fault, the Sierra Madre frontal fault system, the Holser fault in the Santa Clarita Valley of North Los Angeles County, the Palos Verdes fault on the north side of the Palos Verdes Hills, and the San Gabriel fault which longitudinally bisects the San Gabriel Mountains.

The major difficulty in designating these faults as active, in terms of the County's adopted policy and code, is the lack of direct evidence for demonstrating historic movement as required by Section 311 of the Building Code. Using this elementary and unsatisfactory criteria, many new structures, as well as existing structures, are unknowingly subjected to high risks. These risks occur when faults presently designated as potentially active suddenly prove to be active.

In-depth investigations of the above-mentioned faults, in order to determine their state of seismic activity, is necessary to more properly apply and modify Section 311 of the Los Angeles County Building Code. Major difficulties involved would be: (1) access to private property; (2) a search for appropriate investigative sites to determine the relative recency of movement; and (3) lack of detailed mapping of the fault's ground traces. This latter is especially true of the San Andreas fault zone, where multiple traces are evident; however, this fault is currently being intensely studied by the CDMG and others.

The principles and techniques involved in the investigation of these potentially active faults could consist of:

- trenching to 20-foot depths across the exposed or projected traces;
- mapping in detail, using a 0.5 meter grid system;
- correlation of borehole data on either side of a fault's trace;
- determination of a groundwater barrier which hypothetically will designate the fault's plane at depth;
- dating of carbonaceous material found intact and uncontaminated;
- geophysical seismic-refraction data to determine fault planes in three dimensions;

- o color and infrared aerial photography to identify regional lineations; and
- o geologic mapping of a zone 0.4 km wide on both sides of these faults at a scale of 1:1,000.

Malibu Coast Fault

This fault extends from West Hollywood westward to Leo Carillo Beach where it continues westward offshore. The latest movement on this fault may have been more than 11,000 years ago, but accurate dating of its latest seismic event has not been determined. Some seismologists and geologists believe that the 1972 Point Mugu earthquake was the result of movement along the Malibu Coast fault. The activity of this fault is therefore questionable. The Malibu Coast fault is approximately 48 miles long, is a north-dipping thrust fault, and is believed capable of generating a 6.8 magnitude maximum credible earthquake.

Palos Verdes Fault

The Palos Verdes fault is at least 9.5 miles long and trends northwestward from Los Angeles Harbor to Malaga Cove. Woodring, Bramlette, and Kew (1946) suggest that there has been major tectonic activity during recent geologic time along the Palos Verdes fault zone. Numerous small (less then magnitude 4.0) earthquakes have been recorded along this zone and may represent activity of this fault. Based on fault length-magnitude relationship, the Palos Verdes fault is believed capable of a 6.8 maximum credible earthquake.

Holser Fault

The Holser fault is approximately 13 miles in length extending from just east of Highway 99 westward to the vicinity of Piru Creek. The surface trace of the fault is inferred to intersect the San Gabriel fault east of Saugus. Subsurface data in nearby oilfields demonstrate the Holser fault is a southward-dipping, sharply folded reverse fault. Subsurface exposures of this fault in the Metropolitan Water District's Saugus Tunnel show at least 14 feet of terrace deposits offset by the Holser fault (Proctor, oral communication, 1974) which suggest that the fault should be classified as potentially active. This fault could conceivably generate a maximum credible earthquake of 6.5 magnitude.

PRODUCT OF PROGRAM

Geologic maps designating the state of activity and zone of faulting deformation along the above-mentioned faults should be developed. These maps should be used to to modify existing land-use planning adopted by the Los Angeles County Department of Regional Planning, and should be supported by geologic reports on the findings of the fault investigations. Recommendations should be made to modify the Los Angeles County ordinances and municipal building laws applicable to construction over, or in close proximity to, active fault traces. Based on age dating and displacement data, more accurate estimates of the fault's maximim probable magnitude could be determined.

The description of the active fault's trace could also be accompanied by a description of the physical integrity of rock types bordering the fault traces and their susceptibility to possible ground motion and ground rupture other than fault displacement. Proximity to ground water from the surface of the ground and to the geographic location of the active fault trace would be rendered. This information would help designate more appropriate land-use for certain types of construction, or possibly disallow construction of habitable buildings.

CONCLUSION

I propose that:

- o studies of earthquake recurrence (from analysis of Quaternary history) of certain potentially active faults within Los Angeles County be initiated; and

- o that these certain faults, designated as potentially active in the General Plan of Los Angeles County by the Los Angeles County Regional Planning Department be investigated through subsurface exploration and detailed surface mapping to determine their recency of fault movement.

The logical approach would be to: (1) research all available and existing subsurface data; (2) map in detail specific faults designated as potentially active; (3) investigate these faults utilizing subsurface techniques; (4) delineate the fault's accurate location where not physically visible as a trace on the ground surface; and (5) delineate the zone(s) of tectonic deformation associated with these potentially active faults.

Difficulties inherent in this proposal are the location of appropriate sites for investigations and lack of observational criteria where faults underlie or cut very recent alluvial materials. However, knowledge of a fault's activity status will facilitate the modification and enforcement of present building code requirements (referred to as the Earthquake Fault Ordinance, Section 311) and the Vital Facilities Ordinance of the Los Angeles County Building Code, as well as facilitate appropriate land-use decisions and policies in the Department of Regional Planning.

REFERENCES

California Division of Mines and Geology, 1975, Guidelines for evaluating the hazard of surface fault rupture: California Division of Mines and Geology Note 49, Sacramento, Calif.

Hart, E.W., 1985, Fault-rupture hazard zones in California: California Division of Mines and Geology, Special Publication 42, 24 p.

Joint Committee on Seismic Safety, 1974, Meeting the Earthquake Challenge -- Final report to the Legislature, State of California: California Division of Mines and Geology Special Publication 45, 223 p.

Los Angeles County Building Code, Title 26, Earthquake faults, Section 311, October 29, 1971.

Nichols, D.R., and Buchanan-Banks, J.M., 1974, Seismic hazards and land-use planning: U.S. Geological Survey Circular 690, p 2-3.

Woodring, W.P., Bramlette, M.N., and Kew, W.S.W., 1946, Geology and paleontology of Palos Verdes Hills, California: U.S. Geological Survey Professional Paper 207, 145 p.

Evaluating Earthquake and Surface-Faulting Potential for Hazard-Reduction Actions

SUMMARY OF WORKING GROUP I AND AUDIENCE DISCUSSIONS

This session was moderated by Bruce A. Bolt. Panelists were Arthur C. Darrow, Steven Sokol, James E. Slosson, and Egill Hauksson. Joining the panel were speakers from the morning session, Joseph I. Ziony, Lucile M. Jones, Kerry E. Sieh, Earl W. Hart, and Robert B. Rigney. Cliffton H. Gray, Jr. was the session commentator. Questioners and commenters from the audience included George Stolt, Gary S. Rasmussen, Jeffrey A. Johnson, Gilbert Dewart, and several others who were not identified. The following text was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Darrow indicated that two questions were at issue: Should we be doing anything additional in terms of basic investigations to develop new data and new techniques to evaluate the fault-rupture and earthquake-generation capacity of faults in southern California? If the answer to that is positive, (and it was suggested earlier that it's not necessarily positive in that sufficient information for applications currently exists), what should we be doing? He suggested that additional work is needed. His personal experiences showed that the results of certain geotechnical investigations were fundamental surprises. He cited the example of finding Holocene faulting in downtown San Diego, California, where active faulting had been previously determined not to exist. He also cited the inadvertent discovery of evidence of late Quaternary displacement on a fault thought to be previously inactive. He suggested the need to (1) continue developing information; (2) collate, assimilate, and disseminate the information currently in hand; (3) reevaluate conventional notions about faults whose behavior was thought ot be well understood; (4) look closely at complex intersections of faults; and (5) continue a strong microzonation program. He concluded by stating that evaluation methods selected should be adaptable to significant changes in the data base and the underlying interpretations.

Sokol defined his position as legal counsel to a constituency of about 104,000 Realtors in the State of California. He indicated that Realtors really do not want to be in a position of determining what (seismic) risks exist to a parcel of property they want to sell. Realtors mostly operate using such regulations as the Alquist-Priolo Special Studies Zones Act's disclosure requirements. In response to an earlier challenge as to how a Realtor would comment to a client about fault activity, Sokol said that most would be comfortable not commenting at all on the risk. This is primarily because of the increasing liability of Realtors, as related to the general societal trend of increasing liability for anybody in business. He indicated that Special Studies Zones for seismic hazards are only one of many, such as flood hazard zones, for which a Realtor's disclosure is required. He also noted the likelihood of new disclosure requirements being placed upon Realtors regarding toxic exposure and other hazards. He commented that whereas the scientists' perspectives are regional and long-term, the homebuyers' perspectives relate to dealing with a problem in a small area during a portion of their lives, or the life of the property. He concluded by mentioning that the current medium of disclosure of a Special Studies Zone for fault-rupture hazard is a single paragraph in the contract of sale for an individual piece of property.

Slosson discussed how new information on the existence of faulting in downtown San Diego should relate to the design criteria for high-rise buildings there. He cited this situation as an example of the need for new data, and further explained that the design should be appropriate to the known geologic conditions. He stated that well-trained engineers are fully capable of designing for conditions given to them, and that the problem is learning what those conditions are. He cited a recent California appellate court decision (which later went to the California Supreme Court) that strips the 10-year statute of limitations from those involved in design and construction who are cited in a cross-complaint (Tech-Bilt, Inc. v. Woodward-Clyde and Associates, California Supreme Court, May 2, 1985). This means that many geologists and engineers could be confronted with a court case despite passing the statute of limitations; therefore, the work should be done properly from the beginning. As a former State Geologist for California, Slosson had signed many of the first maps of Alquist-Priolo Special Studies Zones (Hart, 1985), but believes there are deficiencies in the way the legislation was written. The intent of the legislation was excellent, but only the surface faulting hazard was considered. Considering damage and lives lost during a major earthquake, surface fault rupture accounts for less than a small percentage of one percent of the losses. The original bill did address much broader geotechnical studies dealing with other aspects of seismic safety. As the Alquist-Priolo Special Studies Zones Act currently stands, it is not cost effective, Slosson stated. He recommended that the bill be amended to include other earthquake hazards, including, for example, landslides, liquefaction, rockfalls, and offset of lifelines such as utilities and roadways that are currently exempt from the bill because of lack of continuous human occupancy.

Hauksson projected a slide to illustrate the location of all magnitude 5 earthquakes in southern California since 1930, plus initial rupture zones and aftershock zones. He indicated his interest in detailed analysis of smaller events to help evaluate earthquake potential, and commented on the University of Southern California's operation of a seismic instrumentation network to detect these within the Los Angeles basin.

Bolt used an example of design studies for a large installation proposed by the Department of Energy, and the fault map of the State of California to point out how little is known about the location and activity of faults in California. He then called for a discussion among the panelists in an attempt to draw questions from the audience.

Sieh reiterated that there is great uncertainty about the location of seismic hazards in California. He expects perceptions about these hazards will increase in some areas and be reduced in others as the result of refined information. From this will come a more complex but accurate view of earthquake hazards.

Jones noted that there is no place in southern California that is incapable of a magnitude 5 earthquake, although magnitude 8 earthquakes are constrained to the San Andreas fault. She called for improved understanding of the potential for moderate sized (magnitude 6 to 7) events in different parts of the region.

Bolt called for questions regarding the PEPPER Project (Earth Sciences Associates, Inc., 1982; H.J. Degenkolb Associates, Engineers, 1984). He emphasized that the greatest danger to Los Angeles comes from a moderate earthquake very close to the site in question rather than from a larger earthquake on the more distant San Andreas fault. He stated that it is not clear what a great earthquake on the San Andreas fault will do to the City of Los Angeles.

Slosson disagreed that a magnitude 8 earthquake on the San Andreas fault would cause little damage in Los Angeles. He emphasized that more damage would occur in the Long Beach - Los Angeles Harbor area than is currently estimated. Bolt pointed out that predicted-intensity maps (Evernden and Thomson, 1985) show lower intensities in those areas of Los Angeles County. Slosson referred to the example of the recent Mexico earthquake of September 19, 1985, where accelerations in the basement rock adjacent to Mexico City were only 4-to-5 percent of gravity, yet serious damage was done where saturated sediments existed. He implied that a similar situation exists for the Los Angeles Harbor area. He noted that these were marine clays unlike the lake clays of Mexico City, but that similar conditions regarding seismic response prevail.

Darrow did not believe the hazard is uniformly distributed in southern California. If it is not uniformly distributed, then analysts are "playing a fool's game" by constantly focusing on the San Andreas fault. Much more information is needed about other faults. Moreover, not enough is known about site response throughout the region to know where resources should be devoted to deal with mitigation. Limited resources for mitigation must be concentrated where the most critical facilities exist and where those facilities are subject to strong ground motion. Overlain upon that must be those areas where the risk or hazard is greatest. The geoscience community, however, is not as far along as the structural engineering community in ability to make such overlays. As an example, if a Los Angeles County building official must make a decision about retrofitting buildings, how does he decide which ones to retrofit? Darrow does not think adequate earth-science information exists for making such decisions. The weakest part of the information base is the understanding of earth materials, and the second weakest part is the knowledge of faults.

Bolt, in reference to the PEPPER Project, pointed out that not enough was known about faulting beneath the Los Angeles basin for consultants to determine the potential for earthquakes on a specific fault. He also indicated that the project used highly generalized assumptions about soils and sediments overlying the basement rock. It was surprising that seismologists predicted intensities using such information, and then applied it to damage estimation.

Rigney cautioned that he knew better than to get between a scientist and his basic science. However, he noted that one need not be any more sophisticated in one's research than the program calls for, particularly for an applied program based upon that research. In the case mentioned earlier by Darrow with respect to decisionmaking by a county building official, it would be a simple matter to categorize the buildings in question and make appropriate decisions as to which ones should be retrofitted. Decisionmaking tools exist to make such applictions. He called for the rapid and beneficial applications of research, and interaction between researchers and practitioners to get research results out promptly.

Stone agreed that researchers should be more closely linked with practitioners, but acknowledged that such a situation is difficult to accomplish. He proposed funds to help accomplish such linkage. He also asked the panel if seismic waves generated by an earthquake on one fault could trigger earthquakes on other, possibly unrelated faults. Members of the panel responded negatively.

Rasmussen queried Sokol about people who sign a waiver, incur damage, and then retain a lawyer to sue the county, city, consultant, or other party. This shows that the risk that the individual was willing to take changed dramatically during the time of failure.

Sokol responded that it is up to society at large to decide whether one can or cannot build under a given set of circumstances. The decision must be made, and economic costs have to be weighed. The government must make the decision, bearing in mind the loss of use of the property, the diminution of its value, and other factors. If government chooses not to prohibit building in a given area, for whatever balance of factors it takes into consideration, then an individual makes the choice whether to build in that area. Thereupon, there is a risk for the expert participating in something that goes wrong. There is a real chance of being sued, even when all the risks and possibilities were disclosed. Engineers have been sued after the fact on the theory it was negligent of them to participate knowing that there were a given set of risks. The general trend in society is toward much more liability, either in negligence law or strict liability; that is, liability without fault. The courts more and more find people liable for consequences. Despite disclosure that a particular piece of property falls within a designated Alquist-Priolo Special Studies Zone, nature often does not respect where the zones happen to be drawn on a map. There is a problem of access to information on these zones; note that Thomas Brothers once published maps of these zones, but no longer does because of potential liability.

Slosson noted that an San Diego County, California, appellate court recently determined that the waiver is not valid and is actually an encouragement for someone to make an error. (Salton Bay Marina v. Imperial Irrigation District, California Appellate, 4th 4 Civ. 26949, September 30, 1985). Therefore, a consultant should seek legal advice if he writes a report which would encourage a person to build with a waiver. He suggested that the consultant should resign from the job if he determines that the client is determined to build no matter what the consultant says.

Johnson queried Bolt about the application of the current formula from the Uniform Building Code to the fundamental period of a site, and its relation to the effects of the recent earthquake on the sediments beneath Mexico City. Bolt referred to an analysis by H. B. Seed, whose opinion it was that the situation beneath Mexico City was unique and may not occur in California. Johnson argued the point, wondering if a surface wave or a shear wave of 2-second period is really influenced by 60 meters of material, no matter how soft it is. Bolt reiterated that he was simply quoting Seed, and not defending the profession of soils engineering. The point was not resolved.

Johnson queried Jones regarding information on dipping structures beneath the Santa Monica Mountains and Transverse Ranges. Jones referred to studies by Corbett and Johnson (1982) showing a dipping plane beneath the mountains, verified by studies from an earthquake in 1978, and another in 1979. She noted that the focal mechanisms for aftershocks from those events show oblique reverse faulting, and that that is the common mechanism throughout the region between Santa Barbara and Palmdale, California.

Dewart queried the panel about the combined probabilities for earthquakes, and to what extent the different fault zones could affect one another. What is the probability that a major event on the San Andreas fault would generate an event on the Newport-Inglewood fault? Jones suggested that there is no evidence of any correlation between earthquakes on separate faults in the region. She does see correlation in space and time for foreshocks along the same fault. Bolt emphasized that the probability for such earthquakes on separate faults is exceedingly small or zero. Sieh pointed out that no earthquakes of magnitude 6 or greater in the Los Angeles basin followed the great 1857 earthquake on the San Andreas fault. He believed the story to be similar for the 1906 earthquake on the San Andreas fault in northern California. He noted that for a 1976 earthquake in China, however, there were several 6.5 magnitude earthquakes within the first two years after the main shock. For California's two great historical earthquakes, however, it appears there were few damaging aftershocks on other fault structures. Bolt noted that investigators did not map faults in 1906, and whether there was any sympathetic movement on the Hayward or Calaveras faults was not known at that time. There were no damaging earthquakes immediately following the 1906 earthquake; however, the statewide seismicity seems to have increased for a year afterwards.

Sieh offered some scenarios for the next great earthquake in southern California, suggesting that the southern 300 kilometers of the San Andreas fault in the state are the likely location for that event. He speculated on the uncertainty of having a single event that would break the entire segment, as opposed to perhaps two very large earthquakes very close in time on adjacent segments of the fault.

REFERENCES

Corbett, E.J., and Johnson, C.E., 1982, The Santa Barbara earthquake of 13 August 1978: Bulletin of the Seismological Society of America, v. 72, no. 6, pt. A, p. 2201-2226.

Earth Science Associates, Inc., 1982, Seismic environment and geologic effects--pre-earthquake planning for post-earthquake rebuilding (PEPPER Project): National Science Foundation Grant CEE 8024724; William Spangle and Associates, Inc., Portola Valley, Calif., 32 p.

Evernden, J.F., and Thomson, J.M., 1985, Predicting seismic intensities in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 151-202.

H.J. Degenkolb Associates, Engineers, 1984, Summary report of structural hazards and damage patterns--pre-earthquake planning for post-earthquake rebuilding (PEPPER Project): National Science Foundation Grant CEE 8024724; William Spangle and Associates, Inc., Portola Valley, Calif., v. 1, text, 38 p; v. 2, tables, 52 p.

Jennings, C.W., 1975, Fault map of California with locations of volcanoes, thermal springs, and thermal wells: California Geologic Data Map Series no. 1, California Division of Mines and Geology, Sacramento, 1 sheet, scale 1:750,000.

Hart, E.W., 1985, Fault-rupture hazard zones in California--Alquist-Priolo Special Studies Zones Act of 1972 with Index to Special Studies Zones Maps: Department of Conservation, Division of Mines and Geology Special Publication 42 (revised), Sacramento, Calif., 24 p.

II. PREDICTING SEISMIC INTENSITIES FOR RESPONSE PLANNING AND LOSS ESTIMATION

II. PREDICTING SEISMIC INTENSITIES FOR RESPONSE PLANNING AND LOSS ESTIMATION[1/]

Working Group Moderator:	Robert D. Brown, Jr.
Plenary Presenter:	James F. Davis
Working Group Presenters:	Jack F. Evernden Michael S. Reichle Paul J. Flores John H. Wiggins
Working Group Panelists:	William E. Spangle Karl V. Steinbrugge Richard J. Roth, Jr. Rachel M. Gulliver
Working Group Commentator:	Brian E. Tucker
Audience Participants:	William J. Kockelman Anthony Prud'homme James F. Davis

[1/] Names and affiliations of all participants are listed alphabetically in Appendix A.

PREDICTION OF SEISMIC INTENSITIES: FUTURE PROSPECTS

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NATURE OF SEISMIC INTENSITY STUDIES

Seismic intensity is a qualitative measure which characterizes felt effects and structural damage resulting from earthquake shaking and ground failure. Several intensity scales exist. These scales consist of levels of successively greater earthquake-induced consequences ranging from felt effects to wholesale destruction of structures. The Modified Mercalli Intensity Scale, which is the most generally accepted frame of seismic intensity reference, has twelve divisions of earthquake-induced results. The scale was developed to express observed post-earthquake conditions in a systematic manner. It also can, however, be employed to portray the outcomes of future earthquakes based upon assumptions of size and fault source.

This paper recounts the principal features of seismic intensity investigations and considers their limitations. The use of intensity measures to portray predictions of damage patterns of future earthquakes is vital to development of scenarios of the consequences of future seismic events. In the following text, we discuss the caveats associated with seismic intensity prediction, and future means of improving the rigor of these investigations.

APPROACH OF POST-EARTHQUAKE SEISMIC INTENSITY INVESTIGATIONS

The intensity scale is employed to characterize the geographic distribution patterns of earthquake effects. This is achieved by canvassing information from witnesses, and observations made by the investigators shortly after the event has occurred. These intensity-scale judgments are contoured to graphically present the damage patterns.

In the study of historical earthquakes in a particular region, news accounts, personal letters, and other reports are searched to identify past events and to establish their damage distributions. In turn, these patterns help to establish conclusions regarding the sizes and fault sources of the earthquakes which took place before the period of instrumental recording networks. This type of analysis has been carried out by the State of California, Department of Conservation, Division of Mines and Geology (CDMG) for historical events in California prior to 1950 (Toppozada and others, 1981; Toppozada and Parke, 1982).

APPLICATIONS AND USES OF SEISMIC INTENSITY MAPPING AND INVESTIGATIONS

The analyses conducted on the effects of both recent and historical earthquakes have been employed by scientists, engineers, and planners in a wide variety of ways:

- The analysis of historical (pre-instrumental) earthquake effects allows an estimate of the magnitude of those events for seismic-hazards analyses. Repeatable regional damage patterns can be identified and used as the basis for probabilistic estimates of ground-shaking potential.

- Comparison of damage patterns associated with various events can provide information on geological factors influencing damage, as well as effectiveness of building code requirements, standard designs, and construction practices.

- Based on these empirical lines of evidence collected from past events, models are constructed which endeavor to predict the damage patterns of future earthquakes.

- Such predictions serve as invaluable input into local emergency response planning. Monetary losses and casualties can be estimated, based on past experience, to assist in response and recovery planning. Analysis of the performance of various lifelines (highways, water and electrical systems, etc.) further assists response planners.

As patterns of geographic damage distribution and corresponding anticipated performance of types of buildings emerge from seismic-intensity prediction studies, these insights can also be employed in long-term mitigation strategies to reduce losses and casualties through land-use and building-code policies.

LIMITATIONS OF SEISMIC INTENSITY INVESTIGATIONS

The major limitation of seismic intensity investigations stems from attempts to rigorously apply the qualitative descriptions of damage within the intensity scale. This judgmental process is necessarily subjective and consequently it must be kept in mind when comparing conclusions of studies conducted by different investigators.

The resolution of the detail of intensity maps is fundamentally limited by the generalized nature of the intensity scales. Most scales are defined in terms of only integer values, with descriptions such as "damage considerable in poorly built structures," or "damage slight in specially designed structures." Hence, the scale, as originally devised and as applied in the field, can discriminate only regional patterns of damage and other earthquake effects. The descriptions combine effects which may not have the same geographic distribution. In the range of VI to IX of the Modified Mercalli Intensity Scale, the descriptions primarily involve building damage. It is often difficult to separate that damage due to strong ground motion from that due to ground failure in applying the scale. In the prediction of damage for future events, however, one would like to separate these effects.

Other limitations of the existing descriptions within the seismic intensity scales result from the types of structures included. Special structures such as bridges or tunnels are not included in the definitions of the various intensity levels. This makes it difficult to establish a straightforward correlation between the intensity scales and performance of these structures. Furthermore, the response of newer classes of construction, only marginally tested by earthquakes to date, can only tentatively be fitted into the existing scale.

These limitations all significantly qualify the projections of predicted earthquake damage which employ seismic intensity insights.

APPROACHES TO PREDICTING SEISMIC INTENSITIES

Modeling intensity is the composite estimation of seismic wave propagation, local ground responses, and manmade structure performance as regional patterns in consequence of a hypothesized earthquake associated within an identified fault source. The uncertainties of all three assessments affect the rigor of the analysis in a cumulative manner.

In the United States, the modeling of seismic intensity distribution has been led by Jack Evernden of the U.S. Geological Survey (Evernden and others, 1981; Evernden and Thomson, 1985). Damage-producing ground motion is assumed (based on the analysis of historical data) to originate along the length of the fault rupture at a certain depth. The equation describing the damage distribution in geographical relation to the fault is derived from empirical ground-acceleration distributions which are normalized to fit historical intensity data.

Evernden and others have used his method to produce predicted seismic-intensity maps for plausible future earthquakes throughout the country. A modification of the Evernden model is used by CDMG in earthquake planning scenarios. They present "worst case" scenarios, based upon data from historical California earthquakes.

Limitations in any approach to predicting seismic intensities stem from the general nature of the scales themselves and from the necessarily generalized modeling. Variations in the frequency content of the seismic source are not easily included, yet they can profoundly influence the consequences. Larger earthquakes or those with low stress drops may be relatively more efficient in generating long-period ground motion than the smaller or higher stress-drop events. The damage resulting from the frequency-dependent response of structures may thus vary significantly from event to event. Detailed variations within individual geologic units are not included in the modeling. All alluvial basins are treated alike, with

Evernden including a factor for the depth of ground water. Neither Evernden nor CDMG consider the local variations in thickness of the sediments or the frequency response of the alluvial basin in modeling intensity.

No existing method of seismic intensity modeling includes the effects of ground failure, such as surface fault rupture, liquefaction, or differential settling. Such effects are often more localized than those due to ground shaking, making them difficult to predict. However, the damage resulting from ground failure may be greater than that due to ground shaking. In emergency response planning scenarios, the effects of ground failure are estimated separately and added to the damage assessment. It is generally recognized that current methods of predicting ground failure are less reliable than those for predicting strong ground motion.

Another qualification required in predicting seismic intensity is the special effects of directivity or seismic focusing. The damage distribution from the 1984 Morgan Hill, California, earthquake may show evidence of directivity-of-rupture propagation effects. The greatest damage was concentrated near the southern portion of the fault rupture. The location of the main shock in the northern portion of the aftershock zone and distinct azimuthal variations in recorded strong motion accelerations suggest that the rupture started in the north and propagated south. The effects of source directivity on damage distribution have often not been appreciated, since they are generally difficult to distinguish from other effects.

In summary, seismic intensity maps generated by Evernden's techniques and similar approaches predict the damage distribution resulting from short-period ground motion. As the 1985 earthquake in Mexico has illustrated, long-period ground motion can have a significant effect at distances greater than 200 miles. Recognizing that the geologic substrate of Mexico City is perhaps a special case, and that construction practices are perhaps different from those in California, applying the insights gained in Mexico to California is an open question. However, we must also recognize that data on the effects of large earthquakes on modern construction in California do not exist at this time.

IMPROVEMENTS IN APPROACHES TO PREDICTION OF SEISMIC INTENSITY

There are several types of studies which may be undertaken to improve the rigor of seismic-intensity prediction for future earthquakes:

- In order to overcome the general deficiencies of intensity scales and their applications, detailed studies of earthquake effects should be undertaken following all moderate and large earthquakes in California. Such surveys should address, in as much detail as possible, the effects due to factors such as variations in ground response, and in the performance of various building types. Any effects which might be attributed to long-period ground shaking should be noted separately.

- If possible in such detailed post-earthquake analyses, accommodation for special structures and new engineering designs should be included in the scale. For example, a particular level of damage to a highway bridge that has been upgraded for earthquake resistance should be assigned a higher intensity than an equivalent level of damage to a non-upgraded bridge. Similarly, damage to a building such as the Imperial County Services Building damaged in the 1979 Imperial Valley, California, earthquake would not be assigned a Modified Mercalli Intensity of IX, since that type of design had been shown to be unsafe during the 1971 San Fernando earthquake. The damage to that building does seem in general agreement with that in the surrounding area (Intensity VII).

- Strong motion data, as raw acceleration or analyzed spectral parameters, could be correlated with such detailed damage and intensity surveys to help improve the predicting capability for newer structures. As this information becomes available, it should be incorporated into the predictive models so that the most accurate estimates of loss can be available to response planners.

PROGRESS WHICH CAN BE MADE IN THE NEXT 10 YEARS

As more detailed damage evaluations become available and as frequency-related effects become better understood, our ability to predict damage distributions will improve greatly. The damage in Mexico City from the September, 1985 earthquake would not have been predicted from contemporary (standard) models. The seismological and geologic factors which are important during great earthquakes have yet to test modern structures in California.

- California earthquakes with magnitudes greater than 7 occur only once every decade or two. We should endeavor to study such events in particular detail, especially in areas where intense damage surveys of modern buildings can be undertaken and where good strong-motion data exist. Smaller events may not have the force to truly test newer structures or to sufficiently excite long-period ground motion to test response in that portion of the spectrum.

- Until improvements in the rigor of the intensity scale or its application can be made, the detail of input to the predictions should be kept in line with the level of rigor. In recent years, the use of building inventories taken from tax records for seismic intensity prediction for scenarios has been proposed. Such comprehensive studies need careful scrutiny because of the significant costs required to process extensive data sets. Optimum level of data input regarding the building inventory should be identified in order to correspond to the rigor that can be derived from the current state of the art of seismc modeling.

In the near term, when predicting damage distributions from future earthquakes, one must keep in mind that the next earthquake will most probably be a surprise. It may occur in an area where we do not expect it. It may have some damage feature we did not forecast. Only detailed studies of future events will enable us to proceed to improve estimates of future earthquake damage.

REFERENCES

Evernden, J.F., Kohler, W.M., and Clow, G.D., 1981, Seismic intensities of earthquakes of conterminous United States -- their prediction and interpretation: U.S. Geological Survey Professional Paper 1223, 56 p.

Evernden, J.F., and Thomson, J.M., 1985, Predicting seismic intensities in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 150-202.

Toppozada, T.R., Real, C.R., and Parke, D.L., 1981, Preparation of isoseismal maps and summaries of reported effects for pre-1900 California earthquakes: California Division of Mines and Geology Open-File Report 81-11 SAC, 182 p.

Toppozada, T.R., and Parke, D.L., 1982, Areas damaged by California earthquakes, 1900-1949: California Division of Mines and Geology Open-File Report 82-17 SAC, 65 p.

SEISMIC INTENSITIES: THEIR IMPORTANCE, PREDICTABILITY, AND USE

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Seismic intensity is the only physical parameter of earthquakes that is both always observable and always directly linked to damage. The widely-held idea that measurements of one sort or another derived from seismometers (peak acceleration, peak velocity, RMS acceleration in a bandpass, etc.) have greater "physical" meaning than intensity is transparently false. Intensity, by definition, is directly linked to damage, while most of the physical qualities measured from seismometers--most particularly, the favorite of engineers and building codes, peak acceleration--have been shown to exhibit, at best, poor correlation with damage. This fact has been noted in the literature by the most competent engineers concerned with earthquake design. Intensity, expressed as it is in terms of damage to structures of particular types, must be a physical measure of the aspects of earthquake-induced ground motion that cause damage to buildings of the types used in the definition of intensity units. Failure to recognize this very simple fact has led to endless misdirected assertions as to the nonphysical character of intensity values.

The possibly fatal flaw in the use of intensities in the future is the general failure of those making and dealing with intensity maps to recognize the sensitivity of damage, and thus intensity, to the detailed specifics of building design. This problem can be circumvented by careful calibration of definitions to building type. Thus, the Chinese have successfully modified definitions of Modified Mercalli Intensity Units for use with typical structures in China, structures vastly different from those used in definitions of intensity elsewhere in the world. In the United States, no such care is being taken. The definitions still used today are those given in 1932, that is, prior to the imposition of building codes for wood-frame structures in California. When those old definitions are applied to observed damage for recent earthquakes in California, "anomalous" results are obtained. Thus, for the Imperial Valley earthquake of 1979, the low intensity contours (contours defined by shaking without structural damage) and a near-field accelerogram were essentially identical to those for the Imperial Valley earthquake of 1940 (an earthquake that resulted from rupture along the identical fault segment that failed in 1979 in the USA). However, the intensity values near the fault were calculated as significantly lower in 1979 than in 1940. There seems little or no doubt that these lower "intensity" values resulted from the fact that most of the structures in the region were built or rebuilt after the 1940 earthquake according to building codes designed to decrease structural damage from earthquakes. The identical phenomenon of "lower than expected" near-field damage occurred for the Coyote Lake, California earthquake of 1979. Damage in Gilroy, near the epicenter, was far less than expected based on the pattern of far-field intensities and expected damage levels based on the original definitions of intensity units. As of 1979, approximately 88 percent of the wood-frame structures in Gilroy had been built since the enactment of California building codes in 1940.

Detailed analysis suggests that damage levels have been decreased so markedly by these new designs that measured "intensity" values are lower by 1 to 1.5 intensity units. If this change in damage versus intensity (or change in intensity) is not recognized and incorporated into future intensity maps, routine interpretation of these maps will be impossible. We still calculate intensities against old definitions, but calculate damage estimates for the style of construction of interest.

Thus, intensity is a true physical measurement and is available for all earthquakes on a variety of ground conditions, both for modern and historical earthquakes. No other physical parameter is as broadly measurable or as relevant. If the physical character of intensity is to be exploited for damage prediction, intensity must be (1) predictable, (2) correlatable with seismometric measurements of one type or another so that predicted intensity can be converted to parameters directly useful in building design, and (3) correlatable with expected levels of damage to buildings of various important types. All three of these conditions can be met at levels adequate for design and damage estimation purposes.

As regards prediction of intensities, we have published several papers which detail the procedures used and the input data required (Evernden and others, 1973; 1981; Evernden, 1975; Evernden and Thomson, 1985). We have documented extensively the predictability of intensity patterns in various tectono-geophysical regions. We have demonstrated that interpretation of observed intensity patterns allows valid estimates of signal attenuation, length of rupture and depth of focus for the earthquake associated with each intensity pattern studied, and improved estimates of magnitude of historical earthquakes. Indication that the regional attenuation characteristics establishable by study of intensity patterns are geophysically real is the fact of their correlation with a large set of other regional geophysical parameters (P_n and S_n velocities, P and S travel times, m_b magnitudes, Rayleigh wave attenuation, heat flow, mean elevation, level of seismic activity, potential length of rupture in a given region, etc.). It is important to note that we incorporate signal persistence into our estimation of intensity, effectively calculating an RMS-type acceleration parameter for the bandpass of relevance to intensities. The incorporation of persistence of the signal into the model resulted from meeting the constraint imposed by us that the theoretical model should be able to predict intensity patterns over a large range of magnitude.

The second condition for usefulness of intensities, that is, their correlation with seismometric measurements, is investigated in Evernden and Thomson (1985). We only note here that, by use of the many strong motion records of the San Fernando earthquake, we have been able to demonstrate rough correlation of a host of seismometric parameters with intensity. Simultaneously, we showed that RMS acceleration over a 10-second window for the bandpass from 0.5 to 3 Hertz achieves nearly a perfect mean fit to the theoretical relationship used in our model, that is, a twofold increase in the parameter for a one unit increase in Rossi-Forel intensity. This condition was used because analysis of both American and Soviet strong-motion data had indicated the correctness of such a model when applied to Rossi-Forel intensities (not to Modified Mercalli intensities).

As an example of converting predicted intensities to a useful ground-motion parameter, we cite figure 78 (in Evernden and Thomson, 1985), a figure showing predicted RMS acceleration over a 10-second period in the bandpass 0.5 to 3 Hertz as a result of the modeled earthquake on the north end of the Newport-Inglewood fault in southern California, using the relationships of figure 71 in the same report. That figure shows comparisons of Modified Mercalli and Rossi-Forel intensities, and RMS accelerations of the 1971 San Fernando, California, earthquake in all frequency bands. We can generate such maps for any of the four bandpasses defined in the paper. Other authors have expressed the view, which we share, that an RMS acceleration parameter, expressed over the bandwidth of relevance to structures being studied, is a far more useful engineering parameter than peak acceleration.

The final requirement of intensities, that is, that intensity values be a device for estimating expected levels of damage to various types of buildings, has been shown to be possible at a useful level. Figure 79 in Evernden and Thomson (1985) presents empirically-derived relationships between intensity, building type, and expected percent damage. Remember again that intensity units on these graphs are defined by use of pre-1940 building design. This point is so important that it must be stressed repeatedly. Figure 79 shows that, if intensity "IX" were to be defined in terms of five percent damage, post-1940 wood-frame structures (on a group basis) would never experience intensity "IX," while unreinforced concrete buildings would experience intensity "IX" at the same time pre-1940 wood-frame were experiencing intensity "VIII" and post-1940 wood-frame structures were experiencing intensity "VII" (all in Rossi-Forel units). As pointed out earlier, our present procedures are to calculate intensities based upon pre-1940 criteria and to then generate maps of predicted loss by use of figure 79. Thus, figures 80 through 83 give maps of predicted percent damage for wood-frame and unreinforced concrete buildings as a result of the modeled earthquake on the northernmost 30 km of the Newport-Inglewood fault. Figures 80 through 83 simply give predicted percent loss for buildings of specified types, the figures being relevant if such buildings exist at the locations of the calculations. There is no inventory of actual building types included in the present calculations.

Further refinements of maps of the type of the last figures would require incorporation of a complete inventory of relevant building types for each grid square of the map. Such data would allow the expression of expected loss in terms of dollars, which is a much more useful parameter. One could then sum expected dollar losses over individual municipalities, counties, or regions to get a more meaningful estimate of the impact of a specified earthquake. At present, the only means we have for estimating dollar losses is through very generalized models. These estimates of loss to structures are probably correct to better than a factor of two, and they do allow determination of the relative impact on the Los Angeles area of various expected earthquakes. Thus, a repeat of the Fort Tejon earthquake of 1857 is predicted to cause relatively minor losses and not be the ultimate disaster often imagined; intensities throughout most of the city of Los Angeles will be no higher (or even less) than they were for the 1971 San Fernando earthquake. The modeled earthquake along the north end of the Newport-Inglewood fault generates higher intensities in the Los Angeles basin and would undoubtedly cause far greater damage and dislocation.

As a last comment, we should note the discussion in Evernden and Thomson (1985) of the great differences in predicted losses reached by different authors for the same earthquake. As is clear from that text, it is our view that the loss estimates given by the Federal Emergency Management Agency (1980) for a repeat of the San Francisco 1906 earthquake are much too large and cannot be supported by analysis. It is of the greatest importance that this difference in prediction of loss be resolved one way or the other as soon as possible.

REFERNCES

Evernden, J.F., 1975, Seismic intensities, 'size' of earthquakes, and related phenomena: Bulletin of the Seismological Society of America, v. 65, p. 1287-1315.

Evernden, J.F., Hibbard, R.R., and Schneider, J.F., 1973, Interpretation of seismic intensity data: Bulletin of the Seismological Society of America, v. 63, p. 399-422.

Evernden, J.F., Kohler, W.M., and Clow, G.D., 1981, Seismic intensities of earthquakes of conterminus United States--Their prediction and interpretation: U.S. Geological Survey Professional Paper 1223, 56 p.

Evernden, J.F., and Thomson, J.M., 1985, Predicting seismic intensities, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 151-202

Federal Emergency Management Agency, 1980, An assessment of the consequences and preparations for a catastrophic California earthquake; Findings and actions taken: Washington, D.C., 59 p.

DEVELOPMENT OF EARTHQUAKE PLANNING SCENARIOS

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INTRODUCTION

Following a major damaging earthquake in a California metropolitan area, the ability of major lifelines and other critical structures to perform and not become hazards themselves is of paramount importance in the emergency response and recovery process. Lifelines can be defined as those systems which receive and transport people, goods (including energy), services, and information. These would include highways, railroads, airports, power grids, water systems, and telecommunications networks. The modern computerized banking system might also be considered a lifeline, possibly under communications. Critical facilities would include hospitals, schools (as mass care facilities), and police and fire stations. In California, since no one agency is primarily concerned with overall lifeline performance during disasters, it falls to the government, public utility, and private sector emergency response planners to anticipate probable and plausible lifeline failures and hazards in their respective spheres.

To assist emergency response planners and others responsible for response and recovery following a damaging earthquake, the California Department of Conservation, Division of Mines and Geology (CDMG) is preparing a series of lifeline scenarios depicting geological, seismological, and engineering judgments of how lifelines in a specific area might respond to a particular damaging earthquake. The first two such scenarios addressed repeats of the approximate magnitude (M)8 San Andreas fault earthquakes of 1857 in southern California and of 1906 in the San Francisco area (Davis and others, 1982a,b). Scenarios currently being developed are based on damaging earthquakes on the Hayward fault in northern California (Steinbrugge, and others, 1986), and on the Rose Canyon and Newport-Inglewood faults in southern California. The latter two are scheduled for completion in 1986.

These latter scenarios postulate a "worst case" event where the maximum credible earthquake is assumed to occur, producing a seismic intensity distribution similar to that of the most damaging historical California earthquakes. This affords the emergency response planner the opportunity to prepare for admittedly somewhat pessimistic, but still plausible, levels of damage. Thus, we emphasize that the scenarios are for emergency response planning purposes only. They will assist in preparing for smaller earthquakes as well.

CHOICE OF SCENARIO EARTHQUAKES

When CDMG set out to develop earthquake planning scenarios for the greater Los Angeles and the San Francisco Bay areas, the initial choices for the scenario earthquakes were obvious. Repeats of the 1857 Fort Tejon and 1906 San Francisco earthquakes would inflict severe damage on the highly urbanized areas. It became clear, however, that smaller events occurring within urban areas could have more damaging effects. These areas include the east San Francisco Bay area of Alameda, Contra Costa and eastern Santa Clara Counties; southern Los Angeles and northern Orange Counties; and metropolitan San Diego County.

For the eastern San Francisco Bay area, the scenario earthquake is based on a rupture of the entire 100-km length of the Hayward fault, from San Pablo Bay to east of San Jose. This event, with a magnitude of about 7.5, is considerably larger than the 1868 Hayward earthquake of M6.8, which had only about 50 km of surface rupture. Similarly, for the Newport-Inglewood fault in Los Angeles and Orange Counties, we are assuming an 80-km rupture, corresponding to M7. Based on the dimensions of the aftershock zone, the M6.3 Long Beach earthquake of 1933 is believed to have ruptured approximately 30 km of this fault zone.

For these two cases, our scenario events are based on historical seismicity. In the San Diego area, however, the seismic hazard is much more ephemeral. No fault has yet yielded conclusive evidence of Holocene activity. There have been no local damaging earthquakes during this century. On the other hand, several events with near M6 magnitude did occur in the San Diego area during the 19th century. There is considerable background seismic activity along the offshore Coronado Bank fault, beneath San Diego Bay, and along the San Miguel fault zone in Baja California Norte, southeast of San Diego. The potential for a major earthquake, although perhaps unappreciated, does exist. Here, however, a scenario event cannot be based on an historical earthquake. The choice of a causative fault is not arbitrary, but should be based on faults with Holocene (within the last 10,000 years) or, if that is not available, Pleistocene (10,000 to 1,000,000 years) movement. The former would be considered active; the latter potentially active. For San Diego, we chose a 50-km segment of the Rose Canyon fault, with a southern end of the rupture just northwest of downtown, which would generate an M7 event. In a related program, the Federal Emergency Management Agency (FEMA), the California Office of Emergency Services (OES), and other agencies will be examining international aspects of emergency response planning, supposing a scenario earthquake which would affect both San Diego (United States) and Tijuana (Mexico). For this study, the scenario earthquake is assumed to occur along one of the mapped offshore faults south of downtown San Diego, which could inflict damage on both sides of the international border.

DAMAGE DISTRIBUTION ESTIMATION

Damage distribution due to strong ground shaking is estimated in our recent scenarios using a method evolved from that of Evernden (1981) and the analyses of Modified Mercalli intensities of historical California earthquakes of Toppozada and others (1981) and Toppozada and Parke (1982). It is evident from the historical data that earthquakes are highly variable in their effects. This is a function of population density, ground condition, the source itself, and/or the path between the source and a given site. In order to account for this variation, we have modified the parameters of Evernden's method to reflect the most damaging of the historical events. The main differences are:

1) We consider only Modified Mercalli Intensities VI to IX -- those that include building damage induced by ground shaking.

2) An apparent source depth of 15 km is used for events from near M7 to M7.5. For events near M6.5 or less an even shallower source should be considered.

3) Intensities attenuate at a rate inversely proportional to distance for distances greater than the apparent source depth.

4) At any given distance from the fault, intensities may vary up to two units, depending on local geology, from igneous and metamorphic rock (0) to alluvium (+2), regardless of the state of saturation of the alluvium. Maximum intensity near the fault on alluvium is IX; on igneous rock, VII.

For events with $M \geq 6.5$, intensity distribution is normalized to give, on alluvium, intensity IX out to a distance of about 8 km from the fault and intensity VII out to about 80 km. These factors combine to forecast somewhat more damaging overall Modified Mercalli intensities than those predicted by a direct application of Evernden's algorithm, but the differences appear to be less than one unit of intensity between the two methods.

The damage distribution is further complicated by the effects of ground failure. In many cases, especially for the larger events, the damage from surface rupture and liquefaction may be greater than that from strong ground shaking. The scenarios examining repeats of the 1857 and 1906 earthquakes assumed (based on the historical offsets) up to 30 feet of fault offset. For the M7.5 Hayward fault scenario, up to 10 feet of fault rupture is assumed. For smaller scenario events, such as an M7 earthquake on the Rose Canyon fault with up to 3 feet of fault offset, the effects are somehwat less pervasive, but could be equally damaging to an important lifeline crossing the fault.

Liquefaction and related ground failure are more difficult to forecast in a lifeline scenario. Liquefaction effects may occur out to about 100 km from the earthquake source and may be spotty or fairly extensive. In our planning scenarios, we primarily consider liquefaction effects on saturated alluvium, and on saturated artificial fill in particular, to be possible especially in the regions of strongest shaking.

LIFELINE PERFORMANCE

The lifeline and structural inventories and the forecast seismic intensity and secondary effects maps we generate are the basic inputs to the damage assessments. These analyses are developed with the owners and operators of the various lifelines and facilities. The resulting scenarios offer emergency response planners a comprehensive starting point. Subjects covered by the Hayward fault scenario are listed in table I (Steinbrugge and others, 1986). The number of deaths and injuries is a strong function of local geology, building age and type, and time of day of the event. As such, only rough, conservative estimates by county are made in that report. This may not please the response planner, who would like to know how many ambulances to station in which parts of a city. Unfortunately, accurate inventories of the factors affecting the number of deaths or injured do not usually exist.

Similarly, damage to buildings depends heavily on the age and type of structure. The performance of structures was not discussed in the planning scenarios for the southern and northern San Andreas fault. The Hayward fault scenario presents a general discussion on building performance and more specific discussions of hospitals and schools. Much of the information in this portion of the report is both earthquake and region independent. It is presented to give the planner an idea of how these specific structure types have performed in the past and, in the scenario, how they may perform in the future.

The discussions of the transportation and utilities lifelines follow the same general organization. The lifeline itself is briefly described. For example, the most used highway routes, possible alternative routes, and those without a reasonable alternative are discussed. The analyses of lifeline vulnerability which follow each inventory are nearly earthquake-independent; in general, they focus on how fault rupture, ground failure, or strong ground motion could contribute to damage of the lifeline. Factors such as access and local facility damage are noted. General planning considerations include the interaction among lifelines (for example, the utilities' need for rapid road access, the dependence of a given lifeline on utility power or water, etc.) and those factors affecting choices of alternative sources and routes.

The discussion of each lifeline to this point is fairly general. The planning scenario and damage assessment portions, on the other hand, present a very specific list of situations. It cannot be overemphasized that the situations are for planning purposes only. They are not damage predictions, but the kinds of damage one could find following the scenario earthquake. Some feel that the scenarios are pessimistic. They are conservative estimates based on what has happened during historical earthquakes in California and elsewhere. Most probably, not all the situations will occur. We hope that the situations listed emphasize the variety of problems which will have to be faced, and the interplay among them. No scenario will prove accurate in detail. Our efforts provide planners with a regional pattern of the types and extent of problems that will confront emergency response personnel after a damaging earthquake.

TABLE I

Subjects covered in Hayward Fault Scenario
of Steinbrugge and others, 1986

Deaths and Injuries

Buildings
general
hospitals
schools

Lifeline Corridors

Transportation Lifelines
highways
airports
BART
railroads
marine facilities

Utility Lifelines
communications
electrical power
water
waster water
natural gas
petroleum refineries and products

REFERENCES

Davis, J.F., Bennett, J.H., Borchardt, G.A., Kahle, J.E., Rice, S.J., and Silva, M.A., 1982a, Earthquake planning scenario for a magnitude 8.3 earthquake on the San Andreas fault in southern California: California Department of Conservation, Division of Mines and Geology Special Publication 60.

Davis, J.F., Bennett, J.H., Borchardt, G.A., Kahle, J.E., Rice, S.J., and Silva, M.A., 1982b, Earthquake planning scenario for a magnitude 8.3 earthquake on the San Andreas fault in the San Francisco Bay area: California Department of Conservation, Division of Mines and Geology Special Publication 61.

Evernden, J.F., Kohler, W.M., and Clow, G.D., 1981, Seismic intensities of earthquakes of conterminous United State — Their prediction and interpretation: U.S. Geological Survey Professional Paper 1223, 56 p.

Steinbrugge, K.V., Davis, J.F., Lagorio, H.J., Bennett, J.H., Borchardt, G.A., and Toppozada, T.R., 1986, Earthquake planning scenario for a magnitude 7.5 earthquake on the Hayward fault in the San Francisco Bay area, California: California Department of Conservation, Division of Mines and Geology Special Publication 78 (preprint).

Toppozada, T.R., Real, C.R., and Parke, D.L., 1981, Preparation of isoseismal maps and summaries of reported effects for pre-1900 California earthquakes: California Department of Conservation, Division of Mines and Geology Open-File Report 81-11 SAC, 182 p.

Toppozada, T.R., and Parke, D.L., 1982, Areas damaged by California earthquakes, 1900-1949: California Department of Conservation, Division of Mines and Geology Open-File Report 82-17 SAC, 65 p.

USING EARTHQUAKE PLANNING SCENARIOS

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Scenarios of predicted earthquake damage, even if they contain a high degree of uncertainty, are a prerequisite to sound, comprehensive earthquake preparedness planning, especially in a region as large and complex as southern California. Preparing for great earthquakes is no different from other regional planning problems such as transportation, environmental quality, or growth management. In all cases, those responsible for planning must have some capacity to anticipate future problems, and thereby promote changes in the status quo to be better prepared to cope with problems when they present themselves. Therefore, the primary uses of damage scenarios are as planning tools within a comprehensive planning process.

The Southern California Earthquake Preparedness Project (SCEPP) has delineated a five-phase process for earthquake preparedness planning. These are:

1) Hazard identification and risk assessment;

2) Development and adoption of seismic safety goals and objectives;

3) Design of hazards-reduction and preparedness strategies;

4) Program development; and

5) Development of a multi-year plan and evaluation mechanisms.

The development and utilization of earthquake damage scenarios are of particular importance in phases 1 through 3 of this process.

Phase 1 identifies the hazards and risks for a particular locality. Most of the information being presented at this workshop can be used in this phase of our planning. Peck (1985) indicates that the ultimate benefits of this information are reductions in injuries, losses of life, and property damage, plus continued functioning of vital services and economic activities following a destructive earthquake. To achieve these benefits, scientists, engineers, planners, and other professionals must interact to produce useful technical products. One of these products should be damage scenarios. Damage scenarios attempt to project and quantify potential losses and disruptions to our urban infrastructures. Even with high levels of uncertainty, the resulting data bases and statistics produced in these scenarios are extremely useful in SCEPP's planning process. Without some quantification of potential effects on a community from a damaging earthquake, it is very difficult to develop seismic safety goals and set appropriate policies. By quantifying potential earthquake effects, damage scenarios give policymakers the ability to visualize a community's level of risk, and thereby determine if it is an acceptable one.

I believe it is also important to bring the international experience into this visualizing process. The September 1985 Mexico earthquake did perhaps even more than the damage scenarios used by SCEPP to help identify the problems we need to confront in our planning efforts.

If a current level of risk depicted by a damage scenario is found to be unacceptable to a community, then the hazards influencing that risk can be identified, and goals and objectives for reducing hazards can be adopted. In meeting community seismic safety goals and objectives, damage scenarios can also assist in designing strategies for reducing hazards in the long term, and aid disaster management and recovery should the earthquake occur in the short or intermediate terms.

Regarding the design of disaster management and recovery strategies, damage scenarios can be very valuable in projecting damage on current assessment of hazards without considering the benefits of long-term hazards-reduction programs. As such, damage scenarios can provide estimates by geographic area. The estimates will fluctuate by geographic area, depending upon the quality of basic geologic information for a given area. The scenarios can give estimates of:

- o Deaths and injuries,
- o Homeless caseloads,
- o Structural damage,
- o Damage and service disruptions to lifeline systems, and
- o Economic losses.

With such information, planners can in turn estimate the basic requirements for personnel and material resources for effective disaster management and recovery. Such analysis can identify resource shortfalls or policy problems that can be corrected before the earthquake occurs.

With a damage scenario as the basis, planners can propose specific programs within a multi-year plan to better prepare for responding to the consequences of a damaging earthquake.

There are three pioneering works on damage scenarios that I would like to discuss briefly. California Division of Mines and Geology (CDMG) Special Publication 60 (Davis and others, 1982) provided for the first time a regional perspective on effects of earthquakes occurring in the short and intermediate term. The report identified problems that could be addressed immediately, and offers an excellent view of the potential problems of utility companies.

Work by Steinbrugge and others, published by the Federal Emergency Management Agency (1980) from an analysis carried out by the National Security Council, gave for the first time figures on deaths, injuries, numbers of people requiring hospitalization, and economic losses. Using the statistics from this document, SCEPP could set policy and focus greater attention on the earthquake problem at all levels of government.

Gulliver (1986) produced a report estimating the expected number of homeless after a M8.3 earthquake along the southern section of the San Andreas fault. That work provides the basis for determining how and where to provide emergency housing. These data are particularly important to the Federal Emergency Management Agency, which has the overall responsibility for providing emergency housing in areas hard-hit by disasters.

In applying damage scenarios at a more local level, there is a problem of collecting the necessary information to correlate with basic studies of intensity (Evernden and others, 1981). Collecting such data is very time-consuming and labor-intensive. We need to study the feasibility of developing damage scenarios at a larger scale, perhaps 1:24,000, and determine whether or not it could be done. To address that issue, and how users at the local government level could take greater advantage of a detailed damage scenario, SCEPP conducted a pilot study for an area of San Bernardino County, California, that I would like to discuss.

SCEPP chose a 20-square-mile area within San Bernardino County to test the applicability of automation to producing damage scenarios, and to address the multi-jurisdictional perspective. Of particular interest was development of an automated data base for response to an earthquake prediction in the short term. If there were a warning of a few days, for example, it would be highly valuable to have damage scenarios in place quickly to help anticipate problems and decide on mobilization of resources. It is also valuable to know about the problems caused by an earthquake that go beyond the jurisdiction of any one entity. Therefore, we included three cities and one county within our study area.

A computer program was developed to access data and produce model damage scenarios. The data files available to the model included geophysical data, such as geology, fault traces, and groundwater levels, and socio-economic data, such as census information, assessors' files, and FEMA facility files. Models tested through the computer program were a shaking intensity model (Evernden and others, 1981), and some liquefaction work done specifically for this project by the CDMG. Models produced were structural damage models, dollar loss models, deaths and injuries models, and homeless caseload models. The products of this study are available through the Southern California Earthquake Preparedness Project (1983).

I believe that the pilot study gave us a reasonable picture of earthquake effects at the local level on the basis of the existing data. Also, we now have a method by which local damage scenarios can be developed. In conclusion, it is clear that a similar detailed data base and computer model are needed at the regional level.

REFERENCES

Davis, J.F., Bennett, J.H., Borchardt, G.A., Kahle, J.E., Rice, S.J., and Silva, M.A., 1982, Earthquake planning scenario for a magnitude 8.3 earthquake on the San Andreas fault in southern California: California Division of Mines and Geology Special Publication 60, 128 p.

Evernden, J.F., Kohler, W.M., and Clow, G.D., 1981, Seismic intensities of earthquakes of conterminous United States--their prediction and interpretation: U.S. Geological Survey Professional Paper 1223, 56 p.

Federal Emergency Management Agency, 1980, An assessment of the consequences and preparations for a catastrophic California earthquake--findings and actions taken: Washington, D.C., 59 p.

Gulliver, R.M., 1986, Estimation of homeless caseload for disaster assistance due to an earthquake: Federal Emergency Management Agency, Region IX, San Francisco, Calif. 176 p.

Peck, D.L., 1985, Foreword, in Ziony, J.I., ed., 1985, Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. iii.

Southern California Earthquake Preparedness Project, 1983, Pilot project for earthquake hazard assessment: Los Angeles, 46 p., 4 app.

IMPROVING ESTIMATES OF FUTURE EARTHQUAKE LOSSES

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J.H. Wiggins Company*

INTRODUCTION

I am very pleased to present my thoughts on the subject of estimating earthquake losses, since I have been heavily involved in the subject for years, at times pleading with government officials and even the United States Congress to acknowledge the need for accurate loss estimation for planning purposes. Planning, as I use it here, implies broad areas of before- and after-the-fact functions which deal, in one way or the other, with the earthquake problem:

- Research
  - Geological
  - Seismological
  - Soil dynamics
  - Structural behavior
  - Reconstruction costing
  - Lifeline engineering
  - Primary and higher-order loss economics

- Government activities
  - Emergency response plans
  - Insurance requirements
  - Rehabilitation funding
  - Congressional actions
  - Interstate and intrastate functional relations

- Private sector activities
  - Insurance companies
  - Corporations
  - Utilities
  - Small businesses
  - Apartment and condominium owners
  - One- and two-family dwelling owners

Loss estimates with associated return periods or probabilities of occurrence within a specified time frame can be quite helpful for planning purposes at all of the levels cited above. Private sector activities can make trade-off decisions

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among insurance, strengthening, self-insurance, and post-event operations. Governments at all levels can forecast the depth of their involvement, and the costs to them for their own losses in terms of function and property, so that they can serve the public at an optimum level. Research can be directed through sensitivity studies of the various loss forecasting models in order to focus on those areas within the loss models that need refinement.

Therefore, I suggest considering the idea of loss estimation in a broader context than just dollars lost. Research, government operations, and private response, both before and after the fact, can be directed so that when the earthquake strikes, losses similar to those suffered during the 1985 Mexico earthquake do not occur here in southern California.

THE DEFINITION OF LOSS

Losses can be defined in many different terms, all of which affect our well-being as a nation and our individual lives. The affected entities in descending order of complexity are as follows:

- Nation
- Region
- Economic sector
- State
- Intrastate region
- County
- Intracounty region (public and private)
- City
- Corporate organization
- Family
- Individual

The above affected sectors of society are often referred to as "stakeholders." These stakeholders and the subgroups within each group, regard impending earthquake losses from various points of view. Common perspectives held by these stakeholders, unfortunately, is:

- "It won't happen to me (us),"
- "It won't happen in my lifetime,"
- "If it happens, I won't lose much,"
- "My insurance policy will pay for everything,"
- "The government will bail us out,"
- "It's so far in the future we don't need to think about it now,"
- "I'll be retired before it happens here,"
- "My structure is designed to code, therefore nothing can happen,"
- "I read in the paper that it won't happen for thirty years,"
- "There are more pressing things to think about like the federal deficit," and
- Similar rationalizations.

If the various stakeholders don't believe one of the above situations to be true, then there are several primary, secondary, and tertiary types of losses that they must consider for mitigation purposes.

PRIMARY TYPES OF LOSS

- Property damage
- Landform change and damage
- Death and injury

SECONDARY AND HIGHER ORDER TYPES OF LOSSES

- Business interruption
- Unemployment
- Mortgage and other loan defaults
- Loss of taxes
- Homelessness
- Defaults on bond issues
- Fire losses
- Toxic effluent releases
- Communication, transportation and power disruption
- Impact on the defense industry
- Impact on government deficits
- Impact on economic sectors which influences foreign goods sales
- Public and private liability

Just one look at the 1985 Mexico earthquake will reveal a host of consequences that our government officials, who are primarily responsible for alerting the Nation to the potential impacts from a major earthquake, should be considering and mitigating. In addition to property and life loss, Mexico is witnessing further devaluation of the peso, the reduction of confidence in the government, an increase in their federal deficit, the serious consequences of possible corruption (for example, steel reinforcement missing in concrete structures), the loss of tax revenues, the increase in federal costs, the effects of poor planning and crowding, and other after-effects.

Thus, losses must be considered in a larger context than simply life and property, which is the sole responsibility of the structural engineer. Types of losses, and the factors that influence the magnitude of the losses which might occur in every sector of life and the economy, must be addressed by a consortium of professionals working as a team in their various areas of expertise. This team must be knowledgeable in:

- Geology
- Seismology
- Soil and rock dynamics
- Foundation/structure interaction
- Structural dynamics
- Structural behavior
- Systems modeling

- o Land-use planning
- o Emergency response
- o Sociology and social psychology
- o Macro- and micro-economics
- o Public and business administration
- o Political science
- o Law
- o Fire safety
- o Toxic chemical behavior
- o Other expertise as needed

FACTORS INFLUENCING LOSSES

There are many sources of primary losses which set into motion all of the secondary and higher order losses described above. The fault break causes vibration, or a tsunami if the fault breaks vertically beneath a body of water. In turn, the vibration can cause damage by various mechanisms and the damage may result in a direct or an indirect primary loss. The action that set everything into motion was the fault rupture. The vibration or tsunami are secondary actions and permanent ground-failure is a tertiary action. Fire, flooding, and the release of toxic substances primarily result from either the damage due to vibration or permanent ground failure.

The sensitivities of the results from each investigator's input to a loss model must be investigated regarding their impact on resulting losses, as well as for policy-making purposes aimed at research planning, government activities, and private activities. If earthquake source models are either too large or too small, the consequences on public policy are tremendous because of the nonlinear behavior of loss models. When I made a simple comparison of the average annual losses that might be estimated by using U.S. Geological Survey (USGS), Applied Technology Council (ATC-3), and J.H. Wiggins Company seismic intensity maps, the results for the entire nation were different by a factor of two. However, the results for individual states were, in some cases, different by a factor of 100 or more.

RECOMMENDATIONS

It is highly recommended that loss modeling enter into vogue at the Federal, state, and corporate levels. It is also highly recommended that sensitivity studies be conducted on the many and varied parts of each model that has been purported to compute losses in order to develop an improved loss-estimation procedure. Lastly, it is highly recommended that losses be categorized, if not estimated, for all of the many and varied types (primary and higher order) cited above.

REFERENCES

Algermissen, S.T., and Perkins, D.M., 1976, A probabilistic estimate of maximum acceleration in rock in the contiguous United States: U.S. Geological Survey Open-File Report 76-416.

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings: ATC Publication 3-06, U.S. Department of Commerce.

Wiggins, J.H. and others, 1974, Budgeting justification for earthquake engineering research: J.H. Wiggins Company Technical Report 74-1201-1, National Science Foundation Grant GI-41071.

SUMMARY OF THE PEPPER PROJECT

William E. Spangle
William Spangle and Associates

INTRODUCTION

This project is an example of the use of regional intensity mapping developed using the Evernden model (Evernden and others, 1981). Specifically, the intensity map used was adapted from the map prepared by the State of California Department of Conservation, Division of Mines and Geology (CDMG) for use in Davis and others (1982). The adaptation for the Pre-Earthquake Planning for Post-Earthquake Reconstruction (PEPPER) Project was done by Earth Sciences Associates with refinements based on more detailed local geologic information than used for the CDMG regional map.

The objective of the PEPPER Project was to evaluate the feasibility of planning before an earthquake for rebuilding after an earthquake. Many factors affecting the feasibility of such planning were identified. These included availability of data on geologic and seismic hazards, information on the building stock exposed to possible earthquakes, the state of the art of earthquake forecasting and making estimates of probable damage, the experience and training of local government staff, together with the local political climate and public support for such planning.

The City of Los Angeles was selected as a site for investigation because of its location in a highly seismic region (figure 1) and the positive responses of the city to the possibility of a large earthquake related to the Southern California Uplift in the mid-1970's. The city has been used for prototype application of research findings and methodology developed in the project. The research team included: William Spangle and Associates, city and regional planning; H.J. Degenkolb Associates, structural engineering; Earth Sciences Associates, engineering geology; and the staff of the Los Angeles City Planning Department. A review panel including structural engineers, scientists, and public officials evaluated methodology and research results. Four members of the review panel with special expertise on seismology, geologic effects of earthquakes, and earthquake damage to structures constituted a validation panel with responsibility for technical review of project work in these subject areas.

This summary is based on research supported by the National Science Foundation under Grant No. 8024724. However opinions, findings, conclusions, or recommendations are those of the author and do not necessarily reflect the views of the foundation.

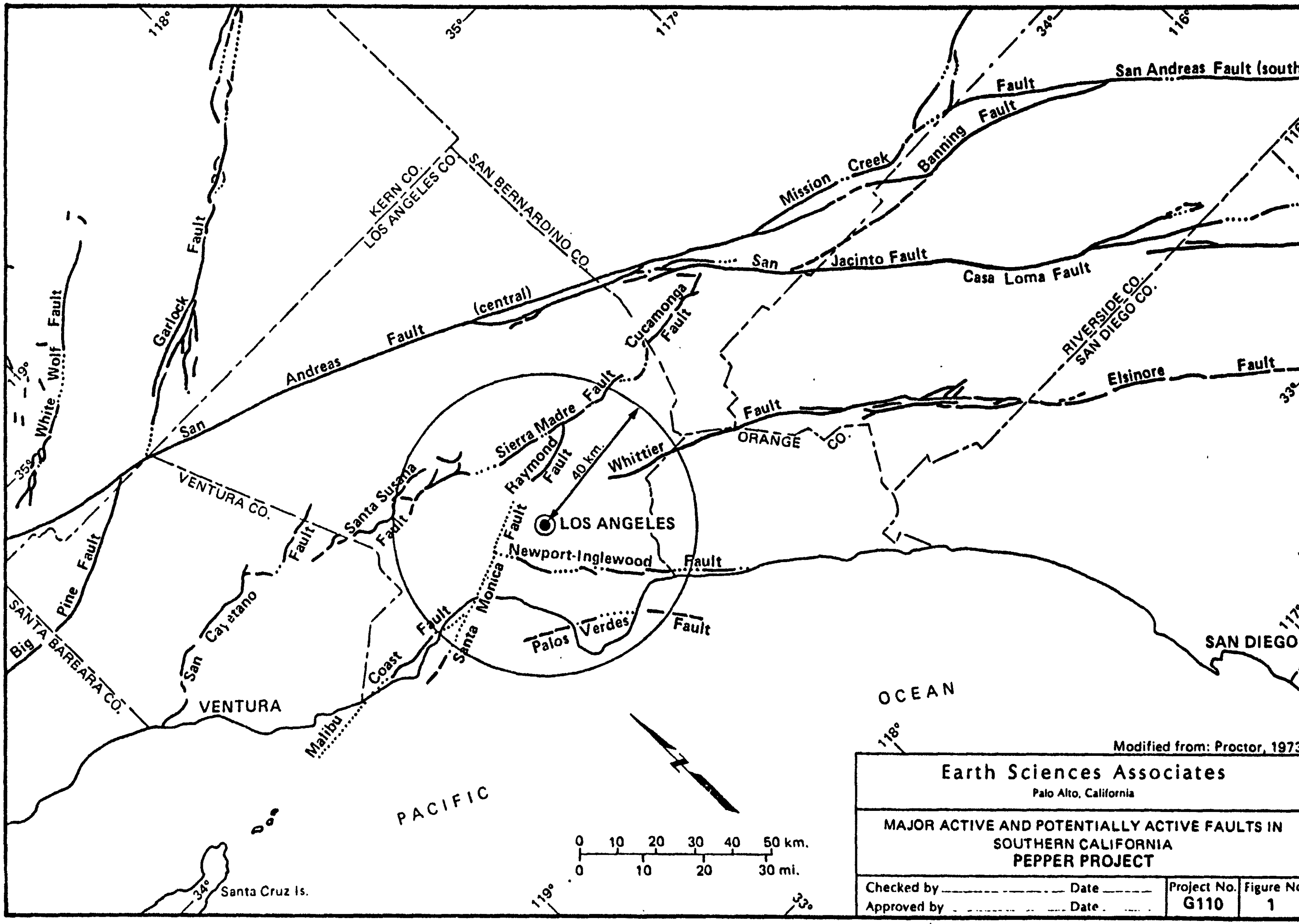


Figure 1. Major active and potentially active faults in southern California.

PROBABILITY OF EARTHQUAKE AND EARTHQUAKE SCENARIOS

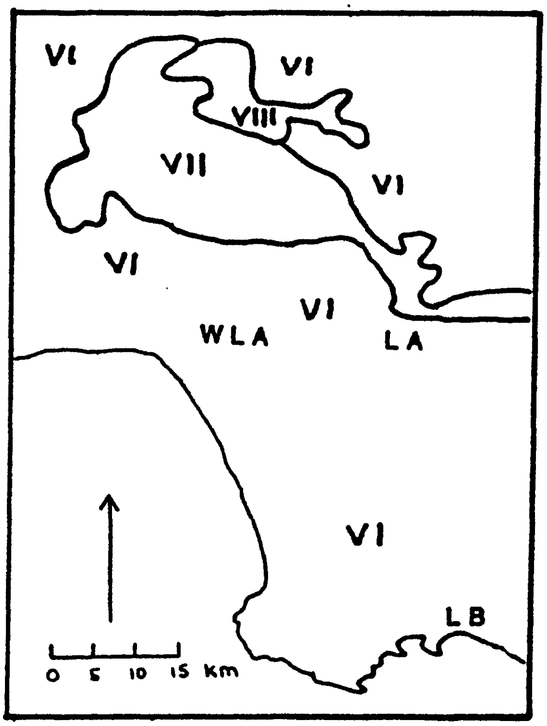
Based on study of the seismic and geologic environment of the city by Earth Sciences Associates, Inc. (1982) it was concluded that there is a high probability (2 percent to 5 percent chance per year) of a great earthquake, Richter magnitude M8.3, on the central segment of the San Andreas fault and about an equal chance of a Richter magnitude 6 or greater event in some location within the city itself. The M≥6 earthquake could occur either on one of the numerous faults underlying the city or in another location associated with an as yet unidentified source of seismic activity.

Based on these conclusions, Earth Sciences Associates developed scenarios for a great earthquake of M8.3 on the central segment of the San Andreas fault and three M≥6 earthquakes at locations chosen to illustrate the potential for damage in different parts of the city from such earthquakes. Locations selected were: Central City, West Los Angeles, and Long Beach (a repeat of the 1933 event). An earthquake shaking intensity map was prepared for each earthquake showing the probable pattern of Modified Mercalli intensities that would result (figure 2). Areas within which some liquefaction or landsliding might occur were also identified. However, information on underlying geology was not sufficiently detailed to pinpoint where such ground failures would be likely to result (Earth Sciences Associates, 1982). The earthquake shaking intensity maps (together with other information developed in the project) have been used in estimating probable damage to structures in each of the thirty-five planning areas in the city portrayed in figure 3. Earthquake intensities, by planning area, for the four scenario earthquakes are listed in table 1.

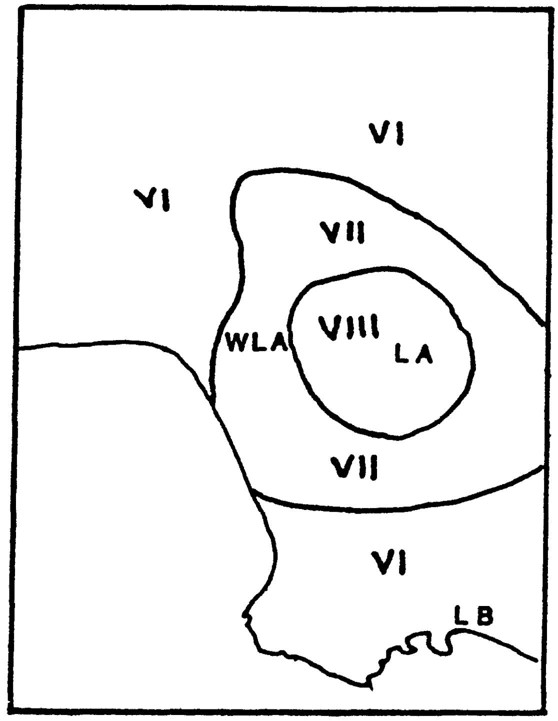
ESTIMATES OF STRUCTURAL DAMAGE

Estimating structural damage depends on several factors. First, it is necessary to obtain an estimate of the severity and areal extent of ground shaking. Next, the severity of shaking must be correlated with damage factors indicating the damage to be expected for the various types of structures in the subject area. Both of these components can be derived by studying the effects of past earthquakes. Then it is necessary to obtain an inventory of structures and their types for the area under consideration. The damage pattern and the amount of probable damage can then be estimated by combining these three components: (1) ground shaking, (2) probable percent of damage due to shaking for the several classes of structures, and (3) the number and type of structures in the study area (Evernden, 1981).

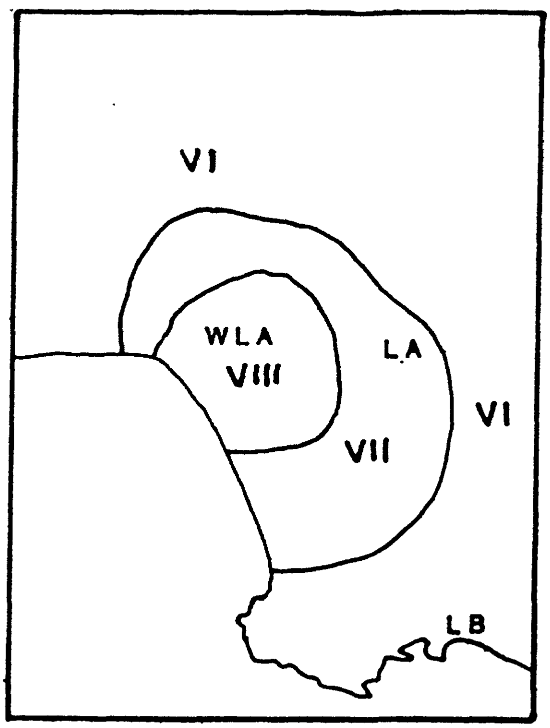
The inventory of structures was derived primarily from the city's Land Use Planning and Management System (LUPAMS) computer file. Because of incomplete or inaccurate coding of structures for the specific data needed for the structural analysis, data in this file were supplemented from several other sources and adjustments were made. Substantial work on the LUPAMS file is needed to make it fully operational for use in making earthquake damage estimates. A fully operational file would be of great value, not only for post-earthquake rebuilding and for emergency response planning and operations, but also for ongoing city planning and programming.



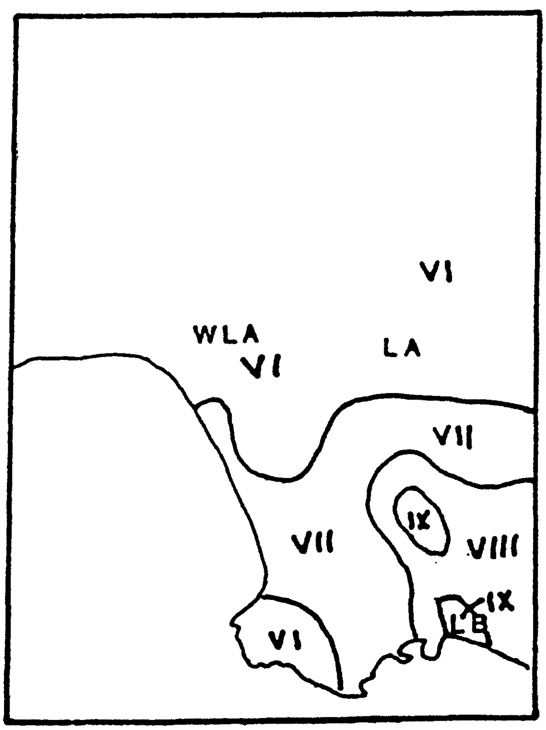
M:8.3 Central San Andreas



M:6.3 Downtown Los Angeles



M:6.3 West Los Angeles



M:6.3 Long Beach

Figure 2. Modified Mercalli Shaking Intensities--four scenario earthquakes

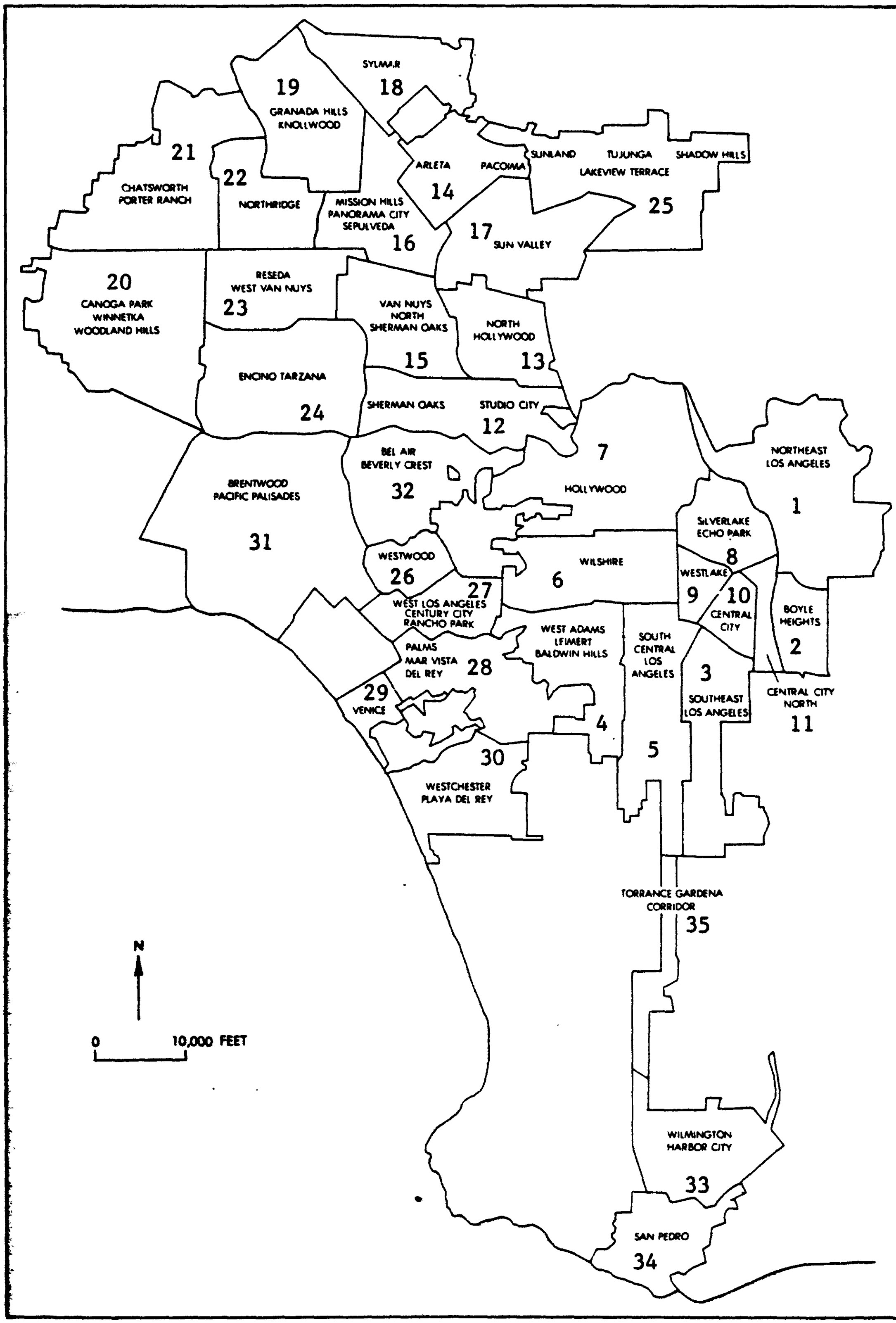


Figure 3. Planning areas--City of Los Angeles (see table 1).

Table 1. Modified Mercalli Intensities for Four Design Earthquakes

LUPAMS NUMBER	PLANNING AREA	SAN ANDREAS 8+	CBD 6+	WEST LA 6+	L.B. 6+
1	Northeast Los Angeles	6+ 7-	7	6	6
2	Boyle Heights	6+	8	7	6
3	Southeast Los Angeles	6+	7-8	7	7
4	West Adams-Baldwin Hills-Leimert	6	8	8	6
5	South Central Los Angeles	6+	8	7	6-7
6	Wilshire	6 6+	8	7-8	6
7	Hollywood	6 6-	7	7	6
8	Silver Lake-Echo Park	6	8	6-7	6
9	Westlake	6	8	7	6
10	Central City	6+	8	7	6
11	Central City North	6+	8	7	6
12	Sherman Oaks-Studio City-Toluca Lake	6+ 7-	7	7	6
13	North Hollywood	7-	7	6	6
14	Arleta - Pacoima	6+ 8-	6	6	6
15	Van Nuys - North Sherman Oaks	7-	6-7	6	6
16	Mission Hills-Panorama City-Sepulveda	7-	6	6	6
17	Sun Valley	7-8	6	6	6
18	Sylmar	7+	6	6	6
19	Granada Hills - Knollwood	6+ 7 7+	6	6	6
20	Canoga Park-Winnetka-Woodland Hills	7-	6	6	6
21	Chatsworth - Porter Ranch	7-	6	6	6
22	Northridge	7-	6	6	6
23	Reseda - West Van Nuys	7-	6	6	6
24	Encino - Tarzana	5-6	6	6-7	6
25	Sunland-Tujunga-Shadow H's.-L.V. Terr.	6-	6	6	6
26	Westwood	6+	7	8	6
27	West Los Angeles	6	7	8	6
28	Palms - Mar Vista - Del Rey	6	7	8	6
29	Venice	6+	7	8	6-7
30	Westchester - Playa Del Rey	6- 6+	7	8	6
31	Brentwood - Pacific Palisades	6-	6	7	6
32	Bel Air - Beverly Crest	6-	6-7	7-8	6
33	Wilmington - Harbor City	6	6	6	7
34	San Pedro	6-	6	6	6-7
35	Torrance - Gardena Corridor	6	6-7	6-7	7
36	Port of Los Angeles	6	6	6	7
37	Los Angeles International Airport	6	7	7-8	6

Note: Arabic numerals used in place of Roman for ease in reading.

Where two or more intensities are tabulated, the Planning Area is subject to two or more intensities for a given earthquake either because an intensity isoseismal divides the area or because of differences in foundation soils conditions within the Area.

Factors relating percent damage to structure type and intensity of shaking were derived from studies of building damage in prior earthquakes (H.J. Degenkolb Associates, 1984; Algermissen and others, 1978). To use these factors the five classes of buildings provided in the LUPAMS file had to be divided into several subcategories related in part to the age of building and in part to other readily identifiable characteristics of steel and masonry buildings. A new set of damage ratio curves was developed for the project (Evernden and others, 1981).

For each of the four scenario earthquakes, estimates were made of probable extent of building damage by type of structure and type of occupancy. In additon, estimates were developed of the probable distribution of building damage by categories "damaged but repairable" and "damaged beyond repair." The "repairable" category is subdivided into "habitable" and "not habitable." Estimates were also made of probable dollar losses. All of these estimates are limited to losses in privately owned buildings because the City LUPAMS file, derived primarily from County Assessor's records, does not include necessary data on public buildings and other buildings not assessed for property taxes.

The relative effects of the four scenario earthquakes are vividly illustrated in table 2 giving estimated dollar losses in the private building stock within the City of Los Angeles. The figure of losses from the Long Beach earthquake is low for the City of Los Angeles because, as illustrated in figure 2, only a small portion of the city is subject to high-intensity effects. Understanding of the level of accuracy of these (and similarly derived) damage estimates is critical to their use. The need to make this clear to the user was underscored by the project validation panel which pressed for a specific definition of level of accuracy.

USE OF DAMAGE ESTIMATES

With recognition of these limitations, such estimates of probable damage can be used in several ways:

- To provide an indication of the nature and magnitude of emergency response needed following a scenario earthquake (or other similar earthquakes);
- To help the City in further defining its earthquake hazards mitigation program;
- To prepare schematic or more definitive plans for rebuilding heavily damaged areas;
- To define the nature of the rebuilding/recovery team needed to respond to damaging earthquakes (or other major disasters); and
- To outline programs for rebuilding/recovery (or to describe the necessary elements of such programs).

Table 2. Private building damage cost summary for City of Los Angeles (millions of 1982 dollars)

	Postulated Earthquake Location and Magnitude			
Use	8 + San Andreas	6 + CBC	6 + West L.A.	6 + L.B.
Residential	$694	$2,401	$1,806	$489
Commercial	$266	$932	$689	$202
Industrial	$115	$458	$339	$86
Other	$22	$78	$59	$16
Total Cost of Damage (all Classes, Uses and Planning Districts)	$1,097	$3,869	$2,893	$793

For the City of Los Angeles, even though there is no specific prediction (time, location, and magnitude) of an earthquake likely to cause damage, the high annual probability of a major to great earthquake on the nearby segment of the San Andreas fault justifies both land use/rebuilding planning and projecting the nature of the problems and responses needed for rebuilding and restoration.

REFERENCES

Algermissen, S.T., and others, 1978, Estimation of earthquake losses to buildings: U.S. Geological Survey Open-File Report 78-441, 161 p.

Davis, J.F., Bennett, J.H., Borchardt, G.A., Kahle, J.E., Rice, S.J., and Silva, M.A., 1982, Earthquake planning scenario for a magnitude 8.3 earthquake on the San Andreas fault in southern California: California Department of Conservation, Division of Mines and Geology Special Publication 60, p. 33-35.

Earth Sciences Associates, Inc., 1982, Seismic environment and geologic effects--technical report: William Spangle and Associates, Inc., Portola Valley, Calif., 31 p.

Evernden, J.F., Kohler, W.M., and Clow, G.D., 1981, Seismic intensities of earthquakes of coterminus United States--their prediction and interpretation: U.S. Geological Survey Professional Paper 1223, 56 p.

H.J. Degenkolb Associates, 1984, Structural hazards and damage patterns, City of Los Angeles. William Spangle and Associates, Portola Valley, Calif., 38 p., 52 tables.

Steinbrugge, K.V., McClure, F.E., and Snow, A.J., 1969, Appendix A in Studies in seismicity and earthquake damage statistics: U.S. Coast and Geodetic Survey. 142 p.

COMMENT ON THE USE AND MISUSE OF MODIFIED MERCALLI INTENSITIES

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Consulting Structural Engineer

INTRODUCTION

In 1982, the author reviewed 25 known loss estimation methodologies as they related to buildings and lifelines, plus several more which also considered casualty estimates. The Modified Mercalli (MM) Intensity Scale, or the data represented by that scale, was the fundamental basis for these methods. Some methods developed spectra or other sophisticated approaches, but the input data almost always were based on MM intensities. An unknown number of proprietary-loss estimation methods exist but, of those known, most make use of MM intensities.

The purpose here is to examine several of the bases upon which intensity determinations and isoseismal maps have been prepared in the United States, and some of their limitations.

SCALE LINEARITY

First, the intensity scale is not linear. In other words, when plotting MM intensity as one coordinate on a graph, a uniform linear spacing of intensity units may be convenient, but it is not necessarily accurate. The developers of this scale (Wood and Neumann, 1931) make no reference to linearity, although it is most likely that they strove for it. They also state: "Most serious, however, is the fact that we do not know exactly what factors combine to constitute intensity as it is ordinarily understood."

A brief examination of intensities in terms of human response, then with building damage, and finally integrating these two, is of value.

Intensities and Human Response

An examination of the scale shows that it requires subjective evaluations which may be characterized by the following extracts relating to human response (parenthetical materials are author's comments).

MM I: Not felt -- or, except rarely under especially favorable circumstances.... (not defined: especially favorable).

MM II: Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons.... (not quantified or defined: few, upper floors, sensitive, nervous).

MM III: Felt indoors by several, motions usually rapid vibration.... (not quantified or defined: several, rapid).

MM IV: Felt indoors by many, outdoors by few.... (not quantified: many, few).

MM V: Felt indoors by practically all, outdoors by many or most.... Frigtened few -- slight excitement, a few ran outdoors.... (not quantified: practically all, many or most (more or less than 50 percent?)).

MM VI: Felt by all, indoors and outdoors....

MM VII: Frightened all -- general alarm, all ran outdoors....

MM VIII: Fright general -- alarm approaches panic.... (difficult to distinguish between MM VII and MM VIII).

MM IX: Panic general....

While intensity as interpreted by human response is on an ascending scale, there is no assurance, for example, that the change from MM II to MM III relates to an equal change in shaking (or whatever) at MM VI to MM VII. Also, except for MM III, it has no relationship to long-period effects such as those common to high-rise buildings at large distances from major earthquakes.

Building Damage

For the second example, examine intensity definitions as specified or interpreted for unreinforced brick bearing-wall buildings having sand-lime mortar. This construction type is very common in the historic record and has had a very wide damage range. Note again the use of subjective terminology.

MM VI: Damage slight in poorly built buildings.... Fall of plaster in small amount....

MM VII: 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....

MM VIII: Damage slight in structures (brick) built especially to withstand earthquakes.... Considerable in ordinary substantial buildings.... Cracked, broke, solid stone walls seriously....

MM IX: Damage considerable in (masonry) structures built especially to withstand earthquakes...great in substantial (masonry) buildings, some collapse in large part....

MM X: Destroyed most masonry and frame structures, also their foundations....

MM XI: Few, if any, (masonry) structures remained standing....

Richter recognized the scale's limitations and restated the scale in abridged and rewritten fashion (Richter, 1958, p. 136-139). Pertinent to the foregoing discussion on building damage are his added definitions of "masonry, brick, or otherwise.":

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at the corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

These restated definitions for unit masonry are substantial improvements, but they remain subjective. "Good," for example, will be differently interpreted as to steel spacing, cleanouts, mortar lip removal, inspection, etc. Additionally, engineers in one area may have a reasonably common definition of "good" which may vary from that found in another region. In California, the Los Angeles practice differs in some detail from the San Francisco practice with each being "good" but not equivalent in the opinion of many competent engineers. In actual practice, Richter's "designed to resist lateral forces" may vary by a factor of 5 or more, depending on local practice variations, depending upon which edition of the building code was used (seismic codes generally have become more restrictive with time), and depending on the designer's capabilities and philosophy (that is, liberal or conservative).

NONCOMPATIBLE EFFECTS

The two examples discussed were each related to a specific kind of seismic effect: (1) to human reactions, and (2) on inanimate objects (in this case, to non-reinforced unit masonry building performance). But intensity determination becomes a different and more complex problem when combining both to arrive at a common intensity.

Voight and Byerly (1949, p. 26) examined the assignment of MM IV through MM VI to human reactions and to effects on inanimate objects. While their MM intensity range was at the threshold values of damage, their findings are worth reviewing:

> If the effects on inanimate objects suggest intensity IV, it seems reasonable to raise the intensity to V if the earthquake was reported felt by all. If the former tests indicate V, it seems reasonable to raise it to VI if it was felt by all. We do not advocate raising the intensity by two grades on the "effects on people" criteria.
>
> The criteria "felt by several" and "felt by many" do not appear to be grounds for differentiation of intensity between IV and V.
>
> "Frightened many" seems to offer justification for an increase from IV to V or from V to VI.
>
> "Awakened all" requires an intensity of at least VI, from the foregoing study. "Awakened many" should justify a V without auxiliary information.
>
> The suggestions given here justify earlier practices of the United States Coast and Geodetic Survey . . . .

It would appear that MM VI on isoseismal maps by the U.S. Coast and Geodetic Survey may overstate the damages indicated by the definition of each intensity, with this overstatement being one intensity unit. This has some significance in monetary loss estimates for great earthquakes which have large areas of intensity VI, for example.

With construction types increasing (many of which were not contemplated when the present MM scale was developed), the problems with intensity determinations from MM VI through MM IX become more complex because the adjustment process must consider additional kinds of effects. Normally, only judgment and experience can assure any semblance of compatibility among intensity evaluations.

Guidelines are necessary in order to give consistency. The following is from a written communication from William K. Cloud (then Chief, Seismological Field Survey) to S.T. Algermissen, dated October 28, 1969, a copy of which was sent to the author:

> . . .The intensity rating for an urban area is based on intensity ratings of many sub-areas. And since factors that control damage vary in an urban area, intensity ratings of the sub-area vary. Now the rating assigned to any sub-area indicates that in the judgment of the person making the rating at least 51% of the observed effects met M.M. criteria for that rating. In turn the rating assigned to the entire urban area indicates that at least 51% of the sub-area ratings were equivalent to the rating assigned. This reasoning suggests that if a small area is considered, a 50% rule might be used, and if a large area is considered, a 25% rule might be used.

> Since an intensity rating can be based on several criteria, the percentages would require some adjustment for applications to a single criteria. For example, in a sub-area rated intensity VIII it would be foolish to say 50% of the chimneys were damaged if there were no chimneys in the sub-areas.

ISOSEISMAL MAPS IN HIGH INTENSITY AREAS

If one examines the isoseismal maps prepared by government agencies after the earthquakes of 1952 Kern County (California), 1959 Hebgen Lake (Montana), and 1971 San Fernando (California), it will be noted that no detailed isoseismal maps exist which show isoseismal lines for the epicentral areas (figures 1 through 3). Conflicts existed among the rating observations to the extent that no isoseismal lines were drawn for the higher intensities.

Other approaches have been used, often with specialized data, giving results not necessarily compatible with Modified Mercalli intensities. For the 1971 San Fernando earthquake, for example, see Steinbrugge and Schader (1973) as well as Johnson and Duke (1973).

Since the higher intensities are of particular engineering interest and also of great importance in vulnerability studies, the writer has certain reservations when these higher intensities are given with precision to areas which have never experienced an earthquake. The value of relevant experience in these situations can not be overestimated.

LONG PERIOD EFFECTS

The Modified Mercalli Intensity Scale was never intended to include long-period effects, and does not fit in these cases. In the 1964 Alaska earthquake, where well-built earthquake-resistive multistory buildings in Anchorage were generally damaged, items rarely fell from the shelves of residences that were not in landslide areas. In the 1985 Mexico earthquake, the author was in a one-story drug store where nothing overturned or fell from the shelves, yet this drug store was in the midst of collapsed and partially collapsed multistory buildings.

No intensity map was drawn for the city of Anchorage, Alaska, after the 1964 Alaska earthquake. The intensity map for this earthquake was prepared under the direction of Cloud and Scott (1967, p. 7) who stated:

> The results of bringing together long- and short- period effects are not serious when attempting to rate moderate earthquakes. However, results are striking when attempting to rate major events, such as the Prince William Sound (Alaska) Earthquake, due to the greatly increased proportion of long-period effects to short-period effects. The effects in Anchorage, Alaska, offer a classic example. . . . The U.S. Coast and Geodetic Survey's solution to this problem was to assign a range of intensities rather than a single intensity . . . .

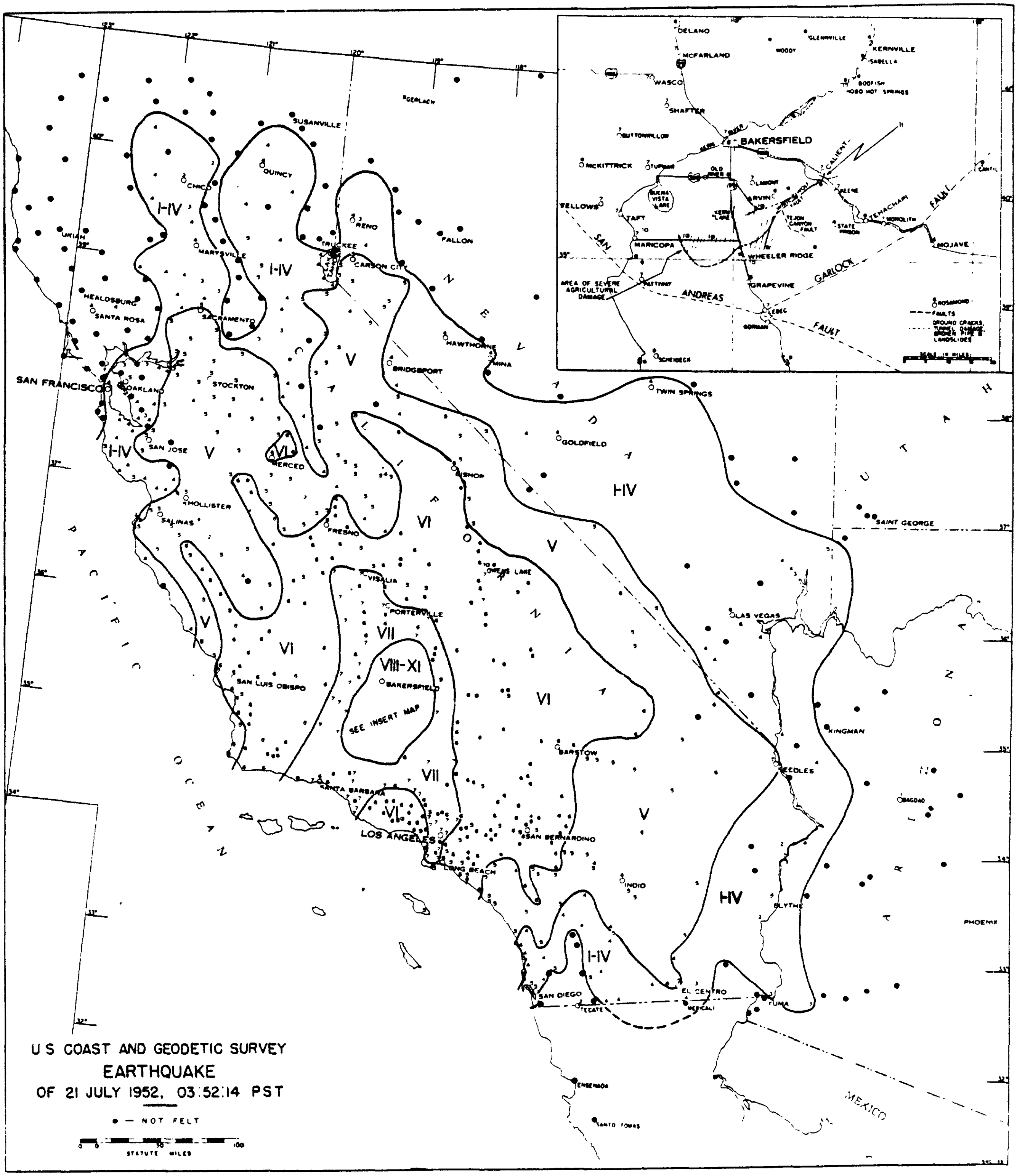

FIGURE 1. Isoseismal map of the Kern County, California, Earthquake of July 21, 1952. -- "Abstracts of Earthquake Reports for the Pacific Coast and the Western Mountain Region", MS-75, USC and GS, 1952.

FIGURE 2. Isoseismal map of the Hebgen Lake, Montana, earthquake of August 17, 1959. -- "United States Earthquakes 1959", USC and GS, 1961. Also, Steinbrugge and Cloud, Bull. Seism. Soc. Am., 52:181/234, 1962.

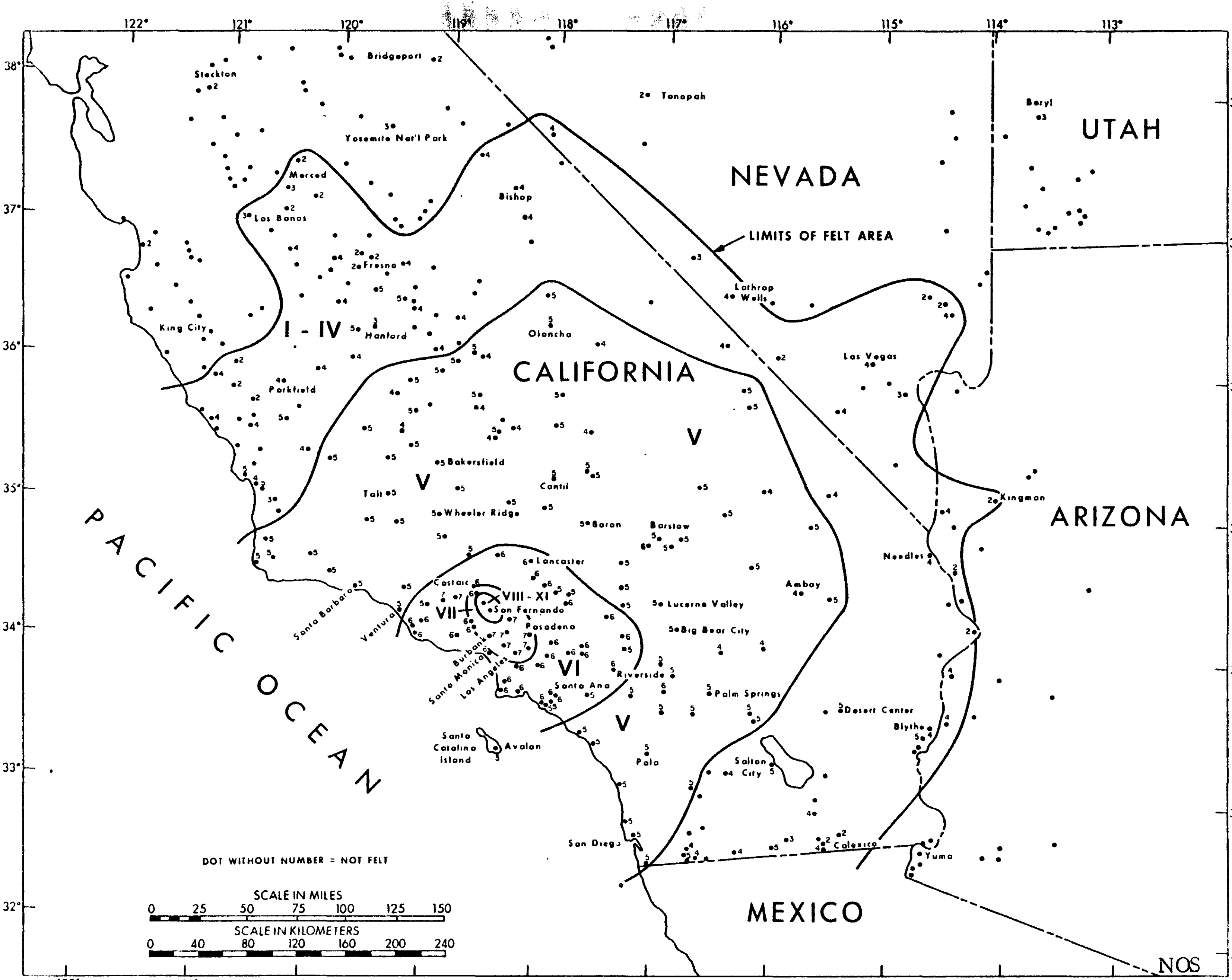

FIGURE 3. Isoseismal map of the San Fernando, California, Earthquake of February 9, 1971. -- Nina Scott, "Felt Area and Intensity of San Fernando Earthquake", in San Fernando, California, Earthquake of February 9, 1971", vol. 3.

MM ARITHMETIC

There have been some engineers and scientists who have related intensities taken from isoseismal maps to damage and to acceleration, sometimes interpolating intensities to obtain building design values to 2 or 3 significant figures. Then there have instances where arithmetic has also been used with these values.

There is no serious quarrel with MM arithmetic, provided the user understands the quality of the data. The author is not at all assured that persons who have never field examined an earthquake, never prepared an isoseismal map, never examined the back-up data which went into an isoseismal map, and never examined the ever-changing code design criteria and engineering calculations required by earthquake-resistive design, have always been able to perform MM arithmetic with any significant degree of accuracy.

SCALE'S USEFULNESS

Most evidently, isoseismal maps are one kind of summary record of what happened. Unpublished basic observed data can be expected as the back-up material. In any applications study, "what actually happened" far outweighs any theoretical model which describes "what might have happened" if there are any discrepancies between results. Obviously, extrapolation is necessary for studies of areas where no previous experience exists, or to evaluate a postulated greater magnitude earthquake than found in local historic experience.

Considering the variables, it is not unreasonable to find that several investigators studying the same area will develop widely differing vulnerability estimates. Evaluating the quality of varying estimates found in vulnerability studies is quite difficult, if not impossible, by persons who have not worked in the subject area. Not having standards to go by, governmental disaster response agencies can and do receive conflicting vulnerability estimates.

REFERENCES

Cloud, W.K., and Scott, N.H., 1969, Distribution of intensity, Prince William Sound earthquake of 1964, in Leipold, L.E., ed., 1969, The Prince William Sound earthquake of 1964 and aftershocks: U.S. Department of Commerce, v. 2B, p. 7.

Johnson, K.E., and Duke, C.M., 1973, Damage distribution in the Sylmar Valley area, in Murphy, L.M., ed., 1973, San Fernando, California, earthquake of February 9, 1971: U.S. Department of Commerce, v. 1, part B, p. 801.

Richter, C.F., 1958, Elementary Seismology: Freeman, San Francisco, 136 p.

Steinbrugge, K.V., and Schader, E.E., 1973, Earthquake damage and related statistics, in Murphy, L.M., ed., San Fernando, California, earthquake of February 9, 1971: U.S. Department of Commerce, v. 1, part B, p. 691.

Voight, D.S., and Byerly, Perry, 1949, The intensity of earthquakes rated from questionnaires: Bulletin of the Seismological Society of America, v. 39, p. 21-26.

Wood, H.O., and Neumann, Frank, 1931, Modified Mercalli Intensity Scale of 1931: Bulletin of the Seismological Society of America, v. 21, p. 277-283.

LOSS ESTIMATION BY THE INSURANCE INDUSTRY FOR A MAGNITUDE 8.25 EARTHQUAKE IN CALIFORNIA

Richard J. Roth, Jr.
California Department of Insurance

Each year the California Department of Insurance sends out a questionnaire to each licensed property/casualty insurance company. The questionnaire is designed to provide the Department of Insurance with an estimate of each insurer's probable maximum loss (PML) on insured structures in the event of an earthquake of M8.25. The industry responses relate only to earthquake insurance coverage on structures and contents. Not included are some insurance coverages such as automobile, workers' compensation, and life and health.

The results have been:

Probable Maximum Loss (PML) by Year
(in millions of dollars)

Earthquake Zone	1982	1983	1984
San Francisco	$3,063	$3,944	$3,381
Los Angeles	$4,174	$5,483	$4,660

The decline in 1984 was due entirely to changes in insurance on commercial risks. The aggregate PML on residential structures actually increased slightly. Effective January 1, 1985, every insurance company selling residential insurance in California must offer earthquake insurance. This new law has increased the public's awareness of earthquake insurance, so that the number of homes insured for earthquake damage has risen from 7 percent to about 15 percent.

Because of this requirement to offer earthquake insurance on residential units and because of the large exposures on commercial buildings, the insurance industry has a great need to know more about the factors which contribute to earthquake insurance losses, such as: the type of structures (wood frame or masonry), soil conditions, proximity to faults, applicability of building codes, and susceptibility to landslides. Also, there is a need to know how quickly the insured losses decrease as the deductible rises.

The better quantified these factors can be, the better the insurance industry can price and market earthquake insurance. Also, this will enable the insurance industry regulatory authorities to know if the insurance industry can pay the insured losses in the event of a great earthquake.

SOME INSIGHTS ON THE USE OF SHAKING INTENSITIES IN EARTHQUAKE LOSS ESTIMATION

Rachel M. Gulliver*
Dames and Moore

INTRODUCTION

Over the past six years, I have had the opportunity of using the Evernden model for the prediction of shaking intensities (Evernden and others, 1981) in a variety of applications for estimation of earthquake losses and development of planning scenarios. I offer here some thoughts and insights on the value, accuracy, and limitations of the existing intensity model, the importance of accurate intensity prediction for similar applications, and some possible directions for improving upon and applying intensity predictions.

Methods available prior to the Evernden model were based largely on distance from the causative fault; they portrayed intensities as concentric circles and ovals, without any direct recognition of the influence of local soils and geologic conditions. This produced a highly generalized portrayal of earthquake effects, similar to the intensity patterns recorded from sparsely-populated regions with relatively few points of reported intensity, and most of them on alluvial soils. However, these methods were not able to predict the striking complexity of intensity patterns that were recorded in urbanized areas of varied geologic and soils conditions, such as the 1906 San Francisco earthquake (Lawson and others, 1908), the 1933 Long Beach earthquake (Poeschel and Stromberg, 1980) and the 1971 San Fernando earthquake (Scott, 1973).

The Evernden model for prediction of shaking intensities (Evernden and others, 1981; Evernden and Thomson, 1985) provides a means of incorporating many of the significant contributing factors in the generation of ground motion. Most significant among these are the attenuation (or die-off) rate characteristic of the specific region, and the general influence of local soils and geologic conditions on the intensity of ground shaking.

My direct experience in applying the Evernden model to earthquake loss estimation and scenario development includes:

- o Estimation of housing losses and homeless caseload over an 8-county region of southern California for a magnitude 8+ earthquake on the San Andreas fault (Gulliver, 1986), as described below;

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- o Pilot project for earthquake hazard assessment and loss estimation in San Bernardino County, including loss estimation for large earthquakes on the San Andreas and San Jacinto faults (Gulliver, 1983); and

- o Estimation of dollar loss for a large portfolio of investment properties in northern and southern California (20 counties).

DISCUSSION OF THE EVERNDEN MODEL

The reliability of the Evernden model was tested for southern California, through an independent comparison of the historical intensities for the 1857 Fort Tejon earthquake with the predicted intensities for the same event. The intensities documented by Agnew and Sieh (1978) from historical accounts were reinterpreted directly as Rossi-Forell intensities by Sieh (personal communication) and compared by Gulliver (1986) with the predicted intensities for the same locations. Out of 16 locations in southern California, the prediction intensities agreed completely at 8 locations, and are within ½ intensity at all but three locations (Gulliver, 1986). Of these, the discrepancy at two locations has been reconciled by subsequent investigation of the location and geologic and structural conditions at the historic settlement sites. This is a very reasonable level of accuracy for first-order regional earthquake modeling. However, it was not possible at the time to test the model against an earthquake with a more intricate pattern of intensity distributions, as recorded in a more densely populated urban area.

In view of its demonstrated success and continuing application, the limitations of the Evernden model should also be recognized. These include:

- o The geologic ground conditions are digitized on a ½-minute grid pattern, which lacks refinement and detail at the sub-regional and community level;

- o The alluvial valleys, which generally contain the largest population densities, are mapped as one geologic unit, Quaternary alluvium, with no further breakdown or distinction;

- o Alluvial areas with high ground water are assumed to have one intensity higher shaking than unsaturated alluvium, whereas recent investigations (Rogers and others, 1985) in the Los Angeles region suggest that depth to ground water is not a significant determinant for ground shaking; and

- o The intensity predictions correlate primarily with high-frequency shaking, as related to the natural period of ordinary low-rise structures. Magnitude-dependent adjustments must therefore be made when applying the intensities to estimation of long-period phenomena such as liquefaction, seiche, and damage to high-rise buildings and other large structures.

AN EXAMPLE USING PREDICTED SHAKING INTENSITIES FOR LOSS ESTIMATION

I have developed an enhanced prediction of shaking intensities for a magnitude 8+ earthquake on the San Andreas fault as background data for the estimation of housing losses and homeless caseload over an 8-county region of southern California (Gulliver, 1986). The objective of the study, conducted for the Federal Emergency Management Agency (FEMA) in 1979 and 1980, was to determine the operational requirements of Federal agencies for meeting the needs of families made homeless in a catastrophic earthquake. Tables 1 and 2 summarize the results of the analysis, which formed the basis for development of a Federal diasaster housing plan for southern California.

This loss estimation study required the development of an overall methodology and several new technqiues to meet the planning requirements:

- Evernden's approach for the prediction of shaking intensities was refined to provide more appropriate information at the community level. The original source maps for geologic ground conditions were used, rather than the ½-minute grid pattern of the Evernden model to provide a more accurate delineation of geologic contracts and for correction of data entry errors transferred from the original model.

- Areas of high ground water were compiled and added to the data base to provide adjustments in shaking intensity corresponding to the scientific thinking of that time. The data base for areas of high ground water was also used in the estimation of losses from liquefaction damage. These refinements have subsequently been incorporated by Evernden and adapted by Davis and others (1982) and the Southern California Earthquake Preparedness Project (1983) for regional modeling of earthquake hazards.

- Shaking intensity was designated with ½-intensity increments, in order to avoid artifically large jumps in homeless caseload across highly gradational boundaries in intensity (as related to distance from seismic source).

- Separate loss-estimation procedures were developed for damage components relating to ground shaking, fault rupture, liquefaction, and earthquake-induced landslides, as well as extended utility outage and dam failure accompanying the earthquake. Local shaking

Table 1. Housing caseload by operational components.

CASELOAD COMPONENTS		HOUSEHOLDS*
Structural Damage		
Permanent Homeless		22,000
Repairable Conditions		37,000
	SUBTOTAL	(59,000)
Utility Outage Only (no structural damage)		46,000
Mortgage and Rental Assistance (no prolonged loss of income, no structural damage)		11,000
PROBABLE CASELOAD SUBTOTAL		(116,000)
Dam Failure Contingency		
Evacuation	66,480**	
Homeless		19,000
POTENTIAL CASELOAD	TOTAL	135,000

* Housing caseloads are rounded to the nearest thousand.

** Short-term shelters for evacuated populations would be the responsibility of local agencies; such shelter is not included in the Federal housing caseload.

Table 2. Homeless households by county for a M8+ earthquake on the Mojave segment of the San Andreas fault. Modified from Gulliver, 1986.

County	Housing Units	Structural Damage			Utility Outage Only	Total Homeless Households
		Single Family	Multi-Family	Mobile Homes		
Kern	142,401	400	100	1,700	700	2,900 (2.1%)
Los Angeles	2,681,915	5,000	12,300	4,500	20,600	42,400 (1.6%)
Orange	698,214	2,500	2,900	2,000	9,800	17,200 (2.5%)
Riverside	253,476	1,100	900	4,000	2,900	8,900 (3.5%)
San Bernardino	296,014	3,900	2,400	9,300	5,300	20,900 (7.1%)
San Luis Obispo	62,176	200	100	500	500	1,300 (2.1%)
Santa Barbara	114,636	400	400	700	1,200	2,700 (2.4%)
Ventura	170,174	1,300	1,200	1,300	5,100	8,900 (5.2%)
TOTALS	4,419,006	14,800	20,300	24,000	46,100	105,200 (2.4%)

intensity became a significant factor in all components except fault rupture.

- Long-period shaking effects were addressed by the development of magnitude-dependent loss rates for liquefaction damage and damage to high-rise buildings. This reflects both the high levels of long-period energy created in an earthquake of this magnitude and the low attenuation (or die-off) rate for long-period ground motion.

- A wide variety of data sources on residential damage in historical earthquakes were correlated with intensity and used to develop homeless loss rates for each of eight building types or structural classes.

- Whereas previous loss estimates focused principally on immediate post-disaster conditions, Gulliver (1986) covers conditions from emergency evacuation on day one, through dwellings posted unsafe after inspection, to victims who have no long-term prospects of rebuilding or relocating within their economic means. The housing caseload is thereby recognized as both an immediate and a long-term problem, which is complicated by economic conditions within the region.

- The more detailed presentation of predicted shaking intensities allowed a breakdown of losses to the community level, providing a better portrayal of the distributions and concentrations of homeless households within the region.

This project was the first loss-estimation study to address earthquake damage as it relates to projected need for disaster housing assistance. As a prototype study, it identifies the necessary components of loss estimation and bridges a difficult gap by providing a means of relating a variety of historical earthquake data to criteria for habitability of dwellings. The procedures and loss rates could also be applied to other earthquake scenarios in areas with similar types of residential buildings, and adpated for use in other regions of the nation that have substantially different types of residential structures or different seismic code standards. Adaptations of the general methodology are currently being used for other categories of loss estimation and for development of detailed disaster planning scenarios.

THE IMPORTANCE OF INTENSITY PREDICTIONS

Predicted shaking intensities are a very important component of earthquake loss estimation, because they are the only current basis for correlating the types and degrees of damage with the size of the earthquake, the regional geologic conditions, and the multiple locations of structures or facilities within the region. The principal components of earthquake loss estimation are shown in table 3. Of

Table 3. Components of earthquake loss estimation.

EVENT DEFINITION

- o Magnitude of earthquake
- o Location, fault rupture length

GROUND EFFECTS

- o Shaking intensities
- o Liquefaction potential
- o Fault rupture

ELEMENTS AT RISK

- o Inventory of structures
- o Lifelines
- o Population characteristics
- o Economic parameters

LOSS RATES FOR THE ELEMENTS OF RISK

- o Life loss, injuries
- o Dollar loss
- o Loss of function
- o Down time
- o Secondary losses

the several ground effects, shaking intensities are a major contributing factor for liquefaction potential, landslide potential, and some types of inundation. In addition, specific loss rates correlate with shaking intensities on a logrithmic basis, with substantial increases in loss with each incremental increase in intensity.

The importance of shaking intensity was demonstrated by a simplified sensitivity analysis conducted within the regional estimation of homeless households (Gulliver, 1986). The sensitivity analysis evaluated potential effects of minor to moderate deviations in input data on the resulting loss estimates. The principal components tested include: loss rates, completeness and accuracy of structural inventories, and intensity. The general results of the sensitivity analysis are shown in table 4 and summarized here.

Building inventories that are not complete (that do not document all the pertinent buildings in the area) create errors in approximate proportion to their degree of incompleteness, with some variations, depending on whether the missing structures are more or less vulnerable than average. Where the structural characteristics of the building inventory are incorrectly identified, errors would range from a few tens of percent (for example, where only one identifier is mis-categorized or the misidentified category is one with a similar loss rate) to several hundred percent where a major misidentification is made (for example, where all the highly resilient, modern wood-frame buildings are identified as highly vulnerable unreinforced masonry).

Inaccuracies in the determination of loss rates are estimated to be within 30 percent, if they are carefully developed from substantial data on historic earthquake damage. However, where significant errors or incorrect assumptions are made in the derivation of loss rates, they may be in error by several hundred percent. Some widely used loss data could not be used for the estimation of homeless households because inaccurate assumptions in the correlation with shaking intensity had produced errors as high as 300 percent.

The evaluation revealed that shaking intensity is a highly sensitive component of loss estimation. Temporary generalizations initially used in the housing study produced an over-all increase of 1/4 intensity, until it was discovered that this modest increase resulted in a 50 percent increase in losses, which was compounded by several other assumptions that also tended to increase the total estimates. When deviations or inaccuracies in predicted intensity are higher than this modest level, the errors are even more striking: an increase of ½ intensity unit produces a 125 percent error, one intensity unit produces a 400 percent error, and two intensity units results in a 2500 percent error. It must be concluded that accurate prediction of shaking intensity or other measure of ground motion is probably the single most important component of loss estimation.

LIMITATIONS OF INTENSITY SCALES

The Evernden model expresses shaking intensities in either the Modified Mercalli or Rossi-Forel scale, as specified by the user. Each of these has inherent limitations relating to the types of construction for which they describe damage.

Table 4. SENSITIVITY RANGES FOR COMPONENTS OF EARTHQUAKE LOSS ESTIMATION. Based on analysis of parameters used in development of disaster housing caseload (Gulliver, 1986).

COMPONENT		DEVIATION	ERROR
BUILDING INVENTORY			
	Completeness		
		-10 %	10 %
		-25 %	25 %
		-50 %	50 %
	Structural Characteristics	minor	10-30 %
		major	100-500 %
LOSS RATES			
		minor	30 %
		major	100-500 %
INTENSITY UNITS		+ 1/4	+ 50 %
		+ 1/2	+125 %
		+ 1	+400 %
		+ 2	+2500 %

The Rossi-Forel scale was developed by Swiss and Italian investigators in the early 1880's, and correlates most directly with damage to the types of construction that were common in Europe through the 1800's. A second limitation, that "an enormous range of intensity was lumped together at its highest level, X" (Richter, 1958), is not a significant problem when used with the Evernden model, because that model predicts only the degree of ground shaking, whereas damages at intensity X and higher are assumed to result largely from varying degrees and types of ground rupture, which can be modeled separately and superimposed on the ground shaking results.

The Mercalli scale originated in Europe in 1902, with substantial modifications in 1923 and again in 1931. Although it benefited from damage observations in Japan and America, and gained additional intensities in the higher range, the Modified Mercalli scale of 1931 is designed to correlate with damage to structural types and seismic design practices prevalent at that time.

Building practices and construction standards have evolved in many ways since the 1930's, and even since Richer's 1956 commentary on the Modified Mercalli Scale. Seismic design standards have been progressively strengthened through earthquake observations, extensive research, and multiple code changes. At the same time, many new types of building systems have been developed. Some of them have superior seismic resilience, whereas others, such as tilt-up buildings, soft first-floor construction, and some prestressed concrete, are generally more vulnerable to earthquake damage than originally anticipated. The Modified Mercalli Scale, in its current form, simply does not describe the respective levels of damage to post-1950 construction types, and must therefore be used with caution, both for post-earthquake intensity designations and for predictive applications to loss estimation and scenario development.

The Modified Mercalli and Rossi-Forel scales are also very limited in their application to long-period effects such as liquefaction, large slump-type landslides, tsunamis, and damage to dams, high-rise buildings and other large structures. The few long-period effects that are mentioned (for example, large landslides), are generally placed where they appear in earthquakes of moderate magnitude (Richter, 1958). Compared to moderate earthquakes, large earthquakes produce much higher levels of long-period ground motion, which has a much lower attenuation rate, allowing it to be propagated to much greater distances than the high-frequency motion. At present, the regional distribution of long-period effects must be modeled separately (Gulliver, 1986).

The recent Mexico earthquake of September 19, 1985, provides a striking example of both the long-distance propagation of long-period waves and the influence of local geologic conditions on ground motion. In Mexico City, approximately 400 km from the epicenter, unreinforced masonry buildings with tall, thin parapets were undamaged and most loose items stayed on shelves and tables (Modified Mercalli Intensity V), whereas many 8- to 15-story buildings were severely damaged or collapsed. The magnitude 8.1 earthquake generated substantial levels of long-period energy, which persisted even at great distance from the energy source. In addition, the deep, unconsolidated lake deposits that underlie the concentrated zone of high damage produced resonant amplification of the long-period motion, especially for waves with periods in the 2 second range (see figure 1).

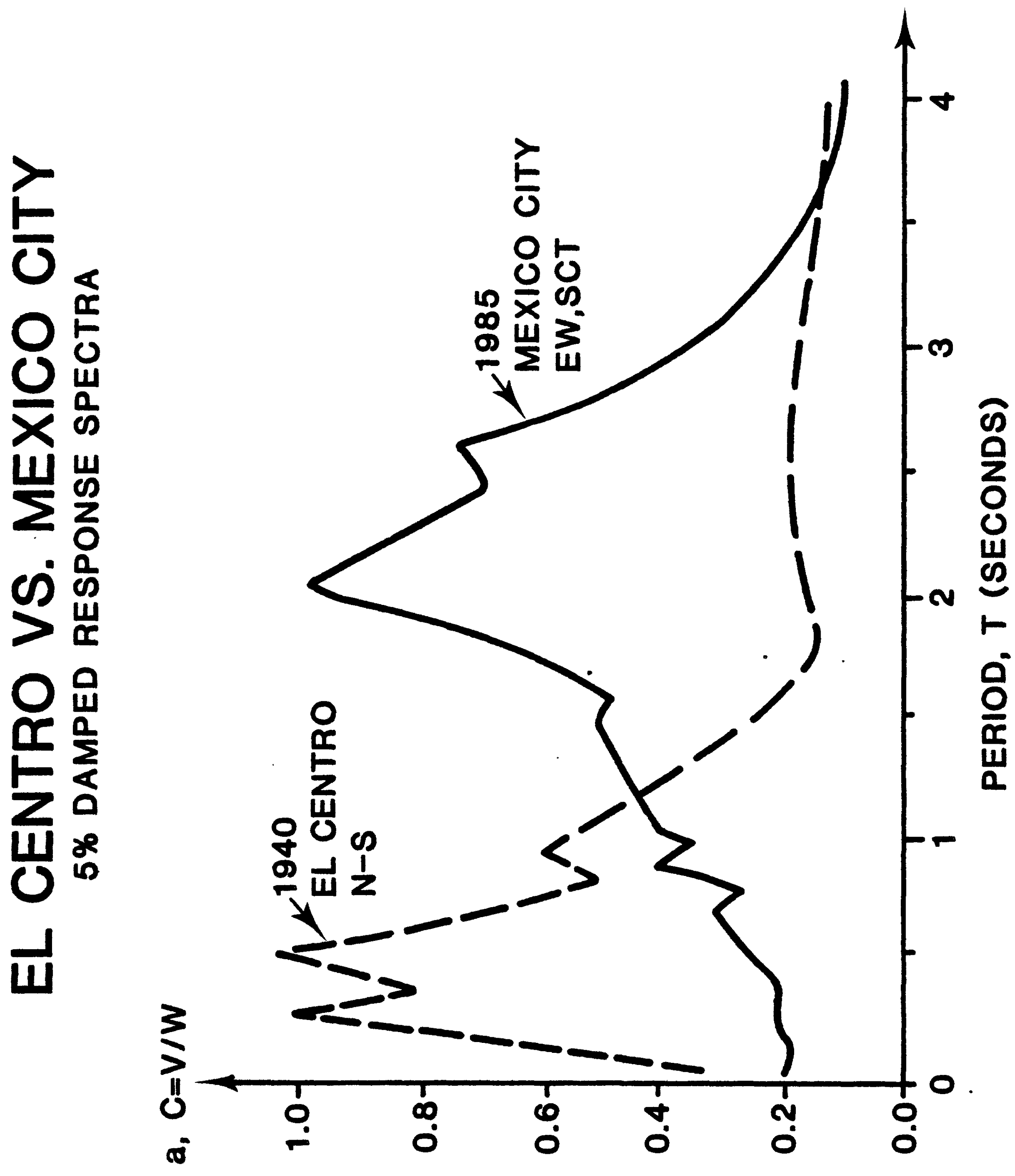

Figure 1. Comparative response spectra for the 1940 El Centro earthquake and the 1985 earthquake as recorded in Mexico City; 5% damping for both.

(Courtesy of W.E. Gates, Dames and Moore, Los Angeles; after Jorge Prince, UNAM, Mexico.)

Further examination of figure 1 reveals another potentially significant factor in the prediction of structural damage. Most modern seismically designed buildings use records from the 1940 El Centro, California, earthquake and similar moderate-size events as a point of reference in their design. These records have the highest ground motions at periods of one second and less, falling off progressively at longer periods. With modern design practice, it is assumed that the ductility of the building will absorb the strongest earthquake energies through minor, non-detrimental deformation of the structure, which also shifts the natural period of the building to a longer period where it will supposedly experience lower levels of acceleration (as would be the case under shaking for the El Centro event). In Mexico City, buildings of 8 to 15 stories generally had natural periods in the range of 0.5 to 1.5 seconds, which received strong, but not severe levels of shaking. However, as these buildings underwent the expected ductile deformation and shifted into longer periods, they were subject to progressively higher accelerations in the longer periods, which produced the unusually high levels of damage.

At present, we do not have the capability to map shaking intensities for intermediate- to long-period ground motion, although some significant work is being done that may eventually contribute to that end (Rogers and others, 1985; Joyner and Fumal, 1985). Also needed is a means of identifying those areas where resonant amplification of the soils at longer periods will increase the levels of damage to buildings with intermediate structural periods, as occured in Mexico City.

FUTURE RESEARCH DIRECTIONS

The accuracy of predicted intensity maps and their usefulness both for public policy development and for earthquake mitigation and preparedness can be significantly improved by upgrading both the detail and accuracy of the input data for ground conditions. The ground conditions, representing the relative ground shaking behavior of soils and geologic units, should be digitized in greater detail than the current ½-minute grid. The more detailed mapping of Quaternary alluvial units and shear-wave velocities that is now becoming available (Tinsley and Fumal, 1985; Fumal and Tinsley, 1985) could provide an initial basis for significant upgrading of ground conditions. However, full development of either of the methods of Joyner and Fumal (1985) or Rogers and others (1985), also requires the evaluation of subsurface geologic conditions to depths of 100 m in alluvium and 400 m in bedrock. In addition, the delineation of surficial deposits necessary to these evaluations (Tinsley and Fumal, 1985) is currently available only at 1:250,000 scale, whereas 1:100,000 and 1:48,000 scale maps are needed for sub-regional and local applications.

The assumption used by Evernden regarding the role of high ground water should be further tested in other settings and by other investigators. The assumed increase of one intensity unit for areas of high ground water has a major influence on the distribution of earthquake losses, when evaluated at a sub-regional level.

A substantial upgrading of intensity prediction could be obtained by careful adaptation of the methodologies developed by Rogers and others (1985) for determination of spectral amplification ratios. This method depends in part on the evaluation of subsurface data to determine sediment void ratios and thickness of Holocene deposits. To date, these data have only been compiled for a 5 by 17 mile strip extending from the easternmost Santa Monica Mountains to Compton in southern California. A high priority should be placed on the extension of this data set by collection and compilation of existing data from available boring logs.

The available methods for intensity prediction are inadequate for use in estimating damage to the rapidly increasing number of large structures in the Los Angeles region that are sensitive to intermediate- and long-period ground motion. Future applications in earthquake-loss estimation and planning scenarios will require a means for systematically predicting the degree or intensity of ground motion at these longer periods. The new methods of Joyner and Fumal (1985) and Rogers and others (1985) for predicting spectral variations in ground motion should be carefully examined for possible adaptation to this end.

The potential for resonant amplification of ground motion by soil needs further development in the Los Angeles region. Resonant amplification of ground shaking in spectral bands corresponding to common structural periods has a significant potential for producing areas or pockets of unusually high damage to the related structural classes. This is particularly important in loss estimation and scenario development for large earthquakes of magnitude 7 and greater, which are likely to produce significant levels of long-period motion. The current methods of Joyner and Fumal (1985) do not address the potential for resonant amplification. However, the incorporation by Rogers and others (1985) of depth to major impedance boundaries, and their evaluation of spectral amplification ratios as related to soil characteristics and depth to major contacts, provides a potential means of identifying such areas of pronounced shaking damage. The potential for expansion and application of their work should be carefully explored.

Regional and sub-regional maps of shaking intensities and ground shaking characteristics, along with their applications in loss estimation and planning scenarios, can have a significant influence on public and corporate policies. Major decisions in land use, earthquake mitigation programs, and preparedness strategies will be influenced by the information provided. It is especially important that both the scientists and the user audience understand the relative accuracy and level of reliability of the information produced. One relatively simple method of evaluating reliability is to test both the current model and any upgraded versions against the documented shaking intensities from historical earthquakes. Evernden uses this method to evaluate regional patterns of intensity and to identify probable causative faults for historical earthquakes (Evernden and others, 1981). However, a great deal could be learned from a more detailed evaluation of the predicted versus observed intensities for historical events in populated areas where there is a relatively high density of intensity observations. This would significantly improve our understanding of the adequacy of data on geologic ground conditions, and help identify potential influence of such factors as resonant amplification and fault rupture characteristics.

The significance of shaking intensities in earthquake loss estimation should be further evaluated by an expanded and more rigorous sensitivity analysis which evaluates each component and assumption used in the loss estimation process.

The working descriptions of damage as correlated with each intensity should be expanded and updated to include a wider range of modern structural types and specific code design levels.

Following the next major urban earthquake, intensive investigations of damage should be undertaken to:

- o Document the pattern of long-period effects;
- o Provide additional data for correlation of intensity with recorded ground motion; and
- o Upgrade the available loss rates by documentation of both damaged and undamaged buildings in statistically significant sample areas of each intensity zone.

If these investigations are properly structured, they could also provide a substantial basis for updating the working descriptions of damage at each intensity level.

REFERENCES

Agnew, D.C. and Sieh, K.E., 1978, A documentary study of the felt effects of the great California earthquake of 1857: Seismological Society of America Bulletin, v. 68, no. 6, p. 1717-1729.

Evernden, J.F., Kohler, W.M., and Clow, G.D., 1981, Seismic intensities of earthquakes of conterminous United States--Their prediction and interpretation: U.S. Geological Survey Professional Paper 1223, 56 p.

Evernden, J.F. and Thomson, J.M., 1985, Predicting Seismic Intensities, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 151-202.

Fumal, T.E. and Tinsley, J.C., 1985, Mapping shear-wave velocities of near-surface geologic materials, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 127-149.

Gulliver, R.M., 1983, Design specifications for the earthquake loss model, Technical Appendix in San Bernardino Pilot Project for Earthquake Hazard Assessment, Technical feasibility study: Southern California Earthquake Preparedness Project, Los Angeles.

Gulliver, R.M., 1986, Estimation of homeless caseload for disaster assistance due to an earthquake: Federal Emergency Management Agency, Natural and Technological Hazards Division, San Francisco, Calif.

Joyner, W.B. and Fumal, T.E., 1985, Predictive mapping of earthquake ground motion, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 203-220.

Lawson, A.C., and others, 1908, The California earthquake of April 18, 1906, in Atlas: Carnegie Institute of Washington, Washington, D.C., 643 p.

Poeschel, K.R. and Stromberg, P.A., 1980, Selected damaging California earthquakes--a reference to earthquake damage with isoseismal maps: California Seismic Safety Commission Report SSC 80-3.

Richter, C.F., 1958, Elementary Seismology: W.H. Freeman and Co., San Francisco, Calif., 768 p.

Rogers, A.M., Tinsley, J.C., and Borcherdt, R.D., 1985, Predicting relative ground response, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 221-247.

Southern California Earthquake Preparedness Project, 1983, San Bernardino pilot project for earthquake hazard assessment, Technical feasibility study: Southern California Earthquake Preparedness Project, Los Angeles, with Technical Appendices.

Scott, N.H., 1973, Felt area and intensity of San Fernando earthquake, in San Fernando, California earthquake of February 9, 1971: National Oceanic and Atmospheric Administration, Washington, D.C., v. III, p. 23.

Tinsley, J.C. and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for areal variations in shaking response, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 101-125.

COMMENTARY ON PREDICTING SEISMIC INTENSITIES FOR RESPONSE PLANNING AND LOSS ESTIMATION

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INTRODUCTION

Talks by Jack F. Evernden, Michael S. Reichle, Paul J. Flores, and John H. Wiggins and comments by William E. Spangle, Karl V. Steinbrugge, Richard J. Roth, Jr., and Rachel M. Gulliver discussed the development and use of methods for predicting seismic intensities for response planning and loss estimation. It was shown that, on the one hand, as crude as these methods are, they are one of the most useful tools of emergency response planners, while, on the other hand, it is not clear how or, indeed, if they should be improved.

The purpose of my commentary is to help answer the questions: "Which hazard-reduction strategies are most effective and how can they be improved?" and "What additional scientific and technical information is needed for reducing earthquake hazards?" This commentary has three parts. First, the principal method used today for predicting seismic intensities is described and its applications and shortcomings are included. Next, possible improvements in the utilization of this method are discussed. Finally, ideas on how the method itself can be improved are summarized. Most of the commentary is based on the working group session, but I have synthesized what was covered and have added my own analysis and opinions.

DESCRIPTION OF EVERNDEN'S PREDICTIVE METHOD AND ITS CURRENT APPLICATIONS

Estimates of seismic intensity were originally used, more than a century ago, to determine the location and size of earthquakes. The scheme developed was subjective and imprecise. Today, seismic instruments are well calibrated and widely distributed, and therefore intensity is no longer used to determine magnitude and location of earthquakes. Intensity estimates remain, however, the only way to determine the location and magnitude of earthquakes that occurred before instruments were available, an activity that has become important recently in establishing the seismic history of several regions in the United States. For example, intensity records of pre-instrumented earthquakes are important in making estimates of seismic risk in the eastern United States, where seismicity is low, and they have been used in developing the prediction of an earthquake for the segment of the San Andreas fault near Parkfield, California.

The use of intensity measurements that concern us here, however, is in estimating the effects of future earthquakes on manmade structures. Intensity has been used for this purpose for decades. Estimates of damage from future earthquakes were first made by relying heavily on the experience of the individual making the estimates. A significant improvement came in 1973 when J.F. Evernden developed a computer program to automatically calculate intensity for any given length of earthquake fault rupture. This program accounts for the effects of variations in local geology on seismic motion and can be calibrated with observations of intensity produced by past earthquakes. It can, in principle, be applied by someone not expert in seismology, the effects of local geology on seismic motion, or the effects of shaking on structures.

Beause of its convenience, Evernden's method has been applied to aid in the preparation of emergency response plans for potential earthquakes in several areas of California. Perhaps the most well-known applications are the earthquake scenarios published by the California Division of Mines and Geology (CDMG) for predicting effects of a repeat of the 1906 San Francisco and the 1857 Fort Tejon earthquakes on lifelines such as modern-day airports, harbor facilities, electric power networks, water distribution systems, fuel depots, freeways, and railways.

Evernden's method has also been applied by the CDMG to postulated earthquakes on the Hayward and San Diego Rose Canyon faults, where the effects on lifelines were estimated and potential hazards to schools and hospitals were discussed. A fifth scenario is now being prepared for a potential earthquake on the Newport-Inglewood fault.

The purpose of these scenarios is to show land use and emergency response planners that a major earthquake is a regional rather than a local problem. Response strategies that work for local emergencies, such as fires, may not work for major earthquakes. Ambulances and fire trucks may not be available from neighboring communities and, even if they were, blocked streets and lack of water might render them nonfunctional. These scenarios conveyed the scope of the problem and have resulted in the preparation of emergency response plans, the discussion of hazard-reduction measures, and the development of post-event recovery strategies.

While this response planning represents a significant improvement over what existed in the past, several shortcomings have been recognized. First, the predictions of intensity are sensitive to the input parameters that are assumed. The effects on the calculated intensity of some of these parameters may be incorrectly estimated since they are poorly known and vary significantly from region to region. For example, the effects of differences in local geologic conditions can change the calculated intensity by as much as three units, which can change the estimated intensity from a VI ("felt by all; many are frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys") to a IX ("damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; damage great in substantial buildings with partial collapse. Buildings shifted off foundation. Ground cracked conspicuously. Underground pipes broken."). The effects of the assumed properties of the earthquake source (such as rupture mechanism, magnitude, and hypocentral depth) are relatively well known but can be large and significantly different from earthquake to earthquake. Thus, the intensity pattern produced by the postulated earthquake used in any scenario could differ greatly from that produced by the actual earthquake for which the response plans are being made. Finally, and perhaps most serious, structural damage is not easy to predict since it is sensitive not only to intensity (a change of 1 unit in intensity can result in a 500 percent change in damage) but also to the quality, age, and type of structure.

Ironically, one of the principal vulnerabilities of Evernden's program derives from its principal advantage: convenience. Since it can be applied by people untrained in engineering, seismology, or geology, it may be misused. For example, some users express the intensities calculated by the program in fractions of a unit (e.g., VII .3), a degree of precision that is unwarranted by the method. Further, uncertainties in the derived scenario may not be appreciated. A scenario based on a postulated earthquake may be treated as a prediction of what will actually occur in the future. Emphasis on the effects of shaking may have obscured the fact that earthquakes can produce equal or greater damage by inducing liquefaction, landslides, ground displacements, and indeed, human behavior that can jam telephone circuits and highways. The very accessibility of Evernden's program, therefore, might underestimate the consequences of a major earthquake.

These shortcomings have prompted suggestions for improvement, both in the utilization of the existing method and in the method itself.

IMPROVED UTILIZATION

Utilization of the Evernden method could be improved by working closely with the users of the scenario in order to establish and clarify the method's reliability. Users should understand the method's limitations, assumptions, range of usefulness, and sensitivity to input parameters. One means of accomplishing this would be to conduct an experiment where different teams of seismologists, geologists, and engineers were asked to predict the damage that would result from a particular hypothetical earthquake. Each team would use the same computer program, the same hypothetical earthquake, and the same building inventory. A comparison of the different estimates of damage would demonstrate the method's uncertainties. Another approach would be to have different teams predict the intensity pattern that will result from the Parkfield, California, earthquake that is expected to occur in the next several years and to compare predictions with observations. (In this case, the predictions of intensity should not make use of observations of intensity from past Parkfield events, but treat this predicted event as any central California earthquake.)

Improvements in our ability to make damage estimates can also be made by working more closely with engineers. Estimates of damage that would be experienced in common construction types are uncertain by a factor of two. For unique structures, such as lifelines, the uncertainty is even greater. The Applied Technology Council has undertaken a long-needed project to compile information on damage as a function of intensity for several different types of common structures. The results of this project should be incorporated in future earthquake scenarios.

A third means of improving the utilization of Evernden's method is to work closely with private industry in order to expand the applications of the method. The insurance industry is one example where application of Evernden's method could benefit both industry, by helping price and market insurance, and local governments, by providing incentives for the appropriate use of land. (Of course, use of Evernden's method is not, by itself, sufficient for these purposes, since other factors such as the probability of an earthquake's occurrence must be evaluated.) Electric power companies and toxic-waste-storage companies could also benefit from use of earthquake scenarios and clearly local governments should know the vulnerabilities of these critical enterprises. More generally, cooperation with private industry would facilitate the important task of identifying all forms of loss that could result from an earthquake, including tax losses, unemployment, and the effects on the ability of a community to make payments on loans and bonds.

Finally, the current method could be more fully utilized by working with the public itself. To date, the principal users of the method and the earthquake scenarios have been planners in local government. While these scenarios helped planners understand the need for better response plans, public support to spend the tax dollars needed to develop and implement these plans has been lacking. A movie, similar to "The Day After," which would describe what happened to a particular family in the aftermath of a large but probable earthquake might be useful in this regard. This movie could be based on a scenario and, therefore, its power would derive from the fact that the consequences of the earthquake would be the scientist's best estimate of what could actually happen. This movie could become part of civic education in schools. KQED (San Francisco, California) has drafted a script for such a movie and is now searching for funds to produce it.

IMPROVEMENTS IN THE METHOD

While there is a consensus that improvements are needed in the utilization of the method, there is considerable disagreement on how and even if the method itself should be improved. The improvement easiest to realize is the complete automation of the method.

As discussed by the Southern California Earthquake Preparedness Project (SCEPP), automation could be realized by combining several computer programs and a data base management system. The data bases would be maps of building inventory and geology. Evernden's program does incorporate a data base of geology from the 1:250,000-scale Geologic Map of California, a matrix to estimate the effects on intensity of different geologic conditions, and a matrix to estimate the percent loss for different types of structures from different intensity levels. This geologic data base and these matrices are not, however, easily modified by the user, nor can the way in which more detailed information on local geology is taken into account be easily changed. The computer programs that are needed for the complete automation of the method would include Evernden's, one that calculates the effect of local geology on intensity and another that calculates the damage to a given structural type for a given intensity level. The sub-programs that calculate the effect of local geology on intensity and the effects of intensity on different structures should be accessible for amendment by the user. Graphics programs would contour the results to any desired scale. The input to the automated program would simply be the magnitude and location of the earthquake of interest; the output would be contours of loss of different structures for the community of interest.

Automation would require rather sophisticated resources. A moderate-sized computer facility with a good graphics capability is needed. A maintained, moderate-sized data base program would be required. Programmers and operators for the hardware and software must be available. Technicians would be necessary to compile and update computer inventories of local geology, water table, census information, buildings, and, possibly, landslide potential and liquefaction susceptibility.

Some of the benefits of an automated intensity-prediction system are obvious. Scenarios for any potential earthquake could be made quickly and cheaply. Calculating several different scenarios would be valuable to planners in order to anticipate the range of expected consequences. Additions and improvements in building inventories, maps of local geology, and relations between local geology and intensity could be easily incorporated and old scenarios easily re-derived.

Other benefits of such a system would certainly develop. One exciting possibility is that a map of expected damage could be made immediately after a large earthquake occurred, using the actual magnitude and location of the earthquake. Such a map would aid search and rescue efforts after earthquakes that occur at night, in bad weather conditions, or during the chaotic hours immediately following a large earthquake, when a clear picture is not yet available from eyewitnesses. This "on-line" system would also be useful in directing response to aftershocks of the large earthquake, since such aftershocks, acting on weakened structures, can be as damaging as the main earthquake.

A second possible improvement to Evernden's method is the inclusion of differences in the frequency content of shaking in the calculation of intensity and damage. While technologically feasible, this may be more difficult than automating the method. The consequences of the September 1985 Mexico earthquake showed how important frequency effects can be. Soils and structures respond differently to different frequencies of shaking. When the soils under a structure amplify seismic motions at the frequencies to which the structure responds--as occurred in Mexico City--the risk of damage is greatest. The currently used method of forecasting damage does not take into account the frequency dependence of soil or structural response.

The combination of automating the method and of including the effects of differences in frequency content would substantially improve the calculation of damage forecasts. Predictions of damage for an entire region, for example, all of southern California, are envisioned as possible with such a frequency-sensitive data base computer program. Predictions have been envisioned to be made for this entire region on a block-by-block basis. Some planners say that such predictions would be useful, while some engineers and seismologists say they would be counterproductive. The decison on whether or not to develop such a frequency-sensitive computer program focuses, therefore, on the question of its usefulness.

The Southern California Earthquake Preparedness Project (SCEPP) conducted a pilot study to test the feasibility and value of an automated computer program (frequency-dependent effects were not considered). SCEPP developed a semi-automated version of the program and used it to forecast the consequences of a repeat of the 1857 Fort Tejon earthquake on a small area of modern-day San Bernardino. The conclusion of this study was that a fully automated version would be valuable for the entire southern California region. All that is needed now, it was claimed, is to develop completely the needed program and to compile the required data bases of building inventories, geology (on a much larger scale than provided in Evernden's program), ethnic composition, and water table for the southern California region.

Another pilot study, Pre-Earthquake Planning for Post-Earthquake Reconstruction (PEPPER) Project for Los Angeles concluded, however, that existing methods for predicting structural damage are not adequate to indicate where damage will be concentrated, except for the special case of unreinforced structures. This suggests, therefore, that application of an automated program on a regional basis might be desirable if it could be made reliable; it is not reliable at present.

Another opinion, expressed by some seismologists and geologists, was that, while technologically possible, such a program is undesirable because its predictions would be unacceptably sensitive to parameters that are inherently difficult to determine, such as soil properties and structural response. Furthermore, even if extremely accurate and detailed predictions could be made, emergency response planners would be ill-advised to tailor their plans to these predictions since the actual future event, for which they are preparing, will certainly be different from the event used in the scenario. The purpose of scenarios, according to this school of thought, is only to give local planners a general picture of the extent and magnitude of the consequences of a major earthquake, not to suggest, for example, that one particular bridge or one particular hospital will be nonfunctional.

Perhaps the most significant accomplishment of this Working Group was airing these different opinions on the feasibility and desirability of a regional, frequency-sensitive, automated version of Evernden's program. In view of this disparity of opinions, improvements of the utilization of the current method should be emphasized.

SUMMARY

- Evernden's computer program, combined with tables of damage versus intensity, is the most effective current method for predicting seismic intensities for response planning and loss estimation.
- Evernden's method could be improved by incorporating it into a computer program that would:
    * store inventories of building types on a regional scale;

* store the response of modern buildings as a function of frequency;

* calculate seismic shaking as a function of frequency;

* estimate liquefaction potential; and

* calculate and contour loss estimates for various types of modern construction.

o There is a disparity of opinion among users of Evernden's method over whether this method should be improved to include frequency effects and data bases of building inventory, some arguing that it is desirable and feasible, others that it is desirable but not feasible, and others that, while costly, it is feasible but not desirable.

o There is a consensus that utilization of Evernden's method should be improved by working with:

* users to clarify the method's reliability;

* engineers to improve accuracy of structural loss estimates;

* private industry to estimate all forms of loss, not simply to lifelines; and

* the public to increase appreciation for the need of earthquake hazard mitigation.

Predicting Seismic Intensities for Response Planning and Loss Estimation

SUMMARY OF WORKING GROUP II AND AUDIENCE DISCUSSIONS

This session was moderated by Robert D. Brown, Jr. Panelists were William E. Spangle, Karl V. Steinbrugge, Richard J. Roth, Jr., and Rachel M. Gulliver. Joining the panel were speakers from the morning session, James F. Davis, Jack F. Evernden, Michael S. Reichle, Paul J. Flores, and John H. Wiggins. Brian E. Tucker was the session commentator. Questioners and commenters from the audience included William J. Kockelman, Anthony Prud'homme, and several others not identified on the audiotapes. The following text was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Brown opened the session with a definition of earthquake intensity taken from USGS Professional Paper 1360. He also pointed out the intensity scale printed on the inside back cover of that volume. Intensity originally was used as a means of locating the source of earthquakes, and not as a means to identify damage. The concept of intensity dates back to 1857, the work of Robert Mallet, and the great Neapolitan earthquake (Naples, Italy). Only in the last few decades has intensity become less of a tool for determing earthquake sources. Intensity is still used to supplement instrumental seismology for that purpose, but it is primarily used for estimating damage and loss, comparing earthquake scenarios, or estimating the effects of future earthquakes.

Spangle, Steinbrugge, Roth, and Gulliver spoke directly from their papers which are included in this chapter.

A participant asked the panel for comments about how tilt-up buildings might fare, and what advantages a subterranean facility might have over a surface facility during an earthquake. One panelist noted that the building code on tilt-up structures was changed after the 1971 San Fernando, California, earthquake. Today, there is a different type of anchoring required between the roof and vertical wall section. The expectation is for better performance of tilt-up buildings because of the changes in construction practices. Steinbrugge verified that comment, and noted that the area of the diaphragm of the roof did not particularly influence the damage pattern during the 1971 San Fernando earthquake. He commented that unfortunately tilt-up buildings are often identified with speculative construction; even within the San Francisco area, for example, tilt-up building construction is not uniform. At an earlier time, tilt-up walls contained pilasters extending into the ground and giving the effect of a vertical cantilever. This was a structural redundancy unmentioned in the building code, and it kept some buildings from collapsing during the San Fernando earthquake. Currently, one can interpret the building code to show that pilasters are not needed. In Steinbrugge's experience, some buildings in San Francisco are no longer built quite as well as they were prior to 1971, although builders are working under improved code conditions.

The participant reiterated his question about the performance of subterranean facilities, referring to an article about the Bank of Mexico's computer facilities surviving the 1985 Mexico earthquake. Was this the result of unique location, or better construction techniques? Wiggins suggested the location was in a lower intensity area. He cited records from the Latino-American Tower basement for the 1957 Mexico earthquake. He noted parenthetically that approximately the same kind of damage occurred in Mexico City in the 1957 earthquake as in the 1985 earthquake, but there was more of it in 1985. Records show a much lesser intensity when one goes underground. Wiggins also cited records from 1000 feet deep in mines, and mentioned that miners in the 1976 Tangshan, China, earthquake felt no shaking from an event that killed 400,000 people at the earth's surface. Essentially, the deeper one goes, the lower the effective shaking. Generally, the harder the rock, the more stable the conditions for underground shaking vulnerability.

Kockelman asked about increased spalling of tunnel-face rocks at depth. Wiggins replied that there were few reported cases of tunnel or mine behavior during earthquakes, and that his primary observations come from the Chinese miners. Robert Brown verified that underground facilities generally behave very well.

A participant asked whether buildings in San Francisco and Los Angeles, California, will fail in the same manner as did those in Mexico City, given similar shaking. A panelist replied that construction similar to that which failed in Mexico City exists in California cities, although buildings of such construction in California generally date from the 1920's. Therefore, if similar shaking is applied to these older buildings (without consideration of soil-site conditions), similar damage will occur. The lessons learned from Mexico City may not be as useful for studies of new buildings as they are for vulnerability estimates for older buildings. Also, the peculiarities of soil-site conditions in Mexico City may not be transferrable. However, the situation was not unique: Caracas, Venezuela, experienced a similar problem wherein great damage occurred in a small area due to local soil conditions. Likewise, Santa Rosa, California, had high-intensity shaking during the 1906 San Francisco earthquake. That shaking resulted in more damage to some of the towns near Santa Rosa and to the north of San Francisco than there was in the firm ground areas of San Francisco itself. The local soil conditions are going to dictate the answer. Robert Brown added that there are some similarities among the soil conditions in Mexico City, San Francisco, and Los Angeles. There are areas in all three cities where unconsolidated deposits will tend to amplify ground motion.

Prud'homme asked if there would ever be a way to estimate site-specific intensities with reasonable accuracy. Can a building be designed for a given site <u>and</u> the maximum probable earthquake from surrounding faults? Robert Brown suggested that for a specific building, one would go to the site-design criteria for that building, and then use a velocity or acceleration based on assumed earthquakes. He noted that intensity is more appropriate as a broad synthesis approach to problems.

Wiggins said site-specific intensities could be estimated from the standpoint of engineering design requirements. Whereas there are large uncertainties involved in making site intensity estimates, there are confidence bounds on those estimates. Structures can then be designed based upon the owner's decision regarding what confidence bounds he is willing to accept. We can estimate site-specific intensities and design for them. We are not going to understand everything perfectly. Thus, it is the safety factor -- the uncertainty we are willing to live with -- that determines our course of action. Owner and engineer must participate equally in the decision about what to do over and above the required code level.

A participant asked Richard Roth about how insurance companies establish premiums for earthquake insurance. Do the companies have hazard maps? Do they have certain formulas that they apply? Are there different rates for individual homeowners versus commercial facilities? To what extent do insurance companies reinsure their risk? Roth suggested that the insurance premium is based on the particular company's willingness to sell an earthquake insurance policy. Also, the insurance industry underwent one of its worst years in history in 1984, and is only now coming out of that bad financial condition. Therefore, industry is very hesitant to write earthquake insurance, and is even more hesitant to do so after the 1985 Mexico earthquake. Companies are required by law to offer residential earthquake insurance, but the law says they can charge any price they wish. The rates vary considerably; however, most companies are offering rates which are set in good faith. The rate is approximately $1.50 to $2.00 per thousand dollars of coverage on a wood-frame residential home; it is about $10.00 per thousand dollars on a masonry home. These rates reflect the insurance industry's current best estimate of what to charge. They are underwriting very carefully on older homes, homes near faults, and homes of masonry design. One may not be able to get earthquake insurance on a residence of masonry design near a fault.

The participant asked if there is any documentation on the manner in which rates are set for earthquake insurance. Roth replied that there is no documentation, and that the rates are set by actuaries who work for the insurance companies. The rates are based on actuarial perceptions of fair prices and strictly catastrophic exposures. The industry currently collects about $70 million in premiums and pays out about $2 million in losses. It is a highly profitable business until a catastrophic earthquake strikes.

A participant commented that the loss experience on conventional, single-story, wood-frame dwellings is less than 10 percent; however, most insurance is being offered with a 10 percent deductible. How is this justified? Roth answered that the standard deductible used to be 5 percent. Once the law mandated that companies offer earthquake insurance, most of them adopted a 10 percent deductible. There was an earthquake insurance program, widely available through agents or brokers, which offered a flat $1,000.00 deductible. It had broad coverage, a rather low rate, and was so popular that 100,000 people bought it. It was so popular that the reinsurance company became uneasy and canceled the program. The California State Department of Insurance felt that most people are interested primarily in insurance with respect to catastrophic earthquakes. The industry adopted the 10 percent deductible at the recommendation of Roth and the companies' actuaries, both of whom wished to reduce the exposure risks of the insurance industry. With a 10 percent deductible, the industry can eliminate large numbers of small losses: the small, mainly affordable losses are assumed by the homeowner, and the insurance companies offer coverage against a total, catastrophic loss. In this manner, the industry is able to insure more homes with the same capital and surplus, while helping to protect the industry's overall exposure.

A participant noted that the common denominator between the engineers and the owners or planners seems to be the intensity scale. Do we need a modern intensity scale that relates to modern structures? Spangle thought that a better scale is needed for large area analysis. He referred to improvements in the damage ratio scales, and adapting the damage ratio scale from Algermissen and Steinbrugge (1979) to the PEPPER Project (H.J. Degenkolb Associates, Engineers, 1984) for the types of buildings that exist in the City of Los Angeles. He suspected that one set of ratios would never be sufficient. Spangle cited a need to understand the existing local building stock, and to develop and apply ratios related to that stock.

Steinbrugge referred to terminology used in the intensity scale and how it means different things to different people in different sections of the country. He noted the word "good" has a different meaning for the same kind of construction in the cities of Los Angeles and San Francisco by an order of almost 5 to 1. (The reader may judge which location has the higher definition of "good"; there is much local pride and many differences of opinion here.) For recent private insurance studies in the Midwest, Steinbrugge found that the definition of the word "good" applied to construction practice in Memphis, Tennessee, means no reinforcing steel in the structure. In St. Louis, Missouri, the definition is different, and a modest amount of reinforcing steel is required. The same definition and amount of reinforcing steel would be illegal for construction practice in California. Thus, the word "good" is very difficult to standardize. One can readily see the problem with defining an intensity scale that matches the differences among the definitions of "good" for newer buildings. Every time our building codes change, the existing building inventory no longer meets code, and a new Probable Maximum Loss (PML) has to be established. An instrumental scale would be of great help in giving us, at least, an input parameter.

Regarding the output, one may view it in terms of casualties or functional loss and come up with different approaches. For example, damage is determined on the basis of which records are used. The records of loss turned in by the building department will be different from those submitted by a consultant who is examining losses for tax purposes. In summary, it is very difficult to arrive at intensities using a number that later will be defined in terms of losses.

Wiggins applied an analogy using the terms "sound" and "noise." The difference between those terms is akin to the difference between the input parameter of earthquake shaking and the response at a given site. To some people, a sound is music. To others, the same sound is noise. The same thing is true of structures. "Intensity" describes the behavior of people and structures in relation to earthquake shaking. Physically, we can talk in terms of the acceleration of gravity, particle velocity, or duration of shaking. Notice that we haven't mentioned the duration of shaking as important to the overall behavior of a structural component. Consequently, explaining to a layman or property owner that the property is "good for a 20 percent 'g' with a 10 percent duration" has little meaning. Speaking in terms of intensity and stating that characteristic kinds of "good" structures will behave in a certain manner will get the message across. Intensity is simply a scale that observes what is and what happens; then it must be correlated with the physical properties that produce the observed effect.

A participant asked about intensities for use in response planning. Several speakers had described broad-brush kinds of scenarios, based upon generalized intensities, that are very good for use in regional studies or statewide planning. How feasible is it to refine that information for use is smaller jurisdictions? Could a local entity use this information for damage prediction, response planning, and preparedness planning? What research is needed to refine intensity estimation for local uses?

Reichle responded that in the past the intensity scale has typically been applied at the regional, county, and community levels. The general level of damage expected for a community was determined by averaging observed effects and comparing those with a table of descriptions. The scenarios developed for several areas of California by the California Division of Mines and Geology (CDMG) and Karl Steinbrugge are just the scenarios a county or community might use. In these scenarios, the damages that might occur and the problems an emergency-response planner might encounter are identified, based on the predicted intensity pattern for a particular earthquake. Reichle felt the scenario development process needed more interaction with local planners, and noted that such interaction was occurring in San Diego. San Diego has a "lifeline task force" of people who are particularly interested in earthquake effects on lifelines, emergency response problems based on those effects, and how all of those factors will probably interact. The final step in scenario preparation is to have local users involved in undertanding some of the problems they are going to face.

The questioner persisted, asking if very specific information could be determined from scenario development. Is it possible to know which streets are going to be blocked by debris? Is it possible to know how many fire trucks to order, or how to allocate specific resources during a given event? Reichle replied that in a sense, it does not matter which specific streets are going to be blocked. If one knows, however, that 5 to 10 percent of the streets are going to be blocked, then one has a reasonable basis for starting a response plan.

Gulliver noted that a large portion of the components for doing detailed loss estimations and scenarios are in place. These need to be upgraded by compiling inventories of structures in local communities, and by ascertaining that those inventories are realistic and reasonably complete. These inventories should be entered into a computerized data base. Without computerization, a great deal of tedious work is often repeated. She felt there are opportunities for major upgrading of the intensity models for southern California, and that such upgrading is fully warranted based on USGS Professional Paper 1360 and other work now in progress. Even at a high level of refinement of intensity models, however, there will always be a level of uncertainty as to whether a precise distribution of shaking intensities will actually occur during a given earthquake. Existing models use major parameters that determine what the shaking intensity will be. However, parameters such as travel paths, constructive and destructive reinforcement of crossing waves, and the influence of unknown layers at depth may not be incorporated in the model. Therefore, there will always be some unexpected variations in the shaking intensity pattern, even after it has been predicted with a fairly high level of confidence. As a result, to precisely predict which streets will be blocked and where would be more a feat of imagination than a realistic expectation of a well-developed scenario or loss model.

Davis emphasized that the current state of the art has a boundary of rigor which the user community must accept, and it must be explained adequately to that community by people with technical backgrounds. Obviously, people want to know and prepare as much as they possibly can. However, the more specialized the response plan, the more likely that plan would not be appropriate. Thus, planning should be a regional process, leaving some discretion as to how "regional" is defined. Additionally, work should be done on bracketing loss estimates, whereby assumptions can be more clearly stated because the planned response will be to a general pattern of loss rather than to a site-specific condition.

REFERENCES

Algermissen, S.T., and Steinbrugge, K.V., 1979, Earthquake losses to buildings in the San Francisco Bay area in Brabb, E.E., editor, Progress on seismic zonation in the San Francisco Bay region: U.S. Geological Survey Circular 807, p. 61-72.

H.J. Degenkolb Associates, Engineers, 1984, Summary report of structural hazards and damage patterns--pre-earthquake planning for post-earthquake rebuilding (PEPPER Project): National Science Foundation Grant CEE 8024724; William Spangle and Associates, Inc., Portola Valley, California, v. 1, text, 38 p., v. 2, tables, 52 p.

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III. PREDICTING GROUND MOTION FOR EARTHQUAKE-RESISTANT DESIGN

III. PREDICTING GROUND MOTION FOR EARTHQUAKE-RESISTANT DESIGN[1]

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[1] Names and affiliations of all participants are listed alphabetically in Appendix A.

PREDICTION OF STRONG GROUND MOTIONS

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INTRODUCTION

The prediction of ground motion has come a long way since the first strong motion records were obtained during the 1933 Long Beach earthquake. What was once one of the weakest links in the reduction of earthquake hazards has been considerably strengthened in the last few years, thanks in large part to the efforts of various groups in developing, deploying, and maintaining strong-motion instruments. These efforts paid off handsomely in the massive data sets recorded during the 1971 San Fernando and 1979 Imperial Valley earthquakes. The data collected from these events have had an enormous influence on specification of design motions, which are usually based on empirical analyses of the data. At the same time, data are lacking for large earthquakes at the close distances of most concern in earthquake hazard evaluation. In these cases theoretical models can be used to guide predictions of strong ground motion. In this paper I will give brief descriptions of both the empirical and theoretical predictions of ground motion.

EMPIRICAL PREDICTIONS

The existing recordings of ground motions within several hundred kilometers of the earthquake source can be used in several ways to predict ground motions for engineering design and seismic hazard planning. The most straightforward use occurs when recordings are available in magnitude and distance ranges for which the design motions must be specified. This is sometimes referred to as site specific prediction. Recordings are generally lacking close to large earthquakes, however, and thus design motions for such cases must be based on extrapolations of the data. This is commonly done by using regression analysis to fit a mathematical function involving distance and magnitude to the existing data and then using this function to make predictions (see Boore and Joyner, 1982, for an extensive discussion).

Predictions of peak acceleration and velocity from analysis of many strong-motion data from western North America (primarily California) are shown in figure 1. Even though the curves are very smooth, they are based on analyses of over 180 data points. The curves represent predictions of the mean values of the logarithms of peak acceleration and velocity; the individual data points have a scatter about the curves with a standard deviation of almost a factor of two. Note that the curves for both acceleration and velocity have similar shapes beyond about 20 km, although the frequency content of the two measures of ground shaking is quite different. This implies that the effective attenuation parameter Q is frequency dependent (e.g., Boore, 1984, Fig. 2). Also note the difference in spacing between

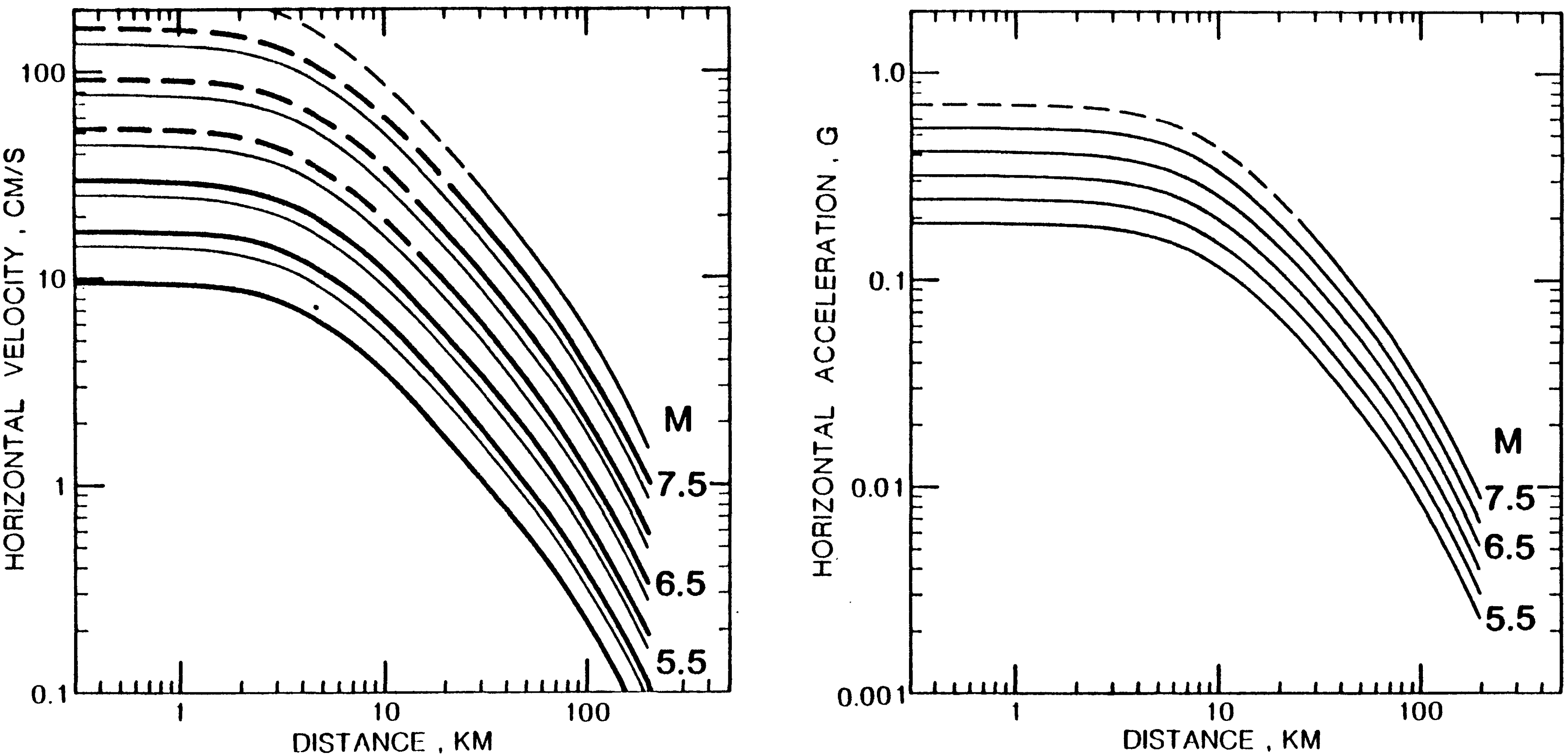

Figure 1. Peak horizontal acceleration and velocity from empirical analysis of randomly chosen horizontal components (from Joyner and Fumal, 1985). Light lines, soil sites: heavy lines, rock sites. Curves dashed where not constrained by data.

the curves: the peak velocity is a more sensitive function of moment magnitude than is peak acceleration. As I will show later, this is in agreement with a commonly used seismological model of spectral radiation.

Although peak acceleration is widely used to specify design motions (often to scale a fixed spectral shape), many engineers and seismologists bemoan this and urge that response spectra be specified directly (response spectra are graphs of the response of a single-degree-of-freedom oscillator of fixed damping, on the ordinate, plotted against the period of the oscillator on the abscissa; a rough rule of thumb is that the resonant period of a building is 0.1 sec/floor). With the increasing amount of digitized data it is now possible to accomplish this, using the same procedures used for the derivation of predictive equations for peak acceleration. Figure 2 shows an example, in which response spectra for a range of magnitude and site geology are shown for a fixed distance. The dashed curves are not constrained by data (and thus emphasize the crucial need for more data close to large earthquakes). Note that the shape of the curves is strongly magnitude dependent, in contradiction to the assumption underlying the commonly used method of deriving design motions by scaling a fixed spectral shape. Also note the strong dependence of the motions on site geology for the longer period oscillators. The separation of site geology into rock and soil classes is very simple; most of the soil sites are underlain by thick deposits of soil, and it is likely that soil sites underlain by thin deposits might exhibit differences between rock and soil at shorter oscillator periods than indicated in figure 2.

The information in figures 1 and 2 is essential in preparing maps showing the expected ground motions in a region with a given probability of being exceeded in an interval of time. Examples of such maps are shown in figures 3 and 4, taken from the work of Joyner and Fumal (1985). Maps such as these are crucial in urban planning for earthquakes, and they represent a synthesis of many different studies, including detailed determination of soil properties and determination of locations and rate of slip on faults in the area, in addition to the studies of strong motion recordings just discussed. Figure 3 is a map of expected response of a 0.2 sec oscillator in the Pomona-San Bernardino-Riverside area. Because the site condition has little influence on 0.2 sec oscillators (figure 2), most of the structure in the map is due to the decay of motions away from the principal faults in the area. In contrast, figure 4 shows the response of a 1.0 sec oscillator. Because of the variable geology in the area, the contours are much more complicated.

THEORETICAL PREDICTIONS

As with the empirical prediction of ground motion, there are many uses for theoretical predictions, both in seismology and in engineering. Theoretical predictions can be used to specify a suite of time series for use in dynamic structural analysis, they can provide estimates of ground-motion parameters in geographic regions or portions of magnitude-distance space lacking observations, and they can be used as an essential part of understanding the physics of earthquake sources and wave propogation. Much effort in seismology has been devoted to deterministic simulations of ground motion from specified faults in laterally-uniform geologic materials whose properties are a function of depth. Although these simulations can be useful in predicting low-frequency motions (e.g.,

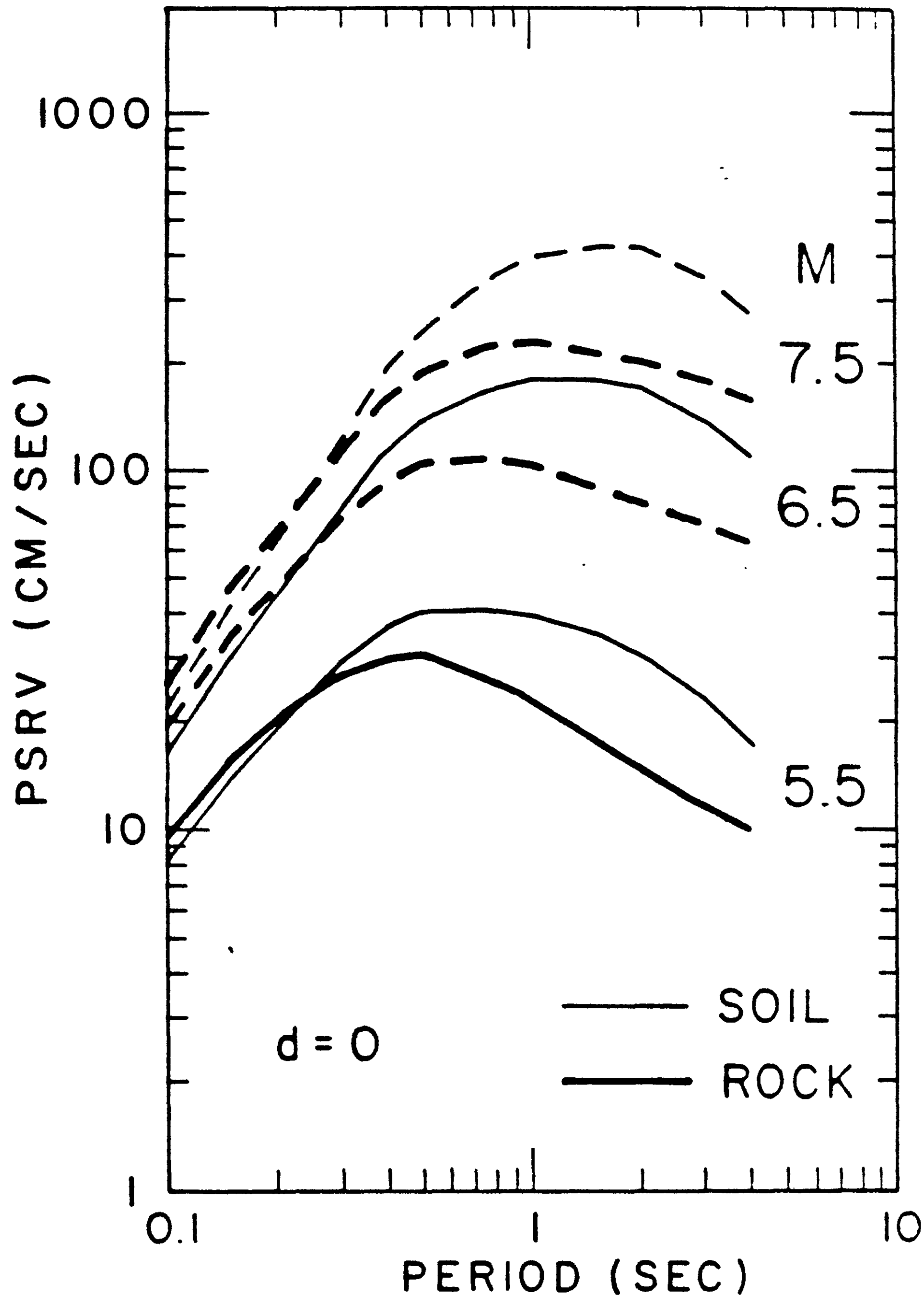

Figure 2. Predicted pseudo-velocity response spectra for 5 percent damping at rock sites (heavy line) and soil sites (light line) for zero distance, for larger of peaks on the two horizontal components (from Joyner and Fumal, 1985). Curves are dashed where not constrained by data.

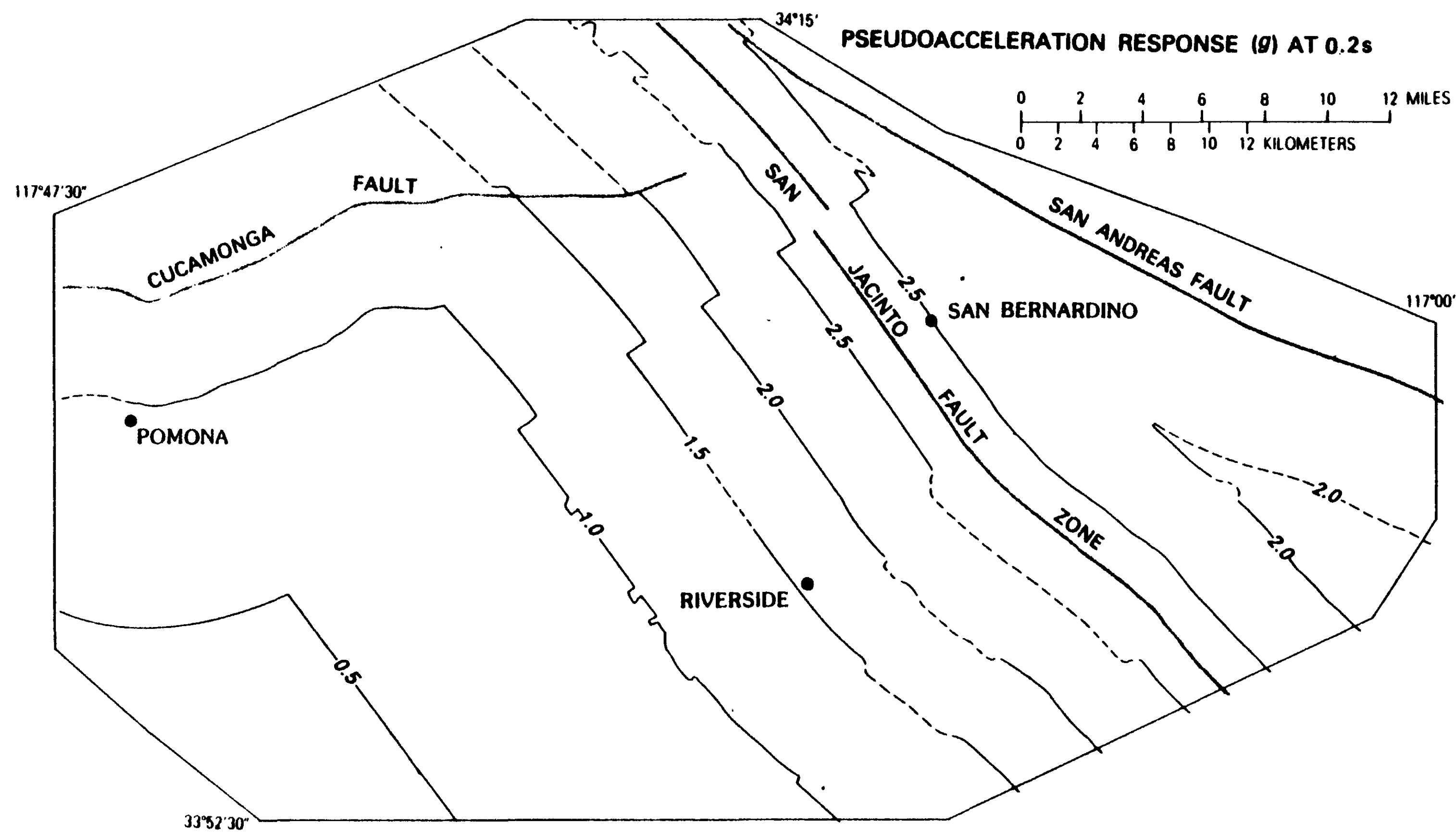

Figure 3. Map of pseudoacceleration response for 0.2 sec period and 5 percent damping corresponding to a return period of 500 years (from Joyner and Fumal, 1985). Curves are dashed where not constrained by data.

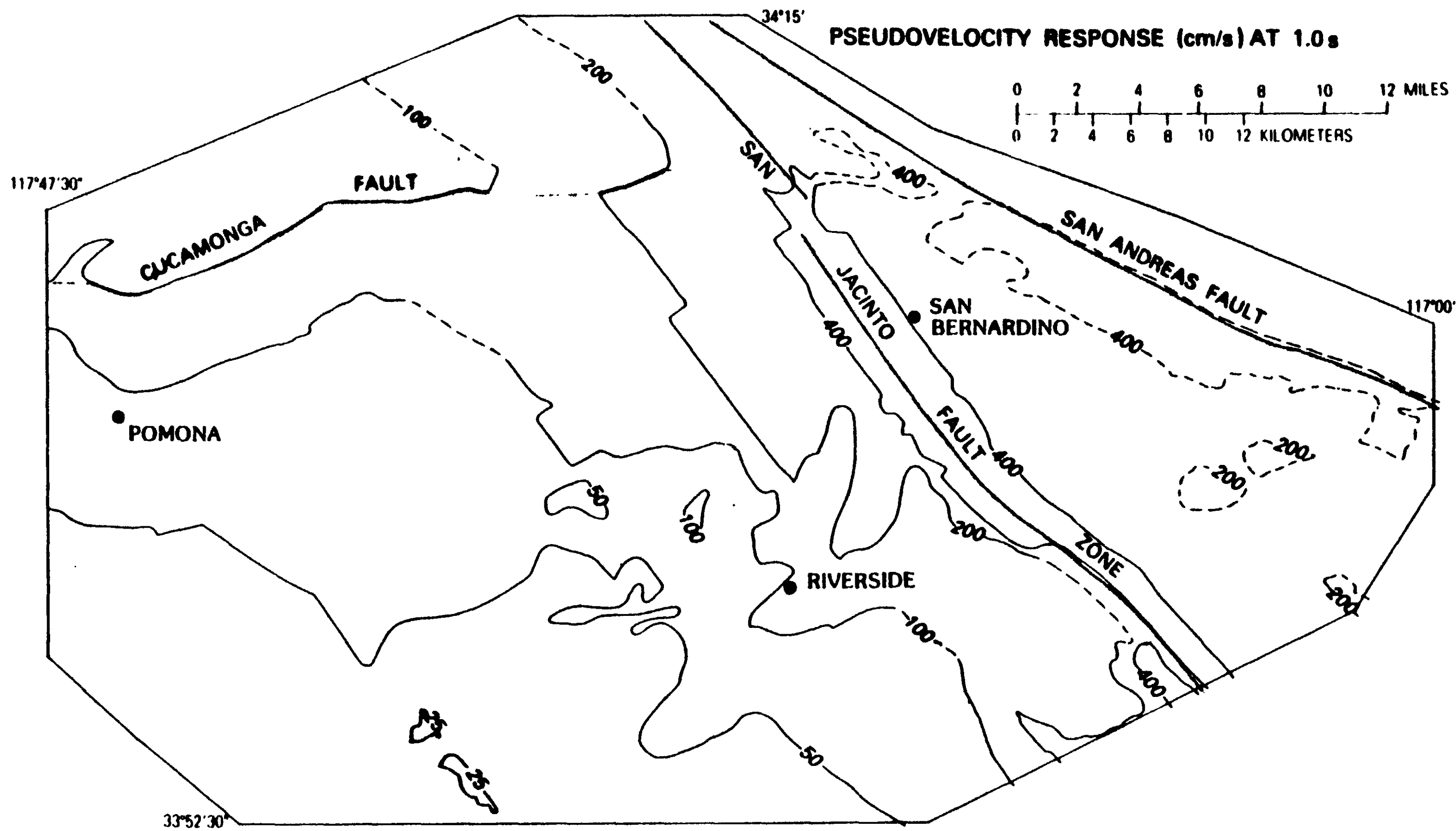

Figure 4. Map of pseudovelocity response for 1.0 sec period and 5 percent damping corresponding to a return period of 500 years (from Joyner and Fumal, 1985). Curves are dashed where not constrained by data.

figure 5), they are generally not relevant for simulations of high-frequency motions: not only does the cost of doing the simulations increase dramatically with frequency, but the basic model assumptions are invalid. Engineers, on the other hand, usually use a purely stochastic approach in deriving time series for design purposes. The parameters that control the duration, frequency content, and amplitude of these motions are taken from empirical analyses of the existing data. Because of this, however, the usual stochastic techniques share the same problems as do the empirical techniques in predicting motions for situations in which no data exist.

Recently a hybrid approach has been developed that assumes random ground motion with properties determined from seismological models of the source and the wave propogation (McGuire and Hanks, 1980; Hanks and McGuire, 1981; Boore, 1983; McGuire and others, 1984; Boore, 1986a). This new method does not have the limitations of the methods just discussed. The basic idea of the method is a simple one: the ground motion is represented by windowed and filtered white noise, with the average spectral content and the duration over which the motion lasts being determined by a seismological description of seismic radiation that depends on source size.

A suite of acceleration and velocity spectra are shown in figure 6. This figure contains an abundance of information, and from it several general conclusions can be drawn without complex calculations, simply from the spectral shapes and the spacing between the spectra. For example, for large earthquakes, the peak velocity will be a stronger function of seismic moment (or, equivalently, moment magnitude) than will peak acceleration. In contrast, the moment dependence of both peak acceleration and peak velocity will be identical for small earthquakes and will have stronger dependence on moment than do either peak acceleration or peak velocity for large earthquakes. The data are in agreement with these theoretical conclusions.

Several techniques are used to predict peak motions from the spectra. One uses time-domain, Monte Carlo simulation, and the other uses random-process theory (RPT). The former method is useful in applications demanding time series and is subject to fewer assumptions than is the RPT. On the other hand, it is much more costly than RPT to predict the peak motion. In the time-domain method, a number of simulations (between 20 and 100 is usually sufficient) are needed to derive a good estimate of the peak motion. The spectrum of any one realization of the process will not match the target spectrum, but the spectrum averaged over the whole suite of simulations will (figure 7).

A comparison of predicted and observed peak acceleration and peak velocity is shown in figure 8, with f_m as a parameter (f_m controls the cutoff of the spectra at high frequencies). The observed values are based on the comprehensive regression work of Joyner and Boore (1981, 1982), which used earthquakes greater than moment magnitude 5. As seen in the figure, the simple theoretical model gives predictions that are in good agreement with the observations. As expected, the effect of f_m is seen to be most important for motions that contain high frequencies (peak accelerations from small earthquakes).

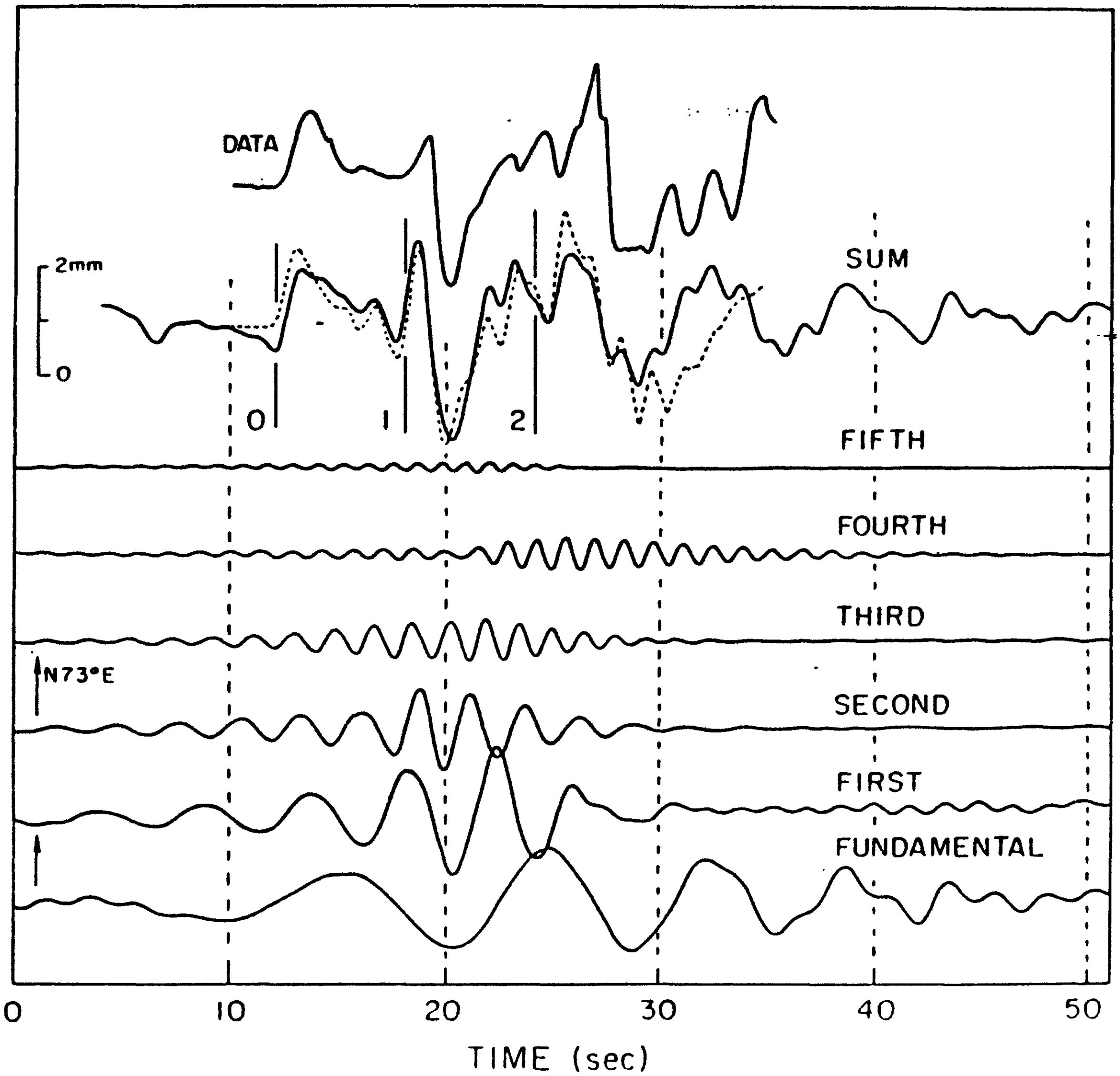

Figure 5. Comparison of Love-wave synthetic ground displacements (solid lines) with Heaton and Helmberger's (1978) model of the 1976 Brawley earthquake as recorded at station IVC, 33 km from the epicenter (dashed lines). The actual ground displacements are given by the top curve. Details are given in Swanger and Boore (1978).

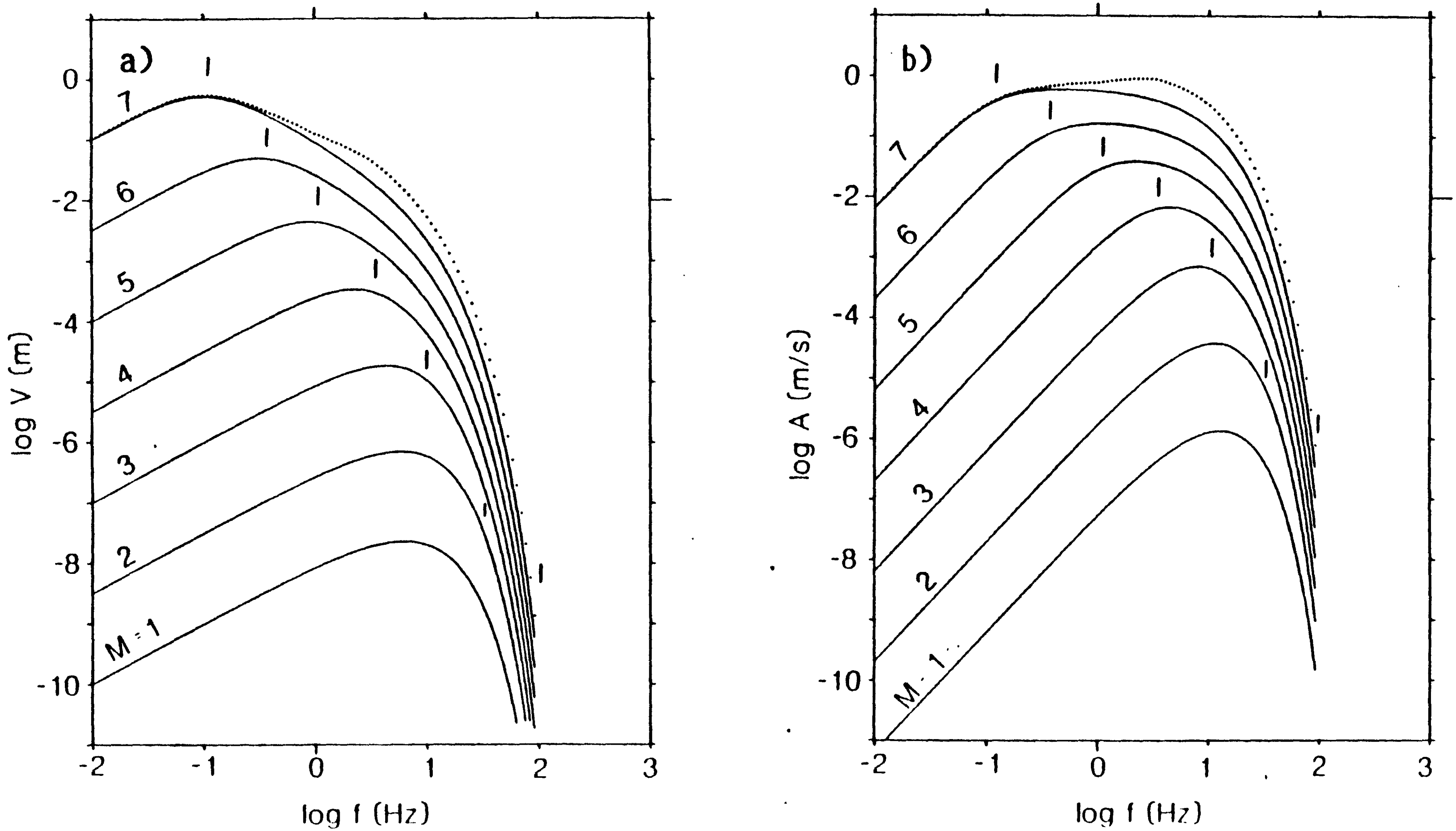

Figure 6. Velocity and acceleration spectra for a range of moment magnitudes, computed for a distance of 10 km. The vertical bars indicate corner frequencies (from Boore, 1986b). Dots show modification of **M** = 7 spectra for amplification factors given in table 3 in Boore (1986a).

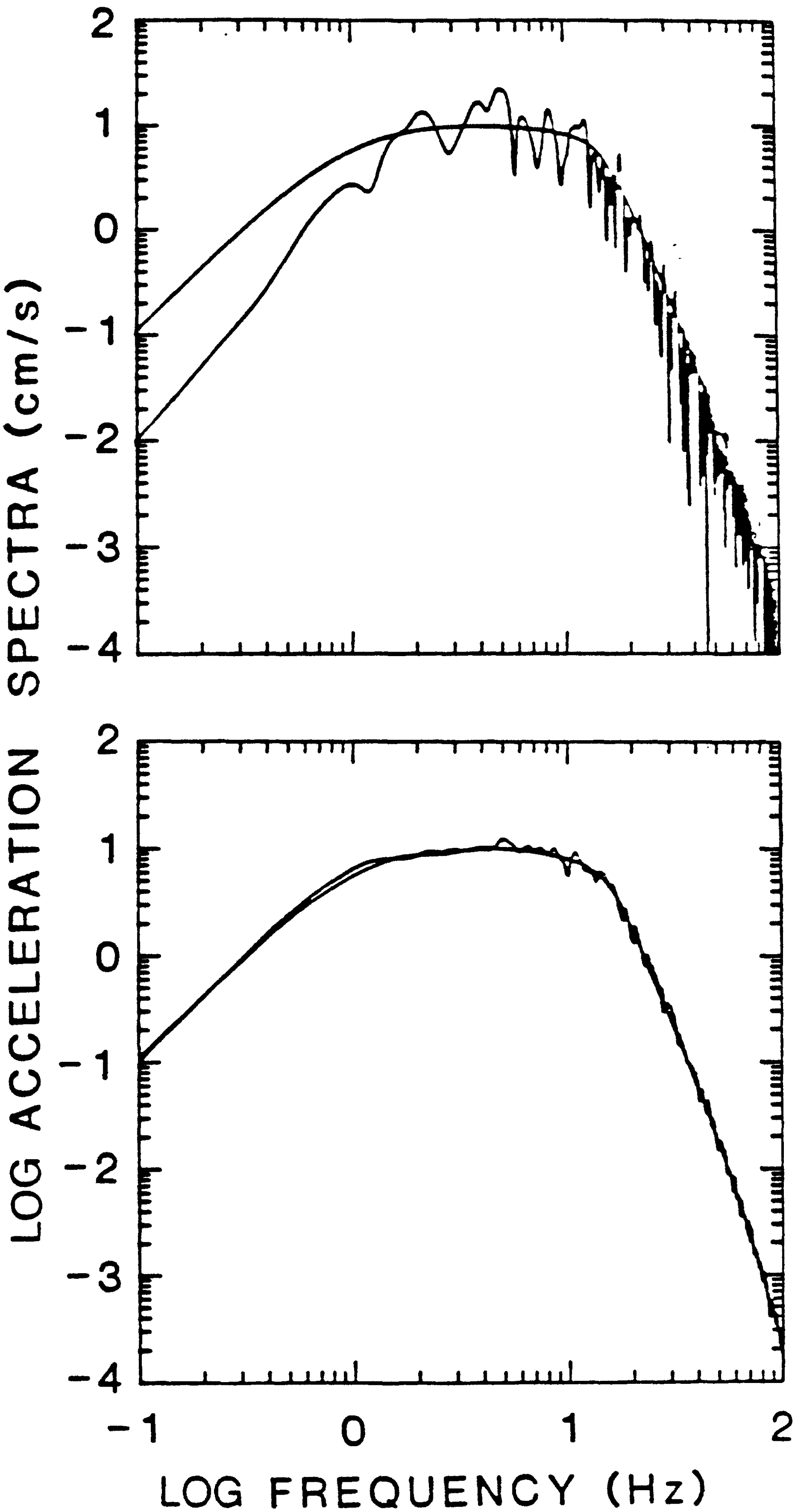

Figure 7. Fourier amplitude spectrum of ground acceleration at 10 km from a magnitude 5 earthquake (from Boore, 1983). Top: smooth curve, given spectra; jagged curve, spectra for one realization of the simulation process. Bottom: as above, but averaged over 20 simulations (the averaged spectrum is the square root of the arithmetic mean of the energy density spectrum).

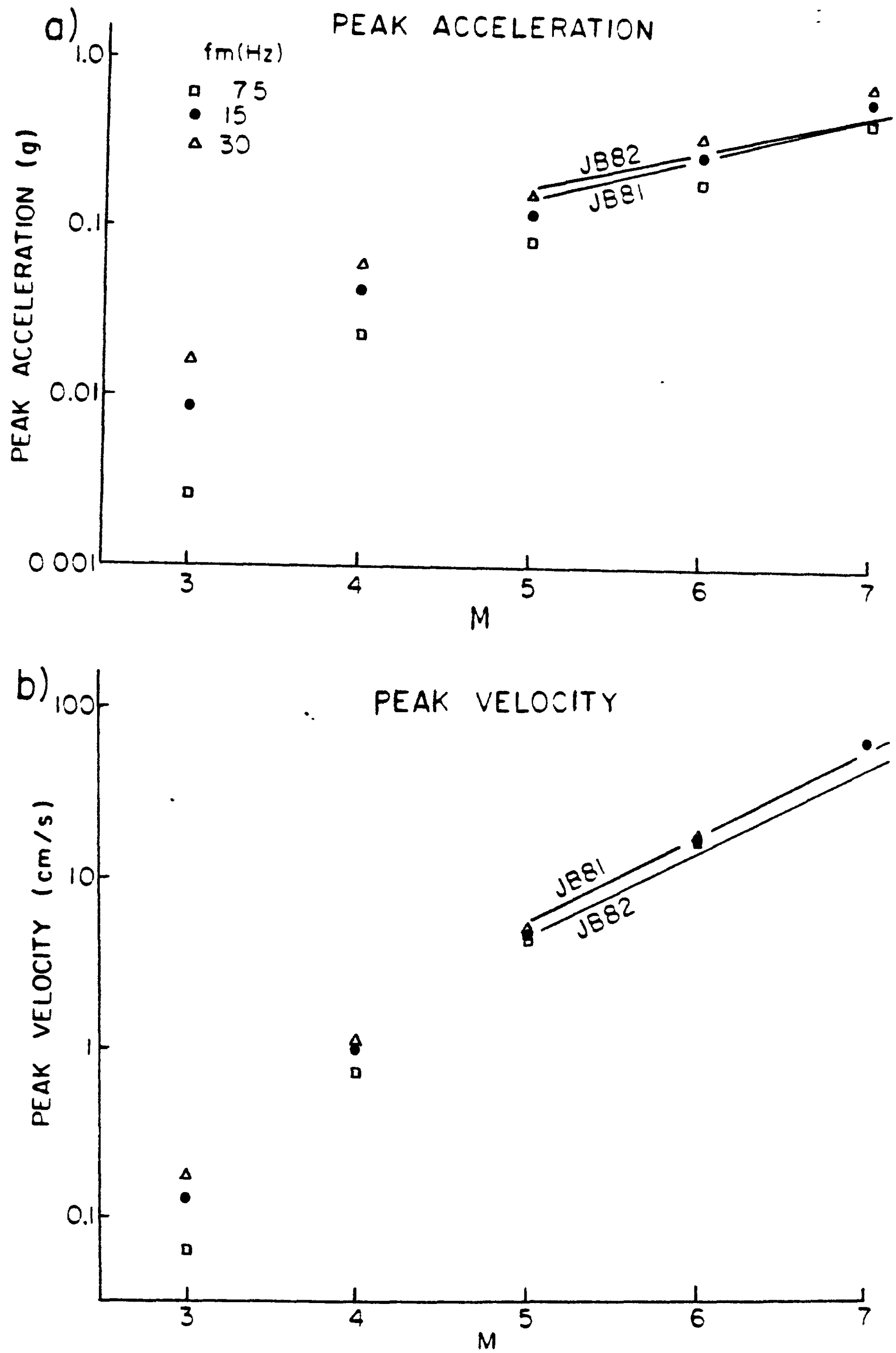

Figure 8. Magnitude scaling of simulated peak ground accelerations and velocities for three values of f_m (from Boore, 1983). The regression curves of Joyner and Boore (1981, 1982) are shown for reference.

DISCUSSION

Where do we stand in our ability to predict ground motions for engineering design and urban planning? I believe that predictions of the mean ground motion for earthquakes of moderate size and sites underlain by normal geologic materials can be made with some confidence. For these conditions we have a fair amount of data, and the theoretical model gives a good fit to these data. I emphasize the word mean in mean ground motion, for there will inevitably be a large amount of uncertainty in the prediction of the ground motions of any one earthquake. This uncertainty may be irreducible in the sense that it may be practically impossible to unravel and determine the precise factors contributing to the scatter.

The greatest uncertainties are in predictions of the motions from the largest earthquakes, especially at longer periods, and in predicting responses of unusual soil conditions, such as clay deposits in marshlands, where significant nonlinear response might be expected. The long-period motions are particularly important for high-rise structures, off-shore drilling platforms, and storage tanks.

The strong-motion instrumentation now in place and that likely to be installed in the next few years will help resolve many of the questions facing us, such as the scaling of earthquake ground motions with source size, the importance of source directivity, and the contribution of nonlinear soil response in the reduction of ground motions. Unfortunately, in the southern California region the one earthquake that would provide the most important information is also the largest one expected. This is a "catch-22" situation: we cannot be sure of the motions needed for design until the earthquake we need to design for occurs. The way out is to collect data in other parts of the world from faults in similar tectonic and geologic environments. There is an active program, funded by the National Science Foundation as well as others, to do this. We are already seeing some payoff for the expenditures in these programs (such as the records from the 1985 Michoacan, Mexico earthquake), and I am sure that the scientific and engineering benefits from these programs will be increasing.

REFERENCES

Boore, D.M., 1983, Stochastic simulation of high-frequency ground motions based on seismological models of the radiated spectra: Bulletin of the Seismological Society of America, v. 73, p. 1865-1894.

Boore, D.M., 1984, Use of seismoscope records to determine M_L and peak velocities: Bulletin of the Seismological Society of America, v. 74, p. 315-324.

Boore, D.M., 1986a, Short-period P- and S-wave radiation from large earthquakes--implications for spectral scaling relations: Bulletin of the Seismological Society of America, v. 76, p. 43-64.

Boore, D.M., 1986b, The effect of finite bandwidth on seismic scaling relationships: Fifth Maurice Ewing Symposium on Earthquake Source Mechanics, Proceedings, American Geophysical Union monograph, in press.

Boore, D.M., and Joyner, W.B., 1982, The empirical prediction of ground motion; Bulletin of the Seismological Society of America, v. 72, p. 5269-5286.

Hanks, T.C., and McGuire, R.K., 1981, The character of high frequency strong ground motion: Bulletin of the Seismological Society of America, v. 71, p. 2071-2095.

Heaton, T.H., and Helmberger, D.V., 1977, A study of the strong ground motion of the Borrego Mt., California earthquake: Bulletin of the Seismological Society of America, v. 67, p. 315-330.

Joyner, W.B., and Boore, D.M., 1981, Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California, earthquake: Bulletin of the Seismological Society of America, v. 71, p. 2011-2038.

Joyner, W.B., and Boore, D.M., 1982, Prediction of earthquake response spectra: U.S. Geological Survey Open-File Report 82-977, 16 p.

Joyner, W.B., and Fumal, T.E., 1985, Predictive mapping of ground motion, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 203-220.

McGuire, R.K., Becker, A.M., and Donovan, N.C., 1984, Spectral estimates of seismic shear waves: Bulletin of the Seismological Society of America, v. 74, p. 1427-1440.

McGuire, R.K., and Hanks, T.C., 1980, RMS accelerations and spectral amplitudes of strong ground motion during the San Fernando, California earthquake: Bulletin of the Seismological Society of America, v. 70, p. 1907-1919.

Swanger, H.J., and Boore, D.M., 1978, Simulation of strong-motion displacements using surface-wave modal superposition: Bulletin of the Seismological Society of America, v. 68, p. 907-922.

PREDICTIVE MAPPING OF EARTHQUAKE GROUND MOTION

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INTRODUCTION

Predictive mapping of earthquake ground motion can take one of two different forms. First, one might postulate an earthquake of a certain size in a certain place and map the ground motion to be expected from that earthquake. On the other hand one might consider all the earthquakes that might occur in a region in a specified period of time and map the ground motion value that has a specified probability of being exceeded. In Professional Paper 1360 both kinds of maps were illustrated (Fumal and Joyner, 1985; Joyner and Fumal, 1985); in this discussion emphasis will be on the probabilistic maps.

A number of different quantities might be chosen to represent ground motion on predictive maps. The quantities of particular interest are those which are useful to engineers in the design of structures. Traditionally, the quantity most commonly used to represent ground motion is the peak horizontal acceleration. Peak horizontal velocity has also been suggested (Newmark and Hall, 1969), though it has not been widely used. The quantities most useful in the design of structures are response spectra.

There are different kinds of response spectra, but they can all be thought of as the response to a specified ground motion of a set of idealized models of structures. The conventional method of estimating response spectra is first to estimate peak acceleration and then to use peak acceleration to scale some standard normalized spectrum. This method would be generally valid only if the shape of response spectra were the same regardless of the earthquake magnitude and the local site conditions. As will be shown, that is not the case, and it is much preferable to estimate response spectra directly.

There are two basic elements needed to make predictive ground motion maps: predictive equations and estimations of earthquake potential. Each will be discussed in turn.

PREDICTIVE EQUATIONS

The predictive equations express the dependence of ground motion on magnitude, distance, and site conditions. Such equations are generally derived by regression analysis of data recorded during earthquakes by strong-motion instruments. The equations of Joyner and Boore (1981, 1982) will be used for illustration; other equations (or curves) have been developed by Schnabel and Seed (1973), Donovan and Bornstein (1978), Idriss (1978), and Campbell (1981). The differences among the various predictive schemes are small relative to the statistical uncertainty of an individual prediction.

The equations of Joyner and Boore (1981, 1982) are of the form

$$\log \underline{y} = \underline{c}_0 + \underline{c}_1(M - 6) + \underline{c}_2(M - 6)^2 + \underline{c}_3 \log \underline{r} + \underline{c}_4\underline{r} + \underline{S}$$

$$5.0 \le M \le 7.7$$

$$\underline{r} = (\underline{d}^2 + \underline{h}^2)^{1/2}$$

$$\underline{S} = 0 \quad \text{at rock sites}$$

$$= \underline{c}_5 \quad \text{at soil sites}$$

where $\underline{y}$ is the ground-motion quantity to be predicted, **M** is a moment magnitude (Hanks and Kanamori, 1979), and $\underline{d}$ is the closest distance from the site where the ground motion is being predicted to the vertical projection of the fault rupture on the surface of the earth. The parameters $\underline{c}_0$ through $\underline{c}_5$ and $\underline{h}$ have been determined from strong-motion data by a two-stage regression procedure described in the original publications. The predictive equations are illustrated for peak horizontal acceleration in figure 1, for peak horizontal velocity in figure 2, and for horizontal response spectra in figures 3, 4, and 5. Note in these figures that the curves are dashed at distances less than 25 km for magnitudes greater than 7.0. At those distances and magnitudes there is insufficient strong-motion data, and the curves are uncertain. One of the most important needs in engineering seismology is for more strong-motion data at large magnitude and short distance. Note in figure 3 that the shape of the response spectra is strongly dependent on both magnitude and site conditions.

In the equation above, site effects are handled by a simple rock-versus-soil classification of sites. In Professional Paper 1360 we have attempted to improve on this treatment of site effects by taking advantage of downhole shear-wave velocity data measured at 33 strong-motion recording sites. There is a basis in traditional seismological theory (Bullen, 1965; Aki and Richards, 1980) for the use of local shear-wave velocity in estimating the site effect on ground motion amplitude. At the 33 sites where shear-wave velocity data are available, we analyze the strong-motion data for site effects in terms of the average shear-wave velocity to a depth equal to one-quarter wavelength at the period of interest (Joyner and Fumal, 1985). Details are given in the paper. This approach enables us to make systematic use of available geologic data in making predictive ground-motion maps (Fumal and Tinsley, 1985).

EARTHQUAKE POTENTIAL

The second basic ingredient in predictive ground motion mapping is specification of where earthquakes will occur, how large they will be, and how often they will occur. Incorporating these factors into probabilistic mapping of the shaking

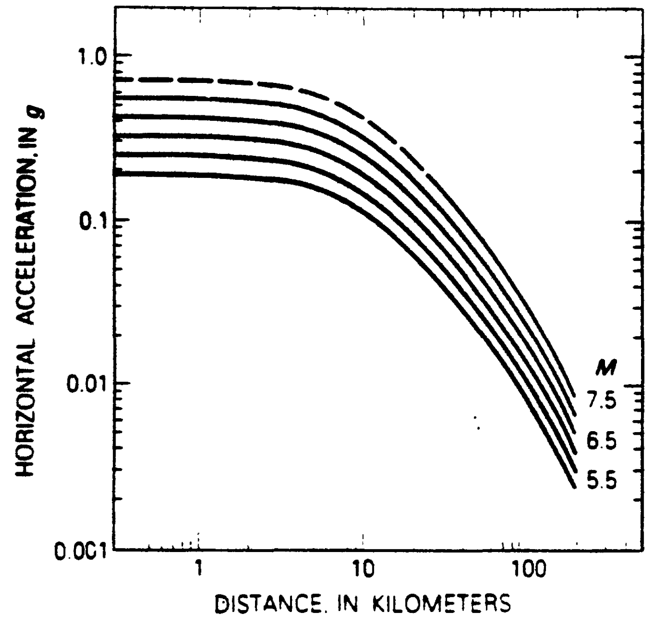

Figure 1. Predicted value of peak acceleration for the randomly oriented horizontal component as a function of distance and moment magnitude. Curves are dashed where not constrained by data.

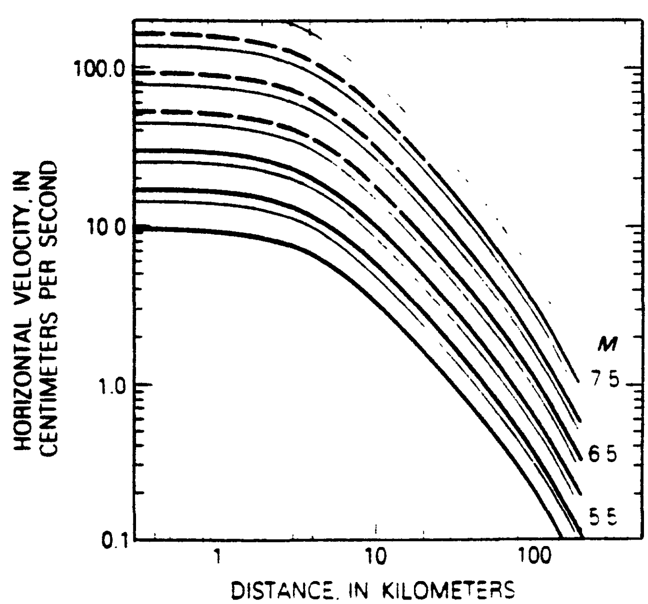

Figure 2. Predicted value of peak velocity for the randomly oriented horizontal component as a function of distance and moment magnitude at rock sites (heavy line) and soil sites (thin line. Curves are dashed where not constrained by data.

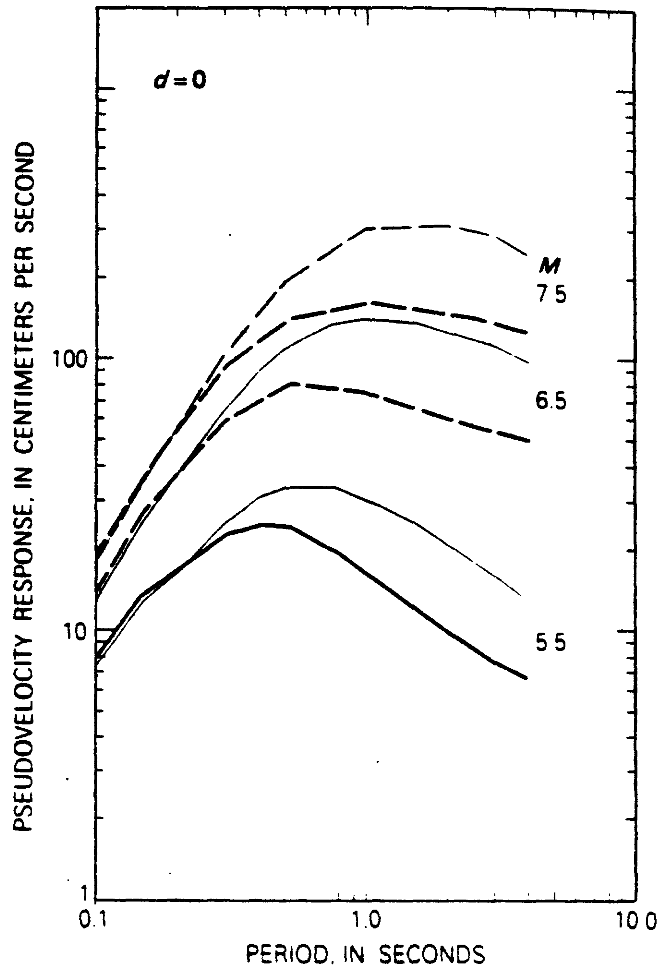

Figure 3. Predicted pseudovelocity response spectra for 5 percent damping at rock sites (heavy line) and soil sites (thin line) for d = 0 and M = 5.5, 6.5, and 7.5. Spectra correspond to the randomly oriented horizontal component. Curves are dashed where not constrained by data.

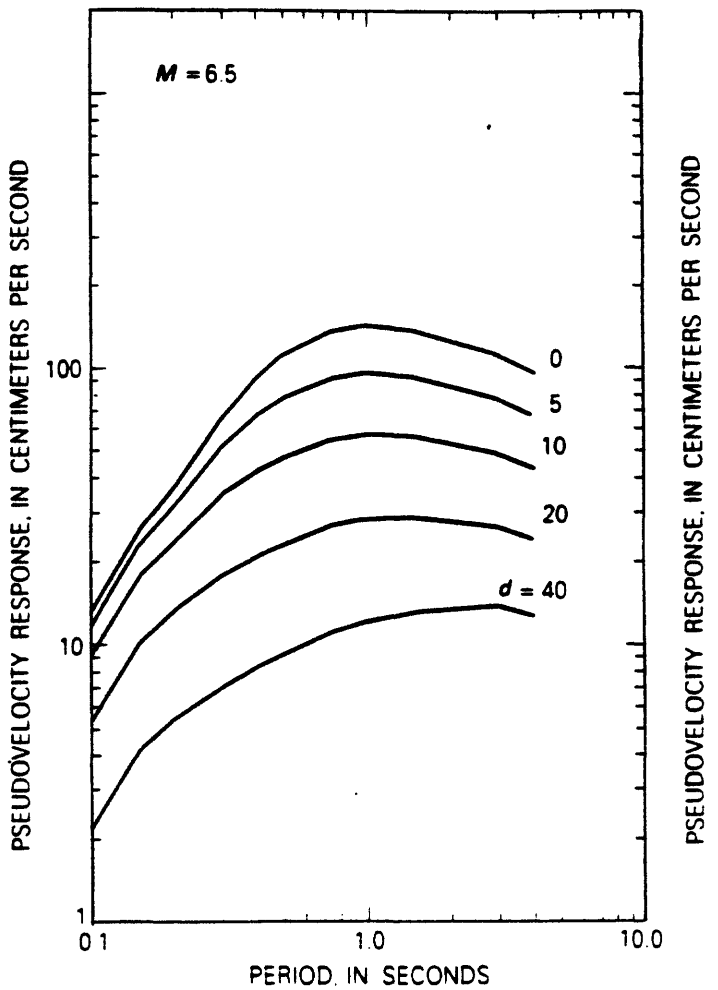

Figure 4. Predicted pseudovelocity response spectra for 5 percent damping at soil sites for M = 6.5 and d = 0, 5, 10, 20, and 40 km. Spectra correspond to the randomly oriented horizontal component.

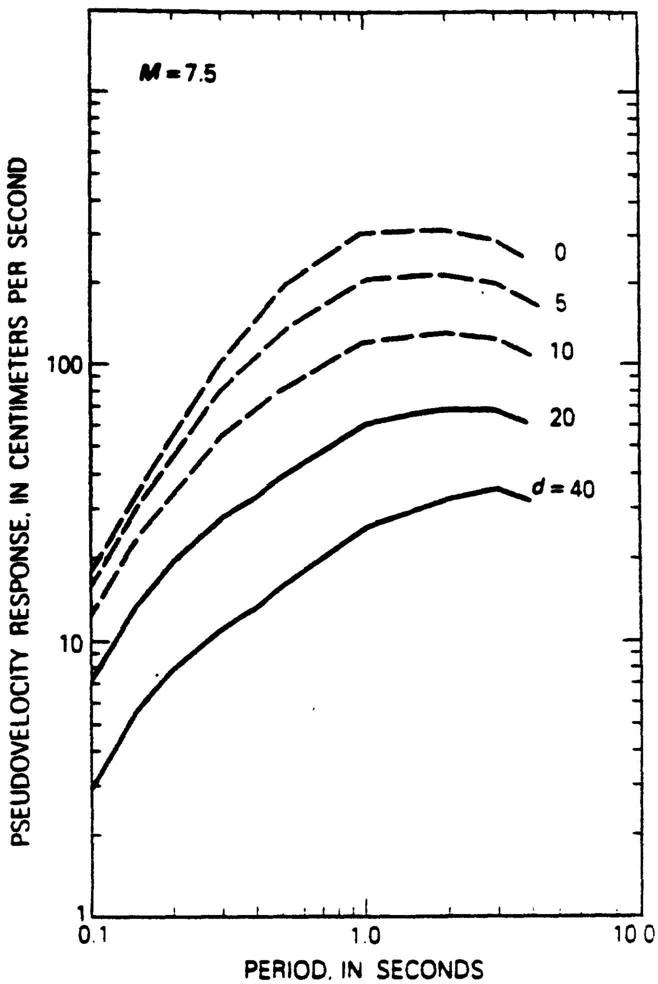

Figure 5. Predicted pseudovelocity response spectra for 5 percent damping at soil sites for M = 7.5 and *d* = 0, 5, 10, 20, and 40 km. Spectra correspond to the randomly oriented horizontal component. Curves are dashed where not constrained by data.

hazard is a classical problem in engineering seismology (Cornell, 1968; Algermissen and Perkins, 1976; Der Kiureghian and Ang, 1977; McGuire, 1978).

Traditionally, the problem has been solved using only historical data on earthquake occurrence, though this does not have to be the case as illustrated by the work of McGuire and Shedlock (1981) on the San Francisco Bay area, which used slip-rate data on the major faults. In the western United States, where the historical record is short compared to the repeat time of the largest seismic events, there is a growing belief that geological slip-rate data, where available, are a better basis for assessing seismic risk than historical seismicity (Wallace, 1970; Allen, 1975; Anderson, 1979; Molnar, 1979). In California, slip-rate data of relatively good quality are beginning to become available for the major faults (Clark and others, 1984). A high priority research goal is the improvement of this data base.

Ideally, all of the data would be used: historical seismicity, geologic slip-rate data, historical creep data, and geodetic data on strain accumulation. Geologic data is important because it is the only information covering sufficient spans of time. Other kinds of data are necessary, however, to correct geologic slip rates for aseismic creep, to incorporate the effects of unknown faults or faults with unknown slip rates, and to act as a check against errors of geologic interpretation. It would be desirable to have hazard maps made in California that incorporate all of these different kinds of data.

Whether historical data or geologic data are used to constrain the seismicity, probabilistic ground motion predictions require specification of the relationship between earthquake magnitude and frequency of occurrence. The traditional way is the Gutenberg-Richter relationship (Gutenberg and Richter, 1954; Ishimoto and Iida, 1939)

$$\log \underline{N} = \underline{a} - \underline{bM}$$

where $\underline{N}$ is the annual number of events with magnitude greater than or equal to $\underline{M}$, and $\underline{a}$ and $\underline{b}$ are constant. The Gutenberg-Richter relationship must be truncated at a maximum magnitude $\underline{M}_{max}$ to avoid an infinite slip rate. The values of $\underline{b}$ commonly used are in the vicinity of one.

The Gutenberg-Richter relationship with $\underline{b}$ values near one works reasonably well when applied to large regions. In recent years, however, there is a growing body of evidence that, for individual faults or individual segments of major fault zones, the characteristic earthquake model is more appropriate (Singh and others, 1981; Schwartz and others, 1981; Lahr and Stephens, 1982; Wesnousky and others, 1983; Davison and Scholz, 1985). According to the characteristic earthquake model there is for each fault or fault segment a characteristic size of earthquake that dominates the seismicity.

I believe it is fair to say that the weight of the evidence is increasing in favor of the characteristic earthquake model. If one decides to accept this model, however, there may still be uncertainty as to how a fault system such as the San Andreas should be segmented and, consequently, uncertainty as to the size of the characteristic earthquake.

Fortunately, near-fault ground-motion predictions are relatively insensitive to the details of the magnitude-frequency relationship, provided that the relationship is constrained by the fault slip rate. This proposition leads to a very simple method for making probabilistic ground-motion maps. The proposition was established essentially by brute-force calculations with normalizations to make the results as general as possible (Joyner and Fumal, 1985). The details will not be repeated here, but a schematic example will be shown in order to give an intuitive idea of how the result comes about. The precise numerical values given in the example are based on assumptions described by Joyner and Fumal (1985) and are not crucial to the discussion here.

Figure 6a shows an earthquake sequence consisting of one magnitude 7.0 earthquake every 250 years. Considering the ground motion at a specified distance, 10 km in the example, the value that will be exceeded once every 500 years on the average is the value that will be exceeded in half the events, that is the median or 50th percentile value, as shown. Now, consider a sequence of repeated magnitude 6.0 earthquakes as shown in figure 6b. In order to maintain the same slip rate, more events are required; figure 6b shows 10 events in 500 years instead of two as in the first case. The ground motion to be expected in any single event in the second case is less, as is illustrated in figure 6, but the 500-year-return-period ground motion in the second case is the 90th percentile motion because there are 10 events in 500 years. The resulting 500-year-return-period motion is not very different in the two cases. The difference computed for the example in figure 6 is negligible compared to other uncertainties in estimating ground motion. The relative insensitivity to the magnitude-frequency relationship results from the compensating action of two opposing effects. Smaller magnitude events give smaller median ground-motion estimates, but the smaller the magnitude the larger the number of events and the higher the percentile corresponding to the estimate for a fixed return period.

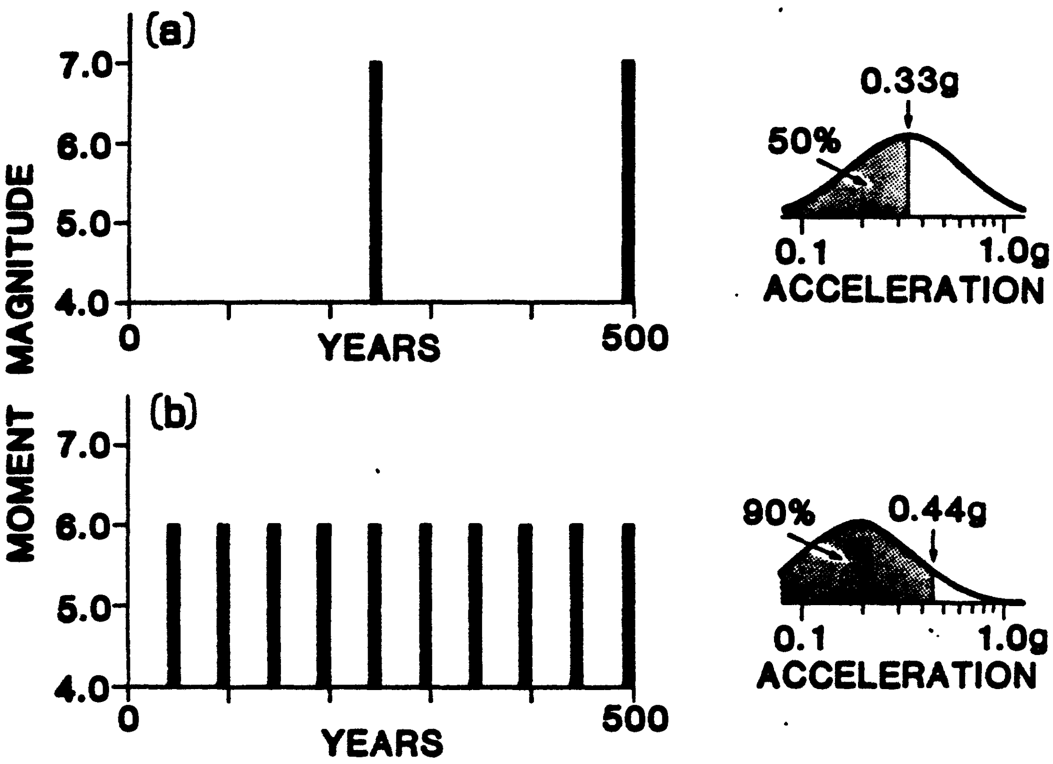

Figure 6. Schematic diagrams of a simple example illustrating that probabilistic ground-motion estimates are insensitive to the details of the magnitude-frequency relationship, provided that the slip rate is constrained.

REFERENCES

Aki, K., and Richards, P.G., 1980, Quantitative seismology: W.H. Freeman, San Francisco, v. 1, 557 p.

Algermissen, S.T., and Perkins, D.M., 1976, A probabiliistic estimate of maximum acceleration in rock in the contiguous United States: U.S. Geological Survey Open-File Report 76-416, 45 p.

Allen, C.R., 1975, Geological criteria for evaluating seismicity: Bulletin of the Geological Society of America, v. 86, p. 1041-1057.

Anderson, J.G., 1979, Estimating the seismicity from geological structure for seismic-risk studies: Bulletin of the Seismological Society of America, v. 69, p. 135-158.

Bullen, K.E., 1965, An introduction to the theory of seismology: Cambridge University Press, Cambridge, 381 p.

Campbell, K.W., 1981, Near-source attenuation of peak horizontal acceleration: Bulletin of the Seismological Society of America, v. 71, p. 2039-2070.

Clark, M.M., Harms, K.K., Lienkaemper, J.J., Harwood, D.S., Lajoie, K.R., Matti, J.C., Perkins, J.A., Rymer, M.J., Sarna-Wojcicki, A.M., Sharp, R.V., Sims, J.D., Tinsley, J.C., III, and Ziony, J.I., 1984, Preliminary slip-rate table and map of late-Quaternary faults of California: U.S. Geological Survey Open-File Report, 84-106, 12 p.

Cornell, C.A., 1968, Engineering seismic risk analysis: Bulletin of the Seismological Society of America, v. 58, p. 1583-1606.

Davison, F.C., Jr, and Scholz, C.H., 1985, Frequency-moment distribution of earthquakes in the Aleutian Arc--a test of the characteristic earthquake model: Bulletin of the Seismological Society of America, v. 75, p. 1349-1361.

Der Kiureghian, A., and Ang, A.H.S., 1977, A fault-rupture model for seismic risk analysis: Bulletin of the Seismological Society of America, v. 67, p. 1173-1194.

Donovan, N.C., and Bornstein, A.E., 1978, Uncertainties in seismic risk procedures: Proceedings of the American Society of Civil Engineers, Journal of Geotechnical Engineering, v. 104, n. GT7, p. 869-887.

Fumal, T.E., and Tinsley, J.C., III, 1985, Mapping shear-wave velocities of near-surface geological materials, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 127-149.

Fumal, T.E., and Joyner, W.B., 1985, Section on Horizontal acceleration, velocity and response spectral values, in Ziony, J.I., and others, Predicted geologic and seismologic effects of a postulated magnitude 6.5 earthquake along the northern part of the Newport-Inglewood Zone, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 423-430.

Gutenberg, B., and Richter, C.F., 1954, Seismicity of the earth and associated phenomena (2d ed.): Princeton University Press, Princeton, New Jersey, 310 p.

Hanks, T.C., and Kanamori H., 1979, A moment magnitude scale: Journal of Geophysical Research, v. 84, p. 2348-2350.

Idriss, I.M., 1978, Characteristics of earthquake ground motions, in Earthquake Engineering and Soil Dynamics: American Society of Civil Engineers Geotechnical Engineering Specialty Conference, Proceedings, v. 3, p. 1151-1265.

Ishimoto, M., and Iida, K., 1939, Observations sur les seismes enregistres par le microsismographe construit dernierement (in Japanese with a summary in French): Bulletin of the Earthquake Research Institute, Tokyo University, v. 17, p. 443-478.

Joyner, W.B., and Boore, D.M., 1981, Peak horizontal acceleration and velocity from strong-motion records including records from the 1979 Imperial Valley, California earthquake: Bulletin of the Seismological Society of America, v. 71, p. 2011-2038.

Joyner, W.B., and Boore, D.M., 1982, Prediction of earthquake response spectra: U.S. Geological Survey Open-File Report 82-997, 16 p.

Joyner, W.B., and Fumal, T.E., 1985, Predictive mapping of ground motion, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 203-220.

Lahr, J.C., and Stephens, C.D., 1982, Alaska seismic zone--possible example of non-linear magnitude distribution for faults (abstract): Earthquake Notes, v. 53, 66 p.

McGuire, R.K., 1978, FRISK--computer program for seismic risk analysis using faults as earthquake sources: U.S. Geological Survey Open-File Report 78-1007, 71 p.

McGuire, R.K., and Shedlock, K.M., 1981, Statistical uncertainties in hazard evaluations in the United States: Bulletin of the Seismological Society of America, v. 71, p. 1287-1308.

Molnar, P., 1979, Earthquake recurrence intervals and plate tectonics: Bulletin of the Seismological Society of America, v. 69, p. 115-133.

Newmark, N.M., and Hall, W.J., 1969, Seismic design criteria for nuclear reactor facilities: World Conference on Earthquake Engineering, 4th, Santiago, Chile, v. 2, p. B4-37 to B4-50.

Schnabel, P.B., and Seed, H.B., 1973, Accelerations in rock for earthquakes in the western United States: Bulletin of the Seismological Society of America, v. 63, p. 501-516.

Schwartz, D.P., Coppersmith, K.J., Swan, F.H., III, Somerville, P., and Savage, W.U., 1981, "Characteristic" earthquakes on intraplate normal faults (abstract): Earthquake Notes, v. 52, 71 p.

Singh, S.K., Astiz, L., and Havskov, J., 1981, Seismic gaps and recurrence periods of large earthquakes along the Mexican subduction zone--a reexamination: Bulletin of the Seismological Society of America, v. 71, p. 827-843.

Wallace, R.E., 1970, Earthquake recurrence intervals on the San Andreas fault: Bulletin of the Geological Society of America, v. 81, p. 2875-2890.

Wesnousky, S.G., Scholz, C.H., Shimazaki, K., and Matsuda, T., 1983, Earthquake frequency distribution and the mechanics of faulting: Journal of Geophysical Research, v. 88, p. 9331-9340.

DETERMINATION OF SEISMIC DESIGN PARAMETERS*

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INTRODUCTION

The purpose of this paper is to provide an overview of the general considerations, steps, and methods necessary to establish parameters for the seismic design of important structures. A thorough treatment of this topic can be found in two monographs published by the Earthquake Engineering Research Institute (EERI), (Newmark and Hall, 1982; Housner and Jennings, 1982) and a document entitled "Seismic Design of Oil and Gas Pipeline Systems," published by the American Society of Civil Engineers (1984), (ASCE). The materials in chapters 2, 3, and 4 of the ASCE document are generic and can be applied to all types of facilities. These chapters deal with the identification and quantification of seismic hazards and the determination of seismic design criteria.

ESTIMATION OF SITE GROUND MOTION

Ground-Motion Paramaters for Seismic Design

The ground motion data required to determine seismic design criteria for important or critical facilities are: 1) peak ground acceleration, velocity, and displacement; 2) accelerograms; and 3) response spectra. The peak ground acceleration is the largest value of acceleration contained in a particular time-history (or accelerogram) of ground motion. Similar defintions apply to peak velocity and peak displacement as well. Although peak ground accelerations and velocities are generally not recommended for the design of aboveground structures, they are commonly used to compute stresses and strains in buried pipelines (Hall and Newmark, 1977). In some cases, these peak parameters are used to compute the design spectra (Newmark and Hall, 1978; Seed and others, 1976). Peak ground displacements have been used to set the level of the design spectra at long periods (Newmark and Hall, 1978). However, ground displacements are generally computed from accelerograms and are highly sensitive to the method of integration. This should be recognized if ground displacements are used to compute spectra.

Response spectra represent the maximum responses on single-degree-of-freedom oscillators to some excitation, generally a ground-motion accelerogram. Response spectra are the fundamental data for establishing smooth design spectra, which have become a well-recognized tool for seismic design of many structures. Design spectra are principally used in the seismic design of aboveground facilities

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that can generate significant dynamic response during earthquake ground shaking. Such facilities include medium- to high-rise buildings, dams, power plants, tanks, offshore platforms, bridges, and electric transmission structures.

Methods of Estimating Ground-Motion Parameters

A number of variables affect the character of earthquake ground motion. These include 1) size, location, and type of earthquake; 2) the regional and local geology; and 3) the location of the site relative to the earthquake source. The earthquake-generation process and the wave-propagation problems are extremely complex and not well understood. For this reason, theoretical approaches, which attempt to model these phenomena, are not directly used to estimate ground motions for design. Rather, empirical methods, which draw on the large number of recorded strong-motion data, are primarily considered. However, theoretical models are sometimes used to gain insight or corroborate the results obtained from empirical approaches, especially in situations where there are few empirical data that are directly representative.

Empirical prediction methods rely on a few parameters to characterize the various factors influencing ground motions. These parameters include the earthquake magnitude (for example, local (M_L), body-wave (m_b), surface wave (M_s), moment (M_w) or other), the earthquake-to-site separation distance (epicentral, hypocentral, center-of-energy release, closest distance to fault rupture), and sometimes local geology. In some cases, parameters have been included to distinguish between horizontal and vertical components (Trifunac, 1976), fault type, and embedment of building recording the ground motion (Campbell, 1983). The most common empirical approach to estimate ground motion is to relate these parameters to the ground-motion parameters of interest. The relationship is often of the form

$$\ln y = A + f(M) + g(R) + h(G)$$

where y is the ground motion parameter (that is, peak acceleration, velocity, displacement, response spectra), A is a constant, M is the earthquake magnitude, R is the source-site distance, G represents the local geology, and f, g, h designate the functions. These equations are often called "attenuation" or "scaling" relationships, and they are generally derived by regression analysis of strong-motion data. An excellent summary of the more widely used attenuation relationships is given in Idriss (1978). Some newer relationships have been published (for example, the Bulletin of the Seismological Society of America, December, 1981), which have incorporated recent ground-motion data recorded near the fault ruptures of moderate to large magnitude earthquakes. Attenuation relationships will continue to evolve as new data become available and the understanding of the earthquake process increases. The literature should continually be searched for the latest developments in this field.

Although numerous attenuation relationships exist, it is important to recognize the conditions under which they best apply. For example, relationships derived from data recorded in the western United States may not be applicable to other regions where the earthquakes and geology are distinctly different. In this case, the development of new relationships, or the modification of existing ones, may be appropriate. If ground-motion data are lacking in the region of interest, attenuation relationships can be based on data recorded in other regions, provided that differences in the attenuation properties and magnitude scales in both regions are properly considered in the derivation. Examples of this procedure can be found in various papers discussing the development of attenuation relationships for the eastern and central United States (Herrmann and Goertz, 1981; Nuttli, 1979, 1981; Campbell, 1981). Attenuation relationships that are derived in this manner should be consistent with any representative, regional data on ground motions and structural performance during past earthquakes.

Another empirical approach to estimate ground motion, which is a slight variation from the one discussed above, involves the analysis of ground-motion data representative of the design earthquake. In this approach, data are selected that were recorded under conditions similar to the design earthquake. For example, if the design earthquake is a magnitude 7 event at a distance of 20 km from a proposed site on deep alluvium, then accelerograms are chosen that best match these conditions. Obviously, some discrepancies will exist and, depending on the size of these deviations, some corrections to the data may be appropriate.

Statistical analysis of the corrected data are performed to obtain the desired level of conservatism for the ground-motion parameter of interest. Although this procedure was originally developed for nuclear power plants (Jennings and Guzman, 1975; Guzman and Jennings, 1976), it can be used to estimate ground motions and design spectra for other facilities also. The procedure is best applied when a reasonable amount of representative data exists. Example applications of the procedure can be found in the Jennings and Guzman references.

No matter which empirical approach is used, the data upon which the approach is based is never completely representative of the conditions at the site. This fact is sometimes ignored, and perhaps should be when the data are fairly representative. However, when significant differences are thought to exist, then modifications of the empirical model or the resulting estimates of ground motion might be justified. Such has been the case for ground-motion prediction in the eastern United States cited previously, and ground motions estimated for soft soil deposits. The important question to consider is whether there is a good theoretical or observational basis for making modifications. A general rule of thumb to follow when making modifications is to: keep them to a minimum so that no unnecessary uncertainties are introduced into the ground-motion estimate; base them on the appropriate theory; and reconcile the resulting predictions with observations to the best extent possible.

DEVELOPMENT OF SEISMIC DESIGN CRITERIA

Considerations

The seismic design of ordinary structures such as buildings is usually governed by provisions in the applicable building code. However, for some high-rise buildings and other important structures, where the consequences of damage due to earthquakes can be severe, careful attention should be given to the development of seismic design criteria. The basic philosophy behind the criteria should be to provide a safe, yet economical, design. What constitutes "safe" and "economical" designs are not only technical questions, but often political ones. In recent years more consideration has been given to satisfying regulatory requirements, and this political aspect is an integral part of the criteria formulation that must not be overlooked.

Seismic design criteria should specify (1) the level of ground motion the structure must resist; and (2) the desired performance of the structure (allowable stresses, strains and deformations). Generally, the geotechnical engineer is responsible for the former and the structural engineer handles the latter. An important point, which is often overlooked or neglected, is the conservatism (or lack of conservatism) inherent in each of the two items. These conservatisms should be estimated and accounted for in the selection of the seismic design criteria. This requires communication between the geotechnical and structural engineers.

Many factors should be considered when establishing seismic design criteria for important facilities. These include:

- ground-motion parameter relevant to seismic design;
- likelihood of strong ground motion at the facility during its lifetime;
- confidence level and conservatism in the estimate of ground motion;
- the maximum motion that might occur;
- type of structure and its importance to the overall operation of the facility;
- type of construction materials and their properties;
- the dynamic characteristics of the structure such as natural frequencies, mode shapes, and damping;
- behavior of similar structures during past earthquakes;
- consequences of failure ranging from temporary loss of operation to long-term or permanent shutdown; and
- local, state, and Federal regulatory requirements.

Because of the large number and variety of factors that need to be considered, some of which are not well known, the development of seismic design criteria is more of an art than a science. Many disciplines--geology, seismology, structural engineering, economics, management, and politics--enter into the decisionmaking. Consequently, no well-defined, unique procedure for developing seismic design criteria has been developed. However, general discussions on the development of earthquake design criteria are given by Newmark and Hall (1982), Housner and Jennings (1977, 1982) and ASCE (1984) on the seismic design of oil and gas facilities. All of the publications elaborate on some of the points discussed here. Out of necessity, much of the development process involves judgment or the interpretation of data. The engineer responsible for formulating the seismic design criteria should be knowledgeable about the ten factors mentioned above and incorporate them to the best extent possible in the design criteria.

Because the basic design philosophy is to produce a safe yet economical structure, a dual approach is perhaps the most popular one for seismic design. In this approach the seismic design criteria are formulated so that: (1) the structure experiences limited or no damage and is able to continue operation under ground motion that is considered likely to occur during the structure's lifetime; and (2) the structure does not collapse or fail in any catastrophic manner under the maximum credible ground motion, or ground motion that has a very low probability of occurrence. The criteria under (1) are generally called the "Operating Level Earthquake," "Probable Design Earthquake," or "Strength Level Earthquake." The criteria under (2) are often referred to as the "Safety Level Earthquake," "Credible Design Earthquake," or "Contingency Design Earthquake."

Determination of Design Ground Motion

Probabilistic seismic hazard analysis is commonly used to determine the likely ground motions for the Probable Design Earthquake (PDE), although deterministic analyses are sometimes used when the probable earthquake is well defined in terms of size and location. Information on the geology, seismicity, and the ground-motion attenuation of a region are integrated into a probabilistic model, which computes the probabilities of exceeding various levels of ground motion in some time period. The probability is sometimes translated into an average return period for each ground-motion level. Ground-motion levels corresponding to 50, 100, 200, and 475 years have been used in the PDE design of various facilities. Probabilistic models for seismic hazard analyses are well documented in the literature (Cornell, 1968; McGuire, 1976, 1978; Der Kiureghian and Ang, 1975; Mortgat, 1976), and computer programs are readily available. Although these models have gained widespread acceptance, the user should bear in mind the uncertainties associated with the input data, the ground-motion attenuation formula, and the probabilistic model, and he should understand the influence these uncertainties have on the computed probabilities.

The ground motions to be used in the design for the Contingency Design Earthquake (CDE) are estimated from either a probabilistic approach, such as the one just discussed, or a deterministic approach. In the latter, a design earthquake is postulated usually in terms of magnitude (M_L, m_b, M_s, or M_w) and distance to the site. This event is the one that will produce the maximum ground motion at the site. Although questions regarding the actual numbers associated with the magnitude and location of the design earthquake are sometimes difficult to resolve, this approach eliminates one variable, the earthquake recurrence, which must be incorporated in the probabilistic approach. Once the design earthquake is established, the computation of ground motion can proceed using the empirical approaches discussed in the section, ESTIMATION OF SITE GROUND MOTION.

The ground motions determined from the probabilistic or deterministic approach may require further adjustments for the unique geologic or seismologic characteristics of the site region. Even after these modifications are made, the ground motion still may not be appropriate for design. The performance criteria, as discussed below, need to be considered. Also, concepts such as "effective peak acceleration," "sustained peak acceleration," and "inelastic response spectra" have been developed in an attempt to account for the actual behavior of the structure during strong ground motion. Because these concepts involve issues such as ductility, material resistance, and structural reliability, the structural engineer should determine the design motions, for example, the effective peak acceleration or the design spectra, from the ground motions estimated by the geotechnical engineer. Before this is done, however, the geotechnical engineer should be consulted with regard to the possible conservatisms in his estimate.

Performance Criteria

The allowable stresses for the PDE are generally set below the yield point or ultimate strength of the members. Response beyond the yield point might be permissible, for example, in ductile members or in parts of the structure where there is a redundancy in design, or in parts that are not critical to the overall stability or performance of the structure.

The allowable stresses corresponding to the CDE are generally set near the yield point or ultimate strength of the member. The allowable deformation of the structure should be such that gross instabilities do not result. Permanent deformations are generally allowed provided catastrophic failure does not occur.

The determination of seismic design criteria following the procedure outlined above is often not practical for some of the less important structures. The use of building codes, for example, Applied Technology Council (ATC-3) or Uniform Building Code (UBC), may be acceptable for these structures.

REFERENCES

American Society of Civil Engineers, 1984, Guidelines for the seismic design of oil and gas pipeline systems: 473 p.

Cornell, C.A., 1968, Engineering seismic risk analysis: Bulletin of the Seismological Society of America, v. 58, p. 1583-1605.

Campbell, K.W., 1981, A ground motion model for the central United States based on near-source acceleration data, in J.E. Beavers, (ed.), Earthquakes and Earthquake Engineering in the Eastern United States: Ann Arbor Science, v. 1, p. 213-232.

Campbell, K.W., 1983, The effects of site characteristics on near-source recordings of strong ground motion-- Proceedings of Workshop on Site-Specific Effects of Soil and Rock on Ground Motion and the Implications for Earthquake-Resistant Design: U.S. Geological Survey Open-File Report 83-845.

Der-Kuireghian, A., and Ang, A. H-S., 1975, A line source model for seismic risk analysis: Technical Report, Civil Engineering, University of Illinois.

Guzman, R.A., and Jennings, P.C., 1976, Design spectra for nuclear power plants: Journal of the Power Division, American Society of Civil Engineers, v. 102, P02, November, p. 165-178.

Hall, W.J., and Newmark, N.M., 1977, Seismic design criteria for pipelines and facilities: American Society of Civil Engineers-TCLEE, The Current State of Knowledge of Lifeline Earthquake Engineering, Proceedings, p. 18-34.

Herrmann, R.B., and Goertz, M.J., 1981, A numerical study of peak ground accelerations: Bulletin of the Seismological Society of America, v. 71, no. 6, p. 1963-1979.

Housner, G.W., and Jennings, P.C., 1977, Earthquake design criteria for structures: Report EERL 77-06, California Institute of Technology, Pasadena, Calif.

Housner, G.W., and Jennings, P.C., 1982, Earthquake design criteria: Earthquake Engineering Research Institute, Monograph, 140 p.

Idriss, I.M., 1978, Characteristics of earthquake ground motions: American Society of Civil Engineers Specialty Conference on Earthquake Engineering and Soil Dynamics, Proceedings, v. III, p. 1151-1266.

Jennings, P.C., and Guzman, R.A., 1975, Seismic design criteria for nuclear power plants: United States National Conference on Earthquake Engineering, Ann Arbor, Mich., June 1975.

McGuire, R.K., 1976, FORTRAN computer program for seismic risk analysis: U.S. Geological Survey Open File Report 76-77.

McGuire, R.K., 1978, FRISK: a computer program for seismic risk analysis using faults as earthquake sources: U.S. Geological Survey Open File Report 78-1007.

Mortgat, C.P., 1976, Bayesian model for seismic hazard maping: Seismic Risk Analysis Conference, Earthquake Engineering Research Institute, Feb. 8-9, 1976.

Newmark, N.M., and Hall, W.J., 1978, Development of criteria for seismic review of selected nuclear plants: NUREG/CR-0098, U.S. Nuclear Regulatory Commission.

Newmark, N.M., and Hall, W.J., 1982, Earthquake Spectra and Design: Earthquake Engineering Research Institute, Monograph, 103 p.

Nuttli, O.W., 1979, The relation of sustained maximum ground acceleration and velocity to earthquake intensity and magnitude: State-of-the-Art for Assessing Earthquake Hazards in the United Sates, U.S. Army Engineer Waterways Experiment Station Report 16, Paper S-73-1, Vicksburg, Mississippi.

Nuttli, O.W., 1981, Similarities and differences between western and eastern United States earthquakes, and their consequences for earthquake engineering in Beavers, J.E., (ed.) Earthquakes and earthquake engineering, in the Eastern United States, Ann Arbor Sciences, v. 1, p. 25-52.

Seed, H.B., Ugas, C., and Lysmer, J., 1976, Site-dependent spectra for earthquake-resistant design: Bulletin of the Seismological Society of America, v. 66, no. 1, p. 221-243.

Trifunac, M.D., 1976, Preliminary analysis of the peaks of strong earthquake ground mottion -- dependence of peaks on earthquake magnitude, epicentral distance and recording site conditions: Bulletin of the Seismological Society of America, v. 66, no. 1, p. 189-219.

STRENGTHENING HIGHWAY BRIDGES

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INTRODUCTION

The seismic design and retrofit of bridges in California made a dramatic turn in February, 1971. The heavy damage during the San Fernando earthquake was unprecedented in the history of bridge design in California (Fung, 1971). In fact, California had seen less than $100,000 in earthquake damage to bridges in the 40 year history preceding 1971 (Gates, 1976). Previous earthquake damage was limited primarily to abutment and foundation movements, anchor bolt breakage, support displacements, and wingwall damage. The San Fernando earthquake caused heavy vibrational damage which had not been observed before (Fung, 1971; Gates, 1976) and as a result a new effort was immediately started to improve the design of seismically resistant bridges (Gates, 1976; 1983; 1984; 1985) and to retrofit existing bridges (Degenkolb, 1980; Mancarti, 1984; Zelinski, 1985).

This paper will briefly discuss the development and current status of the California seismic retrofit program and the methods used for the prediction of ground motions for both new and retrofit bridges in California.

THE CALIFORNIA RETROFIT PROGRAM

About 1247 bridges (out of about 13,000) were identified as having deficient seat widths and bearings. Selection of bridges was made totally on the structural configuration of the bridge and estimated ground motions were not considered in the selection process. Selection was based on both a detailed field inspection and a plan review by design personnel (Degenkolb, 1980; Zelinski, 1985).

The objective of the retrofit program was to increase the seismic resistance of the existing bridges to a level which would prevent collapse. The restraint of the deficient joints and bearings then became the prime focus of the California retrofit program. The individual retrofit projects were grouped geographically into proposed design projects. The projects were sized by economic and contractual factors. Projects were then prioritized to utilize the available funds each fiscal year. The prioritization considered the level of expected ground motion, the replacement cost of the bridge, the available detour length, and the average daily traffic on or under the bridge (Mancarti, 1984; Zelinski, 1985). Estimated ground motions were determined using the same criteria used for new bridges (American Association of State Highway and Transportation Officials, 1983).

The average retrofit project consists of the addition of steel restrainer cables at expansion joints (Degenkolb, 1980; Mancarti, 1984; Zelinski, 1985). The California design details for restrainer units have evolved to the point where reliable and economical systems are performing satisfactorily under service conditions in the field, although none have yet been tested by an actual earthquake. To date, 1173 of the 1247 bridges have been retrofit at a cost of $44.7 million. The $54 million project, which started in 1971, is expected to be completed in 1986.

RETROFIT ON THE NATIONAL LEVEL

The Federal Highway Administration funded a research project with the Applied Technology Council (ATC) to develop retrofit guidelines for bridges on a national basis. This project (ATC-6-2), was completed in 1983 (Applied Technology Council, 1983). The project objectives were to review the current retrofit methodologies in use worldwide and draft a set of guidelines for the retrofit of United States bridges. The project defined the following scope:

- o Provide a preliminary screening process for the initial selection of bridges to be retrofit.
- o Provide a methodology to evaluate the seismic capacity of existing bridges.
- o Provide a subjective criteria for the determination of retrofit details for existing bridges.
- o Present examples of various retrofit measures.

These guidelines used the current national design guidelines (American Association of State Highway and Transportation Officials, 1982) to define the ground motions at a site. Discussion of the use of these guidelines in found in (Nutt, 1985; Nutt and Cooper, 1984).

CALTRANS SEISMIC BRIDGE CRITERIA

In 1973, a new design criteria was introduced which considered the fault activity in California and the soils at the bridge site as well as the vibrational properties of the bridge itself (Gates, 1976). The California Department of Transportation criteria departed from the traditional seismic design criteria and presented for the first time:

- o Site specific response spectra based on active faults in the region.
- o Specified reductions for ductility and risk.
- o Modular arrangement of variables for future adjustment.

The force level defined in this criteria has been used for retrofit work as well as new designs.

SITE-SPECIFIC RESPONSE SPECTRA

The current seismic design criteria for bridges defines an elastic response spectra to represent the motions at a site. The spectra is composed of three components:

A -- the maximum credible acceleration in bedrock at the site;

R -- a normalized elastic spectra representing motions at the rock level; and

S -- a soil amplification spectra.

The criteria also permits the special development of spectra for specific sites. For example, the design spectra for the new Century Freeway in Los Angeles, California (Gates, 1984) was constructed by computing special soil amplification spectra and applying them to the standard R spectra.

The general method used is discussed by Gates (1976, 1983, 1984, 1985) Bell and Hoffman (1978) and Hays (1980) and consists of performing a single dimensional analysis of the site under consideration using the SHAKE program (Schanbel and others, 1972). The approximate acceleration level and frequency content of the rock level motion in this analysis should be as close as possible to the expected motion; however, studies have shown that the results are not too sensitive in this area. The spectral acceleration is computed by dividing the resultant surface spectra by the input rock spectra. The design spectra is then computed by multiplying the standard R rock spectra by the amplification spectra. The normalized spectra is scaled by peak acceleration. The attenuation curves developed by Seed and Schnabel (1972) are currently used to determine the bedrock acceleration level. The current R spectra is based primarily on the work of Seed and others (1968) and is close to other rock spectra such as those defined by the National Research Council and ATC.

The standard criteria contains 28 different elastic spectra which have been in use for bridge design in California since 1973. These spectra were developed from an extensive parameter study using the SHAKE program (Gates, 1976) which studied the spectral variations for average alluvium in California. As a result of these studies, four soil depth ranges were selected: 0 to 10 feet of alluvium (or rock sites); 11 to 80 feet of alluvium (or shallow sites); 81 to 150 feet of alluvium (or medium sites); and over 150 feet of alluvium (or deep sites). Each of these four site types is assigned a rock acceleration range of from 0.1g to 0.7g in 0.1g increments, giving a total of 28 spectra.

Accelerations are currently being determined using the Greensfelder map (Greensfelder, 1974). This map, which was originally published in 1974, was funded by the California Department of Transportation for criteria use. An updated version of the map is currently in preparation and should be released in 1986.

FUTURE RETROFIT RESEARCH NEEDS

An accurate definition of the ground motions and force levels close to faults is needed to permit a more reliable estimation of the overall structural response. Any refinements in the definition of the spectra now in use should reduce the conservatism which is now present and thus reduce overall costs.

The amount of out-of-phase displacement present over distances comparable to the length of a long bridge is currently unknown. Even more important is the design problem of dealing with these displacements once they become known.

As bridges are being retrofit around the world to improve their seismic resistance, there is an increasing need to establish a data bank of retrofit case histories. These data could include information about any tests which were performed on the bridge, as well as the costs of the retrofit.

Methods to evaluate the seismic resistance of existing bridges taking into consideration their age, structural configuration, and vulnerable details should be developed to facilitate the inventory of the thousands of existing bridges located in seismically active areas.

Full-scale testing is probably the only way to definitely answer questions about the ability of critical portions of bridges to withstand heavy seismic loading. There is an urgent need to pool research money from a number of sources and develop a full-scale testing capability which can test a number of complete bridges to destruction. New retrofit techniques could be evaluated at such a facility without having to wait for an earthquake.

REFERENCES

American Association of State Highway and Transportation Officials, 1983, Bridge Design Specifications Manual, Thirteenth Edition; with interim revisions through 1984, Washington, D.C., and revisions by the California Department of Transportation, Office of Structures Design, Sacramento, Calif., through August, 1985.

American Association of State Highway and Transportation Officials, 1982, Guide specifications for seismic design of highway bridges 1983: Highway Subcommittee on Bridges and Structures, Washington, D.C..

Applied Technology Council, 1983, Seismic retrofit guidelines for highway bridges: Federal Highway Administration Report No. FHWA/RD-83-007, Palo Alto, Calif.

Bell, J.M. and Hoffman, R.A., 1978, Design earthquake motions based on geological evidence: American Society of Civil Engineers Geotechnical Engineering Division Specialty Conference, Earthquake Engineering and Soil Dynamics, Pasadena, Calif., Proceedings, v. 1, p. 231-271.

California Department of Transportation, 1984, Memos to designers 15-10--earthquake design criteria (commentary): Office of Structures Design, Sacramento, Calif.

Degenkolb, O.H., 1980, Retrofitting bridges to increase their seismic resistance: Proceedings US/Japan Cooperative Earthquake Engineering Research Program, Seminar on Repair and Retrofit of Structures, 1st, National Science Foundation, University of Michigan, Ann Arbor, Michigan, v. 1, p. 109-114.

Fung, G., and others, 1971, Field investigation of bridge damage in the San Fernando earthquake: Bridge Department, Division of Highways, California Department of Transportation, Sacramento, Calif.

Gates, J.H., 1976, California's seismic design criteria for Bridges: Journal of the Structural Division, American Society of Civil Engineers, v. 102, no. ST12, p. 2301-2313.

Gates, J.H., 1983, Seismic restraint bridge design in California: Proceedings Joint Meeting of the U.S.-Japan Panel on Wind and Seismic Effects, 15th Tsukuba, Japan, Paper No. 2-19.

Gates, J.H., 1984, Seismic considerations for the Century Freeway: American Society of Civil Engineers Symposium on Lifeline Earthquake Engineering, presented by the American Society of Civil Engineers Technical Council on Lifeline Earthquake Engineering, San Francisco, Calif., Proceedings.

Gates, J.H., 1985, Earthquake resistant bridge design in California: Joint Meeting of the U.S.-Japan Panel on Wind and Seismic Effects, 17th, Tsukuba, Japan, Proceedings, Paper No. 2-7.

Greensfelder, R.W., 1974, A map of maximum expected bedrock acceleration from earthquakes in California: California Division of Mines and Geology, Map Sheet 23, Sacramento, Calif., scale 1:2,000,000.

Hays, Walter W., 1980, Procedures for estimating ground motions: U.S. Geological Survey Professional Paper 1114.

Mancarti, G.D., 1981 (rev. 1984), New concepts in earthquake retrofitting of highway bridges" Northwest Bridge Engineers Conference, 6th, Boise, Idaho.

Nutt, R.V., 1985, Seismic retrofitting guidelines for highway bridges: Joint U.S.-New Zealand Workshop on Seismic Resistance of Highway Bridges (ATC-12-1), San Diego, California, Proceedings, p. 12-1--12-6.

Nutt, R.V., and Cooper, J., 1984, Seismic retrofitting guidelines for highway bridges: World Conference on Earthquake Engineering, 8th, San Francisco, Calif., Proceedings, v. 1, p. 635.

Schnabel, P.B., Lysmer, J., and Seed, H.B., 1972, SHAKE: a computer program for earthquake response analysis of horizontally layered sites: Earthquake Engineering Research Center Report No. 72-12, Berkeley, Calif.

Seed, H.B., and Schnabel, P.B., 1972, Accelerations in rock fropm earthquakes in the western United States: Earthquake Engineering Research Center Report No. 72-2, Berkeley, Calif.

Seed, H.B., Idriss, I.M., and Kiefer, F.W., 1968, Characteristics of rock motions during earthquakes: Earthquake Engineering Research Center Report No. 68-5, Berkeley, Calif.

Zelinski, R.J., 1985, California Department of Transportation bridge earthquake retrofitting program: Joint U.S.-New Zealand Workshop on Seismic Resistance of Highway Bridges (ATC-12-1), San Diego, Calif., Proceedings, Applied Technology Council, Palo Alto, CA, 1985, p. 13-1--13-6.

IMPROVING BUILDING CODES

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HISTORICAL PERSPECTIVE

Nearly sixty years ago the Uniform Building Code (UBC) contained its first earthquake provisions. Not only did it prescribe lateral forces proportional to building mass, but also adjustments for type of foundation materials. The provisions were placed in an appendix to the UBC and hence few, if any, jurisdictions adopted the regulations as law. The Long Beach, California, earthquake of 1933 provided the impetus to enact mandatory requirements, including those of the 1933 Los Angeles City Code.

In more contemporary times, the Structural Engineers Association of California (SEAOC) has been the dominant author of new seismic codes. In 1957, the Seismology Committee was directed to develop a new code. Their work produced the first "Recommended Lateral Force Requirements" (the "Blue Book"), in 1959 and numerous subsequent revisions. The new codes were tendered to the International Conference of Building Officials (ICBO) for possible inclusion in the UBC. That process includes a review by an appropriate code development committee of ICBO and subsequent final vote by the building officials adopting the regulations into the UBC. Public testimony and debate are an integral part of that process.

The 1971 San Fernando, California earthquake, among other things, demonstrated that further work was needed to improve codes. The event accelerated the continuing SEAOC efforts and produced major revisions in ensuing years. It also led to creation of the Applied Technology Council (ATC), a SEAOC subsidiary, for practical research applicable to structural engineering. Under the sponsorship of the National Science Foundation, ATC undertook a project to develop a comprehensive document representing the state of the art in the fields of seismic engineering. In 1978, "Tentative Provisions for the Development of Seismic Regulations for Buildings" (ATC-3-06) was completed and published. The report is not a code, but a resource document intended to guide and assist code development.

ATC-3-06 contained many new concepts and procedures that require further study and analysis before condsideration could be given to code adoption. The Building Seismic Safety Council, established in 1979 under the auspices of the National Institute of Building Standards, has pursued a program designed, in part, to establishing the validity, workability, and cost implications of the tentative provisions as construction standards. Their work has produced the National

Earthquake Hazard Reduction Program "Recommended Provisions for the Development of Seismic Regulations for New Buildings" currently being balloted by their member organizations. Once adopted, it will serve as a source document for use by interested members of the building community.

WHERE ARE WE NOW?

With this backdrop, let us look at the current status of building codes. In his paper presented to the Department of Energy Natural Phenomena Hazards Mitigation Conference, Messinger (1985) compares the requirements of the 1982 UBC, ATC-3-06, and the proposed (second draft) new Blue Book. The latter document represents the culmination of the work of the SEAOC Seismology Committee commenced in 1980 and directed to "cleaning up" the Blue Book in light of many small problems that had arisen in the previous document. In addition, the Committee included certain material from ATC-3-06.

Messinger presents a rather comprehensive comparison, but only certain items are excerpted here for the purpose of this workshop:

- The proposed Blue Book as well as the UBC are based upon a "working stress" concept whereas ATC-3 is based on "strength."

- The new Blue Book proposes to use the ATC-3 zone factors (seismic coefficients representing effective peak velocity-related acceleration and effective peak acceleration) using zone maps similar to ATC-3 for California. Thus, frequency of occurrence is taken into account in addition to intensity of ground motion.

- Both the new Blue Book and ATC-3 use a site coefficient dependent only upon the physical characteristics of the soil, whereas the UBC value is dependent upon a relationship between building period and the characteristic period of the site.

- ATC-3 Importance Factors are handled by tighter drift/damage control plus a quality assurance program. The UBC assigns base shear coefficients prescribing higher design loads for essential facilities and high occupancy buildings. The new Blue Book retains the UBC approach, but assigns two levels of review and quality assurance requirements. Level I involves normal UBC special inspection. Level II requires a design review by a peer group of structural engineers, review of construction by the engineer of record, and a construction quality assurance program. Because of the Level II review, the Blue Book reduces the design base shear from UBC values for essential facilities by approximately 17 percent (that is, Importance Factor I from 1.5 to 1.25).

- The UBC requires dynamic analysis for structures having irregular shapes or framing systems, but provides little guidance in defining irregularity. ATC-3 criteria selection is extremely complex. The new Blue Book expands on the UBC procedures but attempts to keep them simple and practical. Regular buildings are defined as having smoothly varying response to ground motions from ground to roof, continuous vertical and lateral load carrying elements, uniformly distributed mass (or gradually increasing from top to bottom), and symmetrical lateral load-resisting elements. The new Blue Book does not intend a dynamic analysis to justify reducing lateral forces, but to establish the correct distribution of such forces.

SEAOC had established a goal of completing the final version of the new Blue Book in time to include the provisions in the 1985 UBC. Unfortunately, as of November, 1985, it is not yet a finished document and hence it is not in the 1985 UBC and not available for local or state enactment into law.

WHAT IS NEEDED?

Although considerable progress has been made in developing enlightened seismic codes, there is much work left to do. In my view, there is a continuing need for directed research into expanding our knowledge and understanding of earthquakes and their effects on buildings:

- Continuing study on the frequency, location, and magnitude of earthquakes is needed to improve reliability of hazard assessments. This should include determining the largest expected earthquake and likelihood of occurrence.

- We must strive to develop ever-improving methods of forecasting and assessing destructive ground motion, including seismic probabilities. The dynamic deformations of foundation soils upon structural behavior should be a continuing topic of study.

- We must further expand our knowledge and understanding on the behavior of buildings and building components during earthquake-induced motions. This should also include nonstructural elements such as electrical and mechanical equipment. The development of suitable uniform strength criteria for all materials of construction, including wood and masonry, is an area worthy of more study.

Incorporating the products of research into codes in a timely, effective manner needs steady attention. It often takes 10 years or more for design codes to embody the knowledge gained from research (National Research Council, 1982). There are communication problems in reporting and comprehending such knowledge plus the challenge of translating the scientific data into practical codes. Other impediments include the time and resources that are needed to develop useful code documents, educating the industry (owners, design professionals, government bodies, building officials, etc.), and resolution of issues arising from dissenting viewpoints.

New or unusual innovations, such as base isolation and epoxy/polyester strengthening, pose special problems. Without having codes and standards to guide their use, local building officials are often pressured to accept these techniques as suitable alternatives to code requirements. Methods of strengthening old buildings having historic value often involve creative concepts designed to improve earthquake safety without major trauma to important architectural features. The design professional and the regulatory agency need a mechanism to evaluate the efficacy of such techniques in a timely manner and in the absence of duly promulgated standards.

One cannot properly evaluate earthquake hazards without addressing the problem of existing buildings erected without due consideration to seismic forces. There must be greater understanding by owners, government, and the public, as well as ever-improving, cost-effective ways for strengthening these buildings. Moreover, attention to more modern buildings is needed to ensure that structural capacities are not compromised by additions, alterations, or deterioration. Nonstructural elements, mechanical, and electrical equipment often change many times in the life of a building and therefore pose a formidable challenge.

Earthquake codes can only be as effective as they are understood by the design practitioner and enforced by the regulatory agency. Local building departments are often under continual seige because of the volatility of the construction economy, the need to run their operations in a businesslike manner, and the resultant lack of resources. Educating government decisionmakers will at least help in gaining support for enforcement actions, but it is unlikely that building departments will ever have optimum staffing levels. It is therefore essential that building codes be understandable and enforcement officials be knowledgeable. Training is the key. Seminars, college courses, workshops, and other educational offerings should be encouraged and supported. The use of video tapes, cable TV, and other modern communication tools offers the potential for wider dissemination of the principles underlying seismic codes and improved skills in their application.

In closing, I would like to quote Glen V. Berg (1982) who states:

> Somehow, the knowledge gained from theory, analysis, research, and field observation all need to be translated into building regulations that are practical for use in the design office, that are enforceable by building officials, and that will lead to safe structures at a cost that society can afford.

This, to me, says it all.

REFERENCES

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings: National Bureau of Standards Report ATC-3-06, Washington, D.C., 28 p.

Berg, Glen V., 1982, Seismic design codes and procedures: Earthquake Engineering Research Institute, Berkeley, Calif., p. 28.

Messinger, David L., 1985, Proposed changes to the seismic design provisions of the Uniform Building Code: U.S. Department of Energy Natural Phenomena Hazards Mitigation Conference, 1985.

National Research Council, 1982, Earthquake Engineering Research, 1982: Committee of Earthquake Engineering Research, Commission on Engineering and Technical Systems, National Research Council: National Academy Press, Washington, D.C., 266 p.

Predicting Ground Motion for Earthquake-Resistant Design

SUMMARY OF WORKING GROUP III AND AUDIENCE DISCUSSIONS

This session was moderated by Wilfred Iwan. Panelists were Christopher Rojahn, Anthony Nisich, and Steven Wesnousky. Joining the panel were speakers from the morning session, William B. Joyner, C.B. Crouse, James H. Gates, and Eugene J. Zeller. L. Thomas Tobin was the session commentator. Questioners and commenters from the audience included Jeffrey Howard, John Kariotis, Gary C. Hart, Victor A. Zayas, and James J. Watkins. The following text was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Rojahn emphasized the need for strong ground-motion data, particularly data close to the epicenter of large-magnitude events. He called for predicting moderate-magnitude events in population centers, and casting predictions in engineering terms. Technology is progressing quickly in the geophysical profession in terms of predicting strong ground motion. However, technology is not advancing as quickly in terms of using that information.

Wesnousky has applied knowledge of earthquake mechanics to geological data, specifically data that describes rates of offset across Quaternary faults in California. These analyses are used for estimating average recurrence intervals of earthquakes on those faults. There is a growing trend toward using geological data, rather than historical data, to predict strong ground motions. The historical record is very short, and may not give information on regions where earthquakes have not occurred in the recent past. These regions nevertheless may be as hazardous as those experiencing historical activity. He commented on relating strong motion to probabilities of recurrence, and how this research was limited by the amount of available data. There are many uncertainties in this type of work; however, the work is at the stage where knowledge of earthquake mechanics can be applied to available geologic data and produce maps of seismic hazard. How can this work be tailored to the needs of the public?

Nisich recounted his experience of attempting to develop an ordinance applicable to the seismic hazards of masonry buildings, as well as other seismic hazards for a given city. The seismic safety elements in reports he reviewed did not give him the information necessary to evaluate buildings. He contacted geotechnical firms, requesting proposals for a report and map that would identify geologic hazards within the city. Three proposals were returned, varying as to the amount of work required, and at costs ranging from $2,000 to $50,000. Because these bids were so disparate, Nisich decided to rewrite the proposal specifications, and request new proposals. He used elements from the initially submitted proposals to prescribe a work statement for resubmittal of bids by the preselected geotechnical firms. He then received many telephone calls from the firms who wanted him to discuss--in great detail--what was needed. Was he interested in finding the faults? Did he want ground motion in terms of acceleration? He asked the firms why they didn't know what he thought he needed to have. The proposers could not define what they should map, and did not know which technique to use even if they did know what to map.

Nisich made a strong point: he is not concerned with what the ground does; rather, he is concerned with what the buildings do, because it is in the buildings that people spend most of their lives. After hundreds of hours of dealing with geotechnical professionals, Nisich was not much closer to his objective than when he started. However, the city politicians thought he should have been able to do this study, write the ordinance in 30 days, and implement it in another 30 days. This was their perception of about how difficult the geotechnical process ought to be. He hoped this workshop would help clarify the process of local officials dealing with geotechnical consultants.

Iwan began the discussion period with a question to Joyner and Wesnousky about predictive ground-motion maps. How well would ground-motion maps have predicted the very unusual response spectrum recorded during the September 1985 Mexico earthquake?

Joyner replied that the predictive equations he had discussed earlier apply only to shallow earthquakes, and not to subduction-zone events such as the recent earthquake in Mexico or those occuring in Japan, for example. Separate equations are needed for those cases. Regarding the very strong site effects observed in Mexico City, Joyner noted that the old lake bed material is very soft, with very high water content and very low shear-wave velocity. Substantially, the techniques he described earlier would allow for part of that. One can divide the amplification due to a soft, near-surface layer into two parts. One part is due to the lower velocity of that layer; the other part is due to the summation of multiple reflections. The described technique accommodates the former kind of amplification, but not the latter. He estimated that, for Mexico City, amplification by a factor of two or more could be accounted for by the velocity of the lake bed sediments.

Wesnousky replied that analysts must use an integrated approach. Theories can be combined in estimating the average return times of earthquakes, and thereby the probability of an earthquake during a specific period of time. These can be combined with empirical relations between earthquake strength and expected strong ground motion. (Those relations generally are averages; scatter is great, and standard deviations are large.) Within those constraints, we would not be able to predict the Mexico City ground accelerations. However, had large ground motions and building destruction been noticed in the same area in the past, we could come to some realistic assessment of the hazard in that area.

Iwan posed questions for structural engineers. How do structural engineers advise their clients as to what form of information to call for? Do we now know enough to know when to ask for a response spectra? When should we ask for a time history? Do we have enough knowledge as structural engineers to know what to ask for, and obtain it from those producing the maps?

Crouse offered that it depends upon the client and the structure being built. One should inform the client, and establish a dialogue. Hypothetically, Crouse would tell the client what sort of ground motion estimates are available, and give him some indication of the conservatism of those estimates. At this point, Crouse would determine from the structural engineer how that information might be used in the building design. Some engineers will do a dynamic analysis; some might do something simpler, such as using an approach embodied in the building code. Crouse would want to know what performance criteria the engineer is going to use; that is, must it behave elastically or is some inelastic response allowable? What are the allowable stresses? Once this dialogue has been established, the designer can better identify what should be provided. The engineer should know the geotechnical basis for all estimates, and how much conservatism may be inherent in those estimates.

Iwan asked Gates about the California Department of Transportation approaches to structural design. CALTRANS primarily uses a response spectrum. Is there any need for a time-history type anaylsis?

Gates said that CALTRANS uses time histories, but indicated some restrictions to that approach. The time-history analysis is expensive, and more than one must be used. Also, one must really understand the structure, because most time histories have gaps and inconsistancies in them. A response spectrum represents an effort to smooth over some of the inconsistancies, and that is why CALTRANS prefers response spectrum. A time-history analysis requires sophisticated and expensive computer programs. CALTRANS does perhaps one time-history analysis per year.

Rojahn suggested that the average practitioner seeks response spectra. He brought up two issues that had not yet been discussed. One is the design of new buildings, and the other, perhaps larger, problem is the evaluation of existing buildings. At the Applied Technology Council (ATC), a project is devoted to evaluating the seismic strength of existing buildings. The approach being taken is that of response spectra. ATC is developing methods for computing response spectra, using new technology and the ATC-3 maps (Applied Technology Council, 1978).

Iwan posed questions for those involved with developing building codes. What things are most important in code development, and what is needed in ground-motion prediction that would be directly applicable and useful in codes? What is needed for the writing and enforcement of building codes? What information, not now available, would make a significant impact on the code?

Zeller commented that those were loaded questions. Even after translating scientific and engineering information into codes, the codes will still contain uncertainties for which there is risk. The contractors do not know what types of ground motion to expect. We must deal with this uncertainty when constructing real buildings. That uncertainty gets translated in the code documents, whether it comes from a "cookbook" approach or a dynamic analysis. And with adherence to code comes a feeling of credibility. The structure was built to code; therefore, it must be 100 percent safe. We all know this is not true. We must reduce the degree of uncertainty, and in order to do so, we must have better information on the extent of ground motion. This information is needed at a much more localized level than is currently available. In 1971, there were some real failures of buildings during the San Fernando, California, earthquake, even though these were built to modern codes. Obviously, the codes did not properly apply to all construction. Also, we could not simply call a halt to all construction while codes were revised. We had to make some hard decisions, and certain codes were perhaps ultraconservative in certain areas so that construction could commence. As we refine these codes further, and as we become more knowledgeable, we will arrive at a more accurate assessment of risk. Then, buildings will be more economical and feasible for society to build.

Nisich argued that the information he needed was the correct information. His problem was understanding the data and telling people how and where to draw lines on maps. Following that was a need to determine an appropriate level of design. The research coming from the scientific community is all very interesting; the application of the research through ATC and other groups for determination of confidence levels and other factors is all well and good. However, these things do not define an acceptable level of risk. There is no framework to define the characteristics of over- and underdesign. The engineer must set forth criteria he uses for a specific design; however, determining the appropriateness of those criteria is an ill-defined process. Currently, an event occurs, a problem results, and a number of people say "I told you so." Where were these people before the event? After the 1985 Mexico earthquake, claims were made about what damages might have been prevented, if only one thing or another had been done. Whether or not this is true is a moot point. The need is for definition of design criteria within basic research and basic engineering. Also, the question of responsibility for setting the criteria must be addressed.

Iwan noted that the discussion had evolved from issues of research to issues of public policy very quickly.

Rojahn commented on prediction of ground motions. He noted that the scatter of data about the mean in the prediction can be fairly large, and in fact can be about one order of magnitude. This refers to the size of ground motions actually observed given the same site conditions, the same magnitude earthquake, and the same distance from that earthquake. The scatter can have fairly profound social effects. Whether the site experiences shaking five times larger (or smaller) than predicted can determine whether or not a building collapses and kills people. Thus, data from the high end of the scatter can result in socially unacceptable consequences. Everyone in the profession is struggling with the problem of designing for a site where the shaking might turn out to be far more than expected. A better understanding of the physics of the problem is needed, especially in reducing scatter that can not be otherwise reduced using the empirical approach. One of the simplest things to do in the short term is to monitor weak ground motions using seismometers, deduce amplification therefrom, and use that information to help understand what will happen during strong motions.

Howard asked about where to look for more data. Where does one find information on large earthquakes similar to the ones that might happen in California?

Joyner replied that a large body of new data exists about subduction-zone earthquakes. These data come from Chile and Mexico, but do not apply to conditions in most of California. The Japanese have a large collection of similar data. Data from central Asia might relate to thrust earthquakes like those of Kern County and San Fernando, California. There are questions about the problems of transferring data from one region to another, but new data from other regions are needed.

Howard queried Joyner about the applicability of theoretical attenuation curves, developed in 1981-82, to events in Coalinga, California (1983), and Morgan Hill, California (1984).

Joyner replied that the scatter of new data plotted on the curves was above and below the curves, but the mean was on the curves. There were no examples where the data were outrageously different from the curves, excepting one point. An acceleration of greater than one "g" was recorded at a dam during the 1984 Morgan Hill earthquake, and this value may have been the result of directivity or other factors. Detailed comparisons and refinements of the curves are currently in progress.

A participant mentioned that there will always be some statistical aberrations, and that, in the intermediate range of acceleration, the work of Joyner and others is a good predictor. The curves, however, may not do a good job of predicting the high-frequency part of the spectrum.

Iwan commented on continuing to look for data close at hand, and using care to install good instrumentation arrays in California. The most germane data will come from a good instrumentation program that records events in the state.

Kariotis remarked on USGS Professional Paper 1360 and its use of Mercalli and Rossi-Forel records. These measures are subjective, and their value lies in making a general damage prediction for a large area. He voiced a concern about ground motion being predicted as a response spectrum. Response spectra, as we use them, are a family of earthquakes, because of the need to look at responses both near to and distant from the earthquake source. A response spectra is inherently not a single equation, but is encompassed by two, or possibly three, time histories. Thus, a response spectra analysis, if properly used by the engineering community, allows for a building being shaken by at least two and possibly three different earthquakes simultaneously. Obviously, this has a severe impact on the response of the building. ATC is now looking at a new term called Effective Peak Acceleration (EPA) which has a relation to Richter Magnitude, and Peak Ground Acceleration (PGA). Why is the seismological research community now tending to use something that is deviating from the EPA concept that the engineering community really needs?

Rojahn commented on getting predictions of response spectra from the geophysicists, and asked how those might be used by the designer. The designer translates response spectra into something he thinks is meaningful. He does that through "R" factors, or structural response modification factors. Rojahn added that he had a lot more confidence in information obtained from geophysicists than that used in the "R" factors now assigned. The "R" factors reduce response spectra provided by geophysicists up to a factor of 10, depending on the toughness of the structure. The "R" factors are not based on hard data; they are based on a committee consensus. A great deal of research is needed in the area of translating response spectra into "R" factors.

Gary Hart stated that there is no right answer for the questions being posed. If one gave the same building to any of several design firms, one would get totally different and separate approaches to its design. Probably all approaches would be basically correct, but no one would know what the "correct" approach is.

The biggest success results in the building official viewing the design process as a flexible one, according to Hart. For example, the City of Los Angeles might ask for a seismic study and allow a firm to perform that study appropriately. In this case, the plan reviewer or planning official should have an intelligent checklist against which to review the study. No checklist items should be overlooked, but different firms will provide different answers to each check item. The engineering firms needs a response spectrum. However, if 20 people in this room wrote down what they think a response spectra means, one would obtain 20 different definitions. For our purposes, for a two-second period and the response spectra at one particular point, we want to know the best estimate of the mean, the standard deviation, and the probability-density function of the response spectrum at that point. Everyone needs to face the fact that the response spectrum must be defined in probabilistic terms. Then building officials must state to the public that there is a chance that the building will fail. They must state that life safety is being protected by rehabilitation of old buildings, and what are the chances of building failure. It is a political decision that has nothing to do with structural engineers. Most clients will not pay for structural engineers to develop a response spectrum unless they know the construction plan won't get through the city permitting process without a response spectrum analysis. The fundamental issue, therefore, is that the building officials must require a suitable analysis, or the developer most likely is not going to voluntarily pay for it.

Zayas asked the panel about the best source of information about the probabilistic variation associated with response spectra.

Iwan answered that there are standard tools for providing the information, if it is requested by the client. The information provided by Joyner and Fumal (1985) and Boore and Joyner (1982) rely on standard methods for probabilistic prediction of ground motion. Many geotechnical engineers have access to this information.

Watkins asked about the appropriate detail of maps. How detailed are maps of predicted ground motion? Can one locate a specific structure, and be confident that a certain level of ground response will not be exceeded at that site? Will the building be standing and functional after an earthquake?

A panelist suggested that one will have rely on a very site-specific investigation rather than taking a number from a regional map.

Iwan asked Joyner if confidence or probability levels were applied to his maps. Joyner replied that there are two kinds of probability. Maps show a probabilistic prediction in the sense of showing a value that will be exceeded at a given probability. He knew of no way of propagating all the uncertainties through the process of making the maps. Much depends on the quality of judgment that goes into choosing a method of making maps. The maps could be made as detailed as one might require, but how much one can trust them depends upon how much one can trust the judgment of the person who made the maps. Different people will use different methodologies and assumptions to make the maps.

A participant commented on the use of maps. An agency might require, for certain zones depicted on a map, that a response spectra analysis must be performed before building in that zone. Therefore, one is not given a response spectrum; he is simply told that one must be obtained. This concept is somewhat different from the direction of the previous discussion. Perhaps a process is needed, as opposed to a standard. Maps then serve the function of introducing one to the process rather than supplying a numerical answer.

Wesnousky commented that the aim of hazard-mapping research is to produce the knowledge one would like to have on a map. However, at the present time, our knowledge of earthquake ground motion is not so well developed that it can with confidence be mapped on a regional basis.

REFERENCES

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings: National Bureau of Standards Report ATC-3-06, Washington D.C., 28 p.

Boore, D.M., and Joyner W.B., 1982, The empirical prediction of ground motion: Bulletin of the Seismological Society of America, v. 72, p. S269-S286.

Joyner, W.B., and Fumal, T.E., 1985, Predictive mapping of earthquake ground motion in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 203-220.

SUMMARY OF AUDIENCE DISCUSSIONS, RECONVENED PLENARY SESSION I

This session was moderated by Richard Krimm. Panelists were Cliffton H. Gray, Jr., Brian E. Tucker, and L. Thomas Tobin, the commentators from Working Groups I, 2, and 3. Gary D. Johnson was the session recorder. Questioners and commenters from the audience included Lee Seigel, Bruce A. Bolt, Howard A. Spellman, Jr., John R. Filson, Robert D. Brown, William Anderson, Wilfred Iwan, Gary S. Rasmussen, Terence Haney, Michael S. Reichle, James F. Davis, Valerie R. Kockelman, Paul J. Flores, and others who were not identified. The following text was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Seigel, a reporter for the Associated Press, asked Krimm about his earlier comments on the National Earthquake Hazards Reduction Program (NEHRP). Krimm had said that the NEHRP funding was too heavily weighted toward research, rendering funding insufficient for implementation purposes. Since those comments were made, Seigel had heard many calls for more research during the Working Group sessions.

Krimm replied that the Federal Emergency Management Agency (FEMA) deals primarily with state and local governments, and is therefore in a position to perceive their implementation needs. In Krimm's experience, there is a great amount of research being done in the earthquake field that remains in the hands of the researchers and is isolated in academia. The research results do not always get into the hands of those who must apply it. FEMA is attempting to transfer research results from researchers to users but has a limited budget for this activity. Therefore, he believed that more money should be spent on applications work and less on research.

Krimm added that those living in earthquake-prone areas have a right to know about and apply research results. He wondered how many local officials would understand what was discussed at this workshop, or at similar scientific meetings. He suggested having sympathy for local engineers, building inspectors, and those trying to enforce building codes: scientific information needs to be presented to them in plain English. Krimm did not want to denigrate research work, or to see research stop, because it provides information that local officials need. He was particularly appreciative of the work being done by the U.S. Geological Survey (USGS) in earthquake prediction, because it would facilitate the channeling of preparedness planning and mitigation dollars into specific areas that have the greatest probability for disaster.

Bolt suggested that discussing the uses and applications of research invited thinking about solutions to the problem. A great deal of attention is currently being paid to the "transfer" problem, and Bolt expected that there would be a stronger and more fruitful flow of information in the next few years. He referred to remarks by Robert Rigney (Working Group I) about a specialized governmental department in New Zealand that deals with the information-transfer function and is responsible for reviewing all research reports in terms of who an appropriate user might be. That department would report on exactly how the connection had been made at then end of a given period. Bolt suggested that a similar mechanism might be part of the function of the proposed California Earthquake Engineering Research Center discussed in his opening remarks.

Spellman asked about the effects on the local community of the prediction of an earthquake near Parkfield, California (Southern California Earthquake Preparedness Project, 1985).

Bolt noted that only about 100 people live in the vicinity. Filson said he knew of no adverse effects on property values due to predictive statements made by the USGS. People living in or near Parkfield have felt earthquakes before, understand what is coming, and know what the USGS is talking about. They are taking the prediction in stride and with fairly good humor, considering all the visiting scientists.

An unidentified participant asked whether there were individual agencies or groups of agencies responsible for transferring research results to those who need or use them.

Robert Brown said that the transfer of information was a shared responsibility, and gave several examples. The USGS has developed a series of interpretive reports during the past few years that are written for people who are not technically oriented. These usually are single-topic maps that address a single problem, such as landslides or fault activity. Through the Alquist-Priolo Special Studies Zones Act (Hart, 1985), the California Division of Mines and Geology (CDMG) provides maps of active faults in California. CDMG also produces many other reports for nontechnical users. No single scientific agency has as its primary responsibility the interpretation of research work, which is probably appropriate because it is much more effective when the people who actually do the research are also the ones responsible for interpreting the information. The first step a scientist takes in order to produce user-oriented products comes from the interaction in groups like this workshop, where the researchers and potential users come together. A dialogue between producer and user must exist before the scientists can derive the interpretive products that are needed. Workshops such as this are the start of those dialogues.

Anderson described the roles of the National Science Foundation (NSF) in research and technology transfer activities. For example, the NSF cooperates with FEMA, USGS, and other agencies to support the Natural Hazards Research and Applications Information Center in Boulder, Colorado. This center is intended to enhance communication between research workers and the individuals, organizations, and agencies concerned with public action in response to natural hazards. The NSF also helps support the National Information Service for Earthquake Engineering which has components at the University of California at Berkeley and the California Institute of Technology in Pasadena, and provides library resources for those interested in earthquake-hazards mitigation. The NSF also supports the Earthquake Engineering Research Center (Berkeley, California) with funding for seminars and workshops throughout the United States for earthquake engineers. In addition to these ongoing services, NSF has supported individual research projects which attempt to identify opportunities for technology transfer and implementation. The NSF has been particularly successful over the years in identifying some of the barriers to information transfer and use, and a recent NSF-sponsored report (Yin and Moore, 1985) identifies a number of these issues. In summary, NSF attempts to add to the knowledge base through sponsored research, and dissemination of research results through implementation programs. As far as NSF is concerned, appropriate funding for research and implementation is one of balance.

Krimm added that FEMA also disseminates information in many ways. As a result of research done on ground motion, FEMA has developed improved model codes for seismic-resistant design. The FEMA and the National Bureau of Standards are preparing publications about these codes that can be used by local officials and incorporated into local building codes. Other means of disseminating information to the public have been the FEMA/USGS workshops (Appendix B, this volume) in which Walter W. Hays (USGS) and Gary D. Johnson (FEMA) have had leading roles, and which have been held in many areas of the country that are subject to seismic risk. The FEMA has worked with other Federal agencies to sponsor workshops by the American Institute of Architects to educate architects about appropriate structural design in seismic risk areas. Krimm maintained that much more of the research needs to be applied.

Iwan suggested that a somewhat different side to the question was being posed: how do those in user professions make their needs known to the research community? A two-way flow of information is a particular concern of the research committee of the California Seismic Safety Commission (SSC). That committee has recently discussed the issue at length, and the Commission wishes to facilitate two-way communication. Iwan encouraged those who wished to express their application-of-research needs to contact the staff of the SSC. Iwan also referred to the proposal for a California Earthquake Engineering Research Center, noting that a basis for the proposal was user involvement in the design of research and experiments. This is a rather new approach to ensure that the research will be applied where it is needed.

Rasmussen spoke as a consulting geologist who would like to be more informed on new research and how private practice can benefit from it. He felt that the issue was largely economic, and that state law should require geologic and geotechnical reports during property transactions. These reports should then be sent to a central organization comparable to the New Zealand department referred to by Robert Rigney, and reviewed for proper dissemination. Also, researchers should work closely with consultants. Rasmussen added that Federal research grants should also be given to private practitioners for applied research. He called for the SSC to sponsor legislation toward these ends.

Haney noted that two important agencies that deal with communication of information had not been mentioned, those being the Southern California Earthquake Preparedness Project (SCEPP) and the San Francisco Bay Area Regional Earthquake Preparedness Project (BAREPP). Both of these agencies were created to produce information and place it in the hands of local government agencies where it can best be used. Haney then asked the panel about the differences between the Rossi-Forel and Modified Mercalli intensity scales. Local planners do not understand why scientists have two scales, and why these scales cannot be condensed, modernized, and clarified.

Tucker suggested that either can be used, depending on the circumstances. Reichle then pointed out that there are different intensity scales just as there are several different magnitude scales. They were invented at different times for different purposes, and it is not a critical issue to try to separate them. The intensity scales are actually very similar, and they have their purpose in explaining what might happen to certain structures in future earthquakes in terms of what happened to similar structures in past earthquakes. The current problem is that those scales do not apply to the kinds of structures that have been built in the last 20 to 30 years in California. After the 1983 Coalinga earthquake, for example, one might have assigned a Modified Mercalli Intensity IX to downtown Coalinga based on damage to the older buildings. Newer buildings, however, were not substantially damaged; therefore, a Modified Mercalli Intensity value of VIII could have been assigned to the area to describe the mix of older and newer buildings. In reviewing damage distribution following large earthquakes, the concepts of what kinds of damage fit neatly into different categories of intensity do not apply for different classes of structures.

Davis made the analogy of a patient asking for an interpretation of a CAT Scan, or even chosing an appropriate CAT Scan. Interpreting or choosing a CAT Scan is a complex procedure that should be left to an expert. Likewise, a predicted-intensity map is a means to an end as far as emergency-response planning is concerned. It is up to geotechnical professionals to produce derivative maps from those intensity maps, rather than to put local officials in a position where they must interpret the intensity maps for themselves. Geotechnical professionals also have a responsibility to explain qualifications about those maps so that they are not misused.

Valerie Kockelman asked what had been learned from the 1985 Mexico earthquake in terms of cooperating with foreign governments. She perceived that problems may have occurred because there was not an appropriate cooperative agreement for disaster assistance that would have smoothed the way for immediate aid from the United States.

Krimm replied that much had been learned from the 1985 Mexico earthquake disaster. The Office of Foreign Disaster Assistance in the U.S. Agency for International Development works with foreign governments in times of disaster. This agency worked very closely with the Mexican government, which had a very specific response plan and some very specific needs. Lessons learned included the importance of search-and-rescue dog teams, the usefulness of European detection systems for locating people buried in rubble, and the role of miners who could tunnel into debris during rescue efforts.

Flores discussed what was learned about governmental organization in times of crisis, and the ability of government to shift from routine operation into an emergency mode. The transition might take hours or days; therefore, the role of public self-help becomes extremely important. Volunteer rescue groups and HAM radio operators stepped in to fill voids in the governmental response activities.

Flores was part of a team sent to Mexico City to evaluate the disaster response, and the team was in the process of writing recommendations for applied research that would be useful for earthquake response in California.

REFERENCES

Hart, E.W., 1985, Fault-rupture hazard zones in California -- Alquist-Priolo Special Studies Zones Act of 1972 with index to special studies zones maps: California Department of Conservation, Division of Mines and Geology Special Publication 42 (revised), Sacramento, 24 p.

Southern California Earthquake Preparedness Project, 1985, The Parkfield and San Diego earthquake predictions -- a chronology: California Governor's Office of Emergency Services, Southern California Earthquake Preparedness Project, Los Angeles, 23 p.

Yin, R.K., and Moore, G.B., 1985, The utilization of research: lessons from the natural hazards field: Cosmos Corporation, Washington, D.C., 101 p.

IV. PREDICTING MAJOR EARTHQUAKES FOR PREPAREDNESS PLANNING

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Working Group Moderator:	John J. Kearns
Plenary Presenter:	John R. Filson
Working Group Presenters:	William L. Ellsworth Keiiti Aki Robert K. Reitherman Shirley Mattingly
Working Group Panelists:	Homer H. Givin, Jr. Thomas H. Heaton Ralph H. Turner Karen McNally
Working Group Commentator:	James J. Watkins
Audience Participants:	Ferne Halgren Jack Stubbs Lucile Jones Valerie R. Kockelman James F. Davis Alvin R. Shasky Stanley J. Roberts

[1/] Names and affiliations of all participants are listed alphabetically in Appendix A.

PREDICTING MAJOR EARTHQUAKES FOR PREPAREDNESS PLANNING

John R. Filson
United States Geological Survey

The prediction of the time, place, and magnitude of damaging earthquakes has been a goal of the National Earthquake Hazards Reduction Program since its beginning in 1978. From that time to the present, however, there have been significant changes in the approaches to and the expectations for this goal. Specifically, there have been unanticipated advances in the ability to make long-term predictions or forecasts. There has also been increased pragmatism about, and a focused effort toward, making short-term predictions.

The terminology adopted for general use in earthquake prediction classifies predictions according to the time interval in which the earthquake is expected. Long-term predictions are statements on earthquake occurrence in time intervals within a few years or decades. Predictions of earthquakes to occur within a few weeks or years are called intermediate-term predictions; those within a few hours up to a few weeks, short-term predictions.

Long-term predictions (or earthquake forecasts) are now commonly made and widely accepted. They are usually cast in probabilistic terms and are based on a statistical treatment of past earthquake occurrences, or on deterministic analyses of tectonic (plate) motions and fault slip in characteristic earthquakes in a region. Long-term predictions have been of considerable value in earthquake preparedness planning. They have been used wisely and prudently by public officials to direct limited preparedness resources and to carry out other earthquake countermeasures on a regional basis. Long-term predictions have brought to the public's attention quantitative statements on earthquake hazards that are widely understood, and have prompted individual actions to reduce private exposure to earthquake risk.

From a scientific standpoint, intermediate-term predictions (those of an event occurring within a few weeks to a few years) will likely be the most difficult to make. The range of errors typically associated with the techniques used to make long-term predictions will have to be drastically reduced (through means that are not now clear) to make accurate intermediate-term predictions. Of additional concern is how the public and private sectors will respond to such statements. Will decisions on private investment and construction be delayed until the event has occurred, or until the earthquake prediction statement has been modified? Will people who have decided to accept the long-term risk of living in an earthquake-prone area leave to avoid an intermediate-term risk? Can emergency facilities be kept in a standby mode for an extended period of time without prohibitive costs? Of course, if it is assumed that all intermediate-term predictions are ended with a short-term warning about the anticipated event, the answers to these questions may be significantly simplified. For the present, it may be a happy coincidence that both the scientific and social difficulty of dealing with intermediate-term predictions appears to be high.

If short-term prediction proves possible (and it is still in the research phase) it will probably be based on the direct observation of physical precursory phenomena. It is likely that statements of short-term predictions will be cast in statistical or probabilistic terms. The research approach to short-term prediction has changed significantly over the past few years. The trend has been to establish dense clusters of geophysical instrumentation in selected regions where a characteristic recurring earthquake is expected. The instrumentation is redundant in number and type to ensure that reliable data are collected. The Parkfield, California experiment is an example of this approach to short-term earthquake prediction research.

Preparedness planners are developing means of dealing with short-term predictions and these efforts should continue. The need for alerting emergency-response planners and those involved in maintaining critical facilities is straightforward. Advice to the general public on how to react and what to do in response to a short-term prediction poses a more difficult problem.

Earthquake prediction has evolved to such a degree that only predictions of specific earthquakes will, in most cases, be given serious consideration. Credible predictions should include information on which fault is expected to rupture, over what length the rupture will occur, and what amount of slip is expected across the fault. An advantage of a well-specified prediction is that it would allow for the theoretical computation of the nature of the ground shaking over the region likely to be affected.

There is a final word of warning about earthquake predictions and preparedness planning. At the current level of knowledge, scientists are trying to predict earthquakes in those regions that are geologically well understood -- Parkfield is such a case. This does not mean that the Parkfield earthquake will be the next damaging earthquake in California. In fact, the next damaging California earthquake may occur elsewhere in the state, perhaps in a location that is not well understood by the scientists. The 1984 Coalinga, California, earthquake illustrated such a case. The point is -- preparedness planning for earthquake response should not be relaxed or forgotten in seismically active regions where no specific forecast or prediction can be, or has been, made.

PROGRESS TOWARD RELIABLE EARTHQUAKE PREDICTION

William L. Ellsworth
United States Geological Survey

The scientific objective of earthquake prediction research is the development of reliable means to determine the time, place, and magnitude of future earthquakes. Translation of a scientific prediction into societal action requires close coordination and accurate exchange of information among the scientific community, local, state, and Federal government officials, and the media if the public at large is to receive the maximum benefit from the available warning.

At present, our knowledge of earthquake physics only provides for the reliable specification of the place and magnitude of impending earthquakes under special circumstances and on very long time scales (decades or longer), or for a reliable warning of imminent strong shaking on very short time scales (tens of seconds). Fundamental research into short- to intermediate-term precursory phenomena and their underlying physics must advance before reliable warnings of hours to days will become practical.

Long lead-time predictions, or more properly earthquake forecasts, have now been formulated for the major plate boundaries of the earth, where most of the great earthquakes (magnitude 7.75 - 9.5) have occured in the past. Segments of these plate boundaries that have not ruptured within the past several decades are identified as seismic gaps, and have higher probability of producing major earthquakes than adjacent segments of the same plate boundary.

The Mexico earthquake of September 19, 1985, at magnitude 8.1, filled a recognized seismic gap (McCann and others, 1979) and thus represents a successful long-term scientific prediction. Although it was the seventeenth major earthquake to be successfully forecast by the seismic gap theory (S. P. Nishenko, personal communication, 1985) the potential benefits that might have been derived from this long-term forecast of the earthquake were obviously not realized.

Before considering the current status of earthquake prediction research in the critical time range of days to weeks before the event, it is worth examing the potential uses of a seismic computerized alert network (SCAN) for warning of imminent strong ground shaking. The idea behind the SCAN system is quite simple. Seismic waves propagate comparatively slowly through the earth (roughly 3 to 6 km/second or 2 to 4 mi/second) but may affect structures hundreds of kilometers from their point of origin. If the earthquake source can be rapidly recognized and quantified once rupture has begun, then an automated, electronic warning can be raised seconds to minutes before the shaking begins at a given site, depending on its location with respect to the epicenter. The concepts behind the SCAN system are firmly established and can be readily implemented using conventional technology. Heaton (1985) describes the SCAN concept in greater detail and illustrates how warning times for Los Angeles of one minute or more could be made for a repeat of the great 1857 Fort Tejon earthquake. If a SCAN system had been operational along the Mexican coast, a warning time of up to 100 seconds might have been possible for Mexico City.

Seismic gap theory and SCAN can be viewed as the limiting cases for earthquake prediction. Each provides an accurate description of the location and size of the shock, but on time scales that are separated by many orders of magnitude. The seismic gaps model, and related earthquake recurrence models (Lindh, 1983; Sykes and Nishenko, 1984) are approximately 10 times more precise than conventional earthquake hazards models in assessing the probability of a specific event occurring in the future. However, even this probability, which may be a 50/50 chance in two to three decades, is only about 1/10,000 per day. Although this probably is too small to be of use for short-term warning, these long-term forecasts can be of great value to society. In contrast, SCAN could in principle provide a warning of strong shaking with great reliability, but with only an extremely short lead time. Users of a SCAN system must be prepared to automate their response to its warning. A prime objective of prediction research must therefore be to develop accurate (even chance, or better) and reliable means for specifying the timing of earthquakes on a more practical time scale.

Current efforts within the National Earthquake Hazards Reduction Program are attempting to achieve this goal in several ways: through fundamental studies of active faults and the physics of earthquakes; through systematic observation of major fault systems and the accumulation of tectonic strain within them; and through highly focused experimental studies in high probability seismic gaps. The third approach is the newest and most exciting one, and is best illustrated by the current program to predict the next magnitude 6 earthquake on the San Andreas fault near Parkfield, California.

The Parkfield, California, earthquake prediction experiment has been described in detail by Bakun and Lindh (1985), who estimated that the earthquake will occur by 1993, with a 95 percent probability. The most likely time for the event is in late 1987 or early 1988, although it could occur at any time, even tomorrow. The concept behind the Parkfield experiment is simply to concentrate our most accurate and sensitive instrumentation atop the rupture zone of the predicted event. Knowledge of the forerunners to Parkfield earthquakes in 1934 and 1966, some of which is anecdotal, are being used to guide the experiment's design and define the instrumental characteristics needed to detect hypothesized precursors. The outcome of the scientific experiment at Parkfield will be measured by our success in understanding how the event occurred and why it occurred in the way it did. We need to develop this basic physical understanding of the earthquake process if we are to attempt predictions in areas where we know far less about the past, and may not even know which faults are active.

The undertaking at Parkfield is more than just a highly focused research project in an unique natural laboratory. It is also the first concerted effort in the United States to make a short-term public earthquake prediction, and thus serves as a prototype operational earthquake-prediction system. The recent signing of California Assembly Bill 938 providing State matching funds for instrumentation and surveillance systems will ensure that many of the critical systems for short-term-prediction and warning can now be completed and brought to an operational state. Only time will tell if precursory signals appear with sufficient clarity and reliability on the best and most sensitive field instruments in our arsenal to lead to a public prediction.

Although the Parkfield experiment is the most advanced of its kind, there are other well-known targets for similar intensified observational studies in the United States. All of these sites are instrumented in some manner at present, most only with high-gain seismometers. However, none but Parkfield possesses an adequate density or variety of sensors to assure that the scientific opportunity will not be lost when the earthquake occurs.

Three of these areas of identified high earthquake potential are located in southern California: the southern half of the 1857 earthquake rupture zone on the San Andreas fault between Wrightwood and Lake Hughes; the Coachella Valley segment of the San Andreas fault, between the Salton Sea and San Gorgonio Pass; and the segment of the San Jacinto fault zone near the town of Anza. Working groups composed of university and government researchers have begun to develop a specific scientific research program for each area. While there is no assurance that any of these fault segments will generate the anticipated event anytime soon, or that the next destructive event in the region will not originate elsewhere, these locations offer the best scientific opportunities for observing precursors to the types of earthquakes that pose the primary threat to the region.

In summary, significant progress has been made in recent years in pinpointing the sites where future earthquakes will occur within the major active fault systems around the world, including California's San Andreas fault system. The development of reliable methods for short-term earthquake prediction can be accelerated by intensifying the study of those sites with the highest potential for future events. As we succeed in capturing earthquakes with specialized observation networks, and in unravelling the physics of earthquake precursors, we will at last be in a position to specify the components of an operational prediction system for general use throughout earthquake-prone regions. Until that day arrives, we must continue our efforts to refine and expand our ability to make long-term earthquake forecasts, make better use of long-term forecasts in decisionmaking and shaping public policy, and give careful consideration to the role automated warning systems will play in the effort to reduce the hazards earthquakes pose to society.

REFERENCES

Bakun, W.H., and Lindh, A.G., 1985, The Parkfield, California, earthquake prediction experiment: Science, v. 229, no. 4714, p. 619-624.

Heaton, T.H., 1985, A model for a seismic computerized alert network: Science, v. 228, p. 987-990.

Lindh, A.G., 1983, Preliminary assessment of long-term probabilities for large earthquakes along selected fault segments of the San Andreas fault system in California: U.S. Geological Survey Open-File Report 83-63, 15 p.

McCann, W.R., Nishenko, S.P., Sykes, L.R., and Krause, J., 1979, Seismic gaps and plate tectonics: Seismic potential for major plate boundaries: Pageoph, v. 117, p. 1082-1147.

Sykes, L.R., and Nishenko, S.P., 1984, Probabilities of occurrence of large plate rupturing earthquakes for the San Andreas and San Jacinto and Imperial faults, California, 1983-2003: Journal of Geophysical Research, v. 89, p. 5905-5927.

VALIDATING POSSIBLE EARTHQUAKE PRECURSORS

Keitti Aki
University of Southern California

INTRODUCTION

I come originally from Japan, where I studied earthquake seismology as a student and as a researcher at the Earthquake Research Institute of Tokyo University for about 10 years from the mid-1950's to mid-1960's. At that time, Japanese seismologists were working on the initial program of earthquake prediction research, and I felt that I was not ready to participate in the program of enormous complexity and difficulty. That was one of the reasons for my move to Massachusetts Institute of Technology (MIT), where I could think about earthquakes without much interruption by local earthquakes. After almost 20 years in Boston, I still could not say that I was ready to face the problem of earthquake prediction, but I felt that my time was running out unless I got involved more directly with the problem. That was one of the reasons I moved to the University of Southern California (USC) last year.

The last year has been a very interesting year for me with the participation in various meetings and workshops relating to earthquake prediction in California. Today, I would like to start my talk with what I found in the last year and focus on the subject title given me, "Validating Possible Earthquake Precursors."

EARTHQUAKE PREDICTION IN CALIFORNIA IS ALREADY IN OPERATION

Most scientists would like to think that the technology of earthquake prediction is in a developmental stage and is not yet ready for day-to-day operation. Attending the July, 1985 Southern California Earthquake Prepapredness Project (SCEPP) meeting at Asilomar with those representing state and local governments, police and fire departments, I realized that earthquake prediction is already in operation here, whether scientists like it or not. For example, in that meeting, we heard about the San Diego earthquake swarms; there were three magnitude 4 earthquakes on June 17, 1985 which raised public concern about a possible major earthquake on the Rose Canyon fault. In response to this concern, the Pasadena office of the U.S. Geological Survey issued a statement that there would be a one out of 20 chance for the swarm being followed by a larger than magnitude 5 earthquake within five days. This statement was transmitted to local governments and apparently they were able to respond to this statement with preparedness measures adequate for the level of probability, in this case, 5 percent; some decisionmakers decided to do nothing and others deployed fire engines for five days.

PROBABILITY IS ESSENTIAL

The probability of occurrence appears to be the key element of earthquake information that decisionmakers want from scientists. I heard in the SCEPP meeting and on several other occasions that the probability is not only useful but essential for decisionmakers. I was very pleased to hear this, because I was afraid earlier that probability might be too technical a concept to transmit to the general public.

Now, we can define the role of scientists in earthquake prediction simply and clearly, to evaluate the probability of earthquake occurrence for a specified magnitude, place, and time window under the condition that a particular set of precursory data was observed.

TWO MAJOR PROBLEMS FOR SCIENTISTS

In order to come up with an objective estimate of probability of earthquake occurrence, scientists need:

- complete data set on precursory phenomena, and
- well established relations between observed precursory phenomena and the corresponding conditional probability of earthquake occurrence.

If the data are not complete, we may miss a precursory signal and underestimate the probability. If the relation between a precursor and the corresponding conditional probability is not correct, we may miscalculate the probability when the precursor is observed. Thus, the validation procedure must include the question about the completeness of the precursor data, as well as the validity of assigning a certain probability to an observed precursor.

INCOMPLETENESS OF PRECURSORY DATA

The Parkfield, California, experiment vigorously pursued by the U.S. Geological Survey trys to collect a complete data set for a segment of the San Andreas fault which is expected to break in a few years. This is a very exciting experiment eagerly watched by scientists around the world.

The Parkfield experiment is along the line of the Tokai experiment in Japan, where a great earthquake is expected in the near future and an intensive monitoring of precursors is conducted in an operational mode of earthquake prediction. The problem in Japan has been that several damaging earthquakes have occurred in the area where precursory data are not intensively monitored. A similar lack of data leaves the vast area outside Parkfield in the darkness. It is impossible to validate precursors when the data are incomplete.

TESTING THE VALIDITY OF A PRECURSOR

Just like a new medicine, a new precursor of an earthquake suggested by a scientist must be tested before being allowed wide public use. A major problem with an earthquake precursor is that testing requires a long time, because an earthquake is an infrequent event. We try to speed up testing by applying it to other countries, but even then, we need at least about 30 years to test the validity of an earthquake precursor and assign a reliable probability estimate to it.

Tested precursors can be processed automatically by a computer at a data center for earthquake prediction, and the probability of earthquake occurrence can be calculated objectively. Almost all the precursors, however, are not yet tested satisfactorily.

WHAT TO DO WITH THE YET UNTESTED PRECURSORS

The public and decisionmakers cannot wait for the completion of testing of various precursors. Thus, scientists must do something with the yet untested precursors. This is the problem that the National and California Councils of Earthquake Prediction Evaluation must solve. This process necessarily involves subjective judgment of the council members, their ideas about earthquakes, and their bias on theories and assumptions. The council may yet come up with the range of probability of earthquake occurrence corresponding to the range of assumptions and theories.

For example, when we discussed the probability of the next Parkfield earthquake triggering a major earthquake to the south of Cholame, one scientist estimated it at about 50 percent, assuming that enough slip will have been accumulated by the next (or the one after the next) Parkfield earthquake to generate the characteristic earthquake south of Cholame. Another scientist estimated the probability to be zero, because he believes that the accumulated slip has been dissipated plastically around the broad area without any stress concentration. I thought that both theories are equally likely, so I estimated the probability to be 25 percent. When I tell this story to a scientist, he/she will frown or laugh. But, this probabilistic approach to the likelihood of competing hypotheses is now seriously considered in the seismic-hazard analysis by earthquake engineers who must make day-to-day decisions.

One advantage I see in this probabilistic approach is that the emotion and polarization among experts seems to diffuse with quantification, making the often agonizing procedure relatively smoother. A serious problem with this approach, however, occurs when the range of uncertainty about the probability is too large, and a decisionmaker cannot deal with it. In this case, either the earthquake prediction will be condemned to be useless, or remedying deficiencies in earthquake prediction research will be encouraged. I hope that the public and decisionmakers are patient enough to choose the latter for the benefit of future generations of mankind.

PROBLEMS WITH VALIDATING SHORT-TERM PRECURSORS

The members of the California and National Earthquake Prediction Evaluation Councils are volunteers who are engaged primarily in teaching or research often unrelated to earthquake prediction. It is, therefore, difficult to summon them at short notice for the evaluation of short-term precursors. In fact, the California Earthquake Prediction Evaluation Council could not react to the San Diego earthquake swarm mentioned earlier.

One way to remedy this situation may be to organize an exercise session for CEPEC members for various hypothetical short-term precursor scenarios, such as the one sponsored by the California Office of Emergency Services for the hypothetical eruption at Mammoth Lakes. Such an exercise may, at least, reveal the range of assumptions and hypotheses held by experts.

CONCLUSIONS

- Scientists must accept the fact that earthquake prediction in California is already in operation whether they like it or not.
- Probability of earthquake occurrence for a specified magnitude, place, and time window is the most essential message that decisionmakers want from scientists.
- It is impossible to validate precursors when the precursory data are incomplete. Scientists need a complete data set for objective evaluation of probability.
- Testing of the validity of a new earthquake precursor suggested by a scientist requires a long time, but decisionmakers cannot wait until the completion of testing. The National and California Earthquake Prediction Evaluation Councils may deal with this problem by offering the range of probability of earthquake occurrence corresponding to the range of hypotheses and assumptions held by experts.

EMERGENCY PLANNING FOR EARTHQUAKE PREDICTIONS

Robert K. Reitherman
Scientific Services, Inc.*

INTRODUCTION

This paper describes the results of an earthquake prediction emergency response planning project carried out under contract to the California Governor's Office of Emergency Services (OES) from June 1985 through January 1986. The project developed draft prediction response plans and related guidance material for use by local and state governments, enabling response to predictions arising out of the Parkfield, California earthquake prediction experiment, as well as for future predictions.

The contract required the preparation of draft state and county prediction response plans. The project included four counties selected by OES on the basis of their proximity to the source of the predicted Parkfield event: Fresno, Kings, Monterey, and San Luis Obispo Counties.

PARKFIELD EARTHQUAKE PREDICTIONS

The April 5, 1985 U.S. Geological Survey (USGS) announcement of the Parkfield prediction was preceded by published articles on the subject and by deliberations by the National Earthquake Prediction Evaluation Council (NEPEC) and California Earthquake Prediction Evaluation Council (CEPEC). There was ample time to lay the groundwork for this emergency planning project. As discussed below, other earthquake predictions which may arise in the future may not be preceded by such lead time.

Probablility

The present prediction states with 95 percent confidence that there will be a characteristic Parkfield earthquake (approximately magnitude 6) in 1988, plus-or-minus five years. As perceived by emergency planners, this is a very high probability, although the time frame is rather long. From the scientists' viewpoint, emergency planners are perhaps difficult to satisfy, since for emergency response purposes the combination of a high probability and a narrow time window is desirable. However, these two aspects of an earthquake prediction are generally inversely related. Thus a basic question concerning probability arises: whether the time window should be held to a narrow width, and the associated probability then stated, or whether a given threshold of probability should be used as a standard, with the associated time window allowed to fluctuate.

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The general perception of state and local level emergency planning communities regarding the Parkfield prediction seems to be that active response measures would not be appropriate until a very short-term prediction is issued. This may be partly due to the limited consequences of the predicted event, or perhaps it indicates that a very short-term prediction will receive greater attention, regardless of probability, than a longer-term prediction. The irony of the situation is that when the motivation is greatest to take protective actions, there is the least amount of time to do so; when there is more time to allow for more thorough measures, the risk is not perceived as high enough to lead to extensive actions.

One useful statistical comparison found in this project was to state the probability as a multiple of the background level of seismicity. Thus, if an earthquake were predicted to occur on a given day with thousands of times greater probability than the long-term, unpredicted probability associated with the recurrence interval, the significance of the prediction would be apparent to nonscientists.

Size of Earthquake

The official USGS Parkfield prediction is related to the recurrence of a characteristic (approximately magnitude 6) earthquake on this segment of the San Andreas fault, similar to the last five events of similar size which have generally occurred at 21- to 22-year intervals. Some geoscientists have seriously considered the possibility that in the next Parkfield earthquake, the San Andreas fault may rupture further to the south to an additional extent, which would more than double the rupture length associated with the smaller characteristic event, and a magnitude 7 earthquake could result (Bakun and Lindh, 1985). Emergency planners must take this possibility seriously as well. Emergency plans are essentially devised to contend with large possible events of low probability, and when two different size earthquakes are associated with an earthquake prediction, the larger event, even if less probable, will usually be selected as the planning basis for emergency response plans.

The difference between the smaller (magnitude 6) and larger (magnitude 7) earthquake in this case is dramatic. The smaller earthquake would generate a minimum intensity ground motion of Modified Mercalli Intensity (MMI) VII, and then only in Parkfield and nearby rural areas that lie near the fault. The larger earthquake would generate MMI VII or greater in portions of six counties, with an approximate population of 150,000. The smaller earthquake would not require a significant emergency response, whereas the larger scenario event would lead to potentially major emergency response implications.

Expected Intensities and Effects

The first intensity maps for these smaller and larger magnitude Parkfield earthquakes were produced by the California Division of Mines and Geology (Toppozada, 1985). The map for the larger earthquake was then refined by adjusting for local geology (David J. Leeds and Associates, 1985), which produced a more irregular zonation of expected intensities. It also had the effect of reducing the expected intensity by one MMI unit for sites where harder (older than

Pleistocene) materials were present. Leeds and Associates also produced a landslide map for this presumed magnitude 7 earthquake.

The intensities were translated into approximate rules-of-thumb, which are keyed to the MMI VIII-IX level. For example:

- o Five out of six unreinforced masonry buildings might be damaged to the point where at least some brickwork would fall; one in four could collapse.
- o One fire could ignite for every 1000 dwellings.
- o Most mobile homes which have not been anchored would shift off their supports.
- o Each typical commercial block would have at least some breakage of large-pane storefront glazing.
- o Unrestrained chemicals on shelves, such as at typical high school chemical labs or hospitals, would fall, perhaps causing the need for evacuation and fire department response.

MMI VII was used as the minimum level of shaking that would require significant emergency response should significant development exist in that area. This MMI VII or greater criterion originated in the intensity mapping of Toppozada (1985) and was found to be appropriate for emergency-planning purposes. While it is true that isoseismcals are somewhat arbitrary dividing lines for a phenomenon that would be better described on a more finely graduated continuum, it must be remembered that the current state-of-the-art of intensity forecasting is of itself imprecise. Also, emergency planners require some guidance concerning the planning limits of significantly affected areas. For example, less than half of each of the six counties would be expected to receive MMI VII or greater shaking (even in the larger, magnitude 7 event). Thus, public information or other activities must be based on less than county-wide areas. It was found, for example, that the Emergency Broadcasting System (EBS) coverage for the counties involved was much too broad; therefore, EBS warnings could not be limited to the significantly affected areas.

Major problems inherent in the MMI scale (or the Rossi-Forel, the Japanese Meterological Agency, or the MSK intensity scales) are commingling of ground failure and vibratory effects of earthquakes and lack of specificity in the indicators used to assign intensities. In addition, the absence of any specific frequency content considerations in the scale complicates its use. The MMI scale is usually interpreted as a scale of high frequency intensities, although some of the effects listed are more likely to be long-period effects (such as the ringing of church bells, or spilling or sloshing of liquids in containers or bodies of water). To provide accurate public information and emergency planning guidance in this project, a much wider range (125 miles or more) was assumed to define the limits of significant long-period effects. Thus, the maps show MMI values and are used for short-period-effects prediction; verbal guidance indicated that for the larger event (approximately magnitude 7), significant shaking at much larger distances from the fault would offset structures such as elevated water tanks, canals and reservoirs, tall industrial towers and stacks, high-rise buildings, and offshore oil platforms.

Warning Time Frame

The Parkfield response plans drafted for this project are predicated by the development of a very short-term prediction resulting from the extensive experiment underway. A prediction within a stated time frame of "the next 24 to 72 hours," gives the emergency planners what they want most -- a very narrow and well-defined time frame. Motivation to respond will be high on the part of the public and private sectors, and mitigation measures will be less costly and less difficult to sustain. A very brief time frame will also place the most severe demands on the emergency response plan.

USGS scientists have advised Parkfield residents to treat a perceptible earthquake as a very short-term (about a quarter-hour) warning. The two prior Parkfield earthquakes in 1966 and 1934 were both preceded by foreshocks that occurred, apparently as precursors, 17 minutes before the main shock. The draft emergency response plans include this possibility by suggesting: the areas in the counties where this advice should be given, what specific response activities are appropriate, and how long this "warning" provided by the foreshock should be presumed to be in effect. A quarter hour should be sufficient time for residents and emergency response agencies to take some beneficial actions, but only if they are prepared in advance to undertake mitigation activities without waiting for advice.

OTHER (NON-PARKFIELD) EARTHQUAKE PREDICTIONS

While the Parkfield earthquake prediction experiement provided the impetus for the emergency response planning project, the contingency of other predictions was included as well. A June 17, 1985 "prediction" or advisory statement was issued by the USGS to the California OES for the San Diego area. It stated that the unusual sequence of several small but perceptible earthquakes in San Diego in the course of a few hours was, statistically based on past California experience, followed 5 percent of the time by a larger earthquake. The USGS did not term the statement a prediction; from the emergency planning viewpoint, the terminology was moot. Since an earthquake-prediction-response situation was created by the statement, regardless of its definition, the specific facts associated with a statement--the probability, the time frame, who issued the statement or its validity--are very important to emergency services agency personnel. They are probably not particularly sensitive to the semantics involved with terms such as "prediction," "short-term," "long-term," or "advisory statement."

Chronologies of the San Diego prediction response situation are found in Goltz, 1985 and Graves, 1985. The Goltz report also discusses the Parkfield case, and both reports deal with the San Diego events in more detail. The only point made here is that the issuance of an "advisory statement" for the San Diego area demonstrated that virtually any location in California could be alerted without any prior warning by a similar foreshock-based prediction. San Diego is probably the least seismically active area of coastal California, and it has not had any historic earthquakes to compare with those experienced in the Los Angeles and San Francisco Bay regions. Thus, San Diego is quite different from the special case of the Parkfield prediction. Areas where extensive earthquake prediction experiments, such as Parkfield, might be underway in the future would certainly be high priority areas for earthquake-prediction-response planning, and these jurisdictions throughout the state should be prepared as well.

AMOUNT OF WARNING TIME

For the unanticipated "prediction" of the San Diego type, it is reasonable to assume a very short-term time window. Predictions based on foreshocks imply that the probability of the earthquake's occurrence would most likely be at a peak when the predictive statement is made; the probability would then decay to background seismicity levels within a few days. Based on the work of Jones (1984), foreshock-related predictions which are based on the statistical history of earthquakes in California can be rapidly made. The appropriate statistical pattern is selected on the basis on magnitude, type of fault, and spacing of the foreshocks in time, all of which can rapidly be made available in many cases. Thus, the contingency of a very short-term (a few days or less) time window for either the Parkfield or non-Parkfield cases must be considered a possibility. In general, it was efficient to devise response measures for this very short-term time window, and then to adapt these measures for the contingencies of longer warning times.

A distinction exists between the warning times for earthquake predictions and warning times for tsunami and hurricane predictions. Most earthquake prediction statements are likely to describe the time window using "within," as in "within the next ___ hours" or "within the next ___ days." Tsunami warnings are tied to expected arrival times: after allowing a conservative amount of time to pass after the expected arrival time, local emergency services agencies can assume that no tsunami will materialize. Hurricane warnings are similarly stated with specific, narrow time windows of perhaps 12 to 24 hours in the future, and emergency response measures revolve around that target time. The earthquake prediction situation creates an ambiguous situation, wherein the probability of the event may be decaying, but could still be above seismic-background levels; therefore, the decision to demobilize the response must be constantly evaluated. In general, most emergency planners would prefer the scientific establishment responsible for validating and issuing the prediction to determine how long it will be in effect, to update the original prediction frequently, and to issue a statement cancelling the prediction, rather than leaving this cancellation decision up to the local emergency planners.

RESPONSE MEASURES

Frequent reference has been made to plans for emergency response measures that could be employed to deal with an earthquake prediction. There is nothing particularly technical about this term, "emergency response measure," however, scientists who are not familiar with the field of emergency planning should not presume that this phrase refers to a well-developed set of procedures upon which all emergency planners agree. When emergency response plans or measures are discussed, it is important to give concrete examples. Because these overall plans vary significantly from one jurisdiction to another, the specific measures employed for a given contingency or hazard can vary greatly from one occurrence to the next within a single jurisdiction. In emergency planning, it is at the detail level where specific operations can be observed and evaluated to determine whether emergency plans are successful or inadequate. In the new field of emergency planning for an earthquake prediction, it is especially necessary to cite specific examples; if this is not done, the topic may be discussed with academic respectability, yet remain void of specific emergency planning.

One report produced for OES by Reitherman (1986e) outlines 19 emergency response measures and 14 hazard-reduction measures that might be considered in the context of earthquake prediction. Some of these measures are discussed below.

SOFT (EMERGENCY RESPONSE) COUNTERMEASURES

The Japanese, who have the most elaborate earthquake prediction response plans in the world, use the terms "hard" and "soft" to categorize earthquake countermeasures. These terms from the English words in the computer field for "hardware" and "software."

Validation, Verification, and Communication

Validation of earthquake warnings is more complicated than for most other hazards. Hurricanes and tsunamis, for example, generally present less complicated scientific and emergency planning implications. Validation of earthquake predictions has long been recognized as a major concern, and NEPEC and CEPEC were established to deal with precisely this problem. On March 1, 1985, the USGS presented NEPEC a draft short-term Parkfield response plan, which now enables the validation of predictions which meet certain pre-established criteria. However, the work accomplished in the OES project prior to the presentation of the USGS response plan is still valid.

From the perspective of state and local government, earthquake prediction validation is a state responsibility, and local governments rely on the warnings provided through state OES channels (even though the prediction may originate with USGS). Verification of the precise nature of a prediction is one of the first steps in a local government response plan. It is essential to verify the source and validity of a prediction, as well as the precise wording. Communication between OES and local governments, various departments or special purposes districts, or organizations at the local and state level, must work smoothly and rapidly. The draft plans developed for the consideration of the state and this project's four counties include specific procedures regarding which communications system would be used to convey an earthquake prediction, depending upon the length of warning time.

Depending upon the validity, time window, probability, location, and expected effects of a predicted earthquake, local and state government would consider their response options according to previously established criteria. Such guidelines must be flexible, but they should provide as much guidance as possible to be useful in an emergency. Following guidelines that have been adopted into local disaster plans will also help to minimize liability exposure.

Increased Level of Staffing

Increasing staff may seem to be an obvious response to implement, regardless of time frame or probability. This measure can take the form of activation of the local government emergency operating center (EOC), which is a well-defined procedure for any emergency situation. It may include the unusual step of having personnel with radio communication capabilty stationed at dams that are not normally monitored. Staffing of some functions on a 24-hour basis can amount to a few thousand dollars per hour in some jurisdictions, depending upon the number of personnel involved and whether they must be paid for overtime work. Also, it is very unlikely under current regulations that a local jurisdiction would be reimbursed with Federal disaster relief funds for earthquake prediction response costs, unless an earthquake disaster occurred.

Another aspect to the decision to increase staffing levels and mobilize reserve personnel is that if the earthquake does not occur, at some point the decision must be made to de-mobilize. This requires some advance thought as to the criteria for such a decision, as well as the public information implications. If the proper preparedness steps were taken, but the earthquake did not occur, it is important to communicate to the public the fact that proper procedures were followed and that the government did not make a mistake by increasing its readiness. A similar issue arises in connection with tsunami warnings, most of which are not followed by destructive tsunamis.

Re-deployment of Vehicles

The least costly measure of this type is to raise the garage doors on a fire station to prevent them from jamming in an earthquake as the "soft front wall" of the typical station distorts under lateral loading. More protection is offered by moving vehicles outdoors. Another benefit is conferred (at a slightly greater cost) by moving vehicles to advantageous locations where for earthquake response, considering possible causes of route blockage such as landslides, collapsed bridges or buildings, or downed wires. As an example, at least one large fire department in California (Orange County) now directs each station to survey its surroundings to determine possible route blockages that could be rapidly bypassed after an earthquake (Nicola, 1986). Such jurisdictions also stand to be able to capitalize much more aggressively upon an earthquake prediction, since they would be able to pre-position vehicles to avoid the potential route blockages.

Response plans for the parkfield earthquake prediction identify for each county the roads which pass through areas susceptible to landslides, and where route blockages would have major implications. Some of the counties have considered how to pre-position ambulances, sheriff's department vehicles, or other radio-equipped emergency services vehicles beyond the route blockage. In this respect, on a much smaller and more rural scale, the Parkfield response planning approach mirrors the very large scale and urban Japanese planning for the Tokai prediction. This is a short-term forecast of a great earthquake that would affect millions of people in the caostal region of Japan to the south of Tokyo. The Shizuoka Hospital, the largest hospital near where the effects of this earthquake would be greatest, has plans to dispatch doctor-nurse teams via helicopter to pre-designated areas where route blockage could hinder emergency medical response (Shizuoka General Hospital, 1985).

While not immediately apparent as a major problem, relocation of a fleet of police or public works vehicles from a central parking structure can necessitate extensive field re-fueling operations.

Public Information

The consensus of the emergency planners involved in the project was that full and complete disclosure of earthquake predictions should occur whenever an official, validated prediction has been released. Extensive public information efforts may be required, even for invalid predictions, to combat rumors. In the case of the June 1985 San Diego prediction-response situation, the last sentence of the message to OES headquaters in Sacramento concerning the 5 percent chance of a larger earthquake was "Not for release to the press or public." In retrospect, this qualifier places a great burden on emergency services officials. Most of the county government emergency planners involved in the project preferred for the state to warn municipalities directly, rather than to have counties perform this role. This would increase the speed and reliability of the process (there is a direct Sacramento-local police department communications system suitable for this purpose), as well as eliminate the need for a county to decide when or if to act on earthquake prediction messages.

Public announcements must not overstate the risk or cause undue alarm. However, if public information is not specific in describing hazards and feasible protective actions, people cannot be expected to take nevessary precautions. As an example, since water heater anchorage procedures can be defined and graphically depicted, such information should be available for dissemination through various media in advance of a prediction.

Evacuation

Area-wide evacuations, which are the primary response to hurricane warnings, are not considered a reasonable earthquake prediction response. An exception would be the case of a potential dam failure where inundation would affect a populated area. In most other cases, however, the use of evacuation should be limited, and even then this is considered by most emergency planners to be one of the more controversial possible responses. The benefits as well as the costs of evacuating high hazard locations are very high. Fortunately, the benefit is only slightly reduced when very specific areas such as individual buildings are vacated, while the costs drop dramatically.

In most United States earthquakes, only a small percentage of the population in an urban area (typically less than 1 percent of the population in urban loss estimates) would become casualties. Most of these casualties would be caused by collapse of buildings whose earthquake vulnerability could be identified in advance as higher than average. On the one hand, there is little need to evacuate most buildings, since most buildings are structurally earthquake-resistant. On the other hand, there is a great potential savings of lives if the most hazardous buildings and adjacent exterior areas are vacant at the time of the earthquake. If high hazard buildings are not evacuated, then no major reduction in casualties can be hoped for, and the benefit of having the prediction is reduced to improving the response to casualties after they occur.

For example, in the 1985 Mexico City earthquake disaster, the fatality total was in the tens of thousands, while the total individuals rescued was in the hundreds. Even improving the number rescued by a factor of ten would have still left the basic point unchanged for this earthquake: the most efficient emergency response system imaginable could have had only a very small impact on the life loss. By far the most important type of losses in earthquakes are human life and serious injury. Most of these human losses will be caused by the poor performance of a relatively small number of buildings. Therefore we cannot make a large change in the outcome of future earthquake disasters unless we attack the hazardous building problem.

It was apparent in this project that the community which has the most extensive hazard reduction program for earthquakes can benefit the most from an earthquake prediction, and the community which has only a nominal earthquake hazard reduction program will have great difficulty finding ways to capitalize greatly upon a prediction. The primary example of this is hazardous building surveys. A city, county, or other organization which already has an inventory of high hazard structures can use this list for the purpose of advising or ordering occupants to vacate these buildings during a short-term earthquake prediction. Cities such as Long Beach or Los Angeles, for example, which have detailed files of unreinforced masonry buildings, have the option of voluntary or mandatory evacuation of the buildings. Cities which do not have such inventories cannot develop them rapidly enough in most cases to use this technique. California Senate Bill 547, signed into law in July 1986, requires local governments in California to inventory their unreinforced masonry buildings, and is a great contribution in the field of earthquake prediction response, even though this is not the bill's primary purpose.

HARD (HAZARD REDUCTION) COUNTERMEASURES

Surveys can be used for emergency response puposes to evacuate hazardous locations, as described above, while temporary or permanent retrofits would directly reduce damage or protect occupants and passersby. Temporary retrofits include shoring and bracing, guy cable installations, reduction of live loads (movable contents) in storage structures, and installation of protective canopies over sidewalks. Engineering techniques exist for designing these particular elements, although they have not been used in the context of earthquake prediction, and some further research would be required to apply these measures with confidence and efficiency. These measures require from several days to several weeks to implement, although for a small number of structures whose temporary retrofit designs were determined in advance, some of these protective measures could be put in place within hours.

Permanent strengthening--for example, strengthening the unreinforced masonry building as is required under the Long Beach or Los Angeles ordinances--is preferable from the reliability standpoint, but typically requires about a year or more. The applicability of hard or soft earthquake prediction countermeasures varies with the time window. Generally, the soft measures are most feasible for very short time windows (a few hours to a few days), while the hard measures are most feasible for time windows of a few months to a year or more.

Nonstructural Surveys, Temporary or Permanent Retrofits

Nonstructural hazard surveys alone could only reduce losses if occupants avoided the most hazardous areas, such as stockrooms where tall pallet stacks are present. This is analogous to the use of a structural survey, without any protective retrofits, to guide evacuation decisionmaking. Temporary retrofits would be more likely to significantly reduce losses. These include: closing blinds to guard the interior space from flying glass; moving vulnerable contents to lower shelves or to the floor; making work spaces more tidy and eliminating ad hoc storage such as boxes placed on tops of file cabinets; and using wire, rope, chain, or tape to secure items. Note that retrofits can reduce property damage as well as casualties, whereas the use of surveys to relocate people can only reduce casualties.

For a slightly greater investment and with more time, permanent nonstructural retrofits are possible within a day to a few days, such as the restraint of water heaters or overhead light fixtures.

Lifelines

Lifelines are perhaps more difficult to strengthen than buildings, but they offer a greater array of operational options. In Japan, earthquake prediction response plans designed for the expected Tokai prediction call for freeway speed limits to be immediately lowered, trains to slow down, and natural gas systems to be compartmentalized using radio-controlled valves. In the case of the Parkfield prediction, the closest analogy is the shut-off or other protective action that a pipeline operator could take, because several pipelines cross the segment of the San Andreas fault expected to rupture. The draft plans call for providing this information to the pipeline operators to let them make their own decisions concerning prediction response. Even a single issue, such as pipelines, turned out to be a potentially complicated topic. Some pipelines could be shut down within minutes, others would require longer lead time. Shutting down some would have a large economic consequence after a few hours, while for others a down time of a few days would be tolerable. The 1966 Parkfield earthquake fault rupture of about one foot did not cause significant pipeline damage, but a magnitude 7 event would probably be associated with several feet of offset.

RESPONSE ISSUES

Liability

A report by the Southern California Earthquake Preparedness Project (SCEPP) on Earthquake Prediction Response: Legal Authorities and Liabilities

(Ingram, 1983) was referred to frequently in the course of the project. The report suggests that the two people most extensively involved in earthquake prediction response planning at the local level are the emergency services coordinator and the city or county attorney. Aside from the physical differences between the Tokai prediction in Japan (a great earthquake in a large urban region) and the Parkfield prediction (a moderate earthquake in a predominantly rural region), this legal aspect would probably stand out as one of the greatest differences from the viewpoint of a Japanese emergency planner. Whereas section 955.1 of the California Government Code specifically empowers the Governor to declare an earthquake prediction warning, thereby conferring extensive liability immunity to local government, this has not yet occurred, even though the June 1985 San Diego situation placed local government in an awkward legal position, and even though the present long-term Parkfield prediction has been validated by the California Earthquake Prediction Evaluation Council. If the Governor does not make such astatement, local government liability protection is best ensured by relying on discretionary rather than ministerial actions as much as possible, according to the SCEPP guidance. This means that following adopted response plans, prepared with an explicit recognition of costs and benefits of various response options, is much preferable to either ad hoc inaction or ad hoc action.

Interpretation and use of Science by Non-Scientists

This issue permeates the subject of earthquake prediction. It is desirable to for scientists involved in the research to help explain their prediction to the emergency response community and general public. This gives the scientists a better understanding of the types of questions which arise and the concerns of the emergency response agencies who represent the interests of the public. The information is less likely to be misinterpreted, and it is important for the scientists and emergency responders to meet face-to-face to develop personal rapport. One of the valuable benefits of disaster exercises is the personal contact between members of various emergency services agencies, who will thereby be better able to coordinate effectively in an emergency. If it is valuable for individuals within the same basic field of emergency services to have such contact, it is probably even more valuable for members of the emergency services field to meet with geoscientists.

FUTURE DIRECTIONS

It has taken a decade of earthquake prediction research to move the topic into the forefront of emergency response planning in California. While many studies of a general policy or sociological nature have been conducted over the past ten years, only recently have emergency planners begun to develop practical, action-oriented response procedures. The trend will probably continue, with the Parkfield earthquake prediction experiment as the near-term focus. The state and local agencies involved in the project described herein have further work to accomplish to develop earthquake prediction response plans.

There is a corollary to the geoscientists' earthquake prediction experiment: an earthquake prediction response planning experiment is also now underway. We should learn from the successes as well as failures as they become apparent in this emergency planning experiment, and adopt the scientist's view that an experiment can be successful even when the results point out what does not work rather than what does. It is likely that emergency response planning for earthquake prediction will continue to grow in the future, and we should document and learn from our experience in this new and developing field.

REFERENCES

Bakun, W.H., and Lindh, A.G., 1985, The Parkfield, California, earthquake prediction experiment: Science, v. 229, no. 4714.

David J. Leeds and Associates, 1985, Intensity forecast for a Parkfield, California, earthquake of approximately magnitude 7 in Reitherman, R.K., 1986, County earthquake prediction response planning report--policy, concept of operations, long-term prediction response, and emergency response checklists: Scientific Service, Inc., Redwood City, Calif., for the California Governor's Office of Emergency Services; Report no. 8508-B-2, p. 55-57.

Goltz, James, 1985, The Parkfield and San Diego earthquake predictions--A chronology: Southern California Earthquake Preparedness Project, Los Angeles, Calif., 23 p.

Graves, Clifford, 1985, After action report--June 1985 earthquakes: Chief Administrative Office, San Diego County, San Diego, Calif.

Ingram, Melanie, 1983, Earthquake prediction response--legal authorities and liabilities: Southern California Earthquake Preparedness Project, Los Angeles, Calif.

Jones, L.M., 1984, Foreshocks, 1966-1969, in the San Andreas system, California: Bulletin of the Seismological Society of America, v. 74, no. 4.

Nicola, C.A., 1986, Orange County Fire Department, Orange, California, personal communication.

Reitherman, R.K., 1986a, State and county earthquake prediction response planning report--threat summary: Scientific Service, Inc., Redwood City, Calif., for the California Governor's Office of Emergency Services.

_____, 1986b, County earthquake prediction response planning report--policy, concept of operations, long-term prediction response, and emergency response checklists: Scientific Service, Inc., Redwood City, Calif., for the California Governor's Office of Emergency Services; Report no. 8508-B-2, 91 p.

_____, 1986c, County-specific emergency planning information relative to the Parkfield earthquake prediction: Scientific Service, Inc., Redwood City, Calif., for the California Governor's Office of Emergency Services; Report no. 8508-B-3, 28 p.

_____, 1986d, State earthquake prediction response planning report--policy, concept of operations, long-term prediction response, and emergency response checklists: Scientific Service, Inc., Redwood City, Calif., for the California Governor's Office of Emergency Services; Report no. 8508-B-4, 73 p.

_____, 1986e, Costs and benefits of earthquake prediction response: Scientific Service, Inc. Redwood City, Calif., for the California Governor's Office of Emergency Services.

_____, 1986f, Memorandum to OES concerning suggested earthquake prediction response follow-up activities: Scientific Service, Inc., Redwood City, Calif., for the California Governor's Office of Emergency Services.

Shizuoka General Hospital, 1985, personal communication, as part of the author's visit to Japan as co-Principal Investigator of a National Science Foundation funded research project on Japanese Private Sector Earthquake Programs and Their Appliciability in the US.

Toppozada, T., 1985, Effects of Parkfield earthquakes: California Division of Mines and Geology, Sacramento, Calif.

U.S. Geological Survey, 1985, Studies forecasting moderate earthquake near Parkfield, California, receive official endorsement: Public Affairs Office, Western Region, Menlo Park, Calif.

RESPONDING TO FORECASTS: A LOCAL GOVERNMENT VIEW

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When confronted with disaster or the potential for disaster, local government clearly is responsible for protecting lives and property. Local officials must be prepared to help protect their communities from any calamity which could strike.

As calamities go, earthquakes pose a special threat due to the infrequency of the really disastrous events. Charleston, South Carolina, had a major earthquake in 1886, but the next major earthquake there is not expected for at least 1,400 years (Sieh, K.E., oral communication, 1985). New Yorkers were recently surprised by minor earthquakes shaking their city, but no one, not even seismologists, really knows whether New York has the potential for a great earthquake, or when one might occur.

Everybody knows that California is earthquake country, but many Californians do not expect to experience a great earthquake in their lifetimes. Occurring on average every 145 years, the "big one" is something "that will happen to other people." The public official hopes it will happen during someone else's tenure in office. Nevertheless, the "big one" is drawing near. Dr. Kerry Sieh (oral communication, 1985) has stated that we probably are now within ten to twenty years of the earthquake. No one, especially public policy officials, can risk ignoring the threat any longer.

The responsibility of local government is an awesome one. Those of us in local government are responsible for translating theory into practice, and then we must have the courage to implement costly seismic-risk-reduction strategies which are developed by engineers and scientists who do not have to be reelected to stay in their jobs. We must make our own earthquake response plan, and then it must be continually practiced so that it works like a well-oiled machine. Our limited resources must be properly allocated to where they can do the most good. Local government officials are the ones who must deal with the cheerful calls saying, "I'm from the Federal government; I'm here to help!" while in the midst of a disaster. We are the ones who have to convince skeptical reporters and constituents that we are not only doing our best, but that our best is the best there is. We are the ones who will have to answer for actions (or inactions) based on earthquake predictions or forecasts which may or may not be scientifically based; which may or may not have been properly evaluated; and which may or may not be officially communicated to us.

Immediately following a major earthquake, local government officials must coordinate and perform search and rescue operations. We will be expected to:

- ensure the delivery of medical care to the injured, as well as the proper handling of the dead;

- immediately evaluate weakened structures; then make and enforce occupancy decisions;

- ensure that the population has shelter, safe drinking water, food, and other supplies; and

- ensure that power and other lifelines are rapidly restored, particularly for critical facilities.

In addition, local government officials will be expected to help business and industry resume business in short order. We will be expected to remove and dispose of debris and rubble. And after we pick up all the pieces, and the Federal officials and reporters leave town, local government will face the most difficult reconstruction and land-use decisions which have ever faced any governmental entity.

Local government's job, in a nutshell, is not to be envied. The local government official is continually faced with the uncertainties regarding legal and liability issues which surround every local official's actions and inactions taken in emergency planning and preparedness, as well as the efficacy of the measures taken. A major disaster, such as a devastating earthquake, is truly the local official's nightmare.

Neither is planning for a local jurisdiction's response to a prediction of a major earthquake a cup of tea. The issues related to earthquake predictions or forecasts and the response of local government do not seem to be changing much over the years. The third in a series of Earthquake Prediction Workshops was presented last July (1985) by the Southern California Earthquake Preparedness Project (SCEPP) under the sponsorship of the Federal Emergency Management Agency (FEMA), the State Office of Emergency Services (OES), and the California Seismic Safety Commission. At that conference, the participants reviewed an "Option Paper for Earthquake Prediction Strategy" (U.S. Geological Survey, 1984) which asked:

> Given the high probability of a great earthquake along the southern San Andreas in next 30 years and the possibility of smaller but still dangerous events from other faults in the region, should a more aggressive strategy be adopted to predict these events?

I was reminded of the Seismic Safety Commission and FEMA-sponsored Japan Research Team's 1981 recommendation advocating the very same thing. I wondered; why were we asking ourselves the same question that had been asked four years before? Isn't the answer obvious? If we are not aggressively pursuing prediction technology and prediction funding and prediction response planning, then we are all spinning our wheels. Of course, progress never occurs as quickly as we would like, and progress takes commitment and funding.

For the local public policymakers, however, their perceptions of the status of earthquake forecasting technology greatly influence their willingness to deal with prediction issues. One way in which local public officials are influenced by their perceptions is the feeling that the scientific community is far from being able to give them validated short-term predictions, therefore they are not going to place high priority on their own jurisdiction's planning for dealing with a prediction. For example, as part of its planning partner agreement with SCEPP, the City of Los Angeles completed (with SCEPP assistance) its draft earthquake-prediction-response plan in July, 1983. It was based on work initiated in 1978 by the Mayor's Task Force on Earthquake Prediction. Much thought went into the document, and there were some heated discussions among the City's emergency planners in different City departments regarding the draft's contents and structure. What has been done since? Few City officials have looked at it.

The City of Los Angeles does have a plan, and it's a good one. However, when local government is not actively involved in the planning process, or in testing its plans, those same plans gather dust and other priorities take over. I am sure that this is not totally the fault of the local policymakers and their staffs. Equal responsibility lies with the scientific community, upon whom local governments rely to make effective prediction a reality. Responsibility lies with the media (as well as with the scientists) to inform policymakers of what progress has been made in prediction studies and technology. If there is reluctance on the part of public officials to deal with prediction issues it is because they think little progress is being made. This perception could come back to haunt them, because the public policymakers, the local officials, will be left "holding the bag." Local officials will ultimately be held responsible by their constituents for actions and inactions taken in relation to earthquake predictions, as well as those taken in relation to the actual occurrence of either predicted or unexpected earthquakes.

In southern California, everyone lives with the earthquake threat. The emergency preparedness efforts of local officials are made with the thought of a devastating 8.3 earthquake lurking in the back of their minds. In Los Angeles, the City's Emergency Operations Organization (EOO) considers itself continuously in a long-term prediction response phase, and is therefore involved in massive ongoing programs in:

- Seismic safety planning
- Structural and nonstructural hazard mitigation
- Preparedness training
- Public information and awareness

We consider the City of Los Angeles to be a highly advanced political jurisdiction in these areas. A sparkling example is our Seismic Safety Ordinance, passed in 1981, which requires the retrofitting or demolition of 8000 unreinforced masonry buildings. Moreover, the City of Los Angeles has taken action to speed up the notification and enforcement processes outlined in the Seismic Safety Ordinance in response to the 1985 Mexico earthquake. This was done so that the City of Los Angeles will be progressively safer with respect to the earthquake threat.

According to **California** magazine (Meyer, 1985), Los Angeles is the only city in southern California that has written emergency plans, a full-time staff, an Emergency Operations Center with necessary communications in place, and an annual earthquake response exercise. Los Angeles also has initiated the City and County Earthquake Preparedness Committee, which motivated the State of California to establish a statewide Earthquake Awareness Week in April, 1985. In addition, the mayor of Los Angeles has taken a leadership role in earthquake preparedness for the local business community by forming BICEPP (the Business and Industry Council for Earthquake Planning and Preparedness).

However, these are long-term and intermediate-term actions. When it comes to short-term response, there are unanswered questions and unresolved problems which include:

- Issuing warnings to the public;
- Implications and mechanics of alerting and mobilizing public and private emergency response groups;
- Vacating hazardous structures and posting warnings;
- Evacuating threatened areas; mass care and shelter problems; and
- Public official liability.

The entire issue of how local government officials are going to communicate the prediction of an earthquake threat to the public is one that needs focus. The mechanics of communicating--the medium as well as the message--must be carefully considered. Who will make it? What will be said? What words will be used? How will a sense of urgency be conveyed without creating panic? In regard to the mechanics of the warning, Los Angeles does have an extremely effective and well-prepared Emergency Broadcast System (EBS). Los Angeles also has an antiquated, virtually useless siren system. The issues related to retention, replacement, or dismantling of this system are currently being studied.

Public policy, from the local perspective, in relation to all the earthquake prediction and response issues, can probably be summed up in two words: **local control.** These are the key words in all our legislative programs. We are constantly telling our Federal and State legislators, "Don't try to take away any of our ability to govern ourselves, to make our own plans, and to pursue our own programs the way we see fit. And, of course, if you require us to do anything, for heaven's sake, pay us for it."

Another public policy issue is public education and awareness. Los Angeles' "long-term" efforts include Earthquake Awareness Week with Yogi Bear and the Quakey Shakey Van. The media is doing an excellent job of covering awareness and education events, and in assembling their own earthquake preparedness programming. A major obstacle is that, in human terms, major earthquakes happen infrequently, giving people the impression that they can live their lives without experiencing a major earthquake. It is a constant battle to keep people interested and aware enough to actually prepare themselves. Another issue that needs to be addressed is public education about a warning for the imminent earthquake--the three-minute warning. A "constructive" public response to a three-minute prediction needs to be determined and planned for accordingly. Again, what and how do we tell people, and how do we reach as many as possible? What will we do to save lives if we have a three-minute warning?

Local government officials must look to cooperative efforts with the scientific community, the media, State agencies, and Federal authorities to arrive at workable answers to these questions.

REFERENCES

Meyer, Nancy, 1985, There are 15,000 earthquakes in this state every year: California Magazine, April 1985, p. 80-86.

U.S. Geological Survey, 1984, Option paper for earthquake prediction strategy: Commentary presented at Southern California Earthquake Preparedness Project Earthquake prediction Workshop, Los Angeles, California, July 1985.

Predicting Major Earthquakes for Preparedness Planning

SUMMARY OF WORKING GROUP IV AND AUDIENCE DISCUSSIONS

This session was moderated by John J. Kearns. Panelists were Homer H. Givin, Jr., Thomas H. Heaton, Ralph H. Turner, and Karen McNally. Joining the panel were speakers from the morning session, John R. Filson, William L. Ellsworth, Keiiti Aki, Robert K. Reitherman, and Shirley Mattingly. James J. Watkins was the session commentator. Questioners and commenters from the audience included Ferne Halgren, Jack Stubbs, Lucile M. Jones, Valerie R. Kockelman, James F. Davis, Stanley J. Roberts, Alvin R. Shasky, and several others who were not identified. The following text was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Givin began the discussion by commenting on the workshop title. He suggested "Earthquake Prediction and Preparedness Planning," noting that whether scientists like it or not, those who apply scientific information are very much involved in any earthquake prediction system in California. A prediction system goes far beyond predicting the event itself, and beyond the physical damage caused by it. Predictions of political, economic, social, other secondary effects, and effects of the prediction itself, are needed. These areas are just as promising and in need of research as the scientific aspects of earthquake prediction. A divided activity must proceed -- physical research on one hand; application research on the other -- and it should not be a serial process that determines how to apply the results of a prediction after it has been determined how to make the prediction. Givin referred to Reitherman's presentation about a prediction planning experiment as an example of a desirable approach. In Givin's opinion, earthquake prediction is a partnership between research and application, and neither should profit at the expense of the other. He favored more work on applications, though not at the expense of research.

Givin suggested that researchers have two obligations. First, particularly in applied research, they need to do everything possible to develop a product that can be readily applied by information users. These users should be involved in the early stages of applied research planning, and the research process should be iterative. The researchers and users together should develop what needs to be done and how the results should be used. Second, researchers should not assume that their results will automatically be useful but rather take positive steps to assure that the results are used.

Heaton discussed how the prediction problem is posed scientifically, and how it is posed in terms of social response. Currently, the charge to the scientific community is to predict the time, place, and magnitude of the next major earthquake. Alternatively, what is the appropriate response of society when given precursory information such as foreshocks, creep, or a new piece of geologic information? He suggested three situations regarding earthquakes: first, there will be earthquakes for which there are no significant precursors; second, there will be earthquakes for which there are significant precursors; and third, there will be changes in seismic activity that will not result in earthquakes. Should such information become available, what intelligent actions should be taken by society? Heaton suggested that it is the scientist's job to recognize when changes occur, and to explain the significance of those changes. The job of the social planners and the rest of society is to educate themselves about what the scientist is saying, and then make an intelligent response.

Turner referred to his publications, **Earthquake Prediction and Public Policy** (National Academy of Sciences, 1975), and **Waiting for Disaster: Earthquake Watch in California** (Turner and others, 1986) and discussed public response to an earthquake prediction. Adequate public response is critical to save lives, and it is critical for support of official action. More research is needed on how to inform the public about the earthquake threat without that information being misread and thereby leading to unforeseen consequences. People tend to take vague or probabilistic statements and read them as either more precise and definite than they were intended, or simply regard them as too vague for action. Turner did not agree with statements made in the morning session about the public's adequate understanding of probability. More research is needed on how to communicate contradictory information, which is inevitably the kind that will come at the time of an earthquake prediction. The evidence is that contradictory information leads to inaction. However, Turner cited results from the 1979 nuclear accident at Three-Mile Island, Pennsylvania, which showed that those people most aware of contradictory information were also the ones most likely to evacuate their homes. Thus, he noted, there are contradictory findings about the consequences of contradictory information, and these must be investigated further and resolved.

There is also a need to know about how to deal with the widespread public suspicion that "They know more than they are telling us." In his study in southern California, Turner found that most people thought scientists and public officials knew more than they were willing to tell the public. The consequence of that reaction is to feed rumor. If the public feels that it cannot get information from official sources, then people will turn to other supposedly authoritative sources, or to non-scientific sources such as their seers. People will also look to their own premonitions, or watch the actions of their pets. Turner called for knowing more about how to satisfy the public's widespread need to understand. He found repeatedly that people were not satisfied to simply take on "authority" that geologic events were going to happen. People wanted to be able to understand and explain these events in their own terms. He suggested, however, that the public's need to understand was a very positive thing; people want to feel that they understand the reason for their actions.

How then can one provide the sense of understanding that people need, and that will facilitate their cooperation with public safety authorities in light of the inherently technical nature of the material? More knowledge about how to translate awareness and concern into action is needed. Turner described fear as a two-edged sword: a little bit of fear enhances the likelihood of action; higher levels of fear tend to reduce the likelihood of constructive action. Most mass media efforts feature the scare tactic, and Turner felt that the usefulness of such a tactic has passed the point of diminishing returns.

In his studies, Turner found that attitudes of fatalism were among the most important deterrents to any kind of preparedness. Behavioral studies have shown that it is more important to clarify manageable steps that people can take than it is to scare them any further. It is also important to support the clarification of manageable steps with facilitation. For example, a neighborhood organization in Berkeley, California alerted people that they should check to see whether their old homes were bolted to the foundation. The organization followed the alert by assisting people in making the examination. This kind of facilitation must be made available to the public.

Turner reiterated his general principle: Once people are generally aware of a problem, concrete and credible suggestions for action are a more effective means of public preparedness than repeated reminders of danger. More knowledge is needed about how to organize and sustain neighborhood preparedness groups. Society cannot have an effective response plan for an earthquake prediction in terms of individual and household safety unless effective neighborhood support groups exist. In general, society has been ineffective in generating those groups. Turner suggested that research is needed to determine situations in which political leaders can assume leadership effectively in the event of an earthquake prediction. The public expects mayors and governors to provide leadership in times of crisis. However, those leaders will not act simply on the basis of scientific warnings, and methods must be found to protect political leaders against the legal-liability and political risks they would take in cases of false alarms or well-intentioned errors.

McNally described her involvement with earthquake prediction and with public planning efforts for response to earthquake prediction through the Southern California Earthquake Preparedness Program (SCEPP) and the California Earthquake Prediction Evaluation Council. She commented favorably on the attendance at this workshop, noting the balance among scientists, planners, and others, and felt heartened about these people and speaking to each other and working together. She had been involved in an earlier conference, "Earthquake Prediction -- A Message from the Earth to the Public," held at Asilomar, California in August, 1985. The theme of that gathering was to remove the divisions between scientists, planners, the press, and others involved in emergency preparedness. She suggested that interested parties review the recommendations of the Asilomar Conference (Southern California Earthquake Preparedness Project, 1985) that pertain to evaluating and responding to earthquake predictions.

McNally also emphasized the importance of terminology in working with the public. A standard terminology is extremely important, and she has worked with James F. Davis, Robert E. Wallace, and public planners, among others, to develop a common language about long-, intermediate-, and short-term predictions. The challenge now is to convince the scientific community and governments to use that terminology.

McNally then discussed the 1985 Mexico earthquake to illustrate some points about communication between the scientific community and the public. Immediately after that earthquake, scientists were explaining the concept of seismic gaps, but at that point the meaning of seismic gaps was almost impossible for the affected people to grasp. After a major earthquake, when scientists say there are still seismic gaps near the earthquake source, what does this mean to people? What can they do about it? Thus, different terminology and clear language are needed for use by scientists when speaking to the public.

McNally discussed the Parkfield, California, earthquake prediction as being borderline between an intermediate-term and a long-term prediction (Bakun and Lindh, 1985; Federal Emergency Management Agency, 1986). There are political consequences to which definition is chosen in such a borderline case. She felt that the state of the art is in intermediate-term prediction; however, it has often been cited that a condition of alert cannot be maintained for the intermediate term of a few years. However, the City of Los Angeles has found that an intermediate-term prediction could be used in terms of doing those things that take longer than several hours to a few days. It is advisable to accelerate certain activities if it is known that an earthquake is only a few years away. When thinking about responding in a time frame of a few hours to a few days, and beginning to apply the steps of responding, it is probable that the execution of those steps will take about two years anyway. By working on response planning in that frame of mind, it would be possible to keep pace with the work of the scientific community.

McNally concluded with an appeal for joint international studies of earthquakes. She stressed that the learning experience based only on California data was too slow because of the long time between major earthquakes. She advocated promoting a sense of kinsmanship with people in those other countries for the furtherance of knowledge about earthquake problems that could be applied in California.

Kearns solicited questions on preparation of a reliable earthquake prediction, and the validation and implementation of that prediction. He queried Turner about the effect of a prediction for a large earthquake in the City of Los Angeles. In Parkfield, he noted, the people are complacent about earthquakes and earthquake prediction. That small community prefers its isolation, and hopes the earthquake prediction will keep the real estate people away. How would one go about announcing a similar prediction for Los Angeles, and what impacts would result?

Turner replied that the Parkfield prediction, with a wide time window and a distant time of occurrence, would not really concern the public very much. Those making earthquake predictions must be much more precise and much more immediate about the time of occurrence if they are to gain public reaction and concern. It is more advisable to talk in terms of risk and general preparedness in a prediction such as Parkfield. People expect something much more precise for a prediction, and will say "We've been waiting, and it didn't happen." Until scientists are close to a short-term prediction, they should speak in terms of areas at risk and the normal precautions people in those areas should take.

An unidentified participant noted that in other parts of the country there are tornado and hurricane watches and warnings, as well as other hazard advisories, and the public seems to be able to handle those. The public seems able to cope, even if the event does not damage their particular area. How would one relate that to the possibility of giving a similar kind of warning or advisory about an earthquake?

Turner replied that he worries greatly about that problem. The public's response to tornado and hurricane warnings is only a partial response. Even after a flood warning, one sees film of people being lifted off their houses by helicopters. These people knew two or three days before the event that there was going to be a flood in the area. The tornado warning, however, is perhaps most effective in getting a desirable response. There is a recurrent tornado season which comes every year, and there is abundant folklore about what happened the previous year, and the years before that. Furthermore, there are external signs by which people can verify the threat by testimony of their own senses. Turner had spent several months in tornado country, and noticed that upon getting a tornado warning, people first ran to their windows to look for the funnel cloud. There is a qualitatively and quantitatively different problem with respect earthquakes. One of the reasons people want so badly to believe in unusual animal behavior as a precursor of earthquakes is their need to verify the threat for themselves.

Reitherman described how the National Weather Service (NWS) has determined ways to predict hurricanes and tornados, and how to express that information to the public in ways that make sense. The NWS casts their announcements in terms of eliciting the proper response from the public. Reitherman felt that the earthquake predictors need to build a record of experience, and to then modify the method of prediction as that experience develops. He noted that the NWS has modified its scientific approaches over time, and has steadily improved its predictions. Also, how the public responds to NWS predictions has evolved over time. Hurricane warnings and the way they are communicated are performed better today than they were 20 years ago. The manner in which local emergency-services officials plan and execute evacuations is superior to that of 20 years ago. The evolution and improvement in NWS predictions comes from dealing with the real problems over time and building from experience a practice of prediction and response. Reitherman liked the idea of calling the Parkfield earthquake prediction experiment an "experiment in emergency planning" as well. Both the scientific and emergency response communities will benefit from more experiments of this type. Of all the things that have affected emergency planning for earthquake prediction, the Parkfield prediction has been the most influential. The situation is real; it motivates people to action; and it begins that necessary record of experience.

Halgren queried Turner about translating information for the benefit of individual ethnic groups. One of the key differences between Japan and southern California is the diversity of ethnic groups in the latter society. Is any research being done on translating information in consideration of groups who have different ways of responding because of their ethnic background?

Turner replied that he didn't know of any such research, and felt that this was a substantial problem. In making comparisons of response mechanisms among Mexican-Americans, Blacks, and Whites, he had found some significant differences. For example, there is far more suspicion of government and far more disbelief in the ability of scientists to predict in the Black community than in the White community. The Mexican-American community has a great deal more faith in government and in scientific predictions. Such differences are very important to the way in which information is announced to the public; however, research in this area is in its infancy.

Filson commented on the scientific meaning of the Parkfield earthquake prediction experiment. It is considered a truly crucial scientific experiment wherein the hypothesis is posed, the experiment is conducted, and the results can be either occurrence or non-occurrence of the earthquake. If the earthquake occurs as predicted, the experiment will be a success. If the earthquake does not occur as predicted, it will have been demonstrated that it is considerably more difficult to make a prediction than was previously believed. The experiment, however, will not have been a failure. The ability or inability to predict an earthquake will have been proven. The experiment will be a failure only if the data obtained were insufficient, the equipment were malfunctioning, or the equipment were insufficient or inappropriately placed. Filson felt comfortable with the way the Parkfield experiment was posed, whatever the outcome.

Stubbs queried McNally and Ellsworth about prior knowledge of seismic gaps near the epicenter of the 1985 Mexico earthquake, and whether that knowledge was shared with Mexican scientists. If so, what preparedness measures or precautions were taken by Mexican officials?

McNally responded that seismic gap analyses are published in scientific journals, and that Mexican scientists were quite knowledgeable about the seismic gaps in Mexico. For United States scientists, as foreigners, it would not have been appropriate to supersede the Mexican scientists and second-guess them by going to their government with such information. The code of ethics of the Seismological Society of America indicates the responsibility of predictors to alert their colleagues in foreign countries about predictions. Transmission of predictive information to authorities is a matter of responsibility and judgment for the local scientists. Whereas there had been no formal announcements about the seismic gaps in Mexico, that information had been in the public domain. This reinforces the need for a common understanding of the term "seismic gap" and what it means in terms of forecasting earthquakes. Currently, there is a keen interest among scientists in examining earlier documents about the existence of seismic gaps in Mexico.

Ellsworth added that in Mexico there are capable seismologists who have contributed very significantly to the literature on seismic gaps in their country. There are experts in Mexico City who are very familiar with international research on seismic gaps. The international scientific community looks to Mexican seismologists for information, just as they look elsewhere. For preparedness considerations, it is a question of encouraging the Mexican government to listen closely to its own experts as well as to scientists elsewhere.

Shasky referred to a specific project in south Los Angeles, and asked the panel about the sources of information used in the design of facilities there. The Los Angeles County Department of Building and Safety had told him that a magnitude 6.5 earthquake within a distance of 15 miles was used for the design of structures. Shasky wondered how that magnitude was determined, and who provided the information? What is the magnitude of earthquake for which buildings in this area should be designed? Shasky felt that the department for which he worked needed to design for a given earthquake magnitude, and was not as concerned about the time or place of an earthquake occurrence. He also described some of his department's preparedness measures, such as a network of automobile radios and decentralized disaster headquarters.

Kearns asked the panel if Shasky was referring to the Newport-Inglewood fault and the San Onofre Nuclear Power Plant. One panelist offered that a local earthquake of magnitude 6.5 is the significant seismic threat in the Los Angeles basin, and is a good design consideration. Reitherman replied that, without regard to specifics about the fault and the site, the question relates to designing buildings in California to resist earthquakes. For most ordinary construction, large-scale seismic zoning is used. A map of the State of California shows the zones which indicate the earthquake magnitude for which structures should be designed (California Administrative Code, 1985). For very important large structures, such as power plants and tall buildings, a site-specific analysis is required. The rules regarding the zone map are derived from an evaluation of faults considered active by the California Division of Mines and Geology (CDMG). Each fault is assigned an earthquake magnitude by a CDMG geologist. The zone maps reflect magnitude and distance from the fault to the site in question. A site within 15 miles of a fault that has been assigned a magnitude 6 is in the most restrictive zone with respect to building standards. Similarly, a site within 25 miles of a fault assigned a magnitude 7 would also be in the most restrictive zone. That zone is called "Zone 4" in the building code. As it happens, everything else in California is in "Zone 3." For most ordinary construction, an earthquake prediction will not make much difference unless the prediction were for an earthquake of greater magnitude than that used to determine the zones, or if the prediction were for a previously undiscovered fault. Buildings now being constructed in Zone 4 should resist the most severe effects ever experienced in any California earthquake in that particular area with no life-threatening damage. This is the thrust of the Structural Engineer's Association of California document, upon which the Uniform Building Code for earthquake design is founded. This discussion summarizes the current status of ordinary building design, insofar as structural engineers are able to meet the requirements for building in Zone 4.

Roberts asked the panel about areas of the world that might be similar to the Parkfield segment of the San Andreas fault. If there are similar situations, might similar experiments be performed to increase the chances of positive results? Here, we are perhaps waiting years for things to happen. Are there other experiments in place? Is national funding needed for studies beyond our own boundaries?

Aki replied that the U.S. Geological Survey has plans for three more experiment sites in southern California. Discussions are also underway regarding experiments on the Cajon-Tejon and Salton Sea segments of the San Andreas fault, as well as on the San Jacinto fault.

McNally replied that scientists in New Zealand are moving closer to a predictive experiment, but are not yet in a real-time predictive monitoring mode. Some of the New Zealand fault systems are similar to those in California. Other than that, only Japan is equipped for prediction experiments similar to the Parkfield experiment.

Heaton responded that Russian and Chinese scientists received great attention in the 1970's for their predictive efforts. The Chinese in particular have made their earthquake prediction program a national priority. However, it is difficult to benefit from their experience because of the political and cultural differences between their society and ours. It is clear, however, that both the Russians and the Chinese have put a great deal of effort into the problem. Some work is also being done in Chile; unfortunately, the scientific community in Chile is small and therefore is not able to provide abundant information on prediction.

Jones noted that the U.S. Geological Survey (USGS) is working with the Chinese State Seismological Bureau in a joint operation in southwestern China. That area has even more earthquakes than California, and it is likely that a magnitude 7 earthquake will be closely observed there before long. Jones was asked by McNally if the USGS-Chinese effort involved real-time monitoring. Jones said yes; various strong-motion instruments and seismic networks are in place.

Ellsworth commented that there are many places in the world where long-term forecasts have been made, and these places presently are all instrumented to some degree. What makes the Parkfield site different from the others is the collection and diversity of instrumentation deployed there. An earthquake in Alaska may be detected before an earthquake at Parkfield, but the best hope for observing a nearby earthquake using a vast array of instrumentation is at Parkfield. With regard to instrumentation at other sites, it is simply a question of money and resources. As Professor Aki indicated, talks are underway for establishing other observational programs in southern California.

Valerie Kockelman asked if there were any heavily instrumented sites in Nevada or Utah.

Ellsworth noted that the National Earthquake Hazards Reduction Program is conducting studies in many regions of the United States. One of these studies involves the Wasatch Front fault zone in Utah and the earthquake hazards there. That program has succeeded in defining the long-term behavior of the Wasatch Front fault and expectations for future earthquakes. Aside from seismographic networks that might detect foreshocks, detailed instrumentation is not in place in Utah. Regional monitoring, wherein instruments are widely spaced, is also the norm for Nevada.

McNally commented to Ellsworth about the meaning of regional monitoring versus the meaning of the Parkfield experiment. The Parkfield experiment involves research into public warning and response, as does the research in Japan. Most other research efforts using regional monitoring are not being actively performed with such goals in mind.

Ellsworth suggested that, if the regional seismic networks are monitored very carefully and if something unusual begins to happen, there would be a chance of notifying the public. Admittedly, it would be something of a long shot, but scientists are looking very carefully at the instrumentation that is in place and on the time scales that are appropriate.

An unidentified participant related an experience from a visit to China. A group from the United States met with the Chinese State Seismological Bureau in April 1985 and found that the Chinese had changed their emphasis from prediction to mitigation. Although they are continuing to work on prediction in southwestern China, a government policy decision was made to direct more resources toward mitigation. Currently, a great deal of money and effort are being put into retrofitting buildings in China.

Davis responded to remarks made by Turner. Perhaps if there is an intermediate-term prediction, public concern will not be so immediate. However, when an experiment is initiated for a short-term prediction, the expectation is that local government should be ready to respond to that prediction. There is such an experiment in progress here in California at Parkfield, and there is a certain immediacy to that experiment.

Kearns noted that the experiment operates not only with instrumentation and the analysis of scientific data, but also with development of a response plan, and perhaps the implementation of that plan.

REFERENCES

Bakun, W.H., and Lindh, A.G., 1985, The Parkfield, California, earthquake prediction experiment in Science: American Association for the Advancement of Science, v. 229, no. 4714, p. 619-624.

Federal Emergency Management Agency, 1986, Short-term earthquake prediction in National Earthquake Hazards reduction Program: Fiscal Year 1985 Activities--Report to the United States Congress: Federal Emergency Management Agency, Washington, D.C., p. 53-58.

California Administrative Code, 1985, Seismic hazard zones: California State Building Code Supplement Part 2, Title 24, 2-2312(m), p. 103-104, 115.

National Academy of Sciences, 1975, Earthquake prediction and public policy: National Academy of Sciences, National Research Council Commission on Public Policy Implications of Earthquake Prediction Report, Washington, D.C., 142 p.

Southern California earthquake Preparedness Project, 1985, Earthquake prediction evaluation warning and response system workshop: Proceedings, SCEPP Asilomar Conference Center, Los Angeles, Calif., 43 p.

Turner, R.H., Nigg, J.M., and Paz, D.H., 1986, Waiting for disaster--earthquake watch in California: University of California Press, Berkeley, Calif., 446 p.

page 285 follows

V. EVALUATING EARTHQUAKE GROUND-FAILURE POTENTIAL FOR DEVELOPMENT DECISIONS

V. EVALUATING EARTHQUAKE GROUND-FAILURE POTENTIAL FOR DEVELOPMENT DECISIONS[1/]

Working Group Moderator:	Richard Spicer
Plenary Presenter:	G. Wayne Clough
Working Group Presenters:	John C. Tinsley I.M. Idriss Raymond C. Wilson David Doerner Arthur G. Keene
Working Group Panelists:	F. Beach Leighton J. Laurence Mintier William J. Petak
Working Group Commentator:	Frank Hotchkiss
Audience Participants:	Robert Holtom Charles G. Suddath Michael Scullin James E. Slosson Bernard W. Pipkin

1/ Names and affiliations of all participants are listed alphabetically in Appendix A.

An important ordinance governing requirements for constructing buildings in areas subject to soil liquefaction is discussed on pages 378 to 381 of this volume.

EVALUATING EARTHQUAKE-INDUCED GROUND-FAILURE POTENTIAL — FUTURE TRENDS FOR RESEARCH

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INTRODUCTION

Earthquake-induced ground failure is a term which conjures visions of landslides, dam failures, and liquefaction, problems which usually include large deformations of the near-surface soil or rock materials. The subject may well relate also to limited deformation situations which can lead to results that are not catastrophic, but serious to emergency operation of lifelines or to the long-term functions of public facilities. For example, a two-foot shift of a bridge abutment may lead to the temporary impairment of traffic flow for a critical period. In another case, a one-foot movement in the backfill of a retaining structure for a drainage network may cause serious problems in regard to the ability of the structure to pass water, if the structural concrete is cracked. Thus, the term "ground failure" is a broad one, encompassing phenomena which are apparent to all, as well as those only noticeable to the expert.

It is difficult to do justice in only a few pages to the subject of recent research and research needs for a field as large as that of earthquake-induced ground failure. Fortunately, our knowledge about this subject has benefited from a series of state-of-the-art and overview reports (table 1), and it is not necessary for this writer to attempt an exhaustive survey. Considerable information is drawn by this writer from the reports listed in table 1. Also, it is notable that in U.S. Geological Survey Professional Paper 1360 contains a number of excellent papers present examples of new technology for general ground-failure potential assessment and applies the same to southern California situations (Tinsley and others (1985); Wilson and Keefer (1985); and Clarke and others (1985). These latter articles amply illustrate that the potential exists for liquefaction and slope failures to occur in future earthquakes in southern California, and that such problems are likely to be the cause of a significant percentage of the property damage.

To reduce hazards from the expected ground failures requires that both basic and applied investigations be done. In some cases this may mean using the existing state of the art to define the potential impact of ground failure, while in others, long-term research may be needed to develop improvements so that the problem can be addressed. Both categories of studies are addressed herein.

Table 1. Recent state-of-the-art and overview reports on seismically induced ground failure

1. Committee on Earthquake Engineering, "Liquefaction of Soils During Earthquakes," Report for MIT Workshop, National Academy Press, Washington, D.C., 1985.

2. Idriss, I.M., "Evaluating Seismic Risk in Engineering Practice," Proceedings, 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Vol. 1, 1985, pp. 255-370.

3. Ishihara, K., "Stability of Natural Deposits During Earthquakes," Proceedings, 11th International Conference on Soil Mechanics and Foundation Engineering, San Francisco, Vol. 1, 1985, pp. 321-376.

4. Keefer, D.K., "Landslides Caused by Earthquakes," Geological Society of America, Vol. 95, 1984, pp. 406-421.

5. Seed, H.B., Idriss, I.M., and Arango, I., "Evaluation of Liquefaction Potential Using Field Performance Data," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 3, 1983, pp. 458-482.

DEFINITION OF HAZARD DUE TO GROUND FAILURE

Since this conference concerns hazards of earthquakes, the subject of ground failure in itself is not necessarily of interest. What is significant regarding hazard is the effect of the ground failure. For example, Youd (1971) describes the significant damages and problems caused by the Juvenile Hall landslide in the 1971 San Fernando earthquake. If this slide had occurred in an unoccupied area, it would have presented no serious hazard. It is therefore incumbent upon us to establish the potential impact of ground failure on human habitations, businesses, and other functional structures. Questions which should be established in regard to a potential slope failure are:

- Are many residences or commercial structures in its path, and if so, how many?

- Will the debris cover a roadway, and if so, how much?

- Can the slide undercut a roadway, and if so, are there segments of population which will be isolated?

- Can the slide debris fall into a reservoir and generate an overtopping wave?

- Can the slide damage water, sewage, power, or gas lines?

Obviously, this list can be extended, and related types of questions also need to also be asked concerning other ground failure categories in assessing hazards.

Another broad issue related to hazard assessment in regard to ground failure is the level of tolerable movement. For example, the soil mass which forms a road embankment may be able to move one foot and cause no impairment of function. At the same time, this level of displacement in a retaining structure backfill may lead to serious consequences. This general area might well be titled "establishment of a failure criterion."

Simply put, in order to reduce a hazard, we must know if there is one, and determine the limits beyond which it will or will not exist. It is important to the southern California area, and others as well, that a ground-failure hazard-assessment effort be undertaken, particularly as regards lifelines. To the writer's knowledge, no such comprehensive study has been made. In most instances this can be done with present technology as described in the excellent paper by Idriss (1985). Refinements can also be developed in the future as the state of the art improves. An initial basis for areas to focus upon could be derived from the work presented by Tinsley and others (this volume) and Wilson and Keefer (this volume).

RESEARCH NEEDS—MANMADE SLOPES AND FILLS

Manmade slopes exist in the form of dams, embankments for roadways, dikes, etc., and fills for housing and commercial developments. While dams have received considerable attention in the literature, the other categories of manmade slopes largely remain to be studied. The latter category is particularly important in southern California where massive cut and fill operations are common in residential development. Further, these cuts and fills have yet to be subjected to a major earthquake, and there is little history to examine for expected behavior. A number of questions need to be answered, including:

- Does cut and fill topography affect ground motion patterns?

- Is there a chance for sliding along the fill natural slope interface?

- If the fills will not fail, what levels of movement might be expected?

- Are the present code limits on compaction of fills adequate for earthquake resistance?

- What is the impact of moisture level on response of the fills to earthquake loading?

In addition to the cut and fill problem, further research is needed into the subject of stability of fills and dikes for major waterways and waterfront structures under earthquake loading. Numerous examples of failures of such systems can be found in the literature, and Pyke, Knuppel, and Lee (1978) cite evidence for liquefaction failures in harbor facilities in the 1933 Long Beach earthquake. Issues of interest are:

- Response of anchored bulkheads.
- Prediction of behavior of fills over soft soils.
- Liquefaction analysis for soils beneath fills.

RESEARCH NEEDS—NATURAL SLOPES

Natural slope failures are common in the southern California area due to static loading, and examples of failure under seismic loading also exist. Ishihara (1985) notes in his state of the art that the subject of natural slopes subjected to earthquakes has not received adequate study. Indeed, while we can identify general areas where slope failures are likely, the present technology is not satisfactory when it comes to predicting whether a particular slope would fail due to a particular earthquake. Subjects in this area which need to be addressed are:

- Response to seismic loading of partially saturated natural soils and rock aggregates with differing degrees of moisture.
- Possibility of reactivation of old landslide masses.
- Levels of cyclic movement which lead to disaggregation of soil and rock masses.
- Degree of movements which can be induced in an earthquake-activated landslide mass by other, subsequent natural phenomena such as heavy rainfall.
- Methods of properly assessing the in situ strength of slope materials.
- Methods to incorporate topographical effects on ground motions into stability analyses.
- Relationship between earthquake-induced slope failures and seasonal rainfall distribution.
- Case history studies of slope failures where possible.

RESEARCH NEEDS—LIQUEFACTION

Liquefaction is generally understood as the process of a saturated soil changing from a solid to a fluid condition as a result of excess pore pressures caused by dynamic or static loading. It is most prominently associated with the effects of seismic events and has been studied extensively (Committee on Earthquake Engineering, 1985). In spite of the amount of work done to date on this subject, there are issues for which we have only limited knowledge. Areas requiring further study are delinated in the Committee on Earthquake Engineering (1985) and Ishihara (1985); those given the greatest emphasis are:

- Response of "dirty", gravelly, and cemented sands.
- Proper testing procedures to identify liquefaction potential, particularly in the presence of "dirty", gravelly, or cemented sands.
- In situ measurement of lateral stresses, especially in projects where site-improvement techniques have been used to reduce liquefaction potential.
- Methods to predict permanent deformations in cases where full liquefaction does not occur.
- Methods to assess liquefaction potential beneath structures.
- Development of information on liquefaction phenomena through continued case-history studies of recent and historic events.

CONCLUSIONS

Ground failures due to past earthquakes have caused loss of life and extensive property damage in southern California. There is no reason not to expect similar results in future earthquakes unless research investigations are performed to identify the hazards and avenues for hazard mitigation. There is considerable room for hazard assessment in southern California using the present state of the art. Also, further long-term research is needed in all categories of ground failure mechanisms during seismic loading.

REFERENCES

Clarke, S.H., Jr., Greene, H.G., and Kennedy, M.P., 1985, Identifying potentially active faults and unstable slopes offshore in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 347-373.

Committee on Earthquake Engineering, 1985, Liquefaction of soils during earthquakes: Report for Massachusetts Institute of Technology Workshop, National Academy Press, Washington, D.C., 240 p.

Idriss, I.M., 1985, Evaluating seismic risk in engineering practice, in International Conference on Soil Mechanics and Foundation Engineering, 11th, San Francisco, Calif., 1984, Proceedings, v. 1, p. 255-370.

Ishihara, K., 1985, Stability of natural deposits during earthquakes, in International Conference on Soil Mechanics and Foundation Engineering, 11th, San Francisco, Calif., 1984, Proceedings, v. 1, p. 321-376.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

Pyke, R.M., Knuppel, L.A. and Lee, K.L., 1978, Liquefaction potential of hydraulic fills: American Society of Civil Engineers, Journal of the Geotechnical Engineering Division, v. 104, no. GT11, p. 1335-1354.

Seed, H.B., Idriss, I.M., and Arango, I., 1983, Evaluation of liquefaction potential using field performance data: American Society of Civil Engineers, Journal of the Geotechnical Engineering Division, v. 109, no. 3, p. 458-482.

Tinsley, J.C., Youd, T.L., Perkins, D.M., and Chen, A.T.F., 1985, Evaluating liquefaction potential in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-315.

Wilson, R.C., and Keefer, D.K., 1985, Predicting areal limits of earthquake-induced landsliding in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 317-345.

Youd, T.L., 1971, Landsliding in the vicinity of the Van Norman Lakes, in the San Fernando, California, earthquake of February 9, 1971: U.S. Geological Survey Professional Paper 733, p. 105-109.

IMPROVING PREDICTIONS OF LIQUEFACTION POTENTIAL

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INTRODUCTION

Ground failures owing to liquefaction of subsurface sediment have been a major cause of damage during past earthquakes in southern California and pose considerable potential for damage and injury during future shocks. During the 1971 San Fernanado earthquake, for example, liquefaction-induced ground failures of the lateral spread type caused irreparable damage to several buildings at the San Fernando Valley Juvenile Hall and caused major damage to the Jensen Water Filtration Plant which was then under construction. The 1933 Long Beach earthquake caused liquefaction-related ground failures near Seal Beach, Long Beach, and Compton. As part of the U.S. Geological Survey's (USGS) earthquake-hazard reduction program in southern California, maps are being prepared that show areas of the Los Angeles region which have the greatest potential to suffer damage owing to liquefaction and ground failure during future earthquakes.

The procedure that has been used to compile the maps requires the compilation of two component maps, a susceptibility map and an opportunity map. A liquefaction susceptibility map shows areas that contain sediment which may be susceptible to liquefaction. The liquefaction opportunity map expresses the likelihood that earthquakes will cause shaking strong enough to cause liquefaction in susceptible materials. These maps are considered together to show liquefaction potential. The procedure that was used is similar to that of Youd and others (1978) and extends the small-scale maps previously produced for the San Fernando Valley to most of the remainder of the Los Angeles region, including the upper Santa Ana Valley and Oxnard Plain areas. The techniques used for making these maps are described in Tinsley and others (1985) and are slightly modified from the techniques used Youd and others (1978) and Youd and Perkins (1978).

LIQUEFACTION SUSCEPTIBILITY MAPS

Susceptibility maps are compiled in the following way: judging from historical occurrences of liquefaction, it is clear that liquefaction typically affects a relatively narrow range of sediment particle sizes--medium-to-fine sand and silt are the sediment types most often affected--and that these sediments are associated with a rather narrow range of depositional and hydrologic environments. In practice, regional liquefaction susceptibility maps are generalized, and reflect the relative likelihood that liquefiable layers of sediment are present. Detailed geotechnical investigations that are beyond the scope of a regional study are required to determine the actual presence, extent, and in situ susceptibility of liquefiable materials at specific sites.

Deposits most likely to contain liquefiable materials are those formed during the past few hundred years to about one thousand years ago (latest Holocene), and to a lesser likelihood, those formed during the last 10,000 years or so (Holocene) that are below free ground water levels. Pleistocene deposits (formed between 10,000 and 1.7 million years ago) are not likely to liquefy. The deposits have been mapped using criteria commonly employed for the analysis of Quaternary sedimentary basins. These criteria include soil profile development, patterns of historical flooding and resulting flood deposits, the relative density of the sediment as determined from penetrometer tests, and the depth to free or perched ground water. Maps showing depth to free ground water (including perched ground water) have been compiled from numerous records maintained by government agencies and from spot observations as noted in reports and studies conducted by governmental agencies and private consultants. The susceptibility to liquefaction depends critically on the depth to groundwater. The development of the ground water basins of the Los Angeles region since the late 1800's and early 1900's has caused ground water levels in most areas to be lowered to the point that liquefaction risks are greatly reduced or effectively eliminated as an earthquake hazard. The historical high ground-water levels used to make liquefaction susceptibility maps do indicate what the areas of risk might be if management practices change or if the region is subjected to seasonal precipitation levels that are far above average for several successive years. Liquefaction susceptibility maps that show areas most likely to suffer liquefaction during future earthquakes include parts of floodplains of the major streams such as the Los Angeles, San Gabriel, Santa Ana, Santa Clara and Ventura Rivers. Also shown on liquefaction susceptibility maps are areas situated near flood control basins and associated ground-water percolation/recharge facilities, and areas within and near present and former coastal marshes, dune areas, and beaches.

LIQUEFACTION OPPORTUNITY MAPS

Liquefaction opportunity maps show how often earthquakes occur that are strong enough to cause liquefaction in susceptible sediment. These maps are compiled using a technique that combines a model of the earthquake-generating behavior of the principal seismic source zones (fault zones) of southern California, and an empirical correlation that relates opportunity for liquefaction to earthquake magnitude and distance from the seismic energy source. In the present study, we used the seismogenic zone maps and probabilistic model compiled by Thenhaus and others (1980), and a correlation that relates earthquake magnitude to the greatest distance at which liquefaction has been observed during historical earthquakes as interpreted by Youd and Perkins (1978). The result is a map (figure 158 in Tinsley and others, 1985) showing expected recurrence intervals of shaking intensities strong enough to cause liquefaction in highly susceptible sediment. The estimated recurrence intervals generally decrease with distance from the San Andreas fault zone, with some local variations owing to major fault zones such as the Santa Susana, Sierra Madre, and Cucamonga fault zones, and the Newport-Inglewood zone. These intervals range from about 30 years in parts of the Los Angeles basin nearest to the San Andreas fault to as much as 45 to 60 years in some of the more distant coastal areas.

IMPROVING REGIONAL PREDICTIONS OF LIQUEFACTION POTENTIAL

Improved approaches to making regional maps showing the relative likelihood of liquefaction (liquefaction potential) that have implications for southern California are likely to emerge from several ongoing studies. Perhaps the greatest improvements are likely to emerge from (1) studies to improve understanding of the hydrology of shallow bodies of ground water, and (2) studies to improve knowledge of the relative density and the relative abundance and distribution of saturated cohesionless sediment within areas of shallow ground water. Alternate approaches to the problem of predicting liquefaction opportunity have some promise as well, and these include sophisticated appraisals of the likelihood of earthquakes and an empirical method for eliminating liquefaction severity, the latter being the probable magnitude of ground failure displacements, should liquefaction occur. In the following paragraphs, we briefly describe these alternatives and mention some of their merits and demerits. These approaches, however, are not likely to obviate the need for site-specific evaluations of liquefaction potential at a particular location.

It is axiomatic that if one can eliminate the water from the sediment, then the liquefaction hazard is also eliminated. Owing to the nature of the ground-water data base that was used in evaluating liquefaction potential as published in USGS Professional Paper 1360, additional studies of the occurrence of shallow ground water might prove illuminating. Exclusive of ground-water recharge operations and interjection-barrier operations, the monitoring of shallow occurrences of ground water in the Los Angeles region is virtually nonexistent. The monitoring program carried out by local and State agencies is designed to prevent conditions of overdraft from deeper water-bearing layers that contain potable water; it is not concerned with shallow aquifers or perched water occurrences that often contain non-potable water. Consequently, it would be desirable to know more about the occurrences of shallow and/or perched ground water. We know that areas characterized by shallow ground water exist, because ground water was encountered during drilling of exploratory boreholes. Yet, we don't know if ground water persists year-round in many of these areas, or if not, how often it does persist, or how much precipitation is required to produce saturated conditions in cohesionless sediment within these areas. Conceivably, additional study of the hydrology of selected areas of shallow ground water could result in identifying a lesser degree of risk for an area in which deposits of loose sands were saturated only for a period of days or weeks following heavy rains, compared to an area in which loose sands were perpetually saturated. It might also turn out that the area could be drained of most of the ground water, thus appreciably reducing the risk of liquefaction. A comment pertaining to the practicalities of such monitoring seems in order. It can be difficult to obtain reliable data in a short time, even if a monitoring program could be instituted, owing to the discontinuous nature of sandy and clayey beds that cause the shallow or perched water conditions. Dewatering may or may not be a feasible alternative.

Within some areas, site-specific studies can discern the relative abundance of potentially liquefiable sediment beneath a site. Perhaps the beds of sand or silt are too thin to allow significant settlement to occur that could damage a lifeline or other critical structure. Perhaps liquefiable sediment is not present beneath the site. Increasing use of the cone penetrometer may make it feasible to study sites rapidly, using closely spaced arrays of holes. Perhaps ground-penetrating imaging or related techniques can be further refined and applied to the problems of locating sand-filled channels of buried streamcourses that are known to lace the subsurface of sizeable areas containing shallow ground water such as the Reseda area in the San Fernando Valley. Such scanning, if proven feasible and practical, might possibly guide a detailed sampling program (if it were advisable to test the liquefaction susceptibility of the sediment beneath a site), or such scanning might permit giving "a clean bill of health" to a site because the site does not contain liquefiable sediment. These investigative techniques will require additional research and development. Presently, ground-penetrating radar apparatus is impaired by the presence of wet sediment, and high-resolution seismic reflection profiling is of little value in identifying targets at depths less than about 20 feet beneath the surface, owing to the obscuring effects of surface waves.

It may be desirable to increase the sophistication of our seismic recurrence models so that they better reflect or model the "real hazard." What does this mean? For example, the earthquake recurrence model devised by Thenhaus and others (1980) that was used in Tinsley and others (1985) presumes that the likelihood of an earthquake strong enough to cause liquefaction in highly susceptible materials is effectively the same from one year to the next. This Poisson-type model which treats earthquakes as random events is reasonable if we don't know anything special concerning earthquake recurrence on the various faults of the region. If we consider the San Andreas fault however, we know from an historical perspective that the risk from liquefaction-related ground failure was really much greater just prior to the 1857 earthquake than it was immediately thereafter. This is another way of saying that we might consider using our emerging knowledge of earthquake recurrence, whether based on geologic slip rate, historical seismicity, or both in ways that may better portray the hazard. Thus, alternatives to a model that treats earthquakes as randomly occurring events in space and time may well come of age. One possibility is the characteristic earthquake model, which has been shown to be a reasonable concept for certain fault zones such as the Wasatch fault zone in Utah. According to the characteristic earthquake model, earthquakes of about the same magnitude recur on a fault and generate ruptures which have about the same amount of displacement each time. If a fault were to produce only small earthquakes, the geographic area in which the fault contributes to the region's annual probability of an earthquake might be much smaller than one might expect from empirical considerations of fault length, or from some other relation commonly employed to predict the likely magnitude size of earthquakes. The applicability of the concept to other types of faults, and indeed, to any specified fault, must be determined in each instance.

Another consideration for refining predictions of liquefaction might be to identify a site-location intensification effect, that is, a condition owing to the seismic-wave propagation characteristics of the sediment. This results in a geometric effect that involves thinning or shoaling of sediment, or a site-dependent effect such as "valley ringing" that might be important at a regional scale. As our knowledge of site effects improves, site effects may be perceived as potential triggers for liquefaction effects, as well as local intensifiers of earthquake ground motion that would be of interest to those designing earthquake-resistant structures.

Another improvement in evaluating regional liquefaction hazards may come from studies by T. L. Youd and D. M. Perkins, who are devising a means to map a quantity termed "Liquefaction Severity Index" (LSI). They hope to address a shortcoming inherent in the present generation of liquefaction maps, which show only the likelihood of liquefaction but give no indication of the severity of the ground effects that might accompany an episode of liquefaction. This is because it is not possible to analytically assess the amount of ground deformation likely at liquefaction sites in various geologic settings. Observations of ground failures caused by liquefaction during past earthquakes show that the amount of ground displacement tends to decrease as the distance from the seismic source increases and as the magnitude of the earthquake decreases. Because LSI is a measure of ground displacement (the most damaging consequence of liquefaction), an LSI map would provide an indication of the hazard associated with liquefaction. By giving a direct estimate of maximum expectable displacement of lateral spreads (the most common ground failure associated with liquefaction) for gently sloping, late Holocene floodplain, deltaic, and other sedimentary deposits (the most common natural materials susceptible to liquefaction), we may be able to improve estimates of severity and damage owing to liquefaction. Looser granular materials (most commonly occurring as uncompacted sand fills) will likely have larger displacements than the present studies would predict; denser materials, such as older floodplain and other deposits, will likely have lesser displacements. More research is required to quantify the empirical displacement relations for the looser and denser materials. A logarithmic relation predicting displacement, according to distance from seismic source and earthquake magnitude, would have to be redefined for each part of the world in which one sought to apply it, because attenuation relations are not the same for the eastern United States as for California, for example.

REFERENCES

Thenhaus, P.C., Perkins, D.M., Ziony, J.I., and Algermissen, S.T., 1980, Probabilistic estimates of maximum seismic horizontal ground motion on rock in coastal California and the adjacent outer continental shelf: U.S. Geological Survey Open-File Report 80-924, 36 p.

Tinsley, J.C., Youd, T.L., Perkins, D.M., and Chen, A.T.F., 1985, Evaluating liquefaction potential, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-315.

Youd, T.L. and Perkins, D.M., 1978, Mapping liquefaction-induced ground-failure potential: Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, v. 104, no. GT4, p. 433-446.

Youd, T.L., Tinsley, J.C., Perkins, D.M., King, E.J., and Preston, R.F., 1978, Liquefaction potential map of San Fernando Valley, California: Proceedings, International Conference on Microzonation, 3rd, Seattle, Wash., p. 267-278.

IMPROVING PREDICTIONS OF EARTHQUAKE-INDUCED LANDSLIDES

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INTRODUCTION

Earthquake-induced landslides have caused tens of thousands of deaths and billions of dollars in losses worldwide during the present century alone. In fact, for many earthquakes, the damage resulting from landslides has equalled or exceeded damage due to other effects of seismic shaking. In the 1964 Alaska earthquake, for example, landslides caused $280 million of the total $500 million damage. All 28 deaths reportedly caused by the 1959 Hebgen Lake, Montana, earthquake were due to landslides; 26 of these occurred in the rock avalanche that buried a campground in Madison Canyon (Hadley, 1964; 1978).

The Los Angeles region, because it is both mountainous and seismically active, faces a potential hazard from earthquake-induced landslides. Parts of the region contain topographic, geologic, and seismologic conditions that are nearly optimum for producing earthquake-induced landslides. A large population dwells among steep slopes and deep narrow canyons in the eastern Santa Monica Mountains. Other areas at risk include uplands such as the Baldwin Hills, Puente Hills, Palos Verdes Hills, San Rafael Hills, canyons in the Verdugo Mountains, and the foothill areas of the San Gabriel, Santa Ana, and San Bernardino Mountains.

Wilson and Keefer (1985) present a new method for predicting the areal limits of various types of landslides triggered by large or moderate earthquakes. The method is based both on empirical studies of landslides that developed during historical earthquakes and on a numerical analysis of slope stability that links the probability of a slope failure with levels of ground motion.

Landslides are characterized by differences in type of movement, degree of internal disruption, water content, velocity, depth to the plane of failure, and whether they occur in rock or in soil. The most abundant landslides that have occurred during historical earthquakes were rock falls, disrupted soil slides, and rock slides, all of which are shallow, internally disrupted, and detach from steep slopes. These landslides are especially susceptible to initiation by earthquakes, and the geologic environment that produce them are widespread in earthquake-prone regions. In addition to rock falls, two less common types of landslides -- rock avalanches and rapid soil flows -- have been the leading causes of landslide-related deaths in earthquakes. The latter two types of landslides are particularly hazardous because they commonly move long distances at high velocities. In addition to rock avalanches, rapid soil flows, and rock falls, soil slumps and soil lateral spreads are leading causes of property damage among earthquake-induced landslides, because they occur on gentle slopes and in manmade fill where human development is common.

The probability of a landslide occurring on a particular slope during a particular earthquake is a function of both the pre-earthquake stability of the slope and the severity of the seismic ground motion. The pre-earthquake slope stability is controlled by the strength of slope materials, the ground water conditions, and the steepness of the slope. The combinations of slope and lithology, which are particularly vulnerable to earthquake-induced landsliding have been determined by study of historical landsliding (Keefer, 1984), by experience in post-earthquake investigations, and by numerical modeling. Another way to express the susceptibility of a slope to seismically induced landsliding is critical acceleration, **Ac**, which may be calculated from the static factor of safety as determined by standard slope-stability analysis.

The severity of the ground shaking required for earthquake-induced landsliding has been investigated using both empirical data from historical earthquakes and a numerical technique developed by Newmark (1965). The Newmark analysis uses static slope stability and a seismic strong-motion record as inputs; thus slope stability can be linked to ground motion. The Newmark analysis computes the displacement of a rigid friction block which is used to represent a potential landslide on the slope being studied. We define "critical displacement" as that beyond which the slope can be considered to have failed and produced a landslide; we have assigned values of 10 cm and 2 cm as the critical displacements for coherent and disrupted landslides, respectively. The severity of seismic shaking required to cause coherent slides is thus defined as that which, according to the Newmark analysis, would produce a displacement greater than 10 cm on a slope with a given critical acceleration value **Ac**. Thus, the severity may be expressed as $(\mathbf{Ac})_{10}$.

IMPROVING PREDICTIONS OF EARTHQUAKE-INDUCED LANDSLIDES

Several avenues of investigation suggest fruitful means to expand and improve upon the methods of predicting seismically induced landslides outlined in Wilson and Keefer (1985) include:

- o Expansion of the methodology to include analysis of other parts of the Los Angeles region and other areas in the world, comparing the predicted distribution of seismically induced landslides against observations made during past earthquakes.

- o Improving our knowledge of, or the ability to characterize, the cohesiveness of potential slide masses in the field. Very little is known about cohesion, yet this variable controls much of the variance inherent in stability analyses.

- Hydrologic effects, including seasonal precipitation thresholds which, if exceeded, will result in slope failures, need to be better determined and require additional study. Indeed, seismic slope stability will shift towards lower thresholds of failure as moisture content of the soil increases, yet it is exceedingly difficult to map this parameter in the field.

- Much additional knowledge is needed concerning dynamic pore-pressure effects, especially for hillslope materials subjected to earthquake loading. Instrumentation is in place in several parts of the world to try to record time histories of change in pore pressure both on slopes and in gently sloping terrains subject to lateral spreads or other liquefaction-related types of ground failure.

- From past investigations of seismically induced slope failures, we have been able to identify a limit beyond which slope failures are unlikely for a given earthquake, and a mean line representing what is most likely or expected. However, future studies should concentrate on learning more about the pattern of distribution of seismically induced landslides, and how that pattern changes with distance from source and magnitude of earthquake.

REFERENCES

Hadley, J.B., 1964, Landslides and related phenomena accompanying the Hebgen Lake earthquake of August 17, 1959, in U.S. Geological Survey Professional Paper 435, p. 107-138.

Hadley, J.B., 1978, Madison Canyon rockslide, Montana, USA, in Voight, B., ed., Rockslides and avalanches, natural phenomena: Elsevier Scientific Publishing Company, New York, v. 1, p. 167-180.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

Wilson, R.C., and Keefer, D.K., 1985, Predicting areal limits of earthquake-induced landslides, in Ziony, J.I., ed., Earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Professional Paper 1360, p. 317-345.

SOME SUGGESTED IMPROVEMENTS TO THE SANTA BARBARA COUNTY SEISMIC SAFETY AND SAFETY ELEMENT

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In order to comply with the California Government Code, section 65302(f), the County of Santa Barbara ordered the preparation of a seismic safety element as an additional element of the County Comprehensive Plan. The Seismic Safety Element was prepared by five geological-engineering consulting firms, who were advised and assisted by several County and university geologists, and obtained much information from Federal, State, County, and city agencies and districts. Seven advisory committees, under the supervision of Britt Johnson, County Planning Director, contributed direction and advice during the preparation of the first edition, which was published in July 1974.

The stated purpose of the seismic safety element was to obtain data and to provide recommendations to aid long-range land-use planning and to ensure that future development would be compatible with the environment. However, as a County guideline in terms of geological hazards and general safety considerations, the seismic safety element has proved to be much more than just a guide for long-range planning. It is a tool of special importance to consulting geologists and engineers, developers and their agents, and to individual members of the community who propose development on their property. In some ways, environmentalists regard the seismic safety element as their special province, but it is used in many county agencies simultaneously.

Much of the environmental protection is the result of forewarning and early planning. Thus, the seismic safety element document provides a good set of guidelines for protection from environmental hazards, with its strongest asset being its clear, understandable language. Intended as a guideline for somewhat technically oriented persons, the style and simplicity of its written text allows any interested person to understand the technical material. It is an educational boon to the nongeologist.

The second printing of this seismic safety element, adopted January 22, 1979, is the document currently in use by the County of Santa Barbara. This second printing also incorporated a fire and flood safety element into the Seismic Safety Element, and the document became the Seismic Safety and Safety Element. It is virtually a reprint of the original, but at a smaller scale. The 1979 edition reduced the original 11 x 14-inch pages and 14 x 30-inch foldout maps to 8½ x 11-inch pages and maps. It sells at the County Planning Office for $12.64 (including tax) or for $13.50 (including mailing; 1986 prices).

The Seismic Safety and Safety Element for the County of Santa Barbara contains 207 pages of text and tables and 49 pages of maps. An introduction and a comprehensive abstract of the geologic and seismologic material is presented in three sections: the general geography and geology of the County; geologic and seismic hazards; and conclusions and recommendations. The chapter on geography and geology is especially slanted toward the lay person; it contains a very small-scale but educational geologic map of the County, as well as a discussion of areas of special geologic interest. The final chapters of the Seismic Safety and Safety Element deal with fire hazards, flood control, and provide an appendix which contains a glossary of terms, a reference list, and an extensive general bibliography.

The section on hazards includes: a geologic problem index; a very good and easily understood section on the fundamentals of seismology; a brief seismic history of the County; and a description of all named faults in the County, classified as inactive, potentially active, active, and historically active. The remainder of the chapter on hazards deals with tsunamis, liquefaction, slope stability, soil problems, high groundwater, erosion, shoreline regression, and subsidence.

The chapter containing conclusions and recommendations is directed more toward the planner. Severity-of-impact categories, a geologic-problems index, land-use planning, subdivision procedures, grading codes, and building codes are included to assist the professional planner in integrating basic earth-science data into the long-range planning process.

The maps for each hazard, which form the heart of the Seismic Safety and Safety Element, are crucial to any application of this data to long-range planning. The maps include a single County-wide map and sets of maps representing five areas of Santa Barbara County: south coast east; south coast west; Santa Ynez Valley; Lompoc; and Santa Maria-Orcutt. However, the small scale of these maps make it difficult to locate specific boundaries of hazard areas. This was not intended but is a result, in part, of the original publication scale being reduced in the second printing (1979) due to economic constraints.

This eleven-year-old document has stood the test of time quite well and is still used daily by many County agencies and the general community. After this amount of use, however, it would be a miracle if some possibilities for improvement did not become apparent. Among the suggestions for improvements to the Seismic Safety and Safety Element which have surfaced over the past eleven years has been the presentation of seismotectonic maps at a much larger scale. This would improve their interpretation at a parcel-specific level, increase their use by geological and engineering consultants, and contribute to the understanding of the maps by nontechnical users. An ideal presentation of the seismotectonic data would be on USGS 7½-minute topographic quadrangles. This set of 20 or more maps could be sold separately as a supplement to the Seismic Safety and Safety Element. It would also be practical to include the geologic map in the same set.

An interesting note is worth adding. All of the geologic quadrangles mapped by Thomas W. Dibblee in Santa Barbara County are presently being edited for continuity and will be published for sale by a non-profit consortium of geologists and geological institutions in Santa Barbara County. This five-year program to publish the Dibblee geologic maps at 1:24,000 scale may provide a mechanism by which the suggested improvement to the Seismic Safety and Safety Element could be realized. At this time, two of these quadrangles at the southeast corner of Santa Barbara County have been published. Twenty-eight more quadrangles along the south coast of the county and the paired set along the Santa Ynez Range are ready for publication in 1986. The balance of the proposed 150 quadrangles in Santa Barbara and Ventura Counties will be published as funding becomes available over the next five years.

There would be little benefit to simply enlarging the scale for other hazard categories considered in the seismic element maps. However, even at their present scale, some improvements can be suggested. For example, the tsunami-hazard map could more clearly show potential tsunami inundation by simply illustrating the forty-foot contour behind those coastlines which are conservatively considered susceptible to tsunamis runup because they do not have a 15-foot seacliff barrier.

The problem rating index seems more complicated than necessary for the other geologic problems illustrated on the Seismic Safety and Safety Element maps, such as liquefaction, slope stability, soils problems, high groundwater and the generalized geologic problems index. Some of the details are lost due to the reduced scale of the maps. A simplified rating system, standardized for all the categories, may be more easily understood and applied to the planning process. Geologically speaking, all of these categories are so generalized that no useful technical information can be retrieved from them on a parcel-specific basis. A standard hazard rating of low, moderate, and high could be used for all of these categories, recognizing that this would constitute a generalization for a broad geographic area, and would indicate only that further site-specific study is needed.

A second suggested improvement for the Seismic Safety and Safety Element is the adoption of a specified method for assimilating refinements, corrections, or new information as it becomes available. This should apply to both the tabular and the map data. Especially important is the addition of new information on the fault maps, as well as adjustments to the inactive/active status of named faults on the classification table. A formal definition of each hazard in the text, including the assignment of responsibility for management of the hazard to a County agency or person seems called for. A great deal of technical information passes through the County's files in the permit approval process; an information-collection scheme should include a method or review process which would assess and validate the data before it could be assimilated into the Seismic Safety and Safety Element. Updated information is an important aspect of the usefulness of this kind of document. The original authors recommended updating the Seismic Safety and Safety Element at least every two years; by this standard the updating is long overdue.

Two geologic processes, which may be important in the County of Santa Barbara, seem deserving of further study or updated methodology:

1) Possible fault creep has been studied in the Santa Barbara area by students at the University of California at Santa Barbara under Professor Art

Sylvester. Although conclusive results on this topic have not been published, the study could contribute to a more comprehensive discussion of the subject in the Seismic Safety and Safety Element, and facilitate further consideration of fault creep and its potential impact on development.

2) Additional methodologies for determing the potential for liquefaction should be considered. One of the present methods of testing this factor is to perform standard penetration tests. In addition to these tests, other criteria for detecting liquefaction potential have been based on the presence of an unconsolidated sediment: a high degree of sorting and the presence of specific grain sizes such that the sorting curve for the sediment would fall within a designated envelope of sorting curves; presence in the sediment of less than 15 percent clay; and a state of soil saturation with water. These criteria should be considered as an alternative to the standard penetration tests, especially in critical cases.

Finally, there are a number of County policies which are related to geologic processes that are published in the Comprehensive Plan. These policies include provisions against development on steep slopes, required setbacks from naturally regressing cliffs, protection of seacoast development from seastorms, and the recent state rules for the abandonment or reabandonment of oil wells. These County policies could be included in the Seismic Safety and Safety Element.

The original purpose of the Seismic Safety and Safety Element "to aid in long-range land-use planning" has been well met. A more direct and daily application of the data for early planning and forewarning by technical and nontechnical users in the community has grown out of the practicality of such an approach. It is hoped that the suggested improvements, perhaps with others not mentioned here, will make the Seismic Safety and Safety Element an even more useful document over the next eleven years.

IMPLEMENTING LAND-DEVELOPMENT REGULATIONS FOR EARTHQUAKE GROUND-FAILURE HAZARDS IN LOS ANGELES COUNTY

Arthur G. Keene
County of Los Angeles, California

INTRODUCTION

Ground failures induced by earthquakes along the San Andreas fault zone have been considered by Los Angeles County since 1962, and have been recognized by the county as hazards as early as the Inglewood earthquake of 1920. However, it was not until 1975 that the final Seismic Safety Element for the General Plan for Los Angeles County was adopted, as required by State law in 1973.

COUNTY GENERAL PLAN

Section 65302(f) of the California Government Code required a seismic safety element consisting of identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, ground shaking, ground failures, and the effects of seismically induced hazards such as tsunamis and seisches. The code required appraisal of mudslides, landslides, and slope stability as geologic hazards that must necessarily be considered simultaneously with possible surface ruptures from faulting and ground shaking. These requirements were partially met in 1975, and are represented in the County's Seismic Safety Element Seismic Zone Map, in conjunction with maps of Relative Slope Stability, Shallow Ground Water, and Generalized Geology.

Potential rockfalls and mudflows were not evaluated specifically, and are not represented on these maps. However, shallow ground water, being an inherent factor in ground failures in general, was represented on a Shallow Ground Water map to reflect potential areas for liquefaction.

In view of the scope of the Seismic Safety Element for the General Plan, these ground failure aspects were evaluated only in a gross manner. For example, the maps are presented at a scale of 1" = 6 miles. For this reason, they are only suitable for land-use planning in the most general sense and are not useful for site-specific studies.

RELATIVE SLOPE STABILITY ZONING

Landsliding is a very common geologic process in the hilly or mountainous terrain, and along the sea cliffs in Los Angeles County. The distribution of landsliding in the county is shown on the Relative Slope Stability Map. A zoning evaluation of slope stability is an important geotechnical element or constraint on land-use capability. The seven relative stability classifications which are shown on the map represent an assessment of average stability conditions within a delineated area. Ratings are based on known information, and it should be apparent that new data could cause a modification of the map.

Although landslides occur in most rock types and in most slope gradients, their potential activity is generally believed to be controlled by:

- Rock type (lithology)
- Precipitation
- Slope gradient
- Geologic structure
- Anticipated ground response from earthquakes

In areas with other severe topographic and land stability constraints, passive open-space use might be the most feasible land-use allocation for unstable slopes. However, it must be pointed out that the mere presence of landslides, or the rating of an area as having "high landslide potential" does not mean that total urbanization or development is impossible. Current geologic and soils engineering techniques are sophisticated enough that only the most challenging hillside-development problems cannot be solved or corrected. Economic constraints, however, play an important role in geotechnical applications to hillside development.

PRESENT DISTRIBUTION OF LANDSLIDES

Knowledge of landslide distribution is necessary to predict areas which most likely will pose stability problems in hillside development. It is reasonable to suspect that areas susceptible to numerous landslides in the past will be more prone to develop landslides in the future. Earthquakes are known to trigger many slides in the landslide-prone areas. These landslide-prone areas are shown as "high landslide potential zones" on the Relative Slope Stability Map.

Adequate landslide-distribution data is available only for about half of Los Angeles County. Cooperative mapping programs with the U.S. Geological Survey (USGS) in the Santa Monica Mountains and with the California Division of Mines and Geology (CDMG) in the Palos Verdes Hills, the San Gabriel Foothills, and portions of the Santa Susana Mountains were invaluable for evaluating relative slope stability for the region.

Adequate geological mapping is generally lacking in the undeveloped hilly and mountainous regions between Newhall, Gorman, and Palmdale, California. The reliability of the Relative Slope Stability Map in the northwest parts of the County is, of necessity, questionable. Although the map does represent the best information available until 1975, new geologic mapping of ground failures is currently underway. This mapping at a scale of 1:24,000 is part of a new state program required by the Landslide Hazard Identification Act (California Legislature, 1983). As new maps become available, it may be prudent to convert the Relative Slope Stability Map to this more appropriate scale.

Studies of mountainous terrain indicated that thousands of landslides (including rockfalls) were triggered by the 1971 San Fernando earthquake. Pre-existing slides were reactivated and new slides were initiated. According to Morton (1975), "The distribution of the slides was controlled primarily by the intensity of ground shaking, but important local variations in the density of landslides reflect variations in the character and structural history of local geologic formations." Potential landslide zones shown on the Relative Slope Stability Map are, in part, a reflection of the anticipated ground-motion intensities from this and future earthquakes.

SEISMIC ZONE MAP

The Seismic Zone Map delineates areas of different relative seismic response. This map is based on interpretation of the dynamic properties of geologic materials shown on the Generalized Geology Map, Relative Slope Stability Map, Shallow Ground Water Map, and also on estimated earthquake parameters. Seismic zoning techniques used for this study were generalized and simplified. The basic variables considered are: geologic structure, geologic materials, depth to ground water, angle of slope, and seismic ground response.

Six seismic zones were distnguished to classify areas believed to have varying seismic responses to shaking within Los Angeles County. These zones are:

- Low ground response
- Moderate ground response
- High ground response
- Liquefaction or landslide potential
- Potentially active fault zone
- Active fault zone

The Relative Slope Stability Map data was integrated with these zones to produce the Seismic Zone Map. The ultimate purpose of the Seismic Zone Map was to indicate the need for site-specific studies, for example:

Low or Moderate Ground Response

Areas classified as "low or moderate ground response" (Seismic Zones 1 and 2) should experience less damaging ground shaking, and no landsliding or liquefaction. Even so, geologic, seismic, and soils reports should be required for high-cost, high-occupancy, and critical-use facilities located within this zone.

High Ground Response

The areas shown as "high ground response" (Seismic Zone 3) have the potential for strong ground shaking, landsliding, or liquefaction. Geologic, seismic, and soils reports should be required within this zone for high-cost or high-occupancy facilities, structures in which failure might be catastrophic, and for large subdivision-type residential developments. The findings should demonstrate the geotechnical feasibility for the proposed use.

Liquefaction and Landslide Potential

The areas shown as "high liquefaction or high landslide potential" on a Seismic Zone Map will be subject to liquefaction, acceleration of active landslides, renewed movement of inactive landslides, and to original movement of rock material. Geologic, seismic, and soils reports should be required within these zones for high-cost or high-occupancy facilities, structures in which failure might be catastrophic, and for large subdivision-type residential developments. The findings should demonstrate the geotechnical feasibility for the proposed use. However, construction of single-storied structures for single-family dwellings is not governed by the liquefaction potential zone.

Were it not for the fact that Los Angeles County is a governing agency which can afford a geotechnical review staff or issue permits, the Seismic Zone Map and the Relative Slope Stability Map would be almost useless for permit issuance. The County.has, in general, complied with the state-of-the-art regulation only because of its geologic/soil staffing and not because of its General Plan guidelines. The emphasis of the General Plan has been in the area of minimal code requirements in order to control seismically induced ground-failure hazards.

THE BUILDING CODE

In an effort to reduce earthquake ground-failure hazards in Los Angeles County, the review process for grading and building permits was upgraded. The process includes criteria limited not only to static stability of landslides, existing and potential, but also includes psuedo-static stability analyses in order to evaluate the response of landslides relative to critical horizontal acceleration. An average horizontal acceleration of 0.15g, adopted by policy, is currently added to the driving force for every calculation for the relative safety factor. A higher critical acceleration may be used if required by a consultant on a specific site or project. However, a psuedo-static analysis only requires a factor of safety equal to 1.1 as opposed to 1.5 required for a static analysis. My question is, have we really gained anything of real merit? Should not the overall safety factor of 1.5 be retained to include horizontal acceleration?

Los Angeles's County's Geology Section (of the former Department of County Engineer) also developed an empirical guideline for seismic-geologic studies in 1972, which is used to this day for in-house geologic/seismic reports and is available for use by private consultants. Empirical estimates for the maximum probable earthquake, maximum acceleration, duration, and predominant period of shaking are determined and are applied to potential landslide failures. This acceleration criteria considers earthquakes located on faults within sixty miles of the site and having the potential for a magnitude of 5.5 or greater earthquake. If a site is underlain by soil and/or thick alluvium (greater than 50 feet total), a soil report is required to evaluate the dampening or accentuating characteristics of the soil column.

LIQUEFACTION

One of the more important secondary seismic hazards, liquefaction, can be described as a quicksand condition in which there is a total loss of foundation support caused by a shock (usually an earthquake of sufficient magnitude). This condition is the result of a sudden decrease of shearing resistance in a cohesionless soil (such as sand) accompanied by a temporary increase in pore-water pressure. Important factors in determining liquefaction potential are the intensity and duration of shaking, and the presence of relatively low-density fine sand and silt in an area of shallow ground water.

Another type of liquefaction, which occurs at some depth from the surface, can result in ground lurching, fissuring, or cracking instead of causing wide-spread loss of foundation support. These effects are ascribed to flow landsliding or lateral spreading landslides, which can occur on very low slope gradients. This phenomenon caused the failure of the San Fernando Juvenile Hall, the Pacific Intertie Converter Station, and the Lower Van Norman Lake Dam during the 1971 San Fernando earthquake.

Identification of areas having the highest liquefaction potential is based primarily on the occurrence of ground water (less than about 30 feet below the ground surface) in major alluvial deposits. These areas within Seismic Shaking Zone I have the highest liquefaction potential and are categorized as Liquefaction Zone I. Areas with Seismic Shaking Zones II or III are included in Liquefaction Zone II.

Because of the general lack of data on subsurface soil conditions, the parameter of soil type was not included in the evaluation of the liquefaction analysis. Therefore, it should be assumed that due to differences in subsoil conditions not all areas within a given zone will have equal liquefaction potential. The zones shown on the Seismic Zone Map are not an absolute measure of liquefaction potential, but rather a relative broad-scale rating to compare large areas for planning purposes. A more definitive liquefaction evaluation of a specific site would require an in-depth analysis of the controlling soil parameters. Guidelines for this purpose have been composed by the County's Soil Engineering Section and are available for use by consultants to meet minimum code requirements.

WHAT IS LACKING IN LOS ANGELES COUNTY FOR FUTURE MITIGATION OF EARTHQUAKE GROUND FAILURE?

Even though Los Angeles County has fairly well complied with state-of-the-art science, the question remains: What is lacking?

I have brought to your attention Los Angeles County's effort to modify its code by policy; for example, a critical horizontal acceleration of requirement 0.15g is added to all landslide-stability calculations. This seismic factor is quasi-equivalent to the critical acceleration factors used by the USGS in producing a map entitled "Map Showing Slope Stability during Earthquakes in San Mateo County, California" at a scale of 1:62,500 (Wieczorek and others, 1985). The USGS approach is a more sophisticated means of evaluating the effects of seismic induction in existing and potential landslides. This level of sophistication is lacking in Los Angeles County, and should, in my opinion, be utilized as part of the Building Code application to seismically induced landslides.

Also, the Regional Planning Department, as part of its update of the Seismic Safety Element for land-use planning, might contract with the USGS to produce similar slope-stability maps for the Los Angeles County General Plan. This is needed because ground failure due to earthquakes may consist of: landslides, lateral spreading, and liquefaction; ground rupture and lurching on topographic highs where seismic waves may focus. To facilitate their prediction, these geologic features should be (1) mapped in detail for site-specific studies, and (2) be generally identified on slope stability maps at an appropriate scale. Critical acceleration factors could then be applied (Wilson and Keefer, 1985) and then plotted on a "Ground Failure Potential Map." A map of this detail could then be a part of the County Building Code.

Lastly, but perhaps most importantly, I believe that ground-failure hazards due to earthquakes could most readily be mitigated by requiring the adoption of the Uniform Building Code as part of the General Plan, and requiring each community to adopt related ordinances requiring geotechnical studies for site-specific developments, even if a reviewing staff is not available.

REFERENCES

California Legislature, 1983, Landslide Hazard Identification Act: California Public Resources Code, Section 2670 and following, West's Annotated Codes.

Morton, D.M., 1975, Seismically triggered landslides in the area above the San Fernando Valley, in Oakeshott, G.B., ed., 1975, San Fernando, California earthquake of 9 February, 1971: California Division of Mines and Geology Bulletin 196, Sacramento, Calif., p. 145-154.

Wieczorek, G.F., Wilson, R.C., and Harp, E.L., 1985, Map showing slope stability during earthquakes in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257-E, scale 1:62,500.

Wilson, R.C., and Keefer, D.K., 1985, Predicting areal limits of earthquake-induced landsliding, in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 317-345.

IMPLEMENTING SEISMIC SAFETY ELEMENTS

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Seismic safety elements, which have been required in local general plans since the early 1970s, have now been adopted by virtually every city and county in California. Ten years of experience has shown that these seismic safety elements (since 1984, "safety elements") provide a useful framework for integrating seismic concerns with other land use issues and establish an effective foundation for development of hazard-reduction programs, although some room for improvement remains.

Two studies in recent years have examined the effectiveness of local seismic safety elements. The first of these studies, "Seismic Safety at the Local Level: Does Planning Make a Difference?" by Mintier and Stromberg, examined the experience of seven cities and counties along the Hayward-Calaveras Fault. The second study, "A Review of the Seismic Safety Element Requirement in California," prepared by the Seismic Safety Element Review Committee of the California Seismic Safety Commission, examined the experience of eight cities and counties statewide and responses by 241 cities to a League of California Cities survey questionnaire. Both of these studies reached similar conclusions.

General Evaluation

The major impact of preparing seismic safety elements has been to heighten the awareness of local officials and the public as to the nature of seismic hazards and the many ways of dealing with these hazards. While it is difficult to assess the effect of the seismic safety element apart from other state requirements such as the Alquist-Priolo Special Studies Zones Act and the California Environmental Quality Act, the seismic safety element has been an important impetus for local governments to pull together and synthesize geologic and seismic data and to adopt and implement hazard reduction programs.

Land Use Controls and Regulatory Procedures

Implementation of seismic safety policies has been carried out chiefly through land-use controls and regulatory procedures, such as reductions in land-use densities and project-review procedures, where the costs of implementation can be passed along to landowners and developers. Information contained in seismic safety elements has been particularly useful in identifying geologic and seismic concerns that need to be addressed in more detailed geologic and environmental reports for specific projects.

Role of Seismic Safety Concerns in Land Use Decisions

Concern for seismic safety is seldom the sole, or even the primary, factor in an important land-use decision on whether or not an area should be developed. Usually, several other concerns along with seismic safety, such as preservation of open space, provision of public services, and flooding, play important roles in these decisions.

Hazardous Building Abatement

Few local governments have adopted strong policies for building inspection and abatement, and even fewer have actually instituted such programs. Four reasons are cited for the failure to pursue hazardous building abatement:

1) Substantial initial cost of inspection;

2) Concern for the economic effects of an abatement program on the owners of older buildings;

3) Fear and confusion about liability problems created for the public agency by inspection programs; and

4) Conflicts with historic preservation goals.

Post-Earthquake Constraints

State law does not require that seismic safety elements address post-earthquake reconstruction, though some elements do. Most local governments, given more pressing priorities, consider this effort too speculative to warrant serious attention.

Emergency Response

There has been little coordination of seismic safety elements and emergency response planning. To improve the quality of seismic safety elements and their implementation, a number of key measures should be considered, including the following:

o California should develop a seismic-safety planning manual to assist local governments in preparing and implementing seismic safety elements. The manual might include:

  - Conducting a simplified risk assessment

  - Surveying, evaluating, and abating hazardous buildings

  - Dealing with special issues, such as tilt-up buildings, computers, hazardous substances, non-structural components

- Planning for post-earthquake reconstruction

- Dealing with post-earthquake economic and social dislocation

- Obtaining assistance in the preparation of a seismic safety element

o State law should require that potentially hazardous buildings be inventoried and evaluated, and that programs be developed for their removal or strengthening.

o State law should require that an evaluation of local emergency response procedures be required as part of the seismic safety element and that emergency response plans reflect the hazards identified in seismic safety elements.

o State law should require that seismic safety elements include plans and procedures for post-earthquake reconstruction.

o State law should require that seismic safety elements be reviewed and updated at least every five years and that new seismic safety elements include an evaluation of the effectiveness of previously adopted implementation programs.

APPLICATION OF EARTHQUAKE-HAZARD-EVALUATION TECHNOLOGY TO GEOTECHNICAL LAND-USE DECISIONS

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INTRODUCTION

Earthquake-hazard-evaluation technology is slowly but surely extending into the decisionmaking process for private land development as well as for large public works. The increasing sophistication of public officials and regulatory agency staffs in California at the State and local levels is forcing the geotechnical consulting community to analyze earthquake-related risks and recommended mitigation measures. However, problems such as liquefaction and earthquake-induced landslides are still the object of very active basic research programs, and only limited field verification has even been attempted. The cost of mitigation or outright prevention measures that are currently available can be astronomical, and in some cases the project cannot be undertaken because there are no practical mitigation measures.

This situation is probably not unusual in cases where science discovers new problems faster than engineering can solve them, but we must all exercise care in the ways in which we incorporate new discoveries into our day-to-day decisions on land use and development.

Evolving technology will be applicable to land-use decisions only by taking advantage of the limited opportunities to collect and analyze earthquake-related geotechnical information. Two important time frames require our attention as geotechnical experts: (1) before the earthquake, we have an important planning function; (2) after the earthquake, we need to be able to collect and analyze relevant time-dependent data quickly and efficiently.

BEFORE THE EARTHQUAKE

More microzonation mapping is needed for earthquake-induced landslide hazards in urbanizing areas. Steep-slope rock falls and soil slides or flows are expected to be far more serious in urban areas now expanding into hillsides than previously had been recognized. Because the hazard is localized at the base of steep slopes, and adjacent to natural slopes with thick colluvium, microzonation maps should be prepared with the objective of triggering a site-specific evaluation of the hazard for the specific local land use. At our current levels of knowledge, it is unlikely that an adequate building code can be devised to cover this hazard. However, geotechnical practice would be well-served by development of good analytical methods to evaluate steep slopes and bluffs for dynamic failures.

Liquefaction potential is widespread in many coastal urban areas in the United States. Methods of reducing the risk have been described by Idriss (p. 316, this volume). These methods are extremely expensive, and in some locations they are impractical because of the scale of the problem. We desperately need more practical and cost-effective techniques. Where liquefaction potential is widespread, what kind of building codes make sense? How can we protect areas the size of entire communities built on low-lying alluvial fans?

Seismic safety elements need to be prepared for population centers throughout high earthquake-hazard regions, and in California they should be updated periodically. Immense amounts of new data are being generated, especially in the western states, on fault activity and hazard levels. In California, the initial seismic safety element prepared by each city and county addressed the overall hazard at the local level for the first time. The updated elements should emphasize presentation of information in a form most usable to planners and regulators; the best of existing Seismic safety elements can be used as format examples. Time is of the essence, because this information should be used to guide decisions on major land-use questions faced by governmental planning agencies.

AFTER THE EARTHQUAKE

More complete case histories of earthquake-induced landslides, liquefaction events, and related earth-failure phenomena must continue to be developed. Earthquakes are relatively rare events that must be observed carefully when, and immediately after, they occur. The information from urban earthquakes must be documented and analyzed to identify those mitigation measures that worked and those that did not work. The 1985 Mexico earthquake provided an important example; it should help to develop a logical and effective post-earthquake reconnaissance plan.

Numerous active or potentially active landslides are currently being monitored by both government and private-sector geotechnical experts. Some are related to distress evaluations, whereas others are to confirm the effectiveness of stabilization measures that are already installed. This data base should be organized and priorities established for post-earthquake instrumental measurements and monitoring efforts. If we are to improve our ability to predict seismic effects on landslide stability, we need more statistically meaningful data. Can we institute a long-term program to identify and monitor seismically induced ground motion? This effort demands much further attention.

After the earthquake, we want to put the lessons learned into practice as quickly as possible. This is done in other segments of the construction industry by gradually revising the building codes to reflect new levels of knowledge. Would there be a better way to incorporate new information into practice? Is publication of research papers in standard journals or in special earthquake volumes the most effective way, or should special provisions be made to sponsor technical and nontechnical workshops or seminars? Much of the mitigation and control of potential ground instability is formulated by geotechnical consultants, working on specific design projects. The degree to which we convert new understanding to practice is the ultimate measure of our ability to benefit from an earthquake's lessons.

Evaluating Earthquake Ground-Failure Potential for Development Decisions[1/]

SUMMARY OF WORKING GROUP V AND AUDIENCE DISCUSSIONS

This session was moderated by Richard Spicer. Panelists were F. Beach Leighton, J. Laurence Mintier, and William J. Petak. Joining the panel were speakers from the morning session, John C. Tinsley, Raymond C. Wilson, I. M. Idriss, David Doerner, and Arthur G. Keene. Frank Hotchkiss was the session commentator. Questioners and commentators from the audience included Robert Holtom, Charles G. Suddath, Michael Scullin, James E. Slosson, Bernard W. Pipkin, and several others not identified on the audiotapes. The following text was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Idriss described several ways of mitigating liquefaction. Liquefiable materials can be excavated and replaced with dense material that would not tend to liquefy. Depending upon the setting at a particular site, the ground water level could be lowered to a level below layers of liquefiable material. Drainage devices, such as rock-filled columns or trenches, can be installed to alleviate water pressure. Materials can be densified in place by several means of compaction. Structures can be supported on deep foundations located below a layer of potentially liquefiable material. Structures can be supported on piles that extend below liquefiable materials. Some of these measures can be very expensive, especially where existing structures overlie or are nearby the area needing treatment.

Leighton called for producing earthquake microzonation maps of potential landslide hazards for urban areas. Landslide-hazard mapping techniques have dramatically improved in the last two decades. However, mapping is not at a stage where it can be applied to property hazard ratings through the building codes. This is a serious problem, considering the many millions of dollars in land and property values at stake.

Leighton noted that the empirical methods are well developed for identifying potential liquefaction conditions. These conditions are widespread in California, and exist not only in the Los Angeles and Santa Ana basins of southern California, but in many nearby desert areas as well. There are engineering methods for reducing the risk of liquefaction, which were described earlier by Dr. Idriss; however, these measures tend to be very expensive. More practical techniques for mitigating liquefaction are therefore desperately needed. In view of the enormous costs of regulating construction in areas of widespread liquefaction potential, what kind of building codes really make sense?

[1/] An important ordinance governing requirements for constructing buildings in areas subject to soil liquefaction is discussed on pages 378 to 381 of this volume.

Leighton recommended obtaining more and better case histories of how areas of landslide and liquefaction potential performed following an earthquake. Reanalysis of pre- and post-earthquake aerial photographs would be a useful technique for certain sites. A large number of active or potentially active landslides are currently being monitored by geotechnical consultants in southern California. It would also be useful if readings at instrumented sites could be made immediately following an earthquake, and the data then pooled and shared. Leighton called for the organization of a clearinghouse where this pooled data could be analyzed.

Leighton then suggested that it is necessary to know how closely the Newmark analysis (Wilson and Keefer, 1985, p. 329-331) describes the physics of slope failure. How closely does it describe the actual slide process, especially rock avalanches and rockfalls, and is it a valid predictive technique? Leighton commented on Seismic Safety Elements (SSE's), agreeing that they needed to be updated based on new data collected during the last decade. California counties have compiled an immense amount of data based on the SSE's, and special funding should be made available to translate those data into SSE improvements. SSE maps should be upgraded and reproduced at larger scales. These upgraded SSE's should also be made to be more easily readable by public officials.

Petak prefaced his remarks with a description of his orientation to science and applications. He began his career as an engineer, and now works in the arena of public policy. Petak sought ways to improve the implementation system, assuming that enough technological information is available in many areas. In general, he found aggressive action lacking. Political variables are of greater importance to the initiation and success of earthquake-hazard-mitigation activities than the state of scientific knowledge or the availability of technological remedies. In order to improve the situation, it is necessary to understand the impediments to implementation. Petak discussed a list of these impediments, and some needs to overcome them:

- To the local official, other problems appear to be far more important than something which may not occur for many years. Like other people, legislators and local officials have other things to do, and can only work on so many things at one time. When they are faced with something that seems to be a remote possibility, they defer action in favor of action on more pressing problems.

- Elected officials respond to political pressure. There is an absence of earthquake-oriented political constituencies. Without an organized constituency behind the adoption, much less the implementation of policy, there is no progress in an implementation system.

- There is a lack of advocates within local agencies. There are not enough Ed O'Connor's in the world. O'Connor started the condemnation of old buildings in Long Beach in 1970, for which he received a great deal of attention. However, it took the 1971 San Fernando earthquake to prompt the Long Beach City Council into action.

- Planners are not expert in many areas of geotechnical research. There is a need for trained professionals at the local level. Petak and Slosson, as members of the California State Mining and Geology Board in 1977, introduced a resolution that called for the amendment of statutes to require reviewers of geotechnical reports for California cities and counties be licensed professionals, as are those who prepared the reports. However, no California legislator would sponsor that resolution towards a statutory amendment. Recently, however, California State Senator Leroy F. Green, influenced by effects of the 1985 Mexico earthquake, stated that he would sponsor a bill that would require all engineers working for cities and counties in California be registered professional engineers. If progress can be made with engineers and geologists, further progress can be made with local governments.

- Complexity and uncertainty is a debilitating problem. Problems which are simply understood and easily solved are given high-priority status. If the issue is very complex, and local officials do not comprehend it, the issue gets little attention and the energy and action of local officials are diverted elsewhere. There is a cost of dealing with controversy and complexity in the political system.

- There are issues of fact and issues of value. The scientific community at this workshop has been talking about issues of fact, trying to resolve these issues empirically and scientifically. When scientists cannot do that, and there is a great deal of uncertainty involved, the problem is handed to political officials for a decision. Politicians are not there to decide issues of fact; they are there to decide issues of value. Fundamentally, they look to their staffs and to technical experts to give them factual answers. The political answer to the scientists will be, "If you can't solve the issues of fact, how can I solve them?"

Petak concluded with several observations on how the implementation system might be improved. Whereas good work is done from time to time on adopting ordinances, the codes are not uniformly implemented. Implementation can be improved through better informed legislators and legislative staffs. Local officials and the scientific community can have an impact on the political process by developing solutions in advance. They can prepare position papers and develop community support. When the time is appropriate, the papers and evidence of support can be submitted to a legislative body, whether it be a city council or the State Legislature. The chances of having recommendations then made into law at that point are better, and there will be fewer problems and errors in them. Furthermore, model legislation and action programs should be adopted <u>before</u> a major earthquake occurs. Constituent groups need to be informed and educated. For example, the Federal Emergency Management Agency took the initiative in placing emergency management in the curriculum of the Society of American Public Administrators. This will help city administrators, budget officers, and those who deal with earthquake-preparedness projects on a regular basis understand the nature and process of emergency management.

Wilson responded to the technical question raised by Leighton regarding the applicability of the Newmark analysis to rockfalls and rock avalanches, saying that for these processes, the analysis is handled in several different ways. The Newmark analysis is a numerical model that treats the landslide mass as a rigid block resting on a slope. A static analysis is performed to calculate the factor of safety, and from that the critical acceleration is calculated, which describes how quickly the ground must move in order to move the block. The Newmark analysis integrates the static analysis with a strong-motion record to calculate displacement of the block. This procedure was designed for analyzing coherent types of landslides, such as block glides and slumps. For rockfalls, the analysis is used to determine the point at which a rockfall will be initiated during the shaking. How far the rockfall moves is a function of the height of the slope from which it detaches. Rockfalls are a result of a brittle fracture mechanism; therefore, initiation depends upon peak acceleration during the shaking. Initiation of other types of landslides depends upon both peak acceleration and duration of the shaking. However, duration of shaking cannot be completely ignored in analyzing rockfall initiation. The work on these analyses is presented in Wieczorek and others (1985), and Wilson and Keefer (1985). For recent work in the Los Angeles area, two displacement criteria have been used: a displacement of 10 cm is used for initiation of slumps and block glides, and a displacement of 2 cm is used for the initiation of rockfalls. For the original work in San Mateo County, California, slope was the primary criteria used for rating rockfall hazards. Analysis of landslide initiation during earthquake shaking is a relatively new procedure within which refinement is still evolving.

Holtom queried the panel about differences in commercial and residential building design for liquefaction problems.

Idriss emphasized that installation of deep pilings is only one solution to the liquefaction problem. Pilings are very seldom used strictly for that purpose. There are a variety of ways to mitigate liquefaction, including replacing the existing soil with non-liquefiable material, densifying the soil using dynamic compaction, and lowering the water table, among other measures. Some of these measures are not usable in built-up areas; some are being used for new residential developments.

Keene suggested that most counties will not consider liquefaction susceptibility as a condition for permitting residential construction unless the structure is more than three stories tall.

Holtom asked if there is a chance of loss to residential dwellings not designed to withstand liquefaction.

Keene replied that there is a chance of loss in areas subject to liquefaction where shallow ground water lies within 30 feet of the ground surface. The potential economic loss, however, is very small; therefore, liquefaction susceptibility for small residential structures is not a critical issue in the building code. Keene asked for comments from his staff on this issue. Suddath indicated that the probability of a failure due to liquefaction is less than one percent for an individual structure, and the cost to mitigate it for a single-family dwelling is extremely expensive. The general policy, therefore, is not concerned with protection of the structure, but protection of its occupants. Los Angeles County will consider liquefaction mitigation measures if there are fill slopes or other slopes over 10 feet high that could fail and affect the structure. Overall, mitigation for liquefaction is very expensive for the degree of benefit to be obtained.

Idriss suggested that the idea of cost should be examined very carefully. It is easy to say that mitigation is expensive, and is therefore not affordable. One should obtain a cost/benefit ratio. For example, the average cost for improving a vacant lot is currently about one to three dollars per square foot in the Los Angeles basin. That translates to five to 15 thousand dollars for an average lot size of 5000 square-feet. Given current (1986) prices for housing in California, that is about five to 15 percent of the median cost of the house. That might not be a very high cost, considering what is being purchased. For structures already in place, however, liquefaction mitigation could be very expensive. In summary, one should not automatically assume that all liquefaction mitigation is overly expensive.

Hotchkiss asked the panel about the interaction of ground-water and wastewater management and seismic safety measures, particularly relative to liquefaction. Water is being percolated into basins throughout southern California for purposes of storage and as barriers to salt-water intrusion. Treated wastewater is applied to hillsides, golf courses, and other areas as a water-conservation measure. To what extent does this extra water affect seismic safety?

Tinsley commented that in his work he had found that there is no systematic effort made to monitor shallow ground-water occurrences. Shallow groundwater reservoirs produced by percolation and irrigation generally are of uncertain extent and are usually not of sufficient quality to attract interest for an economic purpose. Therefore, most are not monitored; however, there are some local exceptions. Major percolation facilities and salt-water intrusion barriers are monitored using observation wells; however, these are relatively few and isolated cases within the entire context of the shallow-water problem. Hotchkiss pursued the question, noting that many programs of and plans for water recharge and conservation facilities are underway. Tinsley offered his view that there should be some concern about such practices. Ground-water levels should be monitored in selected areas; however, the practicality of monitoring shallow aquifers is a problem in itself.

Scullin made a statement about irrigation on hillslopes in the Los Angeles area. He claimed that the average homeowner applied the equivalent of 75 to 100 inches of rainfall per year per lot. That quantity, added to the average annual rainfall, produces oversaturated slopes and fills. This would tend to add to the problem of slope failures during an earthquake.

Scullin then asked Petak about the relationship between codes and the enforcement of codes. During 1974-75, Scullin had found that 92 percent of the cities and counties in California had adopted a grading ordinance, but only about 13 percent had a grading inspection division. Has that situation improved in recent years? How can the cities and counties become more agrressive regarding grading inspection?

Petak suspected that the situation has not gotten any better. He would want to know which cities are inspecting properly. If a small community in Alpine County is not inspecting properly, the issue is minor. If the City of Los Angeles is not inspecting properly, it is an entirely different matter. Across the spectrum of all communities, in California as well as across the country, small communities are understaffed and underfinanced. They are unable to do the kinds of things for which the ordinances were written. Los Angeles, San Francisco, and larger communities generally are able to do a much better job because they can afford to hire professional inspectors. Petak stressed the need for upgrading the staffs of medium-sized communities--those of 50,000 to 100,000 people--that are not doing an adequate job of inspection.

Scullin cited a list of cities in southern California with strong grading-inspection programs, and commented that the list comprised only a small percentage of medium- to large-sized communities.

Petak added that cities could contract for services. If a community does not have a grading inspector, it might contract with one in order to enforce its codes. The county might also do inspections for the city. These alternatives should be explored in an effort to resolve the issue of proper inspections.

Slosson commented on discussions during the morning session on the potential for failure of artifical fills during an earthquake, saying he had yet to see a properly engineered and inspected fill fail during an earthquake. Is the U.S. Geological Survey (USGS) attempting to differentiate between well-constructed and poorly constructed fills? Earlier commentary suggested that engineered fills would suffer during an earthquake, and that is detrimental to those involved in quality-control inspections of such fills.

Wilson indicated that, as a geologist, he would not be able to make a personal inspection and distinguish between properly engineered and poorly engineered fills. The example discussed earlier came from Japan where very strong grading codes exist. That Japanese failure occurred on an engineered slope. Wilson had no evidence regarding the quality of engineering. He stated, however, that a fill which survives an earthquake is by definition well-engineered; a fill that fails is by definition improperly constructed. Therefore, it would be impossible to locate a properly constructed and inspected fill that did not survive a major earthquake. It is not impossible to design and construct a fill that would survive the most severe earthquake shaking. If the fill is properly densified and drained, there should be no particular problems with it. In many areas, however, the grading code for fills is written in terms of a static factor of safety. In addition to that factor, one should also calculate a critical acceleration factor. The formula for that calculation is contained in Wieczorek and others (1985). Any fill that has a critical acceleration factor greater than about 0.25g should perform well, even in a very severe earthquake.

Slosson pursued the discussion, referring to studies of fills that survived or failed during the 1971 San Fernando, California, earthquake. If fills contain alluvium, they will suffer aseismic consolidation that may lead to failure under seismic loading. Many fill failures during the San Fernando earthquake involved alluvium. Nevertheless, these were included as "modern-engineered-fill failures" in post-earthquake evaluations. Slosson did not consider such fills "well-engineered," and thought such distinctions should be made in reporting those failures.

Wilson made a further point about analyses of slope-failure potential by the USGS. These analyses are not intended to be site-specific. They are intended to show areas where one might wish to take a closer look at the design of fills and the enforcement of grading codes.

Spicer asked whether Los Angeles County has enforcement policies regarding fill construction.

Keene replied that Los Angeles County has had a seismic analysis requirement for artificial fills since 1973. For massive fill slopes, factors other than seismicity usually govern the design. Seismicity governs in the case of buttress fills and cut slopes where one is analyzing potential bedding-plane failures.

Pipkin asked Keene and Doerner whether any projects within their jurisdictions had ever been rejected or greatly modified because of high liquefaction potential.

Keene replied that the code requires evaluation of liquefaction potential for major structures, but because liquefaction potential has been evaluated before permits are issued, no projects have been rejected.

Doerner said that liquefaction concerns are sometimes a factor in the environmental review process for a given project. When that is brought to the attention of decisionmakers, requirements for mitigation are applied before construction is allowed to begin. Therefore, no cases where a project has been rejected were recorded.

Spicer pursued the topic, asking Mintier about adjustments made to projects in the interest of seismic safety. Mintier replied that drainage improvements and special foundation work were the principal adjustments with which he was familiar.

Petak commented on the intentions of the Seismic Safety Element (SSE). It is intended to be part of the general plan of a city. The SSE really does no more than indicate areas of a community in which there is a potential for a hazard or a ground failure. If hazards are expected for certain areas, then site-specific studies to verify and mitigate the hazards are required. The SSE itself would never be directly involved in a decision whereby a project would be approved or denied.

Mintier verified Petak's comments, adding that the SSE by itself is only an indicator for further studies. In the incidents he had observed, consultants were retained to determine the existence and degree of a liquefaction hazard for a particular site before mitigation measures were applied.

Doerner noted that in areas of liquefaction potential, there were usually other values under consideration, such as open space. Concern about liquefaction therefore became integrated with other concerns, and a land-use decision was made on a comprehensive basis. It is difficult to review the final decision and say it came about solely because of a seismic safety concern.

Spicer asked the audience and panel for comments on how to transfer updated scientific and technical information into SSE's, which are now at least 10 years old and of mixed quality.

Doerner replied that Santa Barbara County has no large program of ongoing geological research. Occasional hydrologic studies are made to establish the capacities of ground-water basins. However, abundant information is generated by the county permitting process, because any application must contain geological, hydrological, and other reports. He recommended setting up a program to assimilate that information, and then having it analyzed by a committee of experts. The results would then be integrated into the SSE.

Mintier thought that an informal process of upgrading SSE's had already evolved, and that most SSE's adopted in the 1970's have either undergone revision, or are in the process of being revised. General plans are typically revised every five to ten years, and as part of the process geological and seismological information is reviewed and updated. It is important, however, that the State (or some other entity) take a much more active role in bringing such information to the attention of those who prepare and update the SSE's. A wide range of concerns need to be more clearly explained to local planners, and Mintier felt that the State of California should publish a technical guidebook to address those concerns. Much interpretive work needs to be done in the area of translating technical information into political decisions.

Petak reminded the audience that becoming educated about geotechnical information is not a user-sided issue. Part of the problem with SSE's is that the connection between technical information and the individuals responsible for using it has not been made clear. The technical community has a fiduciary, as well as an overall, responsibility to be more aware and understanding of the problems of local government. The technical community should assist rather than inundate local governments in understanding and using technical information. Society needs a multi-disciplinary approach to earthquake-hazards reduction, or little progress will be made toward seismic safety.

REFERENCES

Hart, E.W., 1985, Fault-rupture hazard zones in California--Alquist-Priolo Special Studies Zones Act of 1972 with Index to Special Studies Zones Maps: California Division of Mines and Geology Special Publication 42 (revised), Sacramento, Calif., 24 p.

Los Angeles County Department of Regional Planning, 1974, Seismic safety element: Los Angeles, Calif., 170 p.

Mintier, J.L., and Stromberg, P.A., 1983, Seismic safety at the local level--does planning make a difference? in California Geology, v. 36, no. 7, California Division of Mines and Geology, Sacramento, p. 148-154.

Santa Barbara County Planning Department, 1979, Seismic safety and safety element: Santa Barbara, Calif., 207 p.

Wieczorek, G.W., Wilson, R.C., and Harp, E.L., 1985, Map of slope stability during earthquakes in San Mateo COunty, California: U.S. Geological Survey Miscellaneous Investigations Map I-1257-E, scale 1:62,500.

Wilson, R.C., and Keefer, D.K., 1985, Predicting areal limits of earthquake-induced landsliding in Ziony, J.I., editor, Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional paper 1360, p. 317-345.

VI. EVALUATING THE SHAKING HAZARD FOR REDEVELOPMENT DECISIONS

VI. EVALUATING THE SHAKING HAZARD FOR REDEVELOPMENT DECISIONS[1/]

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Working Group Presenters:	Albert M. Rogers Gary C. Hart Allen A. Asakura John P. McCann
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EVALUATION OF THE SHAKING HAZARD FOR REDEVELOPMENT DECISIONS

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INTRODUCTION

Redevelopment decisions involve replacement of structures or their adaptation for a different use. Redevelopment is usually controlled by economic considerations and, except for unreinforced masonry buildings, the shaking hazard has not entered as an explicit factor in establishing the need for redevelopment. A new complex of structures has to comply with building code and zoning requirements. Since the shaking hazard is a factor that enters into the formulation of codes and zoning regulations, it is indirectly taken into account when authorizing a redevelopment plan. Redevelopment after an earthquake is another matter. Decisions for redevelopment after an earthquake should be based on pre-earthquake planning, and an understanding of the shaking hazard is necessary during pre-earthquake planning.

Shaking hazard evaluation consists of the assessment of the probable earthquake damage to buildings and lifelines. The characteristics of structures within a region as well as the earth-science-based predicted or postulated earthquakes are necessary components of the shaking hazard.

Four levels of evaluation of the shaking hazard may be stipulated, each level or category requiring a higher degree of refinement of the evaluation technique. These levels refer to shaking hazards for:

1) A large region containing different types of buildings; for example, the City of Los Angeles.

2) A single category of structures, in large numbers, but scattered throughout several regions; for example, unreinforced masonry buildings.

3) A group of buildings with single ownership; for example, buildings owned by an institutional or industrial organization, such as a university campus or a company-owned group of buildings.

4) A single structure of critical importance such as a hospital, emergency center, or a high-rise office building.

In recent years, earth-science-based research has yielded prediction methods that include possible epicenters, magnitudes, and seismic intensities for southern California. In engineering practice, this information has been utilized by postulating a finite number of earthquake scenarios with specific parameters that are applicable to each of the above four categories. The following information is usually specified:

- For Category 1, epicenters, magnitudes, and seismic intensity maps of three to five postulated earthquakes.

- For Category 2, several seismic-hazard levels that are region dependent, usually given in terms of effective peak accelerations, seismic intensities, and response spectra.

- For Category 3, seismological and geological characteristics of the site, strong motion records from similar sites, and statistical data compiled from past earthquakes leading to response spectra associated with several earthquake recurrence intervals.

- For Category 4, same as Category 3, except that additional information on durations of postulated earthquakes given as time histories of ground shaking.

SHAKING HAZARD FOR A LARGE REGION WITH DIFFERENT BUILDING TYPES

It has become standard practice to postulate several possible earthquakes when predicting seismic intensities in the Los Angeles region. A recent study on pre-earthquake planning for post-earthquake rebuilding (PEPPER Project, William Spangle and Associates, 1984) includes an evaluation of structural hazards and damage patterns for the City of Los Angeles. Four earthquakes were considered: an 8+ magnitude on the central section of the San Andreas fault, two events of 6+ magnitude, under the central business district and in West Los Angeles, and a repeat of the 1933 Long Beach earthquake. The area considered included 35 planning areas; the inventory of more than 700,000 buildings was divided into construction types (steel, concrete, reinforced and unreinforced masonry, wood, and a special category). The inventory was further subdivided into use categories (single family, 2-4 units, 5-plus units, commercial, industrial, and other). Each type of construction was subdivided in turn according to its earthquake-resistance characteristics. For example, concrete buildings were subdivided as follows: frame, shear wall, ductile, and low ductility, and they were also subdivided according to occupancy (table 1). The investigators note that this subclassification is judgmental.

Damage estimates were made for each class of structure in each planning area. These estimates were given in terms of a damage ratio which is the amount of loss as compared to the replacement cost of the building. Thus, for a given earthquake scenario, damage ratios can be estimated for each type of building and for each planning area within the City of Los Angeles. An example of a summary of this evaluation is in table 2.

TABLE 1. CLASSIFICATION OF CONCRETE BUILDING TYPES IN LOS ANGELES (Wm. Spangle and Associates, Inc., 1984)

Occupancy	Percent of Concrete Buildings			
	Frame	Shear Wall	Ductile	Low Ductility
Offices, high rise	20	0	60	20
Offices, low rise	20	40	20	20
Apartments, high rise	20	40	20	20
Apartments, low rise	20	40	20	20
Commercial	20	30	25	25
Industrial	20	10	35	35
Institutional	20	30	25	25

TABLE 2. ESTIMATED DISTRIBUTION OF DAMAGE TO BUILDINGS RESULTING FROM POSTULATED M = 6+ EARTHQUAKE, WEST LA (Wm. Spangle and Associates, Inc., 1984)

Building Class	Total Buildings (All Planning Districts)	Undamaged* (0%)	Damaged but Repairable		Damaged* Beyond Repair (80%-100%)
			Habitable (<50%)	Not Habitable (50%-80%)	
Steel	215	100	110	2	3
Concrete	420	85	315	10	10
Poor Masonry	8,380	600	6,800	460	500
Good Masonry	11,620	4,200	7,200	130	100
Wood	679,509	366,000	280,000	13,000	20,000
Total All Building Classes	(700,200)*	371,000	295,000	13,600	20,600

*All units rounded off, so totals will not match up exactly.

TABLE 3. DISTRIBUTION OF DAMAGE FOR UNREINFORCED MASONRY BUILDINGS (Wm. Spangle and Associates, Inc., 1984)

Earthquake Scenarios	Undamaged	Damaged but Habitable	Not Habitable	Damaged Beyond Repair
M8+ at San Andreas Fault	1800	6300	250	80
M6+ at City Business District	250	6500	700	950
M6+ at West Los Angeles	600	6800	460	500
M6+ Repeat of Long Beach, 1933	475	7600	250	75

TABLE 4. EXAMPLE ILLUSTRATING COST OF REPAIR AND REPLACEMENT DUE TO EARTHQUAKES OF DIFFERENT SEVERITIES (Agbabian, M.S., 1985)

Building	Replacement Cost ($ Millions)	Percent Damage* at			Cost in ($ Millions) of Repair or Replacement at		
		0.20 g	0.30 g	0.40 g	0.20 g	0.30 g	0.40 g
A	1.000	35	100	100	0.350	1.000	1.000
B	5.000	23	100	100	1.150	5.000	5.000
C	0.500	5	28	85	0.025	0.140	0.425
D	1.000	10	26	58	0.100	0.260	0.580
E	2.000	2	18	48	0.040	0.360	0.960
F	3.000	0	0	15	0	0	0.450
Total	12.500				1.665	6.760	8.415

Similar summaries are also given for the other three postulated earthquakes. Detailed information for each of the four earthquake scenarios, for each planning area (35 areas), and types of construction (6 types), and occupancy (6 types) provide a matrix that a planner can use for redevelopemnt decisions. The authors caution that there are limitations to the accuracy of such a prolific data base, and the planners should take note of this. The quantified values for the shaking hazard for this type of analysis are based on some fundamental general criteria for seismic intensities and knowledge of building behavior during earthquakes based on engineering experience.

SHAKING HAZARD FOR UNREINFORCED MASONRY BUILDINGS

Damage ratios for masonry buildings have been published. For Los Angeles, the City survey gives approximately 8400 unreinforced masonry buildings constructed before 1934 and 11,500 post-1934 reinforced masonry buildings. Figure 1 shows the predicted performance of the two types of masonry buildings as a function of seismic intensity.

For unreinforced masonry, estimates are also made for the distribution of damage (William Spangle and Associates, Inc., 1984). The results in table 3 are based on the distribution of these buildings in the City of Los Angeles with respect to the seismic intensities corresponding to the postulated earthquakes.

An obvious conclusion is that these buildings are indeed hazardous. Experimental and analytical studies (ABK Joint Venture, 1981) investigating the strength of anchors between structural elements, shear strength of walls, roof and floor diaphragm response, and out-of-plane instability of walls have given considerable data on the behavior of unreinforced masonry buildings. Figures 2a and 2b show simplified models of buildings subjected to earthquake motions. Results of these studies have substantiated the effectiveness of strengthening measures that can increase the earthquake resistance of unreinforced masonry buildings. To bring them to the same level of resistance as building code-based reinforced masonry construction would make the cost prohibitive. In most cases, the only alternative would be to demolish the structure or accept the fairly high probability that an earthquake will destroy it in the future. A departure from the code provisions for new construction was devised (ABK Joint Venture, 1981) to be used as a retrofit guideline for three seismic hazard levels -- based on effective peak accelerations of 0.1, 0.2, and 0.4 g (Applied Technology Council, 1978). Figure 3 gives the seismic regions of continental United States for which a retrofit methodology was developed (ABK Joint Venture, 1981, v. 8). The 0.4 g level applies to the Los Angeles area.

In this paper, rather than explaining in detail how these retrofit measures are carried out, it is more pertinent to note that, although the shaking hazard still relates to postulated earthquake scenarios that have resulted from earth-science studies, practical and economic considerations have indicated that mitigation of the hazard is a matter of degree, and the main issue is what level of damage should be tolerated. If as a result of the retrofit, the earthquake resistance of a structure improves from the category of "damage beyond repair" to "not habitable," or from "not habitable" to habitable," then the hazard mitigation measures will be

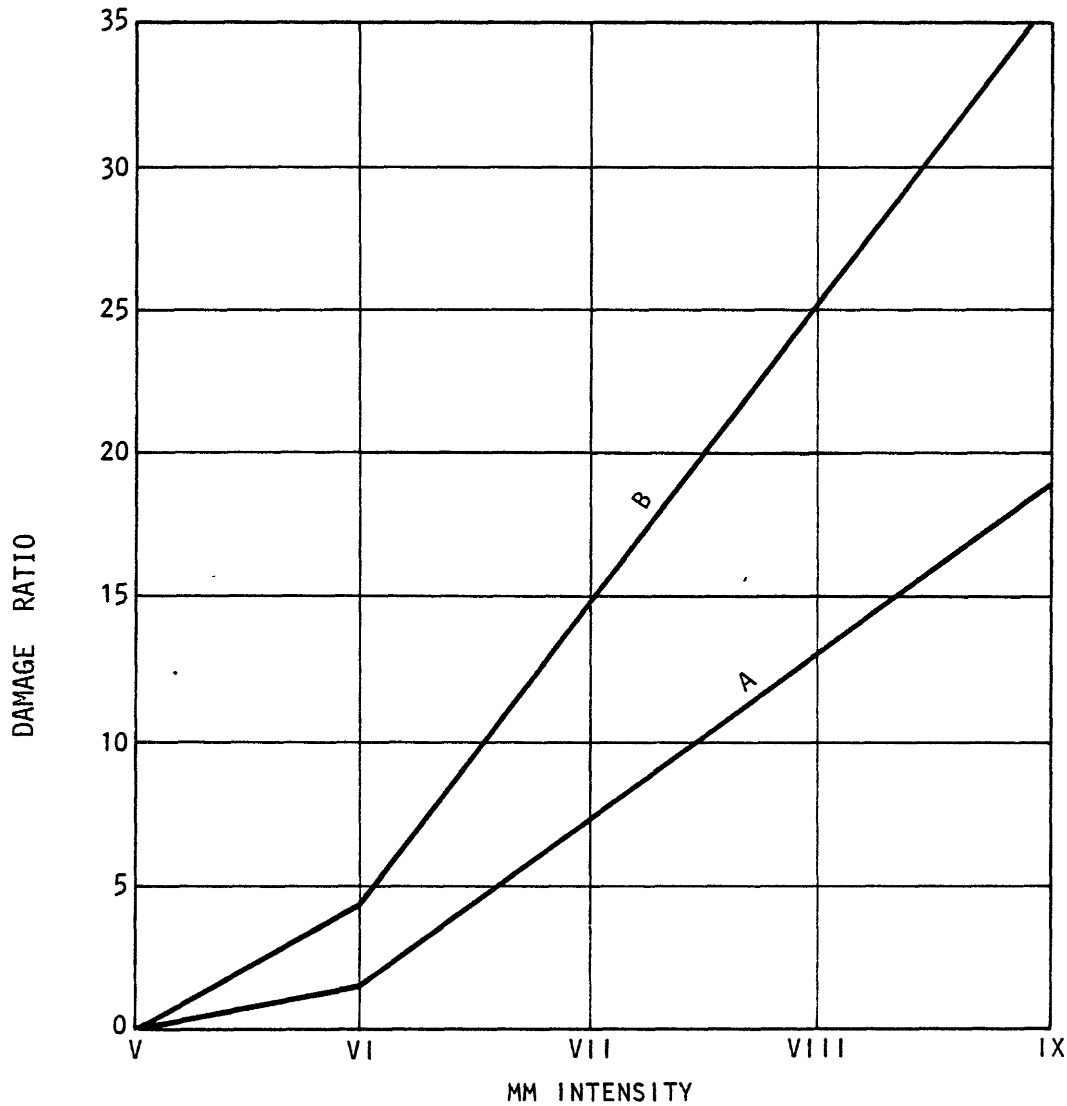
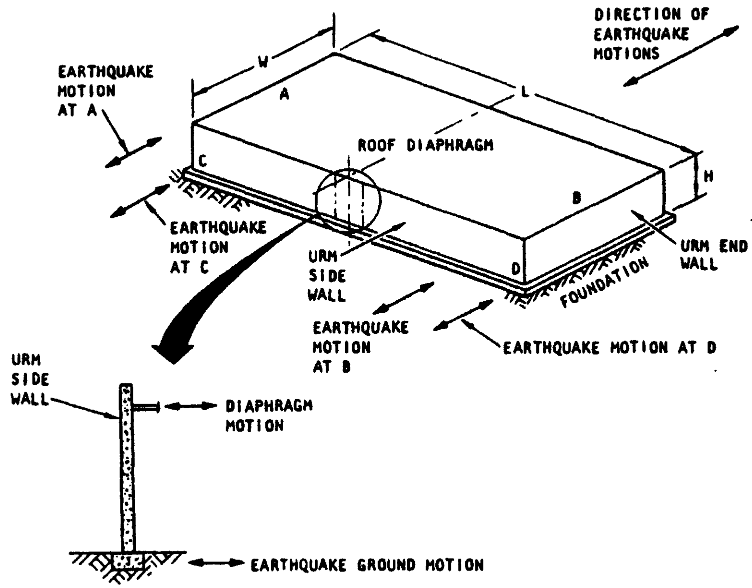
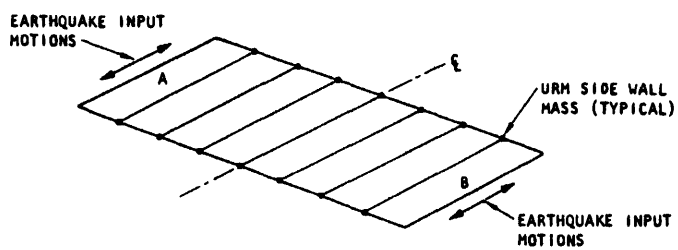


FIGURE 1. AVERAGE DAMAGE FOR REINFORCED (A) AND UNREINFORCED (B) MASONRY BUILDINGS (Wm. Spangle and Associates, Inc., 1984)



(a) Interaction between diaphragm and side wall



(b) Diaphragm/wall model

FIGURE 2a. DIAPHRAGM/WALL CONFIGURATION MODEL

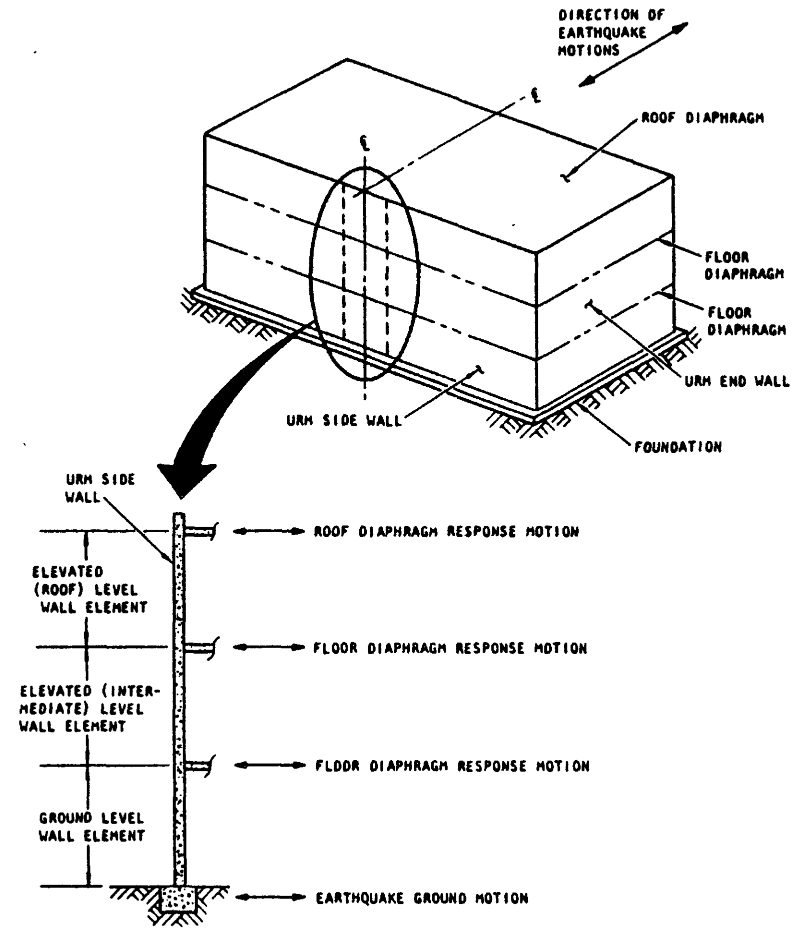


FIGURE 2b. WALLS, OUT-OF-PLANE, MULTI-STORY BUILDING

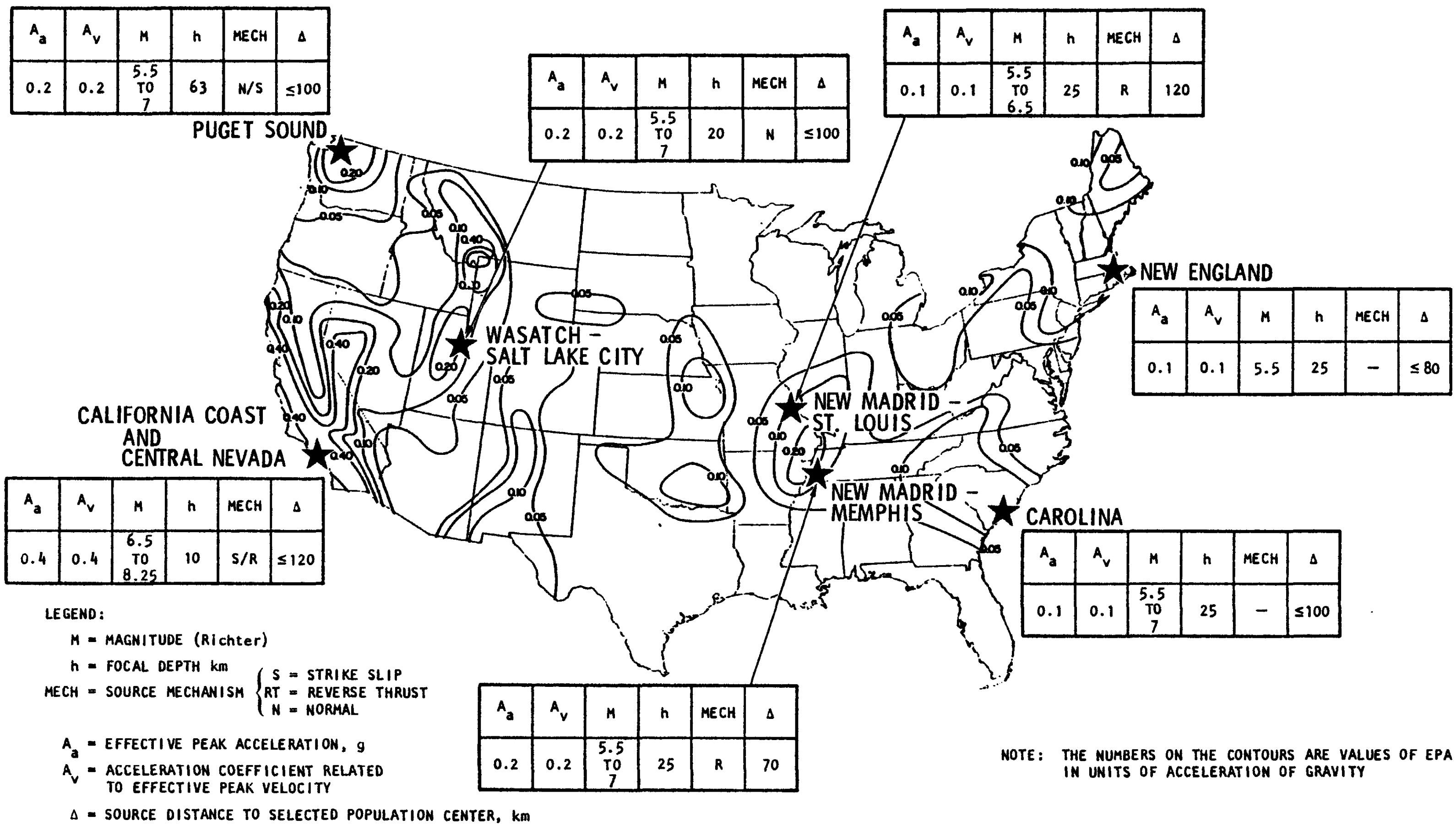


FIGURE 3. SUMMARY OF SEISMIC INPUT DATA FOR SEVEN MAJOR U.S. GEOGRAPHICAL REGIONS (Applied Technology Council, 1978)

warranted, provided of course that the types of tolerated damage will not appear to cause loss of life or serious injury. Such considerations are not new. Building codes do not expect design for no damage. In fact, the philosophy so well articulated by the Structural Engineers Association of California states that structures should be designed to "resist minor earthquakes undamaged, resist moderate earthquakes without significant structural damage even though incurring nonstructural damage, and resist severe earthquakes without collapse."

In comparing the shaking hazard criteria for Categories 1 and 2, we note that by using equivalent peak accelerations as a definition of the shaking hazard, the criteria for Category 2 provides parameters that may be used in the numerical analysis of actual structures whose geometric and material properties are determinable.

SHAKING HAZARD FOR A GROUP OF BUILDINGS UNDER SINGLE OWNERSHIP

Evaluation of the shaking hazard for a relatively small number of buildings is generally based on a systematic approach to criteria development, analysis, and design for strengthening. The steps may be outlined as follows:

a. Estimate the seismic hazard from geological and seismological characteristics of the site, strong motion records from similar sites, and statistical data compiled from past earthquakes. Express the hazard in terms of the expected occurrence of earthquakes of various intensities.

b. Establish the seismic risk in terms of loss of life, material damage, functional loss, and degradation of buildings.

c. For each building, identify the structural system and develop a model for analysis.

d. Evaluate the responses of the buildings to earthquakes of various intensities.

e. Determine type and degree of damage as related to earthquakes of various intensities.

f. Determine damage criteria. These may be obtained by setting limits of strength, stiffness, ductility, and stability. Damage to structural as well as to nonstructural components should be considered.

g. Develop methods of upgrading structures for which damage is expected and assess their associated costs.

h. From the seismic risk data (b), type and degree of damage (e), and cost of upgrading (g), establish a plan for increasing the seismic resistance of buildings in the group, based on allocated budgets.

i. Develop schedule, cost, and management for implementing the seismic safety program.

The "expected occurrence of earthquakes of various intensities" in Step (a) must be more specific than just intensity levels. Structural systems have to be analyzed to determine their dynamic response, and it is necessary to define the intensity levels with parameters that are significant for such an analysis. For a first level analysis of structures, the intensity is given as a function of frequency or period and damping level. (For a more refined analysis, duration is also required.) The best way of representing this information is with the use of response spectra. This is a plot of the maximum response of single-degree-of-freedom systems, of various damping levels, to a given time history of ground motion. Figure 4 shows such a response spectrum. Because the jaggedness of the plot is dependent on the "frequency content" of a particular ground motion record, and since records of ground motion differ considerably from each other, it is acceptable to smoothen the spectra for design purposes, as shown in figure 5. The same design spectra may also reflect the potential shaking from different types of earthquakes by combining their spectra. For instance, for sites in southern California, the high frequency portion of the design spectra may be governed by a nearby earthquake of magnitude 6.5, while the low frequency portion would be controlled by a magnitude 8+ earthquake on the San Andreas fault (Housner and Jennings, 1982).

In Step (e) of the above procedure, it is desired to "determine type and degree of damage as related to earthquakes of various intensities." In an analysis of the behavior of a structure, type and degree of damage is usually defined in terms of the structure's ability to absorb energy. Nonductile structures have little ability to absorb energy whereas ductile structures absorb energy by yielding under the influence of the earthquake-induced vibrations. The design spectrum describing the seismic criteria can account for the ductility of the structure. The permissible stresses and strains can be incorporated into the design spectrum by modifying it to accommodate various levels of ductility (Newmark and Hall, 1981).

As an example illustrating different degrees of damage of buildings in a group as a function of earthquakes at various levels of intensity, consider six buildings of different characteristics. Figure 6 plots the percentage of damage as a function of maximum ground acceleration obtained from a family of response spectra. It is seen that their responses are very different, Building A being most vulnerable and Building F being the least vulnerable. The owner of these buildings may wish to make a decision as to whether the costs of strengthening are justified. On the other hand, he may not want to strengthen them, but he may want to know the cost of repair when the buildings are damaged. Table 4 gives the replacement costs, percent damage at various levels of seismic severity, and cost of repair or replacement. No estimate of loss of life or injury can be made in such a simple analysis, and loss of the function of the buildings following the earthquake is not included in the cost estimate.

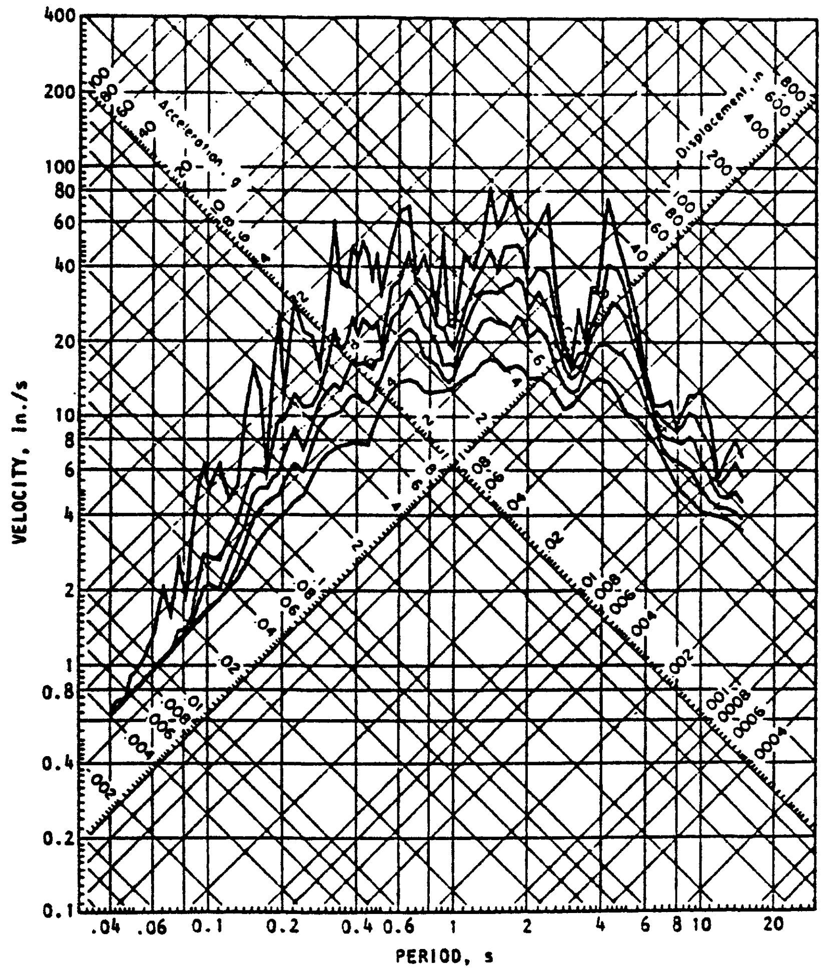


FIGURE 4. RESPONSE SPECTRUM — SAN FERNANDO EARTHQUAKE, FEBRUARY 9, 1971 (Holiday Inn, approximately 5 miles from causative fault)

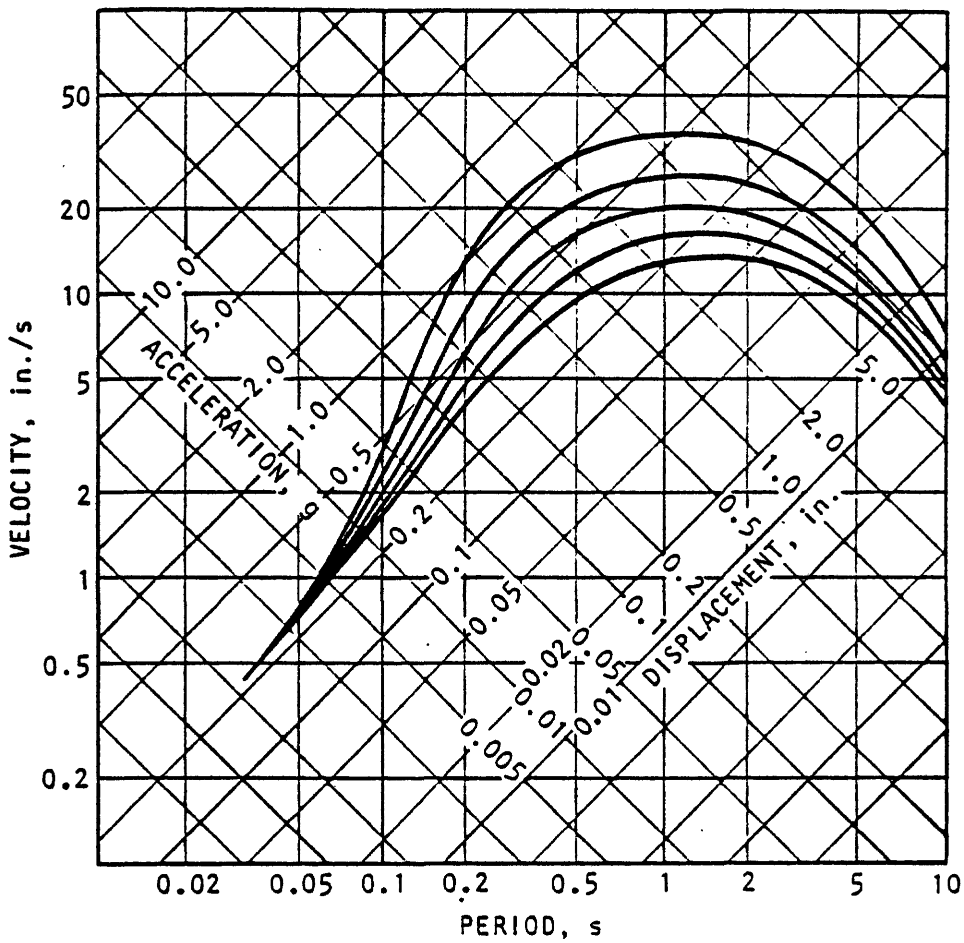


FIGURE 5. EXAMPLE OF SMOOTH DESIGN SPECTRUM - SAN FERNANDO EARTHQUAKE, FEBRUARY 9, 1971
(Housner, G.W., and Jennings, P.C., 1982)

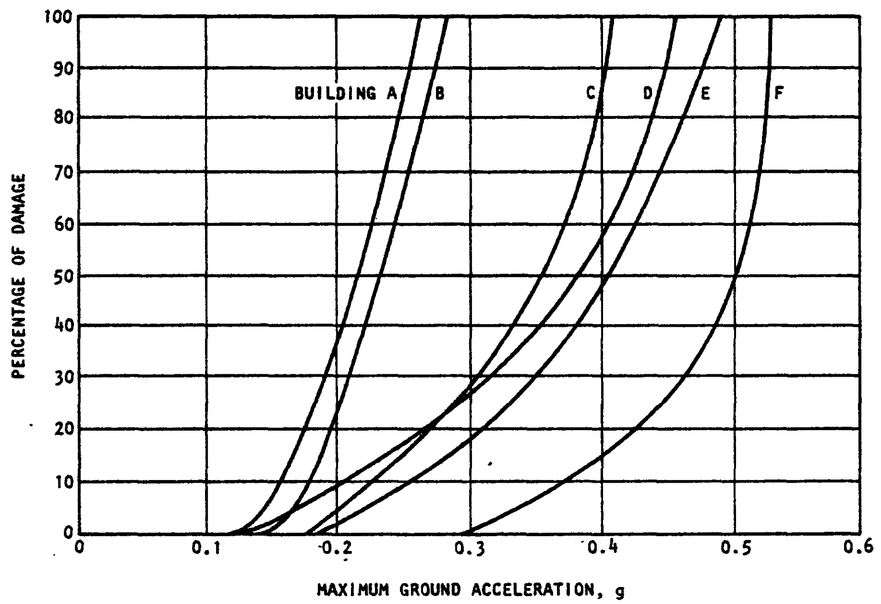


FIGURE 6. EXAMPLE ILLUSTRATING DIFFERENT DEGREES OF DAMAGE OF BUILDINGS IN A GROUP AS A FUNCTION OF ASSUMED EARTHQUAKES (Agbabian, M.S., 1985)

In this example, the replacement cost for the six buildings is 12.5 million dollars. At an anticipated 0.4 g level earthquake, the cost of repair is 8.4 million dollars. This is only a starting point in the economic analysis of the advisability of repairing after an earthquake or strengthening before an earthquake. A legitimate question is whether or not the owners should make their decision strictly on the merits of these financial considerations. If the buildings provide utility services or are a part of a hospital complex, or casualties are a real possibility in the six buildings being considered, or functional disruptions will affect public convenience if not safety, how will these factors be quantified in making a determination? This paper covers only the shaking hazard on buildings, but redevelopment decisions must face the issue of whether to strengthen before or to repair after an earthquake.

SHAKING HAZARD FOR A SINGLE STRUCTURE OF CRITICAL IMPORTANCE

Researchers investigating structures damaged during earthquakes sometimes speculate in their reports that "if the earthquake had lasted five more seconds the building would have collapsed." Such speculation is sometimes based on rational analyses. A damaged structure goes through a sequence of degradations. Traces of accelerograms in a damaged building, such as the Imperial County, California Services Building, have been studied to relate the record to the sequence of damages the building has experienced (Housner and Jennings, 1982). Lengthening of the period of the structure and increase in damping are indications of the structure going into a highly nonlinear regime. Sudden changes between records of accelerograms placed at different locations in the building may show significant increases in torsional motions due to failure of columns or walls that introduces strong asymmetry. A mathematical model considering extended duration of the shaking could be used to predict collapse. Often, however, this prediction is based on engineering judgment. Imminent collapse due to failure of critical structural members will lead to total collapse if the shaking continues.

The criteria for a structure of critical importance must have an explicit statement on the duration of the postulated earthquake. It is noted here that the response spectrum has the effect of duration incorporated indirectly. An earthquake of longer duration will have a larger number of large peaks, and their influence will appear in the calculation even though no explicit duration is given by the spectra.

A refined analysis of the structure can be made by using as seismic input a number of strong-motion time histories, each time history having its own characteristics of period and duration. Figures 7 and 8 show records of different earthquakes, and records of strong motions at different locations for the same earthquake. A judicious selection of seismic input motions is important. Modifications of strong motion records are often made for criteria. For example, a given record may be scaled up by a multiplying factor to increase the acceleration amplitudes, and its duration is extended by repeating a segment of the record at a selected point in time. The end result is an artificial accelerogram that retains the characteristics of a particular record from a known earthquake. By increasing the amplitude and duration it is possible to obtain a time history of strong motion that represents the "expected occurrence of an earthquake of a specific intensity."

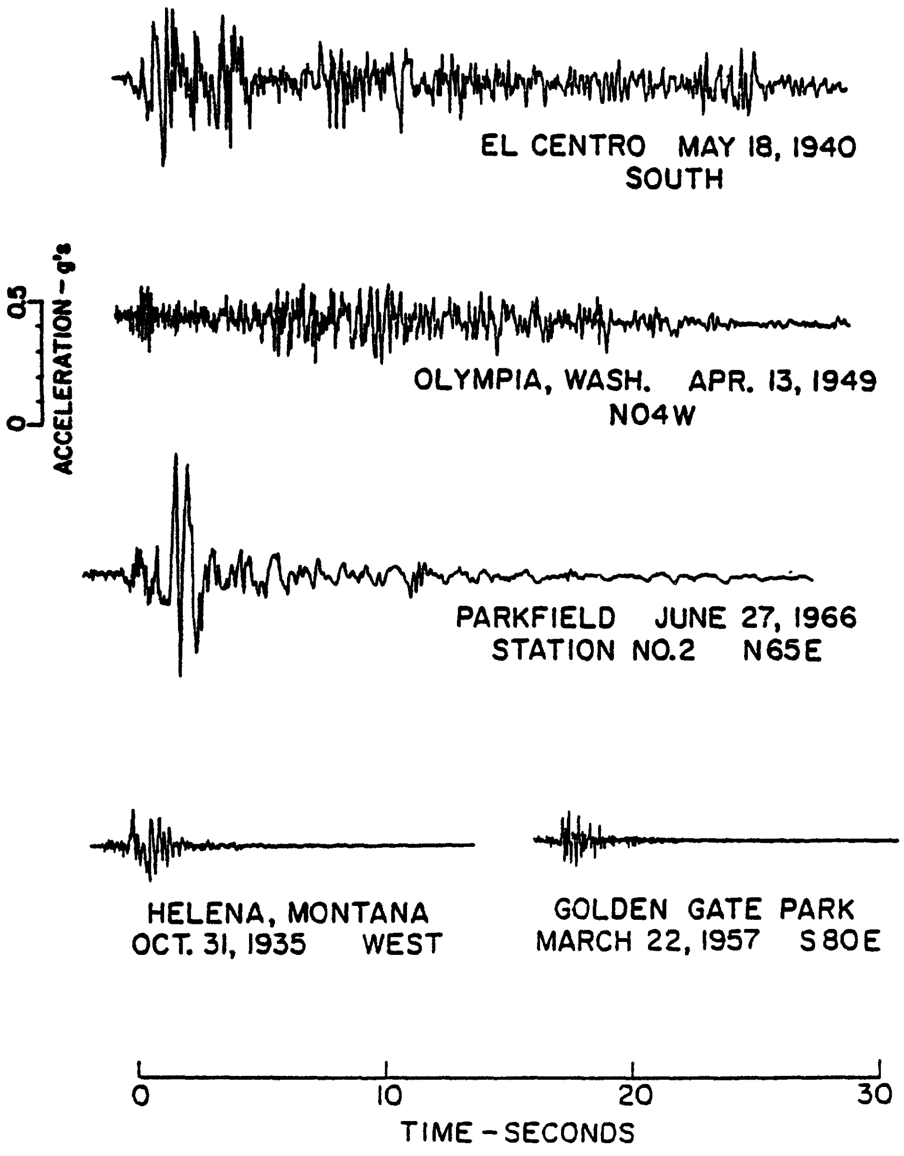


FIGURE 7. EARTHQUAKE GROUND ACCELERATIONS
(After D. Hudson)

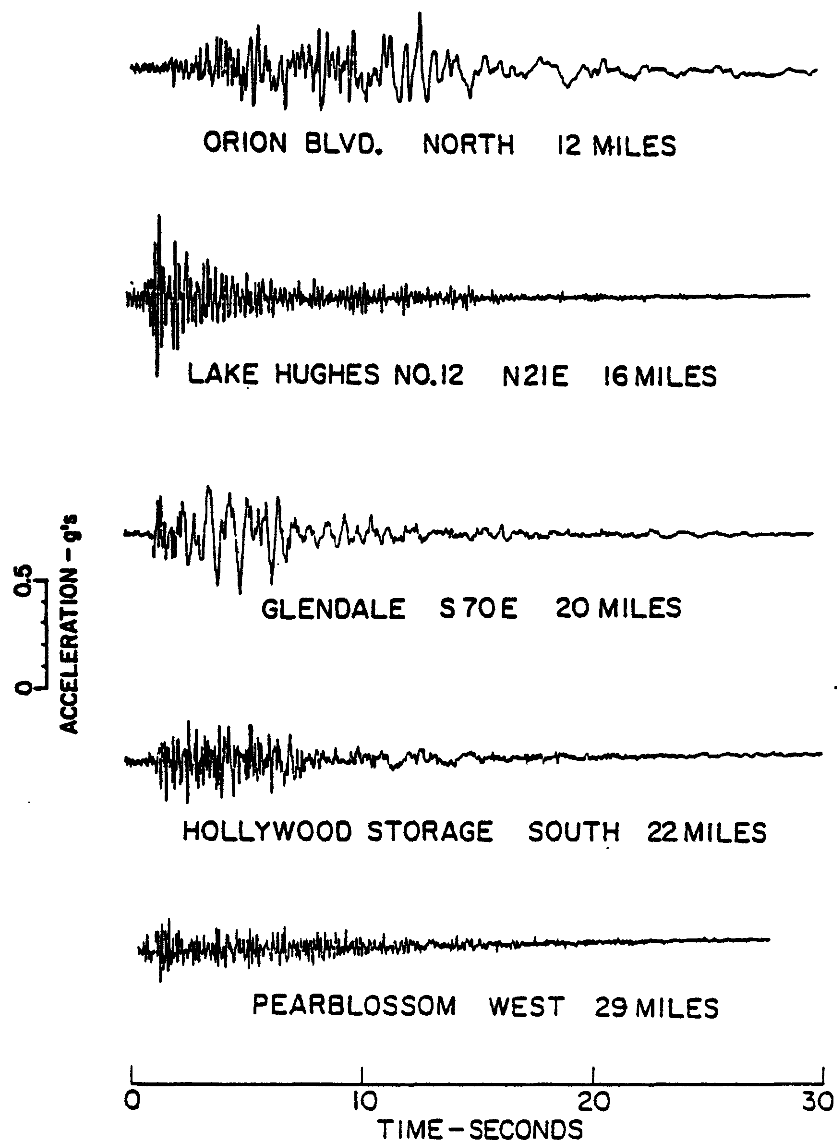


FIGURE 8. SAN FERNANDO ACCELEROGRAMS – FEBRUARY 9, 1971 (After D. Hudson)

In order to stay within the consensus of scientists and engineers whose collective wisdom provides the basis for seismic intensity predictions, time histories must be matched with response spectra that have already been matched to seismic intensities. An example of this is given in figure 9 where the response spectrum of the selected time history is shown to agree well with a well-defined spectrum for a seismic region. In this case, the Los Angeles region is used.

CONCLUSIONS

Evaluation of the shaking hazard for redevelopment decisions must include the characteristics of structures within a region along with the earth-science-based predicted or postulated earthquakes.

The evaluation should be carried out with a degree of refinement that is compatible with the size and content of the area under consideration. Four categories are suggested:

1) A large region containing different types of buildings, for example the City of Los Angeles.

2) One type of structure in large numbers distributed in several regions, for example unreinforced masonry buildings.

3) A group of buildings with single ownership, for example a university campus or a company-owned group of buildings.

4) A single structure of critical importance, for example a hospital, emergency center, or high-rise building.

The shaking hazards for the above categories are usually defined at different levels of refinement, as follows: For a large region, epicenters, magnitudes, and seismic intensities of several predicted or postulated earthquakes will define the general hazard for broad and general determinations of the effect of shaking on buildings and lifelines. For a large number of structures of a single type, several levels of intensity, defined by parameters that can be used in structural response calculations, such as effective peak accelerations or response spectra, may be defined for use in estimating damage and strengthening or repair requirements. For a small group of buildings, site-dependent earthquake response spectra may be devised based on geological and seismological data and strong motion records from similar sites. For a single structure of critical importance, the information developed in the third category must be supplemented by predicted or postulated time histories of representative earthquakes at the site.

It has been shown in this paper that such information may be used effectively in estimating the earthquake shaking hazard. There is, however, a need to continue research efforts for more reliable data and more effective methods.

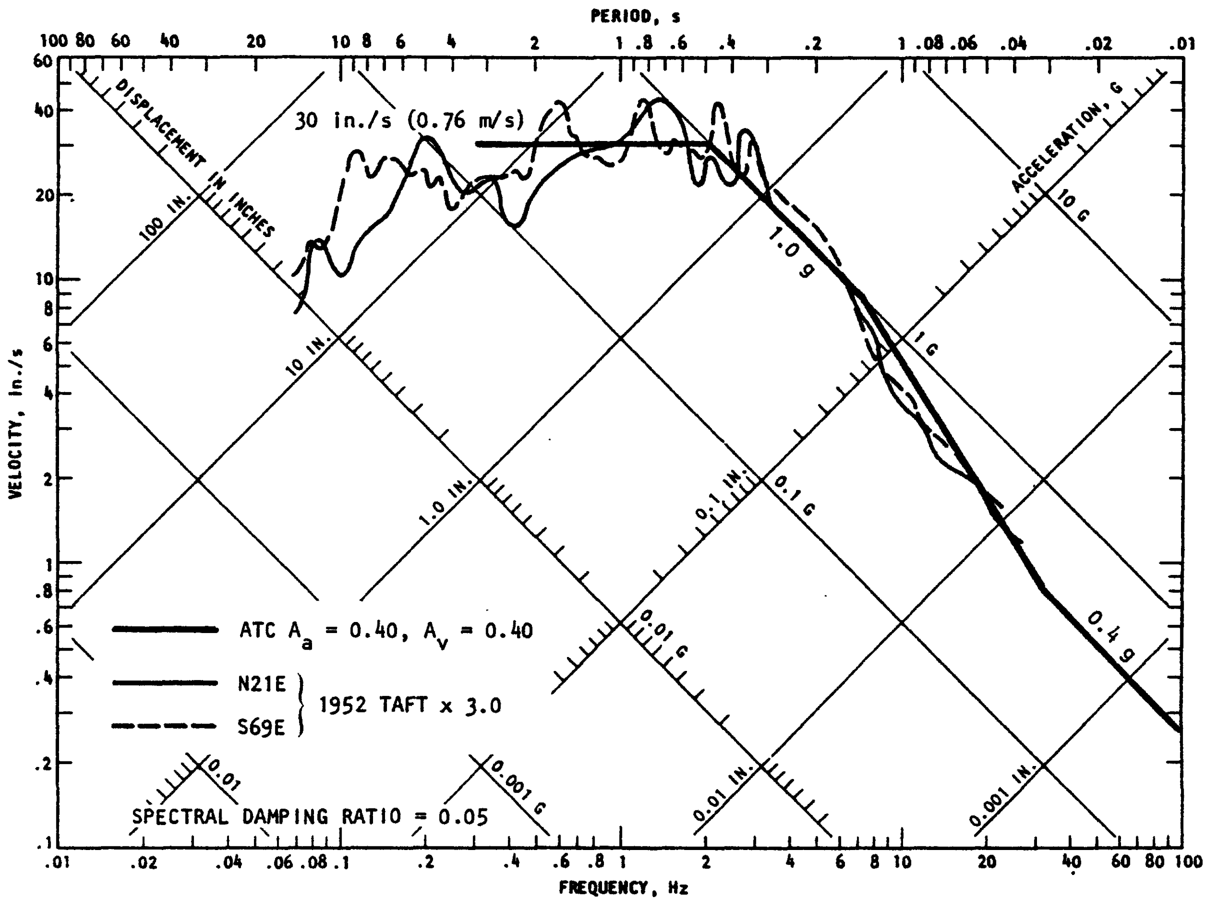


FIGURE 9. COMPARISON OF ATC SPECTRA FOR CALIFORNIA COAST AND CENTRAL NEVADA REGION AND 1952 TAFT RECORD SCALED BY A FACTOR OF 3.0 (ABK Joint Venture, 1981)

CRITICAL RESEARCH NEEDS

- Exploration of methods for estimating the inventory of buildings and lifelines in an urban region. This inventory should include the type of data that is useful and necessary for the evaluation of shaking hazards at increased levels of refinement.

- Experimental and analytical research to develop methods of predicting material damage and degradation of buildings for a better definition of damage severity. The research should establish reliable measures of damage criteria in order to make better predictions of damage severity for different seismic intensities.

- Methods of incorporating in the shaking hazard model all significant functional, economic, and loss of life parameters, in addition to physical damage of buildings and lifelines.

REFERENCES

ABK Joint Venture, 1981, Methodology for mitigation of seismic hazards in existing unreinforced masonry buildings, v. 8: Agbabian Associates, El Segundo, Calif.

Agbabian, M.S., 1985, Evaluation and screening for large groups of buildings, in Seismic Performance of Existing Buildings, U.S.-Japan Cooperative Earthquake Engineering Research Program, May 1983, Proceedings: v. 1, Cornell University Press, 135 p.

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings, ATC 3-06: National Bureau of Standards, Washington, D.C., 28 p.

Housner, G.W., and Jennings, P.C., 1982, Earthquake design criteria: Earthquake Engineering Research Institute, El Cerrito, Calif., 63 p.

Newmark, N.M., and Hall, J.W., 1981, Earthquake spectra and design: Earthquake Engineering Research Institute, El Cerrito, Calif., 46 p.

William Spangle and Associates, Inc., 1984, Pre-earthquake planning for post-earthquake rebuilding (PEPPER Project): Part I -- Seismic environment and geologic effects (Earth Sciences Associates, Inc., 1982, 32 p.); Part II -- Summary report of structural hazards and damage patterns (H.J. Degenkolb Associates, Engineers, 1984, text 38 p.; tables 52 p.): National Science Foundation grant CEE 8024724; William Spangle and Associates, Inc., Portola Valley, Calif.

SUGGESTED DIRECTIONS IN EARTHQUAKE SHAKING MICROZONATION RESEARCH

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INTRODUCTION

Rogers, Tinsley, and Borcherdt (1985) described an empirical technique for predicting relative site response by comparing ground motion spectra in three period bands (total period band is from 0.2 to 10 seconds) relative to the thickness and the physical properties of the earth materials which lie beneath the instrument sites. A set of three-component recordings of Nevada Test Site nuclear tests and a compilation of geologic attributes at each site comprise the set of basic data employed in the analysis. A suite of site types (clusters) is defined statistically in terms of common geologic attributes. The attributes defining each cluster are those attributes that most strongly correlate with, or influence, site response in a given period band. Maps showing the distribution of these geologic attributes are prepared as overlays and are used to construct derivative maps which, in turn, depict relative site response for part of the Los Angeles area.

Future research is desirable, both to explore further the methodology and to test the predictions of the model compared to patterns of damage caused by historical earthquakes, as well as applying the technique to basins other than the Los Angeles region. The principal goal of these and related studies is to develop microzonation technology so that sites which are especially at risk can be identified and appropriate measures can be adopted to reduce significantly losses of life and property.

VARIABLE GROUND RESPONSE IN THE LOS ANGELES REGION

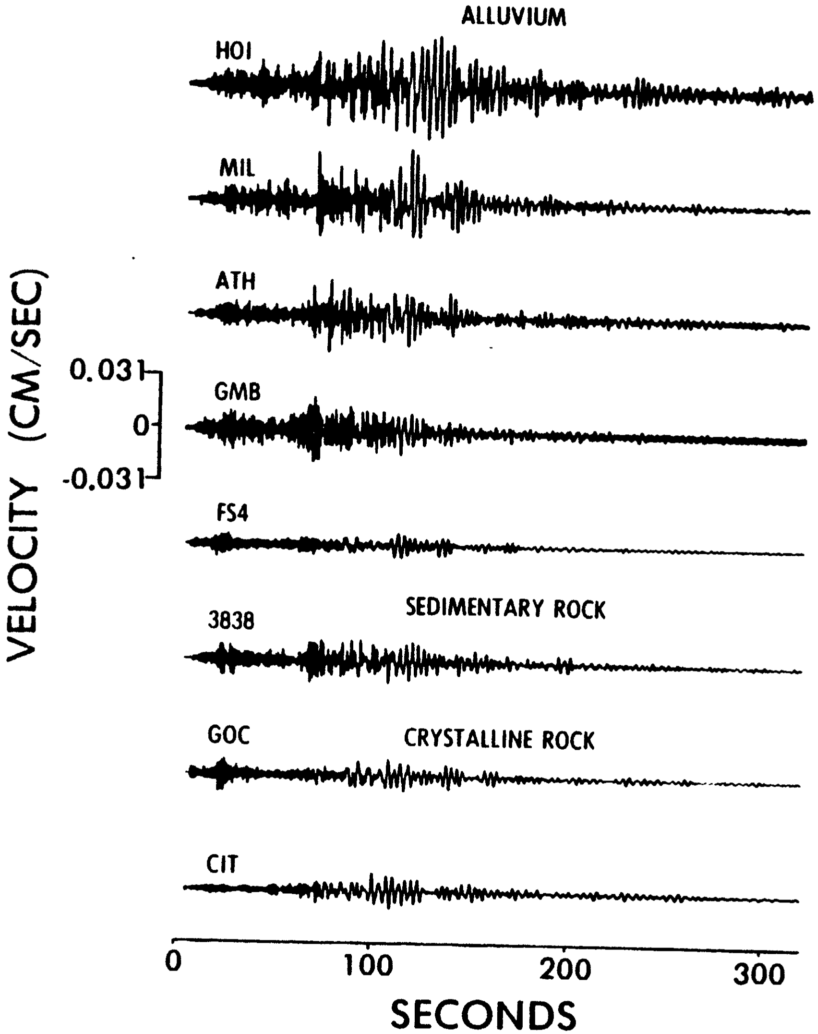
Local geologic conditions long have been recognized as a significant factor influencing ground shaking (Kanai, 1952; Gutenberg, 1957; Medvedev, 1962), although the quantitative prediction of site effects using either empirical or theoretical models is still developmental. We have extended to the Los Angeles area the technique developed by Borcherdt and Gibbs (1976), recasting the technique to include the effects of near-surface site properties and geologic structure. To determine relations among local geologic factors and site response, 19 nuclear explosions were recorded at 98 sites throughout the Los Angeles region (Rogers and others, 1980). Sites were selected to obtain as complete a sample of underlying geologic conditions and as broad a geographic coverage as possible. The seismic source (Nevada Test Site) lies some 400 to 450 km from the recording sites; effects of azimuthal variations in the radiated energy are similar for all sites. Each site's response characteristics over the period band 0.2 to 10 seconds was estimated by computing Fourier spectra and alluvium-to-crystalline rock spectral ratios (Rogers and others, 1980). The site CIT, underlain by crystalline rock, was instrumented for every nuclear explosion and was the rock site against which recordings measured at all other sites were compared (see figure 1A).

Distant nuclear explosions generate ground motion records in which the effects of site conditions are readily apparent. Figure 1A shows time histories recorded simultaneously at eight sites from a single Nevada Test Site nuclear explosion. This example illustrates several effects of local site conditions that are observed commonly in recorded time histories when the source of shaking is distant. Maximum amplitudes of motion recorded on the alluvial sites are several times larger than those recorded on the sedimentary and crystalline rock sites. The degree of amplification occurring in the long-period peak amplitudes visible in these records is greatest at sites underlain by the thickest sediments (HOI: 300 m; MIL: 370 m; ATH: 370 m; GMB:120 m; FS4: 15 m).

The amplitude spectral ratios computed for the simultaneous recordings shown in figure 1A are presented in figure 1B. These ratios show that the effects of site conditions relative to those at CIT are strongly frequency dependent, and amplification occurs for many of the sites over most of the frequency band for which the signal-to-noise ratio is favorable (Rogers and others, 1980). Amplification factors of the horizontal component of ground motions range from 2 to 7 at frequencies less than 1 Hz for those sites on thick sections of alluvium; lower amplification factors are found at these frequencies for the site FS4 underlain by a thin alluvial section. Considerable amplification at intermediate frequencies (1-2 Hz) and at higher frequencies (2-5 Hz) occurs at several sites, notably FS4, where a prominent ground resonant frequency is observed. Resonance is not apparent for thick alluvial sites (spectra are relatively flat across the entire observed frequency range). Spectral ratios at site GOC suggest that the response of the two crystalline rock sites (GOC, CIT) is similar at lower frequencies, but at intermediate and high frequencies, ground motions at GOC are higher than at CIT. Relative to CIT, site 3838, located on sedimentary rock, shows a uniformly greater response than GOC, but a lesser response than the sites underlain by thick alluvial sections.

COMPARISON OF GEOLOGIC FACTORS AND GROUND RESPONSE

Geologic parameters were chosen to characterize the recording sites because either the parameters have some direct application in a theoretical model of site response or, in past studies, the parameters have been reported to have some influence on ground shaking. Parameters such as percent (silt+clay) and depth to water table have been reported to influence site response, whereas shear-wave velocity (or void ratio, which strongly influences the shear modulus), thickness of Holocene deposits, thickness of Quaternary deposits, and depth to crystalline basement rocks are parameters that might be used directly to model site response. Most of these data are available in the literature or are obtainable from published geologic maps, records of water wells, and geotechnical studies conducted for engineering purposes; these data are of especially great value if they can also be used to estimate site response in some quantitative manner.



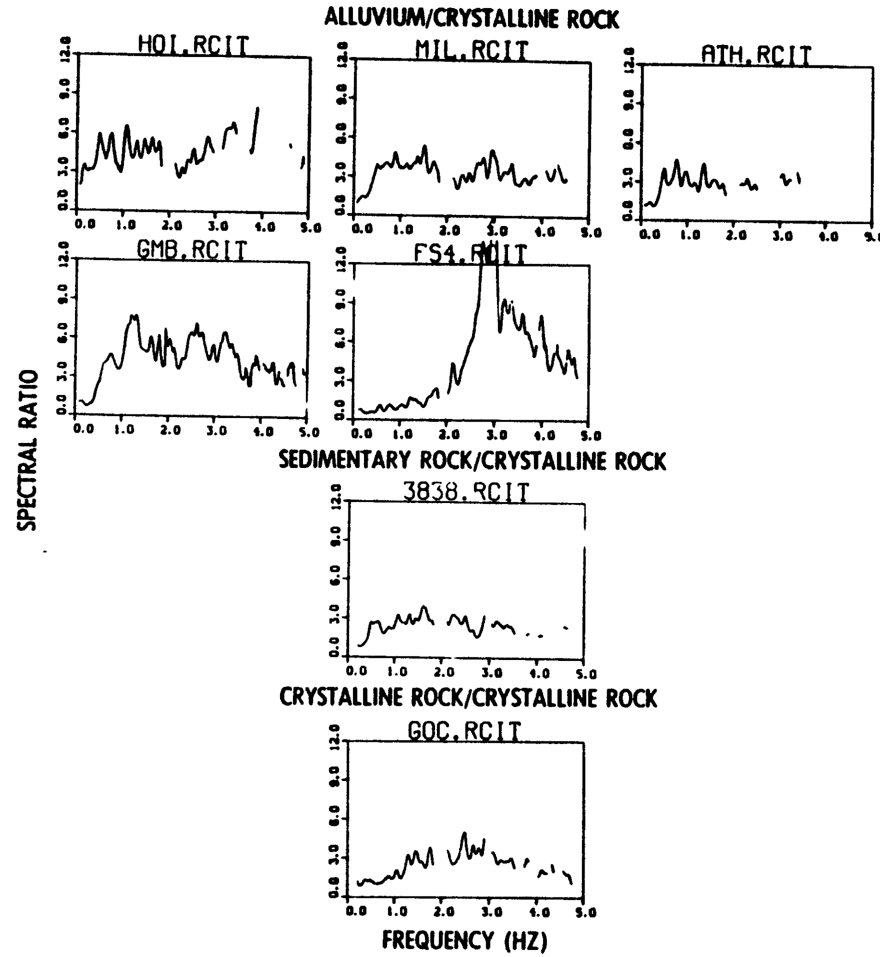


Figure 1A. Radial component time histories recorded simultaneously at 8 sites, grouped according to the type of geologic materials immediately beneath each recording station.

Figure 1B. Spectral ratios of the radial components of ground motion shown in figure 1A, relative to station CIT, a crystalline rock site.

We examined the relation between site response and the geologic parameters by grouping the sites according to variations in one of the geologic factors and then computing mean response for each group. The following ground response characteristics emerged:

- o Sites underlain by Holocene and Pleistocene sediments undergo levels of shaking 2.6 to 3.4 times greater than those sites underlain by crystalline rocks, for all period bands,
- o The void ratio of near-surface deposits has a strong influence on short-period response, with void ratios in the 0.8-0.9 range indicating a mean response on soil six times greater than on crystalline rock and three times greater than on low-void-ratio soils, and
- o Amplitudes in the long-period band (3-10 seconds) generally increase with increasing thickness of Quaternary deposits and/or depth to crystalline basement rocks.

Additional detailed studies of the influence of all geologic parameters were conducted using data analysis and regression techniques (Mosteller and Tukey, 1977). These studies indicate that the most pronounced changes in site response were correlated with changes in void ratio, thickness of Holocene deposits, depth to crystalline basement rocks, and thickness of Quaternary deposits.

CLUSTERING OF SITES BY GEOLOGIC ATTRIBUTES TO REFLECT VARIABILITY IN SHAKING RESPONSE

Sites that have similar response characteristics can be clustered (grouped) by computing an analytical measure of similarity among a list of items based on their attributes. In our analysis, the items are the recording sites and the attributes are the geologic properties of each site. We cannot use the response factor (amplification factor) as an attribute, because we are attempting to predict response as a function of the geologic properties of the site. The clustering algorithm (IMSL, 1982) is used to establish a hierarchy showing which items are most nearly alike, and also show the level within the hierarchy at which clusters of similar items are most alike.

Once this procedure is used to form clusters based on any chosen set of factors, discriminate analysis (Nie and others, 1975) is used to determine the degree to which these factors define unique clusters; the significance of each factor's discriminating power is computed based on the statistical relations among factors within and between the respective clusters. One can calculate the probability that any single member of a cluster belongs to that cluster or to any other cluster; based on these probabilities, the percentage of sites that have been correctly classified can be calculated. In our study, the cluster sets that were selected were those having the lowest dispersion in the defining variables while incorporating only those factors having the most pronounced effect in a given period band. The final sets of clusters are a compromise between the many clusters required to preserve the complexity in site response as a function of geology, and the requirement that each cluster contain enough cases to impart statistical validity to the estimate of the average response for the cluster.

Two clusters for rock sites and eight clusters for alluvial sites were derived for the short-period band (0.2-0.5 sec) and the respective attributes of each cluster are shown in figure 2. To understand figure 2, an example may be helpful. Cluster 4A includes sites that have a depth to crystalline basement rocks of greater than 0.5 km, a thickness of Holocene deposits that is greater than 20 m, void ratios in the range of 0.6-0.7, and a geometric mean response of about 3.6, relative to crystalline rock sites. Moreover, if an attribute such as Holocene thickness is held fixed, response increases as void ratio increases (compare clusters 1A, 3A, and 6A). Response also increases, for a constant void ratio, as the thickness of Holocene deposits increases and passes through a critical range (compare clusters 6A, 7A, and 8A). Not surprisingly, rock sites 1R and 2R indicate a geometric mean response that typically is less than that of the clusters of alluvial sites. A comparison of clusters 1A and 2A shows that sites underlain by shallow alluvium over crystalline rock (2A) have a response two times higher than does the same type of site overlying a deep sedimentary basin, a relation that emphasized the importance of a high impedance contrast at shallow depths as a factor in ground response.

Although we have identified 10 clusters, with a moderate range in the geologic and response factors in each cluster, it is useful to compare average spectral level with shaking intensity. From Borcherdt and others (1975), if we adopt the reasonable assumption that a factor of two in mean spectral level corresponds to a change of one Modified Mercalli Intensity unit, then from the data in figure 2, we can infer that the 10 clusters predict the true site-response more closely than one intensity unit increment for 90 percent of the cases (the geometric 90 percent confidence interval (1.45) is less than a factor of two). Clusters also were derived for intermediate- and long-period bands on the basis of Quaternary thickness and depth to crystalline basement rock (Rogers and others, 1985), but these clusters will not be discussed here.

Map Showing Predicted Site Response for a Portion of the Los Angeles Region

The response maps for the intermediate- and short-period bands for a small area centered in the Los Angeles Civic Center are shown in figures 3A and 3B. These figures are based on the clusters just discussed and on a set of maps delineating the geographic distribution of the important geotechnical attributes of each cluster.

The intermediate-period map (figure 3A), of significance to structures between five and 30 stories high, predicts that low response will characterize areas underlain by rock and thickness of alluvium of less than about 150 m; intermediate levels of response will occur in areas where the thickness of alluvium is greater than 150 m and/or where the depth to crystalline basement rock ranges between 0.15 and 4 km; highest levels of response will be observed in areas where depth to basement rocks ranges from 4 to 6 km. Slightly lower levels of response are predicted in the deepest parts of the Los Angeles basin. Lowest levels of response

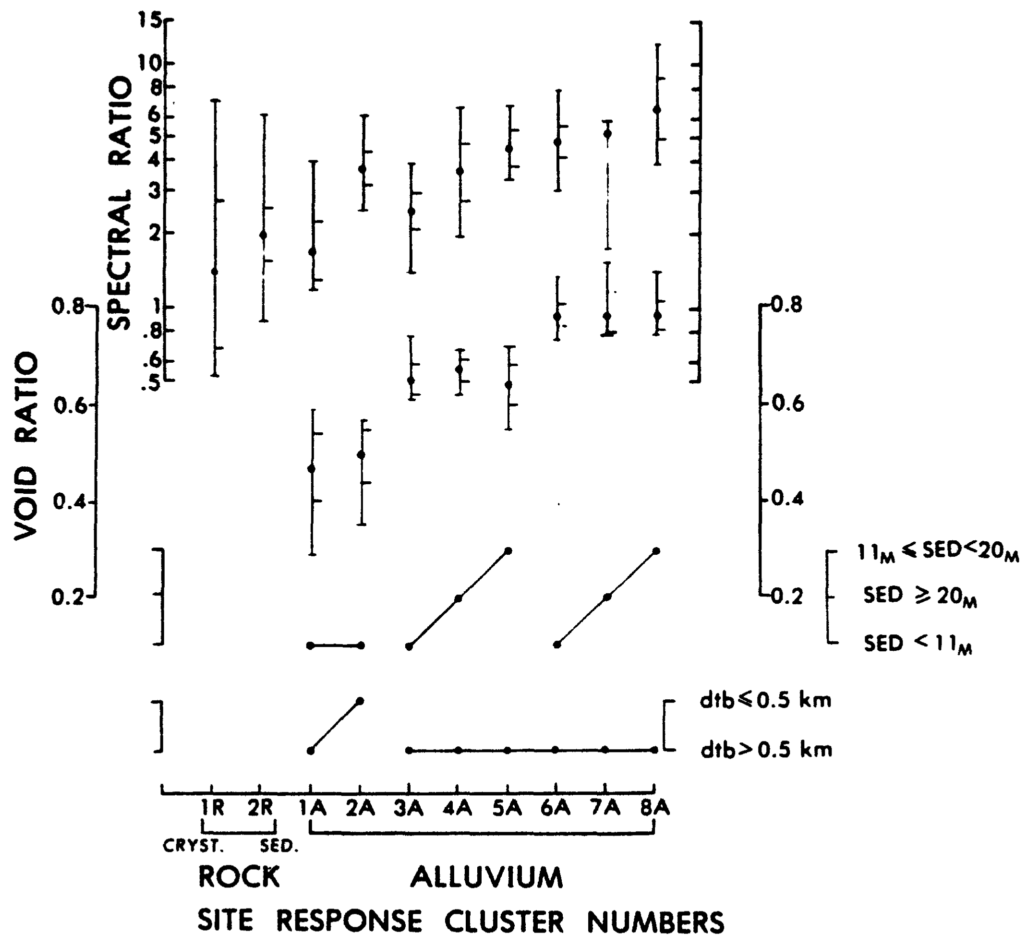
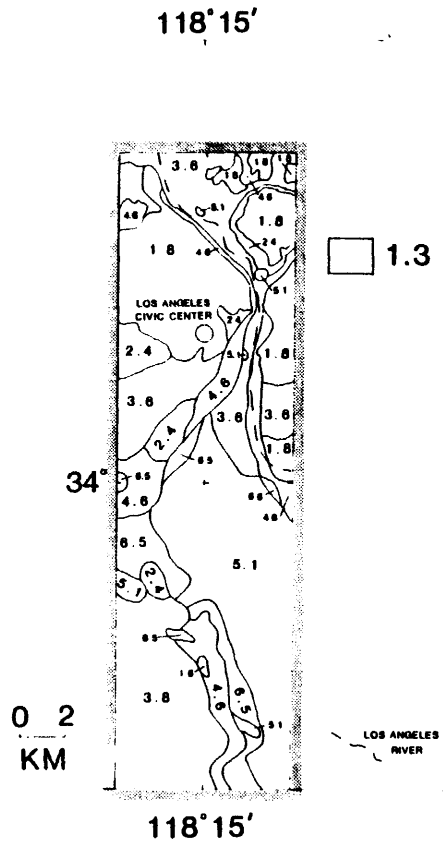
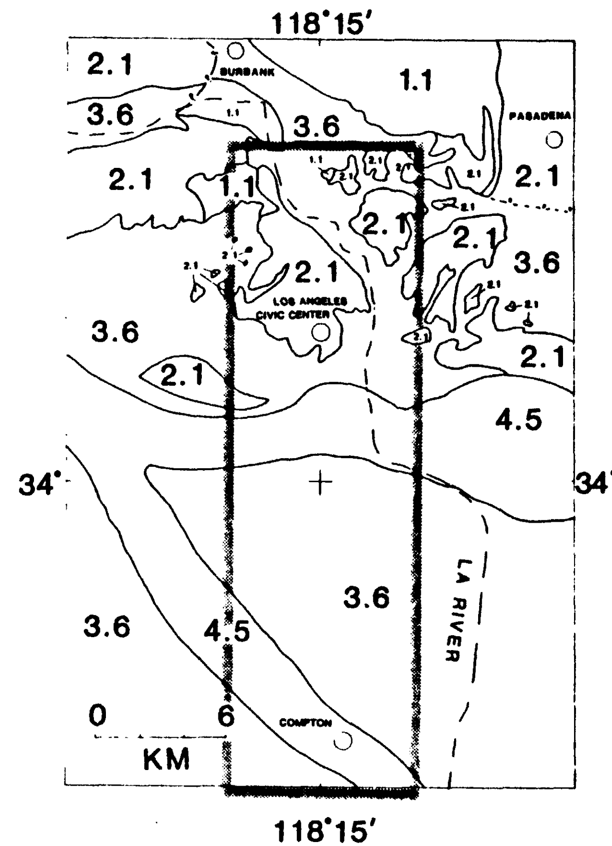


Figure 2. Site clusters for short-period ground motions in the Los Angeles region. Solid dots indicate the mean of the short-period spectral ratios for a given cluster, mean void ratio, Holocene deposit thickness, and depth to crystalline basement rock groups, as appropriate. Vertical bars indicate the range in the variable for a given cluster, and side ticks indicate the 90% confidence intervals.





Figures 3A and 3B. Maps showing predicted relative shaking response for part of the Los Angeles Basin. Numbers are mean amplification factors, comparing levels of shaking to sites on crystalline basement rock. Fig. 3A is a map for intermediate periods (0.5-3.3 sec). Stippling outlines area of Figure 3B. Fig. 3B is the map for short-periods (0.2-0.5 seconds).

are predicted in the areas where crystalline basement is at or near the surface in the Santa Monica Mountains and the Verdugo Mountains.

The short-period map, which is most relevant for buildings in the two- to five-story class, has been prepared for the central third of the area shown in the long-period map. The lowest response is predicted for areas underlain by crystalline and sedimentary rock, and the highest response will be observed in regions where thickness of near-surface alluvium (range 11 to 20 m) and high void ratio (exceeding 0.7) produces significant resonant response in this period band. This map rather closely approximates a surficial geologic map: details of alluvial valleys, including that of the Los Angeles River, are delineated. The southwest part of the map depicts an area where silty deposits (characterized by high void ratios) comprising parts of the recent floodplain of the Los Angeles River are widespread in the section and wedge out against the east flank of the Newport-Inglewood zone of deformation. There, Pleistocene deposits characterized by low void ratios are exposed. We note that high levels of short-period response may occur at rock sites if these sites are located near the crest of a ridge or other pronounced topographic convexity, as shown by the range of high response for clusters 1R and 2R (figure 3).

AVENUES FOR FUTURE RESEARCH

We anticipate that several avenues of inquiry seem to be especially important in analyzing the overall significance of the empirical approach used in our analysis of ground response in the Los Angeles region. In particular, testing of the methodology is essential, and an experiment that will be conducted in the near future will use data obtained following the March, 1985 Chilean earthquake. Digital recordings of aftershocks were made there at a suite of sites that are underlain by a wide variety of earth materials and geologic site conditions, in zones of high, intermediate, and low main-shock intensities, and at strong-motion main shock recording sites. The testing could proceed along several lines:

- What is the correlation between the change in Modified Mercalli Intensity level and aftershock (low strain) alluvium-to-rock mean spectral ratios? Preliminary results indicate a strong correlation exists between intensity change and the short-period (0.2-0.5 second) mean spectral ratios in the Santiago, Chile, area (Algermissen, 1985).

- How well do the short-period site clusters derived for the Los Angeles region (Rogers and others, 1985) predict geographic changes in intensity observed in Santiago, Chile? A strong correlation would demonstrate a broader applicability of the technique.

- Comparison of the mean site-response spectral values observed during the main shock and aftershocks in the Chilean earthquake would help support the validity of the numerical values of relative ground shaking predictions for strong motion conditions.

In our view, the methodology should also be expanded, both in an applied sphere and in a research sphere. We would apply the technique to a broader geographic region of the Los Angeles area; mapping of predicted ground response according to the clusters derived for the Los Angeles area but involving parts of the San Fernando Valley is in progress. Depending on the success of this endeavor, continuation of the work in other basins of southern California may be advisable. In the research sphere, we must collect additional data to permit improved estimates of the mean values and standard deviations for the respective clusters and add new clusters and perhaps redefine or regroup components of the existing clusters as necessary using new data from many regions. Further evaluation of the effects of site response relative to peak acceleration, velocity, and displacement parameters is needed, in order to translate the results of the study in terms which are more directly useful in engineering practice. The results could also be cast in terms of modifications to design spectra.

Microzonation maps should have potential applications for land-use planning purposes, where it may be desirable to avoid the siting of critical facilities and lifelines in zones of predicted high levels of shaking and siting of high-rise structures in zones of long-period intense shaking. In the latter case, it is particularly important to avoid the siting of high-rise structures having resonant period equal to or nearly equal to that of the predominant period of ground shaking of the site, as demonstrated by the 1985 Mexico earthquake and building damage to high-rise structures in Mexico City.

Where avoidance cannot be accomplished, special consideration (at least for critical structures) should be given to the design of these facilities when they are sited in zones of predicted high shaking intensity. For instance, it is possible to use design spectra that account for site conditions; or modify the design of buildings in order that the predominant period of the building does not coincide with the predominant period of ground shaking.

Microzonation maps have been and will continue to be important to studies of earthquake losses. Accurate estimates of future losses depend heavily on understanding the geographic variation in ground shaking. In turn, such studies are important elements of emergency preparedness and response.

In summary, application of ground shaking microzonation techniques to determine the nature of any increased risk owing to geologic site conditions should, over the long term, help to significantly reduce losses of life and property that stem from collapse of and structural damage to buildings.

REFERENCES

Algermissen, S.T., 1985, Preliminary report of investigation of the central Chile earthquake of March 3, 1985: U.S. Geological Survey Open-File Report 85-542, 180 p.

Borcherdt, R.D., Joyner, W.B., Warrick, R.E., and Gibbs, J.F., 1975, Response of local geologic units to ground shaking, in Borcherdt, R.D. (ed), Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941-A, p. 52-67.

Borcherdt, R.D., and Gibbs, J.F., 1976, Effects of local geologic conditions in the San Francisco Bay region on ground motions and the intensities of the 1906 earthquake: Bulletin of the Seismological Society of America, v. 66, p. 467-500.

Gutenberg, B., 1957, Effects of ground on earthquake motion: Bulletin of the Seismological Society of America, v. 47, p. 221-250.

IMSL, 1982, IMSL Computer Programs, IMSL, Inc., Houston, Tex.

Kanai, K., 1952, Relation between the nature of surface layer and the amplitudes of earthquake motions: Bulletin of the Earthquake Research Institute, University of Tokyo, v. 30, pt. 1, p. 31-37.

Medvedev, J.V., 1962, Engineering seismology: Moscow, Academia Nauk Press, Translated into English by Israel Program for Scientific Translations, Jerusalem, 1965, 260 p.

Mosteller, F. and Tukey, J.W., 1977, Data analysis and regression: Addison-Wesley Publishing Company, Reading, Mass., 588 p.

Nie, N.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K., and Bent, D.H., 1975, SPSS statistical package for the social sciences, McGraw-Hill, N.Y.

Rogers, A.M., Covington, P.A., Park, R.B., Borcherdt, R.D., and Perkins, D.M., 1980, Nuclear event time-histories and computed site transfer functions for locations in the Los Angeles region: U.S. Geological Survey Open-File Report 80-1173, 207 p.

Rogers, A.M., Tinsley, J.C., and Borcherdt, R.D., 1985, Predicting relative ground response in Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region--an earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 221-247.

IMPROVING PREDICTIONS OF SITE RESPONSE DURING EARTHQUAKE SHAKING

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INTRODUCTION

The topic of this paper was proposed to us by the conference organizers, we hope because of our reasonable breadth of experience in the last decade in using the "output of seismology and geotechnical studies." The title of this paper implies that the geotechnical information we are now obtaining has some value which can be improved with further research along a direction we might suggest. The title also implies that we know what we are seeking in terms of improved predictions. In agreeing to present this paper, we are confident that we know what we are seeking, and believe that certain directions of research toward improved predictions are the correct ones. In this vein we have proposed specific items which are of immediate need to us.

We are primarily seeking a site response prediction that can be used to evaluate potential damage to existing buildings and resulting life-safety threats. Site response predictions for new buildings are also important; however, the priority here is the condition of existing buildings.

SUSPECT BUILDINGS

Buildings constructed in southern California under any building code before the 1976 Uniform Building Code (UBC) are suspect as to their ability to satisfy current life-safety standards. The San Fernando earthquake of 1971 and the Imperial County earthquake of 1979 were not great earthquakes. Nonetheless, they both caused the near collapse of two reinforced concrete buildings constructed in the late 1960's. It is reasonable to assume that a major loss of life would have occurred in both structures if the Richter magnitude of the earthquakes had been greater than 8.

As a result of the 1971 San Fernando earthquake, major design detailing changes appeared in the 1976 UBC. In addition, selected structural engineering designers implemented many of the principles of ductile design well before the 1976 UBC. However, we must be suspicious of buildings designed and built prior to 1976 and not designed with ductility in mind.

As an example, many multi-story buildings in the 4-to-12-story height range are business investment structures which are designed to be sold as soon as possible at a maximum profit. Because of the competitive nature of this design (including the structural engineering fee), these buildings are typically designed to minimum code standards with a minimum number of structural design/check hours. Thus, this height range of buildings is particularly vulnerable to potentially high loss of life.

THE SITE MOTION

The evaluation of life safety in existing buildings cannot be rationally done using the prescriptive formulas in the current editions of building codes. Specifically, we need a quantification of the ground motion parameters which define the probabilistic nature of the ground motion. Within today's state-of-the-art earthquake design of buildings, we need a description of the maximum five-percent damped elastic response spectra expected for an established design life of 50 years. We must also accept the fact that the maximum site response is what we want, and must accept that we do not know it with certainty. It is a random variable.

The analytical tools of reliability analysis enable us to combine our description of the building's strength characteristics, in probabilistic terms, with our probabilistic description of site response.. This analytical combination produces a measure of risk to failure, such as loss of life, which can be measured against the implied acceptable risk of current building codes.

ACCEPTANCE OF FINANCIAL CONSTRAINTS

Existing buildings must be evaluated for their risk to life safety. This is usually done without the benefit of a detailed site study. Therefore, the structural engineer, at least in the preliminary phase of the analysis, must have some "off-the-shelf" predictions of site response. The map of peak ground acceleration by Algermissen and Perkins (1976) provides a valuable source of site response prediction. It enables us to obtain the magnitude of the peak ground acceleration which has a 90 percent chance of not being exceeded in a 50-year time period (the so-called 90 percent quantile of the distribution).

SUGGESTIONS FOR A SECOND "OFF-THE-SHELF" DOCUMENT

A probabilistic seismic-hazard evaluation at a site, due to a particular seismic source, involves convoluting three probabilistic functions related to the recurrence rate, the source geometry and location with respect to the site, and the attenuation relationship (Idriss, 1985).

By combining the effects of different sources that could potentially affect the site, one can obtain the average return period as a function of a certain strong motion parameter (for example, peak ground acceleration or response spectra ordinate). In a probabilistic view, this could be expressed in the form of cumulative distribution functions (CDF's) for the specified parameters. Idriss (1985) presents such CDF's for two locations in southern California.

The common feature of the two CDF's seems to be that the decimal logarithm of the average return period is rather linear with the peak ground acceleration (PGA). An exception is the left tail which corresponds to a range (PGA less than 0.2g), which is of little interest from the viewpoint of structural damageability. The slopes of these two straight lines are approximately equal.

Assuming this linearity, as well as the Poisson distribution for the earthquake occurrence, analytical developments lead to the following expression for the CDF's of peak acceleration:

$$F_{(x)} = \exp\left[-\exp(\ln(t/T_0)-x\ k\ \ln(10)\right] \qquad (1)$$

where

x = random variable of peak ground acceleration for the exposure time t

k = the slope of the straight line

T_0 = the Y intercept of the straight line

t = the exposure time

As we can see, this is an extreme Type I distribution. The derived CDF is valid for PGA $>$ 0.2g, a range which corresponds to small probabilities of exceedance. Therefore, the proposed closed form for the CDF fits reasonably only the right tail of the actual distribution, which is our range of interest.

Equation (1) is derived using southern California recurrence curves. Other advantages are discussed below. Current proposed closed forms for the distribution function of the peak acceleration are the extreme Type II distribution (Cornell, 1968) and the lognormal distribution. Both of these have the shortcoming of giving unreasonably high accelerations for small probabilities of being exceeded. For instance, starting from a value of PGA = 0.4g which corresponds to 10 percent probability of being exceeded (National Bureau of Standards, 1980, p. 122) one obtains for 1 percent probability a PGA = 0.69g using extreme Type I approach. This can be explained analytically using the following property of the distributions (Benjamin and Cornell, 1970): If Y has Type II distribution ($F(y) = \exp(-u/y)^k)$) then Z = lnY has the Type I distribution with parameters μ = ln u and s = 1/k.

Looking at the left tail of the distributions, both the extreme Type II and the lognormal have zero probability for PGA $\leq$ 0. In fact, especially for shorter exposure times, the probability that no significant event will occur is far from being zero. The extreme Type I has a CDF value different from zero for PGA = 0 (the CDF must be slightly modified by adding a spike in zero equal to the area under the negative tail). This feature works successfully for a series of applications related to economic estimates.

The extreme Type II distribution also presents some mathematical inconsistencies. This distribution results when the distribution of the initial random variable from which the extreme distribution is derived does not possess finite moments (Bury, 1975).

One more shortcoming of the extreme Type II and lognormal distributions is that one cannot provide reliable values for the coefficient of variation for these distributions. The extreme Type I distribution should overcome these shortcomings. The two parameters of the distribution are μ , the location parameter, and s, the scale parameter (Bury, 1975). These parameters are related to the mean value and standard deviation as follows:

$$E[x] = \text{mean of } x = \mu + .57722s \tag{2}$$

$$\text{Standard deviation of } x = 1.28255s \tag{3}$$

From Equation (1) the value of these parameters result:

$$s = 1/k \ln(10) \tag{4}$$

$$\mu = [\ln(t/T_0)]/(k \ln 10) \tag{5}$$

One can observe that s is dependent only on the slope k. Therefore, the standard deviation of the PGA should be a site constant. Based upon the results in Idriss (1985), it seems that, for large areas of southern California, k should approximately equal 3.5. From Equation (3), the standard deviation of PGA in these southern California areas should be 0.16g.

The second site constant, the intercept T_0 can be determined from the 90 percent quantile of the PGA, that is, $a_{90\ \text{percent}}$.

$$\mu = a_{90\ \text{percent}} - 2.25s \tag{6}$$

The 90 percent quantile of PGA for t = 50 years could be found in Algermissen and Perkins (1976).

Equating (5) and (6) for t = 50 years one can eliminate T_0, and the expression for μ as a function of the exposure time will be:

$$\mu(t) = a_{90\ \text{percent}}(50) - s(6.162 - \ln(t)) \tag{7}$$

and the expected value of PGA:

$$E[a] = a_{90\ \text{percent}}(50) - s(5.58478 - \ln(t)) \tag{8}$$

Another useful value is the 90 percent quantile of PGA for a given exposure time, as a function of $a_{90\ \text{percent}}(50)$:

$$a_{90\ \text{percent}}(t) = a_{90\ \text{percent}}(50) - s \ln(50/t) \tag{9}$$

This probabilistic description allows for changing the design value of PGA when the expected exposure time is smaller than that assumed for the new construction. This can be done by the structural engineer using Equation (9). It also allows for the selection of the appropriate load factor function of the material and/or structural element in order to meet an acceptable target reliability index. This can be done by the specification writer using reliability analysis methods. The target reliability indices can be chosen on the basis of the values accepted by the profession (National Bureau of Standards, 1980). One could derive different earthquake load factors for life safety and for serviceability as a result of different levels of required reliability.

CONCLUSIONS

Acceptance of financial constraints implies the use of "off-the-shelf" documents when estimating the site response for a particular existing building. Starting from the peak ground acceleration which has a 90 percent chance of being exceeded in a 50-year time period, a probabilistic description of the site PGA is provided using the extreme Type I distribution that seems to be the most appropriate for southern California. This allows for changing the design value of the PGA function of the expected exposure time as well as for selecting appropriate earthquake load factors to satisfy a target value for the limit state reliability index.

REFERENCES

Algermissen, S.T., and Perkins, D.M., 1976, A probabilistic estimate of maximum acceleration in rock in the contiguous United States: U.S. Geological Survey Open-File Report 76-416.

Benjamin, J.R., and Cornell, C.A., 1970, Probability, statistics and decision for civil engineers: McGraw Hill, N.Y., p. 279-280.

Bury, V.K., 1975, Statistical models in applied science: John Wiley and Sons, N.Y., p. 638-371.

Cornell, C.A., 1968, Engineering seismic risk analysis: Bulletin of the Seismological Society of America, vol. 58, p. 1583-1600.

Idriss, I.M., 1985, Evaluating seismic risk in engineering practice: International Conference on Soil Mechanics and Foundation Engineering, 11th, San Francisco, Calif., August 1985, figs. 18 and 19.

National Bureau of Standards, 1980, Development of a probability based load criterion for American National Standard A58, NBS Special Publication 557, p. 59-61.

STRENGTHENING OR REMOVING UNSAFE MASONRY BUILDINGS

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INTRODUCTION

It is well documented that unreinforced masonry buildings do not perform well in earthquakes. The 1971 earthquake in San Fernando, California provided the impetus for adoption of an Ordinance by the City of Los Angeles that would require the structural upgrading of these most hazardous buildings. The first official action by the City took place in 1974, when the City Council instructed the Department of Building and Safety to formulate an abatement ordinance to upgrade pre-1934 unreinforced masonry motion-picture theatre buildings. In 1977, the Los Angeles City Council approved a four-point earthquake study plan. This plan consisted of:

1) Instructing the Department of Building and Safety to survey and identify all pre-1934 unreinforced masonry bearing-wall buildings in the City of Los Angeles;

2) Having the Building and Safety Council committee appoint a special study committee to develop an earthquake ordinance;

3) Instructing the City Planning Department to prepare an environmental impact report; and

4) Having the City's representative in Congress investigate and seek means of financial assistance.

Step I was completed by the Department of Building and Safety in 1979. Data was collected on survey forms from which pertinent data could be input and extracted in computer format. In addition, photographs were taken of each building for identification purposes. The information collected allowed the Department to inventory unreinforced masonry bearing-wall buildings by:

- addresses
- local districts
- use
- rating classification
- occupant load
- floor areas

This format enabled the Earthquake Safety Division to extract the information in various ways, as dictated and needed for its operation.

In order to comply with step 2, two subcommittees were formed: the Technical Development Subcommittee, to formulate the technical design standards for the new code; and the Impact Evaluation Subcommittee, to investigate social and financial ramifications of the code. The committees, representing professional organizations, building owners, property managers, attorneys, financial/banking, and building trades, completed their study in 1979 with the formulation of "Division 88--Earthquake Hazard Reduction in Existing Buildings" (City of Los Angeles, 1985a).

After many meetings, public hearings, and revisions, the proposed ordinance was submitted to the full City Council in 1979 and the ordinance was adopted in January, 1981 and became effective in February, 1981.

The 1985 earthquake in Mexico renewed the concerns about the social, economic, and life-safety effects that hazardous buildings can have on a city. An ordinance amendment was developed that accelerated the existing earthquake program by requiring all of the unreinforced masonry buildings be structurally upgraded to meet the ordinance by 1992.

In order to comply with step 3, the City Planning Department completed their environmental study in 1979 (amended in 1980). In essence, the environmental impact report did recognize that the proposed ordinance would have a significant adverse effect on "population" and "housing" in the City of Los Angeles. However, there were "overriding considerations" (life safety) that outweigh this environmental cost.

Step 4 regarding financial assistance remains an on-going effort, and is a primary concern of all interested parties. To date, efforts have resulted in passage of California Assembly Bill 604 and Proposition 23. California Assembly Bill 604 authorized cities to pass bond issues for seismic strengthening work on residential buildings. Proposition 23 is a constituitional amendment exempting earthquake modification work from property tax reappraisal (with conditions). New efforts to develop financing for the upgrading of older unreinforced masonry buildings have been initiated by the Community Development Department and the Community Redevelopment Agency. It is recognized that much more state and federal assistance must become available to help mitigate the "population" and "housing" problem.

EARTHQUAKE HAZARD REDUCTION ORDINANCE

(Division 88 - City of Los Angeles Building Code)

The scope of this ordinance encompasses all unreinforced masonry bearing-wall buildings constructed (or under permit) prior to October 6, 1933 except residential buildings with less than five dwelling units. It was on October 6, 1933 that the City of Los Angeles adopted earthquake regulations (precipitated by the 1933 Long Beach earthquake) that would require buildings constructed on or after that date to be designed for earthquake forces, and outlawed unreinforced-masonry bearing-wall construction.

The earthquake ordinance categorizes buildings into four rating classifications based upon importance and hazard. Owners of buildings with higher rating classifications have less time to structurally upgrade the buildings to a higher earthquake force level. (The recent amendment to the ordinance, accelerating the program, considerably shortens the time constraint of the lower risk buildings). The rating classifications and time sequencing of the ordinance was developed to help mitigate the effects of the ordinance on "population" and "housing" while achieving its goal of saving lives and limiting injuries. The earthquake that damaged Mexico City in 1985, however, realigned priorities for Los Angeles and accentuated the importance of an accelerated program.

The basic structural philosophy under which the ordinance was developed was life safety. However, the ordinance does bring pre-1934 buildings up to force levels similar to buildings constructed in the 1950's and 60's. The intent is to prevent a social and economic disaster resulting from a total loss of the usage and housing that are provided by these buildings, in the event of an earthquake.

The value of this ordinance is rooted in the fact that it gives structural value to unreinforced masonry walls. These walls must meet certain minimum standards (based on testing) and limitations, and it is this development of standards for unreinforced masonry walls that allows the economical seismic upgrading of these buildings.

The work that is required for each building differs depending on its own existing structural make-up. The most common structural upgrading requirements are:

- Installation of tension wall anchors;
- Installation of diaphragm shear anchors;
- Vertical shear resisting elements, such as
  - new shear walls,
  - strengthening existing walls by infilling of openings,
  - strengthening existing walls by adding Gunite,
  - strengthening existing wood-frame walls by adding plywood,
  - new lateral frames;
- Strengthening existing horizontal diaphragms;
- Providing vertical supports for major beams and trusses;
- Bracing unreinforced masonry walls over standard height;
- Providing proper ties and struts to assure proper transfer of loads; and
- Providing diaphragm chords.

PROGRAM STATUS

There are 7,900 unreinforced masonry buildings identified in the City of Los Angeles. The breakdown by "Rating Classification" is as follows:

Rating Class		Number of Buildings
I	(Essential)	50
II	(High Risk)	1800
III	(Medium Risk)	4950
IV	(Low Risk)	1100

Although the program, to date, has not progressed at the maximum rate allowed by the ordinance, there has been significant progress in the program as the following statistic will show:

- o Compliance Order Issued 2160
- o Building Permits Issued
  - -- Full compliance 774
  - -- Anchors only 814
- o Buildings Vacated 43
- o Buildings Demolished 150
  (based on 2160 buildings surveyed)
- o Completed Jobs
  - -- Full compliance 255
  - -- Anchors 670
  - -- Voluntary jobs 224

Because of the ordinance amendment requiring acceleration of the program, the remaining 5000+ unreinforced-masonry buildings will receive their full compliance orders to perform earthquake strengthening within an 18-month period following the effective date of the ordinance. This will significantly affect the incoming workload of the Earthquake Safety Division and will require a significant increase in staffing.

PROGRAM OPERATION

A key factor in the enforcement program has been the public's recognition of the potential life hazards associated with unreinforced-masonry buildings. Since it is especially important to have public acceptance of a mandated retroactive enforcement program such as this, an effective ongoing outreach program is of prime importance. This outreach program must originate from all levels of government, as well as professional organizations and concerned citizens.

An ordinance that mandates an owner to perform work on an existing building results in different types of relationships between the owners, engineers, contractors, tenants, and the enforcing agency. Generally, the enforcing agency is more aware of the problems that arise between involved parties. It goes without saying that a cooperative effort by all results in the completion of a job with minimal time and effort. Plan changes have created more problems and time delays in a project than any other single item. Failure of an engineer to perform a good field survey with necessary exposures to a building prior to starting design work usually results in plan changes and time delays. Contractors should also "walk the job" and compare engineered plans with the actual site conditions prior to starting the job. A properly engineered plan, which reflects the actual site conditions, results in the completion of the project in a cost effective, time-saving manner.

The ordinance provides for two alternative compliance methods, each with various compliance dates. This requires the establishment of an elaborate tracking system for each job. This tracking system is further complicated by time extensions, reclassifications and partial compliance. A computer system has recently been developed to replace a cumbersome manual tracking system. New and revised compliance dates must be entered into the files so that each job may be "tracked" and compliance attained at the proper time. This system requires that dates be accurately and diligently monitored. It is a time-consuming requirement of the ordinance.

The program has uncovered many major code violations in these older buildings. Among the most important are the extensive number of illegal occupancies being maintained and the amount of unauthorized construction work which has taken place. Illegal occupancies and construction work generally create a hazardous condition which must be taken care of either by compliance, or by removing the illegal work or use, and reverting to the original permitted use. In many instances, compliance is attained along with the structural upgrading work.

Party walls, or walls which are common to two buildings each with separate ownerships, present a unique problem, especially where only one of the building owners has been cited with a compliance order. How does one structurally upgrade one-half of a structural system? How does one meet the anchorage requirements? For the installation of tension anchors, guidelines (Guideline #4, included herein) were developed where the most economical solution would take a cooperative effort of both owners (City of Los Angeles, 1985b). For full compliance, it is assumed that each owner could use one-half of the wall thickness in resisting the in-plane loads contributory from each building.

One structural element that has great impact on the design of Division 88 buildings is "crosswalls." A "crosswall" is defined as a full-story wall of masonry or wood frame with a minimum length of 1½-times the story height, and spaced less than 40 feet apart in each direction in each story. Because of the limitation of the definition, and since other structural elements could perform the same function as a "crosswall," the City developed a guideline (Guideline #5, included herein) to help engineers use "crosswalls" in their design (City of Los Angeles, 1985c). Crosswalls are beneficial because buildings in rating class II and containing crosswalls may use a 25 percent reduction in seismic forces, and all buildings (except rating class I) are allowed an increase in height to thickness values of unreinforced masonry walls. This reduces the cost of rehabilitation by reducing the size or number of some elements (frames, shearwalls, shear bolts, and tension anchors) or eliminating the need for others (wall braces, or a new diaphragm). The need to eliminate "opening up the roof" for the installation of a new diaphragm must be investigated when rain would result in substantial losses to goods and equipment maintained in the building. Installation of crosswalls could eliminate this potential problem.

Divison 88 limits the maximum spacing of tension wall anchors to 6'-0" maximum. This ensures that the wall, roof, and floors will act together in an earthquake. Systems such as a horizontal spanning beam, where the anchorage spacing exceeds 6'-0" would not be permitted. The interaction of walls with the floor/roof in this type of system would produce a force level much greater than in a system where the elements are tied together to act in unity.

An important consideration in our attempt to reduce the life-safety risk during an earthquake is to adequately anchor storefronts or street elevations to the floor or roof diaphragms. This anchorage must be designed for the in-plane capacity to transmit the lateral forces to the ground level, and the loading normal to the wall that must be transferred to the diaphragm or bracing elements. The two most common strengthening techniques are the introduction of a steel frame into the streetfront, or Guniting the existing masonry wall sections. These are both effective means of increasing the lateral load capacity in line with the unreinforced wall. New steel frames must be detailed to extend to the diaphragm level, and connections must be verified that are adequate to resist the out-of-plane loads. This requirement is often overlooked because the engineer is preoccupied with the lateral load calculations, and ignores the fact that the added elements must withstand lateral loads perpendicular to the plane of the frame. Since Gunited piers require fixity at the top or bottom or both, a horizontal element is needed to resist the moments and provide the necessary fixity at the top and/or bottom. It is also important for the engineer to give special consideration to how the load is transferred into the steel frame or Gunited element. A complete continuous stress path from every part or portion of structure to the ground must be provided.

RESEARCH NEEDS

The upgrading of hazardous buildings is not limited to unreinforced-masonry bearing-wall buildings. There is much research work needed to identify what other buildings are "hazardous," and what can be done to mitigate the hazard. Research work is needed on hazards created by nonstructural elements, including their effect on the overall performance of a building. It is important that research work be translated into a format that is useable. Research grants should include a provision for synthesizing the results into practical, useable forms. There should be a study done on research work that has already been accomplished which could be used in the identification and strengthening of earthquake-prone buildings. Other technical research needs are:

- A better understanding of the relationship between the stiffness of horizontal and vertical elements, their reaction with the earthquake, soil, and with each other;

- The overturning action of walls, especially multi-story wooden shear walls;

- How unreinforced masonry walls and portion of walls react and distribute in-plane loading;

- Effects of open fronts and rotational/cantilever action of diaphragms;

- Analysis of chord stresses of diaphragms and effectiveness of chords in diaphragms;

- Strength and ductility of existing structural elements, including connections; and

- Isolation techniques to minimize the earthquake forces induced into the structure.

CONCLUSION

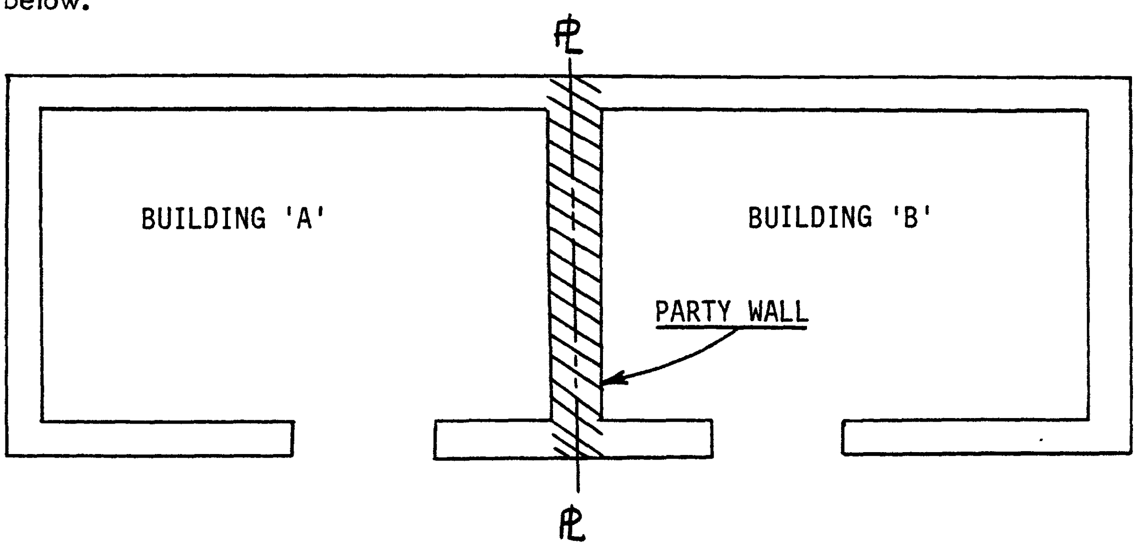
All of California is earthquake country. This effort to mitigate the earthquake problem needs the cooperative effort of all levels of government, as well as the private sector. New buildings and structures must utilize state-of-the-art knowledge in their design and construction. Existing hazardous buildings and structures must be identified and the hazard mitigated. We must reduce the impact of an earthquake on a community and its individual citizens to the greatest practical level. Government needs to provide the leadership and financial assistance to allow the mitigation program to develop and be effectively completed. This must be combined with an equal effort from professional organizations, universities, financial institutions, and building owners. There has been much progress to date, considering the infancy of this field. There is still much growing and expanding to be done. As the population increases and more buildings and structures are exposed to the dangers of earthquakes, the problem becomes more acute.

The program currently being enforced in the City of Los Angeles was developed to fit the community. Since the technical standards were developed based upon research and testing combined with existing knowledge and information, this portion of the ordinance can be applied to any unreinforced-masonry building in Seismic Zone 4 (California Administrative Code, 1985). Communities in less hazardous seismic zones should use other state-of-the-art standards such as those described in ABK Joint Venture (1984). The true effectiveness of the City of Los Angeles' program of hazard mitigation for unreinforced-masonry buildings will be measured when an actual earthquake event occurs. It has been estimated that 8,500 lives will be saved, 34,000 casualties would be prevented, and hundreds of millions of dollars in buildings and inventory saved. Otherwise, potential building and inventory losses, combined with the housing and economic losses that compound the hardship on a community and its citizens, are a foolish price to pay when preventive measures are available and can be taken.

CITY OF LOS ANGELES
DEPARTMENT OF BUILDING AND SAFETY
EARTHQUAKE SAFETY DIVISION
GUIDELINE 4

ANCHORAGE OF PARTY WALLS

The following guidelines shall be used in determining the location of the required tension anchors in common or party walls. A typical party wall plan is shown below.



GENERAL REQUIREMENTS

Each building in the above diagram is treated as a separate structure and, as such, the common or party wall must be attached to the floor and/or roof diaphragms by tension anchors located on each side of the wall. The anchors on each side must be designed using the tributary weight from the full thickness of the wall.

Separate building permits for party wall anchorage must be secured for each building; however, the permits may be issued at different times.

ALTERNATIVES

Alternatives to the above general requirements are possible if each building owner files a recorded affidavit in which he agrees to the Conditions stated in Alternatives 1 or 2.

ALTERNATIVE 1

Anchors designed using the tributary weight from the full thickness of the wall may be installed on one side of the wall and satisfy the party wall anchorage requirement for both buildings.

Conditions

1. The owner of the building which contains the required tension anchors agrees that a demolition permit for his building will not be issued until a permit is issued to the owner of the adjacent building for the installation of the required tension anchors. Further, he agrees that his building will not be demolished until the required anchors are installed.

2. The owner of the building which lacks the required tension anchors agrees to file plans and obtain a building permit for the installation of the required tension anchors prior to or in conjunction with the issuance of the demolition permit for the adjacent building. Further, he agrees to complete the anchor installation in a timely manner prior to the demolition of the adjacent building.

ALTERNATIVE 2

Anchors designed using the tributary weight from one-half the thickness of the wall may be installed on each side of the wall and satisfy the party wall anchorage requirement for both buildings.

Conditions

The owner of each building agrees that:

1. A demolition permit for his building will not be issued until a permit is issued to the owner of the remaining building for the installation of tension anchors designed for the full tributary wall weight.

2. Plans shall be filed and a permit obtained for the installation of the required tension anchors prior to or in conjunction with the issuance of a demolition permit for the adjacent building.

3. Anchor installation shall be completed prior to the demolition of the adjacent building.

(ES101783EG4:95)
R3.28.84

CITY OF LOS ANGELES
DEPARTMENT OF BUILDING AND SAFETY
EARTHQUAKE SAFETY DIVISION
GUIDELINE 5

USE OF CROSSWALLS FOR BUILDING RECLASSIFICATION

The following guidelines shall be used when evaluating existing or new crosswalls for the purpose of building reclassification pursuant to Section 91.8803 of the Los Angeles Municipal Code (Earthquake Hazard Reduction Ordinance).

I. EXISTING WALLS

1. Wall length shall be a minimum of 1½ times the story height. Story height is measured from diaphragm to diaphragm.

2. Wall length shall be measured in one continuous section.

3. Wall height shall extend from diaphragm to diaphragm.

II. NEW WALLS

A. Wall Length Equal to or Greater Than 1½ Times the Story Height.

1. Guidelines under Section I above shall apply.

2. Wall shall be attached by positive connection to roof and/or floor diaphragm.

3. Plans must be submitted which show connection details and materials of construction.

B. Wall Length Less Than 1½ Times the Story Height.

1. Wall shall be designed to resist a force equal to a minimum of 200 pounds per foot times 1½ times the story height.

2. Design and plans shall be provided for wall construction and connection of wall to upper and lower diaphragms. Design calculations are to include all bolted and nailed connections, hold downs, overturning, drag struts and footings (if needed).

3. Rigid frames may be used as crosswalls provided the overall deflection of the frame and diaphragm is limited to the same deflection that a wood-frame crosswall would allow.

(ES101783EG5:95)
R3.11.85

REFERENCES

ABK Joint Venture, 1984, Methodology for mitigation of seismic hazards in existing unreinforced masonry buildings: Prepared for National Science Foundation Contract Number NSF-C-PFR78-19200 by Agbabian Associates, S. B. Barnes and Associates, and Kariotis and Associates; Topical Report 08, January, 1984 (revised).

California Administrative Code, 1985, Seismic hazard zones: California State Building Code Supplement Part 2, Title 24, 2-2312(m), p. 103-104; 115.

City of Los Angeles, 1985a, Earthquake hazard reduction in existing buildings: Building Code, Division 88, Los Angeles, Calif.

City of Los Angeles, 1985b, Guideline 4, Anchorage of party walls: Earthquake Division, Department of Building and Safety: Los Angeles, Calif.

City of Los Angeles, 1985c, Guideline 5, Use of crosswalls for building reclassification: Earthquake Division, Department of Building and Safety: Los Angeles, Calif.

USING SHAKING-HAZARD EVALUATIONS FOR PRIVATE INVESTMENT CONSIDERATIONS

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Insurance Information Institute

INTRODUCTION

The Insurance Information Institute is a national, educational, fact-finding, and communications organization for companies providing all lines of insurance except life and health insurance. It is a nonprofit organization supported by some 300 property-liability insurance companies and provides services on a subscribership basis to many major industry organizations.

One of the Institute's important roles has been to bring public and industry attention to various hazards that can cause loss of life and damage to property. In the field of earthquake preparedness, the Institute has frequently provided the public with information about the hazards they might face, how to protect themselves in an earthquake, and the availability of earthquake insurance. Recently, the Institute has been particularly active, publishing an article on earthquake preparedness in Insurance Review (McCann, 1985), and reporting on the status of earthquake preparedness around the nation in an IBIS Report (a computerized data system now called Data Base Reports, McCann, 1985). The Institute also published "How to Prepare for an Earthquake: A Guide For Businesses."

OBJECTIVE

The task of this paper is to determine the value to financial institutions of "using shaking-hazard evaluations for private investment considerations." This topic raises many critical issues, most of which have far-reaching public policy implications. In general, the actions of financial institutions that make decisions, which are based on a greater knowledge of the geologic and seismic nature of areas that are developed or slated for development, will tend to support long-term public policy. While their actions support public safety, health, and welfare, their actions could adversely affect those who have built or would choose to build in those areas designated hazardous or near-hazardous. Therefore, in order to avoid unnecessary conflict between lenders or insurers and private property owners, several public-policy measures should be considered. Governmental agencies and legislative bodies should make decisions about zoning, land-use control, and the development and enforcement of building codes.

KEY CONSIDERATIONS

No definitive analysis of the benefits to private investors of knowing about ground shaking hazards is possible without considerable research. Even with such research, the results would probably provide less than clear-cut answers. Most of the respondents in an informal telephone survey done for this paper felt that the information would be basically useful, but were hard-pressed to be specific about how and to what extent. More expansive answers might be obtained by using the techniques of focus-group interviews and delphi surveys. The participants in such surveys would benefit by the ideas of others and would tend to examine the concept more thoroughly.

Key considerations brought out in the interviews with the executives from the financial community were:

Rating vs. Underwriting

The use that a financial institution will make of information such as shaking-hazard evaluations may vary from time to time. The reasons for the variations stem from the essential nature of the business, which is a complex mixture of seemingly opposing processes. One department has the goal of developing objective mathematical probabilities of loss for the development of credible insurance and interest rates. Properties with a greater chance of loss pay higher rates. While this principle is more rigid for insurance companies, lending institutions likewise charge higher interest rates for riskier loans. In contrast are the activities of the underwriting department. Its responsibilities are to select the properties for which a company seeks to provide a loan or insurance. Underwriting tends to be more an art than a science. Underwriters tend to use judgment, albeit influenced by facts, that relate to an individual's ability to repay a loan or likelihood to suffer a loss.

Depending upon a variety of circumstances, a company may use empirical information, such as a shaking-hazard analysis, and in one case it may considerably influence both underwriting and rating decisions. In another case, a company might all but ignore the data. The factors affecting such decisions include: market penetration strategy; emphasis upon growth to offset high administrative costs or to gain funds for high-interest investments; an accommodation to an otherwise very attractive client; or competition.

Market Conditions

The current condition of the property-liability insurance business in the United States provides general testimony to the principle stated above. Starting in 1979, the companies began a price war that lasted for an unprecedented six years. In 1979, in all lines of the business, the insurance industry lost $1.3 billion in underwriting (in other words, the incurred losses and expenses exceeded the earned premiums by $1.3 billion) while its investments of $9.3 billion more than offset those losses. However, over the next six years underwriting losses made quantum leaps each year: by 1984 they had increased 1538 percent to $21.3 billion. At the same time, investment income rose only 89.2 percent to $17.6 billion. The result was a net operating loss of about $3.7 billion for the first time in the industry's history, making 1984 the worst business year on record. The point is, that during this six-year cycle, and particularly near the end of it, the value of shaking-hazard evaluations to the insurance business probably would have been slight.

Normal Market

In times when the insurance market is more stable, shaking-hazard evaluations have the prospect of being more useful. Normally, insurance companies are interested in obtaining a structural analysis of a building when considering a request for earthquake insurance. A more extensive analysis might be required if the building is on unconsolidated soil. Some companies may choose not to insure any building on soil that is subject to liquefaction or other problems, while some companies may choose to insure only those buildings that are well-engineered, and only at a higher rate.

Probable Maximum Loss (PML)

No discussion of shaking-hazard evaluations would be complete without mention of the California of Department Insurance probable maximum loss (PML) report (California Department of Insurance, 1985). Since 1981, the Department has required all property insurers to submit data on their earthquake insurance coverage. Using a formula furnished by the Department, each company computes the total losses that a catastrophic earthquake would cause in each of eight geographic zones. Each company then submits the data to the Department. The purpose of the report, which is published each year under the title "California Earthquake Zoning and Probable Maximum Loss Evaluation Program," is to determine the extent of each company's liability. The Department will compare a company's PML exposure with its surplus (net worth or assets minus liabilities) to determine if it would be able to meet its obligations. Likewise, all companies are concerned about their PML in each geographical area quite separate and apart from the Department's interest. Companies will stop insuring additional property for earthquake if they reach their limit in a zone. Therefore, even if a property had a shaking-hazard evaluation that virtually no damage would occur in an earthquake, an insurance company might have to ignore the report because it had already reached its PML for the zone.

Mandatory Earthquake Insurance Offer

A new law requiring insurance companies to offer earthquake insurance to their insureds who have homeowners, tenants, mobile homeowners, or policies on residential dwellings of one to four units, might have an effect on making shaking-hazard evaluations more useful. The law, based on California Assembly Bill 2865 (California Legislature, 1984), requires insurers to offer earthquake coverage when policies are renewed after January 1, 1985, or to new policy holders. Many companies made the offer by sending a certified letter with return-receipt requested. The offer has increased the percentage of Californians with earthquake coverage from about 5-7 percent at the beginning of 1985, to an estimated 12-15 percent by the end of 1985. As many companies approach their maximum limit of capacity to sell earthquake insurance, it is conceivable that shaking-hazard evaluation could be used in the underwriting process for new risks. If a company has to become more selective, it might consider the shaking-hazard evaluation a critical criterion for weeding out bad risks. Some companies are reportedly already rejecting earthquake coverage requests from homeowners located in areas that are highly likely to suffer liquefaction problems during a major earthquake. The shaking-hazard evaluation would add a great deal of sophistication to the selection process.

Lending Policies

Lending institutions have tended to pay less attention than property insurers to the condition of the soil upon which a building is situated when considering a request for a loan. The questions have traditionally been, "Is this a major project and is it along some fault?" The value of shaking-hazard evaluations to lenders would not be as significant as would knowledge about flood, brush fire, and other natural hazards potential. This is principally because there has not been a lot of data about shaking hazards on which an investment consideration could be based. A few smaller institutions have taken more precautions than larger ones against earthquake hazards by requiring mortgagees to obtain earthquake coverage if the property is near a fault line. Yet, lending institutions stand to lose a good deal in a catastrophic earthquake because mortgagees in California may walk away from buildings that are substantially or totally destroyed.

CONCLUSIONS

At this time, insurance companies use two basic factors in developing insurance rates for homes; the type of construction and the rating territory. There are two rating territories in California, Zone 3 and Zone 4 (California Administrative Code, 1985). Zone 4, the higher-rated territory is comprised of some 29 counties that form the shape of a "U" running from the Oregon border along the coast to southern California, where it includes all of the counties from Kern south and then north along the Nevada border to a point south of Lake Tahoe. Zone 3, the lower-rated territory is the remaining 29 contiguous counties cradled in the "U" from the Oregon border to, but not including, Kern County on the south. Ninety-two percent of the potential insured losses are in the higher-rated territory.

Site-specific soil conditions are not rating factors as much as they are underwriting factors. A house on unconsolidated soil might have difficulty obtaining earthquake coverage while a commercial building most certainly would. However, as the process for evaluating the shaking hazards of soil becomes more sophisticated, it could conceivably be added as a rating factor. It should be pointed out, however, that any rate differential for shaking hazards would have to be based on judgment until actual loss costs might be developed to replace them.

The PML Report (California Department of Insurance, 1985) probably best summarizes the value of shaking-hazard evaluations. It makes the following comment on page 7:

> By promoting and encouraging the development of improved methods of measuring the earthquake damage risk, the Department of Insurance believes that a better earthquake insurance product will develop in terms of price and

coverage. It can be shown that certain types of homes, because of the construction and location, have a very limited risk of damage from earthquakes. Such homes could have earthquake coverage at a nominal cost. Other homes, on the other hand, have a demonstrably high risk of damage from earthquakes (because unreinforced masonry or located on a landfill) and must be insured at a higher premium and perhaps more restricted coverage. Some homes may not be readily insured except through a governmental mechanism.

ACKNOWLEDGEMENT

This presentation was prepared by John McCann, author of the book and much of the literature on earthquake preparedness published by the Insurance Information Institute. In addition, Mr. McCann is a member of the Finance, Insurance & Monetary Services Committee (FIMSC) of the California Governor's Earthquake Task Force. He also is a board member and secretary for FIMSC, Inc., which with VSP Associates of Sacramento, has helped sponsor research into the development of guidelines for making computer systems more resistant to earthquake damage. When the project is completed, FIMSC, Inc. and VSP Associates will have channeled more than $250,000 into the research, with some $150,000 of it coming from a National Science Foundation grant (1985). The rest was raised from private corporations. Mr. McCann assisted in the development of an Integrated Emergency Managment Course on earthquake preparedness for the Federal Emergency Management Agency. This course will be used in training city and county officials in responding to and mitigating the results of a catastrophic earthquake.

REFERENCES

California Administrative Code, 1985, Seismic hazard zones: California State Building Code Supplement Part 2, Title 24, 2-2312(m), p. 103-104; 115.

California Legislature, 1984, Earthquake insurance: Assembly Bill 2865, Chapter 8.5, Part 1 of Divison 2 of the Insurance Code, sec. 10081 ff.

California Department of Insurance, 1985, California Earthquake Zoning and Probable Maximum Loss Evaluation Program: Code Title 10, Chapter 5, Subchapter 3, Section 2307, 42 p.

McCann, J.P., 1985, Earthquake preparedness: Insurance Information Institute Data Base Reports, N.Y., 6 p.

McCann, J.P., 1985, A stitch in time: Earthquake preparedness management: Insurance Review, March/April 1985, New York, p. 24-29.

National Science Foundation, 1985, Seismic design guidelines for data processing facilities and systems: Grant No. ECE-8503913, Washington, D.C.

THE NEED FOR ALTERNATIVE APPROACHES TO EARTHQUAKE-HAZARD REDUCTION IN EXISTING BUILDINGS

Michael E. Durkin
Michael E. Durkin and Associates

The huge inventory of potentially hazardous buildings in the United States will continue to be a significant problem for those designing hazard-mitigation programs.

Unfortunately, many marginal businesses and low-income residents occupy a significant number of these existing buildings, which include some of the most hazardous types, such as unreinforced-masonry and tilt-up construction. These businesses and residents lack the time, money, or personnel to engage in hazard-reduction activities. In addition, many of these occupants lease rather than own their space, and consequently, they have limited control over what actions they can take.

To be effective, measures to reduce existing building hazards must reflect these realities of limited resources and limited responsibility.

Although structural retrofit to prevent complete collapse is still a first priority for research and practice, we need other partial or interim solutions for the many buildings that at a later date will be affected by new measures such as hazardous building ordinances, and the many hazardous buildings that will never meet acceptable levels of seismic safety. But even if all hazardous buildings could be structurally retrofitted, we would still face, in the absence of complete collapse, serious dangers to people and property.

Effective alternate measures for increasing life safety and reducing property loss include selective strengthening of specific areas within the building, securing hazardous nonstructural items, occupant training, and recovery planning. Short of complete collapse, the chief safety hazards depend on the occupants themselves, the performance of certain nonstructural elements, and the types and placement of building contents. In addition, the viability of small businesses depends on effective recovery planning.

Our studies of occupant actions during earthquakes reveal that building occupants have considerable time to engage in protective actions, but that their behavior often exposes them to injury. Lacking unlimited resources, we need to base our hazard-reduction measures on a better understanding of how people actually respond in earthquakes. For example, if we find, as recent studies have, that some people will always try to escape buildings, despite the potential danger, then we need to provide selective structural intervention to protect exit routes including corridors and stairways.

In addition to training occupants, we need to lessen nonstructural and building content damage. Short of complete collapse, nonstructural damage and damage to equipment and inventory far outweigh the cost of structural damage. This kind of damage affects lessees as well as owners. Since much existing building space is leased or rented, we need a range of low-cost hazard-reduction measures appropriate to non-owning occupants, even those occupying "new" construction. In past earthquakes, many modern buildings that avoided structural collapse experienced significant damage to nonstructural elements and building contents. Therefore, up to a certain level of damage, methods to reduce nonstructural and content damage are needed; only after that level would they prove ineffective.

We also need to develop recovery plans to lessen the long-term effect of earthquake damage. Experience in past earthquakes has shown that recovery problems can range from relocation to financial problems, and include employee relations. Sometimes these difficulties result from choices, made by the owner or occupant, that had unanticipated consequences (for example, the move to temporary trailers). Sometimes they were caused by external factors, like the decision to cordon off the downtown area of Coalinga, California immediately after the 1983 earthquake. If owners or occupants understand the problems that they could face, they will more likely engage in appropriate preparedness activities. Furthermore, knowledge of the consequences of policies such as restricted access will lead to more realistic response plans to support recovery.

A key characteristic of the research on hazard reduction should be its usefulness to those deciding what measures to take. The choice among the various hazard-reduction measures possible, short of complete structural retrofit, depends most on whether the subject leases or owns the facility. Lessees are concerned with equipment, inventory, and leasehold improvements. Owners are mainly concerned with structural and nonstructural damage but not damage to building contents. Owners who occupy their buildings are concerned with all of the above. Information not tailored to these situations will not be well received.

Therefore, we need to tailor both our research and our solutions to owners and occupants in general, and to the specific needs of certain types of occupants such as small businesses in particluar. At present, the data are too general to meet specific needs. The existing building problem is a complex one and therefore requires multi-faceted and comprehensive solutions.

EARTHQUAKE-HAZARD-REDUCTION EFFORTS BY THE CITY OF SAN DIEGO

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City of San Diego, California

INTRODUCTION

The Building Inspection Department of the City of San Diego has, within the past five years, initiated two major efforts to reduce the hazards from earthquakes. The first of these was to establish requirements and design criteria for the construction of buildings in areas where the soil is subject to liquefaction. More recently, the Department has prepared a proposed ordinance for the rehabilitation of old, existing, unreinforced-masonry bearing-wall buildings.

REQUIREMENTS FOR CONSTRUCTING BUILDINGS IN AREAS SUBJECT TO SOIL LIQUEFACTION

In 1974, the City of San Diego developed a Seismic Safety Element (SSE) for its General Plan in compliance with California law. This element identified areas of the city that might be subject to soil liquefaction in the event of an earthquake, but it did not establish design criteria for buildings to be located in these areas.

Prior to the creation of the SSE, it was not common in San Diego for soil engineers to discuss the possibility of soil liquefaction in their soil reports for specific buildings. After the adoption of the SSE, the San Diego Building Inspection Department began to notice (in the review of plans, calculations, and soil reports for building permit purposes) that soil engineers might mention the possibility of soil liquefaction, but usually not provide any recommendations or design criteria. A typical statement found in a soil report at that time was, "The effects of liquefaction are beyond the scope of this report."

Engineers in the Building Inspection Department did not feel that the liquefaction issue should be ignored, but there was nothing in the building code or municipal law that gave them the specific authority to require a liquefaction investigation. In addition, when the subject was discussed in connection with various building projects, the soils engineers for these projects would point out that it would be necessary to assume an earthquake magnitude and ground acceleration value if a proper investigation was to be made. Existing law defined neither of these.

As more and more buildings were being constructed in possible liquefaction areas, it became apparent to the San Diego Building Inspection Department that some criteria for the design of buildings would have to be established.

Accordingly, in 1980 the department requested the help of the Structural Engineers Association (SEA) of San Diego in addressing this problem.

Under the direction of SEA, a committee of geotechnical specialists and structural engineers was formed, and meetings and discussions began in April 1980. The first questions that the committee was requested to consider were: were the Building Inspection Department's concerns valid, and should design criteria be established? The committee agreed that the concerns were valid and that they would attempt to establish design criteria.

In developing the criteria, the committee identified three major areas of concern:

1) What earthquake ground acceleration should be presumed to determine if liquefaction could occur at a particular site?

2) What structures could be considered minor enough so that a liquefaction investigation and mitigation measures would not be required?

3) If liquefaction was considered to be a problem for a particular building, what would constitute mitigation of that problem?

The committee worked for over a year on the development of a proposed ordinance that would address these areas of concern, and in July 1981, their recommendations were submitted to the Board of Directors of the Structural Engineers Association of San Diego. The Board then forwarded the recommendations to the Building Inspection Department and, in March 1984, the recommendations were adopted by the City of San Diego as amendments to its building code.

The 1985 code provisions are included at the end of this paper. It is anticipated that they will be continually improved and updated as they are applied to more and more buildings

REHABILITATION OF EXISTING UNREINFORCED-MASONRY BEARING-WALL BUILDINGS

Earthquakes in California have continually demonstrated that unreinforced-masonry buildings present a serious hazard to life and property. In recognition of this, several jurisdictions in California have adopted ordinances which require structural reinforcement of these buildings over a specified period of time. The City of San Diego Building Inspection Department has recently prepared a proposed ordinance which, if adopted by the City Council, would require within reasonable time limits structural reinforcement of the approximately 750 unreinforced masonry buildings in San Diego. The proposed ordinance for San Diego is patterned after an ordinance now in effect in the City of Los Angeles.

The San Diego City Manager's Office has established a committee made up of both technical and nontechnical representatives to review the proposed ordinance and make recommendations concerning it. At this time, 1985, it is impossible to say when and if the committee will recommend adoption of the ordinance.

SEC. 91.02.2312 EARTHQUAKE REGULATIONS

Section 2312 (m). Soil Liquefaction. These requirements are applicable to "potential liquefaction" areas as identified in the Seismic Safety Element of the General Plan for the City of San Diego.

EXCEPTION: An evaluation of the liquefaction potential and mitigation measures if necessary are required for any site, regardless of location, if an essential facility as defined in Section 2312(k) is to be located at that site.

1. Investigations: An investigation conforming to Section 2905 shall be made of subsurface soils to evaluate their susceptibility to liquefaction from earthquake induced ground shaking for the following structure or occupancy categories.

A. Essential facilities as defined in section 2312(k).

B. Buildings with an importance factor greater than 1.0 as specified in Table 23-K.

C. All buildings over two stories in height.

D. All buildings containing the following occupancies:

(i) Group A, Divisions 1, 2, and 2.1.

(ii) Group E, Division 1.

(iii) Group H, Divisions 1 and 2.

(iiii) Group I, Divisions 1 and 3.

E. All buildings with an occupant load of more than 300 as determined by Table 33-A.

F. Tanks of more than 20,000 gallons capacity intended to store toxic, hazardous, or flammable contents.

G. Tanks over 35 feet high.

H. Towers over 35 feet high.

I. Other structures not included in categories A through H, except construction of a minor nature as determined by the Building Official, must either have an investigation made to evaluate if hazards are posed by the effects of liquefactions, and if so, to incorporate appropriate measures to mitigate the hazards or obtain a waiver from the Building Official. The waiver, which shall be executed by the legal owner, approved by the Building Official, and recorded by the County Recorder, shall state the applicable facts relative to potential liquefaction and shall attest to the legal owner's knowledge thereof. Waivers are not permissable for categories A through H.

2. Mitigation: Where the evaluation indicates that liquefaction is likely, the hazards that reasonably might be

caused by liquefaction shall be mitigated. Mitigation measures shall be suitable for the particular circumstances and hazards of the site and the proposed construction. Possible mitigation measures may include, but not be limited to, one or more of the following:

A. Treatment of Liquefaction Susceptible Materials.

(i) Removal of susceptible materials and replacement, as appropriate, with materials of low susceptibility.

(ii) In place densification of susceptible materials by means of vibroflotation, compaction piles, dynamic consolidation, surcharging or other suitable methods.

(iii) Controlling pore water pressures in susceptible materials by means of subsurface drains or water table level control.

B. Provision of retention structures to contain liquefied soils subject to mass lateral displacement.

C. Structural considerations for the proposed construction.

(i) Piles and batter piles.

(ii) Other deep foundations.

(iii) A structural frame or system that can accommodate the anticipated differential ground displacements.

SEC. 91.02.2905 FOUNDATION INVESTIGATION

Section 2905(g). Soil Liquefaction.

1. Investigations. When an investigation for potential earthquake induced soil liquefaction is required by Section 2312(m), a peak ground surface acceleration equal to 0.25 Z I g and earthquake ground shaking characteristics typical of a magnitude 6 earthquake shall be assumed as a minimum seismic exposure level. The symbols "Z" "I" and "g" are defined in Section 2312(c).

The use of the assumed magnitude 6 earthquake and the acceleration levels above for the purpose of this analysis is not to be construed to mean this exposure level should be used for other engineering purposes, including building design.

2. Mitigation. If mitigation of liquefaction hazards is required the report shall, when applicable, contain appropriate recommendations.

3. Qualification. The Building Official may require that any or all of the work described in Sections 2905(g) 1 and 2 be made and reported by a civil engineer, engineering geologist, and/or geologist licensed by the state to practice as such for each portion of the work applicable to his discipline.

Evaluating the Shaking Hazard for Redevelopment Decisions

SUMMARY OF WORKING GROUP VI AND AUDIENCE DISCUSSIONS

This session was moderated by Hal Bernson. Panelists were Michael E. Durkin, Calvin S. Hamilton, John Kariotis, and Richard L. Christopherson. Joining the panel were speakers from the morning session, Albert M. Rogers, Gary C. Hart, Allen A. Asakura, and John P. McCann. John D. MacLeod was the session commentator. Questioners and commentators from the audience included Brian E. Tucker, Victor A. Zayas, David C. Breiholz, John H. Wiggins, John F. Meehan, and several others who were not identified. The following was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Durkin spoke about supplemental hazards-reduction methods in unreinforced masonry buildings and other hazardous buildings. Whereas there are ordinances that regulate use, retrofitting, abandonment, demolition, and other aspects of hazardous buildings, there is a time lag between enactment and effect of those ordinances. Action is needed during that period to provide protection for building occupants. In addition to structural upgrading, there are three types of actions that should be taken:

1) Nonstructural hazards-reduction methods should be employed. These measures can range from selective upgrading of building interiors to the protection of building contents. An example would be the addition of interior shear walls in a way that complements ongoing renovation practices.

2) Research on occupant behavior should be undertaken so that occupants can be instructed how to reduce risk of injury. Occupant behavior should be assessed in terms of what people actually do and what they are capable of doing under different kinds of earthquake shaking and expected building performance. From studies in California, Mexico, and Chile, Durkin found that many people are injured while exiting from buildings. The direct implication is that during the retrofitting and upgrading of hazardous buildings, special attention needs to be given to exit routes and nonstructural elements at the exits of buildings.

3) Hazards-reduction techniques should be communicated to those most responsible for taking action, including building owners, small-business tenants, and other

building occupants. Public policy directives have been oriented towards building owners and have excluded tenants who stand to lose greatly during earthquakes. Information should be developed and packaged in a format that can be used by different kinds of small businesses and occupant groups.

Using the PEPPER Project (H. J. Degenkolb Associates, Engineers, 1984) as an example, Hamilton discussed his planning role, which is to synthesize many seismic-safety factors and recommend policies to to the Los Angeles City Council. Which factors in the Seismic Safety Element can be used to develop policy that will guide various city departments in adopting programs to minimize the effects of an earthquake? Which policies will ensure that facilities and services are adequately provided following an earthquake?

Hamilton described the differences between organizing emergency operations and developing a rebuilding and restoration team. Following an earthquake, most of the emphasis should be on protecting life, restoring services, and helping people. Simultaneously, many buildings should be placed off-limits and slated for demolition. The planner must be prepared to help the mayor and city council make immediate decisions about these buildings. The owner who loses a building loses his income and tenants. Therefore, he may want to repair, restore, or rebuild the building. In so doing, he must meet various regulations that were not in place when the building was originally built. Thus, the planner must prepare plans for post-disaster recovery and reconstruction. What kinds of plans does a planner make? For example, a given intensity of earthquake shaking is predicted to destroy 70 to 80 percent of the buildings in an old industrial area. Should the area be restored for industrial use, given that occurrence? Should commercial or residential buildings replace industrial ones? How is such a decision made?

Durkin described the Environmental Planning and Operational System (EPOS) to be used in post-disaster decisionmaking. The EPOS uses a variety of map data wherein geological and cultural information can be integrated to estimate post-disaster scenarios. Using these, reports are developed and submitted to a team that will have the power to quickly make recommendations to the city council and mayor following a disaster. In this manner, city officials can make informed decisions, and economic loss to individuals can be minimized. However, environmental impact reports currently take about one year of processing. This means that most city policies and ordinances need to be changed if immediate post-disaster recovery is to be accommodated.

Kariotis discussed the importance of historical buildings and society's desire to retain them. Agbabian Associates, Steve Barnes and Associates, and Kariotis and Associates formed ABK Joint Venture to analyze and retrofit historical buildings. Kariotis described the methodology developed by ABK Joint Venture (1981), and explained that it produced an end product similar to that for which the Los Angeles City ordinance on historical buildings was written. The methodology gives importance to preserving historical features of buildings in addition to reducing life-safety threats. In October, 1985, the methodology was presented to the State of California Department of Parks and Recreation and the U. S. National Park Service.

Christopherson described the City of San Diego's earthquake-hazard reduction efforts during the past five years. The Seismic Safety Element for San Diego was developed in 1974-75, and it showed areas subject to liquefaction. The Building Department would review plans in order to issue permits for buildings to be located in these areas. Frequently, the soils reports in the plans would not address the questions of liquefaction, or there would be a statement in the report saying, "The effects of liquefaction are beyond the scope of this report." The Building Department would call the soils engineer for an explanation, and the soils engineer would say, "Where in the building code is liquefaction addressed?" Indeed, liquefaction was not addressed in the building code. The engineer would ask for the design earthquake and the local acceleration, and the Building Department could not provide those numbers. Thus, there was a stalemate.

Christopherson referred the problem to the Structural Engineers Association (SEA) of San Diego. An SEA committee agreed that there was a problem, and that it needed to be solved based on three major considerations. First, there was a need to establish the design earthquake and ground acceleration. Second, there was a need to determine which buildings should be subject to a new liquefaction ordinance. (For example, a small storage building would not warrant an investigation for liquefaction potential.) Third, the level of acceptable mitigation needed to be determined if liquefaction was deemed to be a problem for a particular site or building. After one year, the committee had developed a recommended ordinance, and returned it to the board of directors of SEA, which submitted it to the Building Department with the recommendation that it be adopted. The suggested ordinance was then sent to the San Diego City Council, along with a recommendation for adoption of the next edition of the building code, and was consequently made a part of that code.

Christopherson described an ongoing effort to develop an ordinance for approximately 750 buildings with unreinforced-masonry bearing walls in San Diego. The proposed ordinance will be similar to the one adopted by the City of Los Angeles. The City Manager of San Diego has formed a committee of about 15 technical and nontechnical representatives who met for the first time in November 1985 to begin writing the recommended ordinance.

An unidentified participant asked the panel about earlier remarks made by Gary Hart, who had alluded to Federal studies that have attempted to quantify the amount of risk acceptable to society.

Hart responded that the study was begun in the early 1970's as part of the structural design process for multiplication factors for different types of loads placed on structures. The National Bureau of Standards (NBS) reviewed buildings designed during the previous 10 to 30 years, and determined a numerical value for a parameter similar to the factor-of-safety parameter. Following that, there were committee hearings related to recommending new load factors in the design of structures. These were reviewed and approved, and constituted what Hart believed to be an acceptable, professional opinion of acceptable risk. Hart felt that if he were sued in court, he could defend himself on the basis of that NBS report. Another view of acceptable risk is contained in the commentary of a report by the Applied Technology Council (1978), called the ATC-3 document.

Tucker endorsed recommendations made by Rogers for testing the latter's method for mapping relative ground-shaking response, and for testing other methods of estimating earthquake shaking effects for different site conditions. Tucker called for the formation of a working group to organize a test to compare the various microzonation methods in connection with the Parkfield, California, earthquake prediction experiment. Scientists using different methods of predicting site response could be invited to use the Parkfield area as a testing ground. Predictions could be made, and the test area then carefully instrumented. When the earthquake occurs, the predictions can be compared with the actual site responses. Tucker invited those interested in participating in such a venture to contact him through the California Division of Mines and Geology.

Zayas asked the panel how differences in ground shaking would cause loss of function of buildings, or would be life-threatening. How would loss of function compare to actual building damages?

Kariotis responded that damage prediction takes loss of function and actual damages into account. Effective peak acceleration or velocity can be closely correlated with damage to the "average building." Nevertheless, analyzing data for the "average building" by using modern analytical techniques will result in the best possible estimates of damage. Kariotis referred to the analytical method he had described earlier wherein buildings are analyzed element-by-element, whereby the probability of a given element being a threat to life safety can be generalized.

Breiholz asked Christopherson about the possibility of a building official being allowed to use new concepts, ideas, methods, or systems for seismic-hazard reduction that deviate from the existing code without incurring serious liability risks. The parameters currently in the building codes took many years to become law, and the most recent information available today might not appear in the law for many years.

Christopherson suggested the use of a board of appeals, to which new ideas could be submitted. This board could then decide whether those ideas are equivalent to code requirements. The City of San Diego Building Department has requested the seismology committee of the SEA to make recommendations about appeals for code variances. Otherwise, there are some ad hoc committees or perhaps other bodies available to make decisions on specific cases.

Wiggins voiced a concern about comments made by Durkin, and spoke from the perspective of the building owner. If the owner advises tenants about the earthquake safety of a building, the tenants might choose to move elsewhere and deprive that owner of rental income. There is a vacancy factor of 15 percent in Los Angeles, and the competition for tenants is very keen. The owner would not want the tenants to think the building is unsafe; therefore, how does the owner advise tenants about proper earthquake-safety behavior?

Durkin felt there was responsibility to take action on the parts of both the owner and the tenants Durkin assumed that a building owner would be interested in tenant safety and in participating with tenants to develop an earthquake-safety program for a given building. The Southern California Earthquake Preparedness Project (SCEPP) has targeted small businesses as recipients of earthquake-safety information that would allow them to take action. SCEPP recommends that business tenants first contact the owner of the building to determine if an assessment of the structural safety of the building has made. There does not appear to be a conflict between owner and tenant using this approach.

Hart commented on the problems with liability and insurance. Errors-and-omissions insurance increased by a factor of eight for Hart's consulting engineering company in 1985. Those insurance payments alone are the equivalent of ten salaries for new professionals entering the company. Furthermore, if a building owner contracts for a seismic-safety study for a building, the cost will be ten to twenty thousand dollars. The firm doing the study could be sued if they declared the building safe and the building then collapsed during an earthquake. Even commenting about the need for corrective safety measures relating to nonstructural damage or safety is not a good business decision given the current climate of liability. The liability situation is a political problem and will probably have to be resolved by the California Legislature.

Durkin suggested that building owners face two liability issues. In one case, the building owner can do nothing about the building and later plead ignorance if problems occur and he is taken to court. In another case, the building owner can take precautions that are consistent with state-of-the-art earthquake-hazards reduction techniques, whereby there is legal recourse if problems should occur.

An unidentified participant questioned McCann about the appropriate level of insurance coverage. People who are knowledgeable about buildings would choose to have partial insurance; however, insurance companies only want to sell full coverage. Why is this so?

McCann first noted that if an earthquake insurance endorsement is added to a homeowner's policy, the insurance company requires that the coverage be for the full face amount of the policy. The problem for insurance companies is their ability to spread the risk. Companies cannot afford to sell partial coverage at reduced rates, given current market conditions. In some places, it is possible to buy a separate earthquake policy that bears no relation to the amount of fire insurance coverage. However, such a policy cannot be purchased in the Los Angeles or San Francisco areas unless the insurance market changes as a result of more people buying earthquake insurance.

Meehan discussed the liability issue with reference to public schools and the Field Act of 1933 (California Division of Mines and Geology, 1974, p. 192-195). When the Field Act was first passed, it did not refer to buildings that were constructed before 1933. In 1939, school board members could be found to be individually liable for the safety of school buildings, particularly if a school building had been examined, found to be unsafe, and continued to be used. In the mid-1970's, the law became, "Thou shalt have thy buildings examined." If the building was found to be unsafe, it had to be repaired or reconstructed to meet current standards. School board members remained liable; however, new legislation provided funds to make repairs. Today, there are very few public schools in the State that do not meet high seismic-safety standards. The issue of liability clearly forced corrections to be made.

Bernson noted that it is unfortunate that none of California's private schools are covered under the Field Act.

McCann discussed professional liability, which is at a crisis point. Purchasers of insurance must pay appropriately for liability coverage, which is almost impossible to buy, such as municipal liability. For example, earthquake insurance for one municipal client has increased from $25,000 to $500,000 per year, and the deductible has risen from $100,000 to $2.5 million. Some engineering professionals now reject giving design advice whatsoever because of personal liability. Most engineering design firms are small, and cannot sustain a loss of three to five million dollars, especially in punitive damages. The insurance industry appealed to the California Legislature after the 1983 Coalinga earthquake and was relieved of the "concurrent causation" problem. Professionals in other fields should begin developing similar insulation and/or legislative protection so that they can practice without fear of prohibitive liability sanctions.

Bernson closed the session with remarks about the responsibility of government for earthquake-hazards reduction. In reviewing the history of earthquakes throughout the world, brick and unreinforced-masonry buildings are responsible for most of the deaths and injuries during a major earthquake. There is also great economic and social loss when buildings are destroyed. Bernson took exception to an earlier description of the City of Los Angeles ordinance on hazardous buildings as a "demolition ordinance." The intent of legislation requiring reinforcement of buildings is not to cause destruction, but to promote preservation, be it historical or otherwise. Historical buildings are important, but not more so than permanently occupied buildings of little historical significance. It is the responsibility of government to develop a program that enables the upgrading of those buildings without creating financial or social chaos. Nevertheless, there are 6000 to 8000 hazardous buildings in the City of Los Angeles which have not been upgraded; however, the City did accelerate the upgrading process after the 1985 Mexico earthquake. By January 1987, all owners of hazardous residential buildings will have been given notice to begin reinforcement and upgrading procedures which must be completed within five years.

Bernson identified a statewide problem, noting that more than 50,000 buildings in California fall into the category of hazardous, unreinforced-masonry construction. Legislation authored by California State Senator Alfred E. Alquist in 1985 provides for a 15-year program of upgrading buildings throughout the State, while a companion bill requires all local governments to prepare an inventory of their unsafe buildings. The former, Senate Bill 548 (California Legislature, 1985), passed and was signed into law by the Governor. The latter, Senate Bill 547, was defeated, which is akin to providing someone with an automobile and then taking the wheels off and telling him to proceed. Bernson expressed the hope that perhaps the California Legislature will act responsibly and revive SB 547 in 1986. The 1985 Mexico earthquake occurred after the final date for legislation in California; however, had it occurred prior to that, SB 547 probably would have passed.

Bernson called for State leadership in earthquake preparedness and noted that the State is rapidly moving forward in this regard. The California Seismic Safety Commission is sponsoring legislation which would require the strengthening of all buildings in the State in order to meet life-safety standards. Such strengthening would only be sufficient for life-safety considerations and would not be required to meet modern codes for new buildings, which would be economically and politically unfeasible. Primarily, the State must be realistic about what it is trying to accomplish, and those affected must have a clear idea of their responsibility and liability. In 1981, the City of Los Angeles considered labeling some buildings as unsafe. That idea was defeated because it would have placed both the building owners and the City in a situation of liability. The targeted buildings were properly built to code when they were constructed, and until the buildings are in violation of a City ordinance, the owners should not be held liable. If the Department of Building and Safety has cited a building for some other violation, the owner is, of course, responsible for responding to that specific violation.

Bernson concluded by discussing the responsibility of government to educate the public about dealing with earthquakes. The government should continually provide the public with information on pre-disaster planning, on strengthening buildings, on preventing injuries by attention to nonstructural components in the home and office, and similar activities. Businesses should also be alerted to the economic aftermath of a destructive earthquake. The loss of property, buildings, equipment, and income should be considered in pre-disaster planning.

REFERENCES

ABK Joint Venture, 1981, Methodology for mitigation of seismic hazards in existing unreinforced masonry buildings: Agbabian Associates, El Segundo, Calif.

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings: National Bureau of Standards Report ATC-3-06, Washington, D.C., 28 p.

California Division of Mines and Geology, 1974, Meeting the earthquake challenge: California Divison of Mines and Geology Special Publication 45, Sacramento, Calif., 223 p.

California Legislature, 1985, California earthquake hazards reduction act: Chapter 12, Section 8870, Divison 1, Title 2 of the Government Code, Sacramento, Calif., Chapter 1491, 91-60 through 91-140.

H. J. Degenkolb Associates, Engineers, 1984, Summary report of structural hazards and damage patterns--pre-earthquake planning for post-earthquake rebuilding (PEPPER Project): National Science Foundation Grant CEE 8024724; William Spangle and Associates, Inc., Portola Valley, Calif., v. 1, text 38 p.; v. 2, tables, 52 p.

SUMMARY OF AUDIENCE DISCUSSIONS, RECONVENED PLENARY SESSION II

This session was moderated by William A. Anderson. Panelists were James J. Watkins, Frank Hotchkiss, and John MacLeod, the commentators from Working Groups 4, 5, and 6. Paula Schultz was the session recorder. Questioners and commenters from the audience included Stanley H. Mendes, Rachel M. Gulliver, Peggy Brutsche, William J. Petak, Hal Bernson, William Spangle, Earl W. Hart, Calvin S. Hamilton, Donald B. Kowalesky, and others who were not identified. The following text was transcribed, condensed, and edited from audiotapes by William M. Brown III.

Mendes, representing a small ad hoc committee of structural engineers that had met earlier in the day, presented a resolution they had drafted. The conference was not in a position to endorse or issue any resolution; however, it was agreed that the resolution would be published in the conference proceedings.

Resolution — an action plan to mitigate earthquake hazards of unreinforced masonry wall buildings

Whereas it is common knowledge among building officials in the cities and counties of California that unreinforced-masonry wall buildings constructed prior to 1934 are potentially very hazardous during anticipated earthquakes;

Whereas very few cities in California have inventoried and developed earthquake-hazard-mitigation plans for such buildings;

Whereas earthquake-hazard-mitigation plans will save lives and materially reduce injuries;

Whereas it is the legal, moral, and ethical responsibility of building officials in California to advise the governing bodies of cities and counties as to the existence of potential earthquake hazards.

Be it resolved that this conference encourage and request every building official in California to inform the governing body as to the probable existence of earthquake-hazardous unreinforced-masonry wall buildings within their jurisdiction.

> **Be it resolved** that this conference send a copy of this resolution to every building official in the State of California.
>
> **Be it resolved** that this conference send a copy of this resolution to the mayor and city council and board of supervisors of every city and county in the State of California.

Gulliver called attention to the efforts of companies and individuals in the private sector. In the course of her work, she had seen notable examples of private-sector attention to the earthquake threat, and called for a mechanism whereby the transfer of usable geotechnical information to the private sector could be facilitated. Although attention to the earthquake threat is not as great as it might be, there are significant instances where businesses are looking for ways to protect their investments. These business should have access to the information they need to upgrade their facilities and reduce their risks.

Gulliver also suggested that the insurance industry protect itself from massive losses during an earthquake by offering reasonable insurance rates to businesses that take measures to reduce their risks. Currently (1985), commercial property owners must pay high rates for earthquake insurance, or simply cannot obtain earthquake insurance, even for new, reinforced-masonry buildings. The panel agreed with the need to focus additional attention on the problems faced by the business community.

Brutsche had heard during a working group session that most seismic safety elements were ten or more years old, and asked if there was a requirement in the government codes for updating the elements. If no such requirement existed, what would it take to mandate updating?

Hotchkiss indicated that there is no specific legal requirement for updating seismic safety elements. Petak, however, felt that there is an implied requirement for updating. If the seismic safety element is part of a general plan for a county or community, then it should be reviewed periodically as a part of the mandated general plan review. If the seismic safety element is not being reviewed on a regular basis, then there is a shortfall in local government procedures. New legislation mandating review of seismic safety elements should not be necessary.

Bernson suggested that there are two considerations involved. In terms of the general plan revisions, perhaps communities are not adequately considering seismic safety elements. However, in terms of building codes, local government is mandated to bring its codes into conformance with the California Uniform Building Code, which is upgraded every two years. Bernson felt that the State should specifically mandate the upgrading of seismic safety elements.

Spangle commented that the basis for adequacy of the seismic safety element should be a test of obsolescence. If any parts of the element are obsolete, the local jurisdiction should be required to update the element by using the best available information.

Hart suggested that the Legislature require State agency review of seismic safety elements, reasoning that if the State requires these elements, the State should also enforce bringing the elements up to date.

An unidentified participant thought that the State should fund local governments to aggressively update their seismic safety elements. Bernson commented that one of the arguments given by the State Legislature for not passing Senate Bill 547 in 1985 was that the State would have to pay for the program if it was mandated. Typically, the State has not funded similar mandated programs in the past.

Anderson asked about the effectiveness of local seismic safety elements. Hamilton responded that the element for the City of Los Angeles is very effective. The element sets forth a number of policies which were formulated by expert consultants and became a major policy document for the City. The element caused the City to review the seismic safety problems in a comprehensive manner for the first time. For example, the element brought to the attention of the City Council and the public the 8000 hazardous buildings within the City. However, the amount of information available today is significantly greater than that used to prepare the original element, and the element should be updated. The existing policies would probably not change significantly, but there would be a greater awareness of the potential for new action. Hamilton felt that the time was right for petitioning the state to mandate updating local elements.

Kowalesky suggested that a set of guidelines be developed by the State for preparation of seismic safety elements. Petak indicated that guidelines were published by the State in 1973, but that local governments and their consultants interpret them differently when producing local seismic safety elements.

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CONCLUDING COMMENTS ON FUTURE DIRECTIONS IN EVALUATING EARTHQUAKE HAZARDS

James F. Devine
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Summarizing what has happened in the past two days of this workshop is obviously not possible for one person to do, or even for a group of people to do thoroughly. I am reminded of an incident that happened recently in the Washington, D.C. area. One of our senior hydrologists was being interviewed on live television about a drastic flood on the Potomac River about two weeks ago. The reporter doing the interview was an intelligent person, and rather than ask common, ordinary questions about the flood, he posed a very insightful question to our hydrologist. He said, as they stood looking at the raging Potomac, "If you could see four feet below the surface of that water, what would you see?" Our hydrologist was perplexed for a moment. Finally, he answered with the only obvious thing he could say: "You'd see a lot of muddy water."

As I try to look four feet into the future of the National Earthquake Hazards Reduction Program, I see a lot of muddy water. Some excellent summaries have been presented about what has been accomplished, not only today, but of work that has led up to today. We heard a truly eloquent discussion by Clarence Allen and Richard Andrews of the two major components of this program. Therefore, I will not attempt to describe all we have accomplished, because it is a huge task.

However, I would like to describe a miniature program that I was involved in some 25 years ago, which I think is of the size that one can readily comprehend, and I hope you see the analogy. As a young geophysicist, I was very proud to be named project chief of a small program that was to determine how much ground vibration could be generated by blasting and still not cause damage to residences. It was a fairly simple program, and the funding was provided from a variety of sources -- the Department of the Interior, the insurance industry, and the explosives industry. Clearly, the ultimate goal was to provide an answer to this very important question; however, the goal of each of the sponsors was different. The insurance industry made it clear that they wanted a simple rule that would indicate when they had to pay a claim and when they did not. The explosives industry wanted to know how much explosive they could put into holes and blast before they were sued. The Federal government, being a research organization, was determined to obtain good, practical rock-mechanics research from this program. The state legislators were interested in results that could be used for legislation that would protect their communities. This sounds familiar, I think, in the context of this workshop.

The first thing in that miniature program was that bright young scientists got together to determine what needed to be learned in order to answer these questions. We talked about attenuation laws, the travel times, the types of rocks seismic waves would travel through, the kind of buildings that would be impacted, the type of explosive, the geometry and configuration of the blasting, and the recording instrumentation. We had it well analyzed, and we presented it to the funding groups. The immediate reaction of the insurance company was that they needed an answer in six months. Understandably, we could not have instrumentation designed in six months. We very quickly had a diverse set of requirements motivated by diverse needs, and we were obviously not equipped to keep everyone happy.

Through perserverance, we did succeed in recording about 150 blasts, from which we derived useful parameters. We developed a simple rule under which it was obvious that building damage could not occur if the user of the explosives kept the vibration level below a specified minimum. This was useful to both the insurance industry and those dealing with frivolous lawsuits. A rather serendipitous finding: it was not the total amount of explosives used that generated the maximum ground motion. Rather, if the explosions in each hole were delayed by some nine milliseconds or more, it was the charge per hole that determined the ground vibration. Ground vibration was not dependent on the total charge. The explosive industry was delighted. It put virtually no limit on the amount of explosive they could use in a total blast, as long as each individual blast was delayed. The rules that were put forth were manageable; legislatures of many eastern states adopted them and passed laws that all vibrations from quarry blasts must be kept below a specified level and the frivolous lawsuits disappeared. Lawsuits for vibrations above that level became manageable because a precedent had been set on how much vibration could be allowed. The Federal government came away from the program with many good research papers on rock mechanics. The moral to this story is that with perserverance it is possible to solve a problem which at first appears to be unmanageable, and everyone can come out a winner.

By analogy, I have tried to put some bounds on this problem of earthquake-hazard reduction in California. I remain confident that if we can maintain funding and avoid being sidetracked, we will indeed one day say that we are all winners. The talks in the last two days have reflected the amount of technical progress that has been made in the last 10 to 15 years. It is mind-boggling to recall that only a few years ago there were people arguing that there was no earthquake threat in southern California -- that the threat was only in northern California. Obviously, we have come a long way in recognizing earthquake hazards, and we can be very proud of that. I would like to read you a newswire from early November, 1985, which is attributed to a very well-known geophysicist in California, that says the following: "The deadly strength of the earthquake that shook Mexico in September (1985) caught scientists off guard, underscoring that technology to forecast tremors and their effects remains years away." Another well-known scientist said, "Initial reports indicate that a major problem was that the high intensities of ground motion, and unusually long duration of shaking, could not have been predicted using our current state of knowledge." The first scientist reported to Congress, "The fact that there were these surprises illustrates that we are still a long way from confidently predicting the effects of an earthquake." For those who feel that the program is nearly over, and that we can sit back and rest on our laurels -- Congress recently heard quite a different story. I think it is clear that there is general agreement that much remains to be done.

It is interesting also to note that Joe Ziony and Bill Kockelman managed to have a major earthquake (Mexico, September 1985) to get everyone's attention prior to this conference. They also were fortunate to have the State of California pass an earthquake-hazards-reduction act just before this conference started. In reviewing the announcement made by the State of California on this hazards reduction act, it seems to be a nice summary of what remains to be done by us all. I'd like to read to you an element of it:

> The bill addresses specifically, but not exclusively, the following: (1) Mitigation, including expansion of scientific and engineering studies; (2) Preparedness, including critical facilities, disaster preparedness education, and prediction; (3) Response, including integration of Federal, State, and local plans, and the improvement in statewide communications system; and (4) Recovery, including military and financial issues for restoration of California's economy.

That is as concise and precise a statement of what yet needs to be done as any I have seen lately, and better than any I could have written; I applaud the State of California for providing me those summary comments.

The California Earthquake Hazards Reduction Act provides both an opportunity and a challenge. The opportunity is clearly for the State, the Federal government, academia, emergency planners, scientists, engineers, local governments, and the general public to be beneficiaries (that sounds much better than users, doesn't it?) and to develop a truly integrated earthquake hazards reduction program. However, accompanying that opportunity is a very strong challenge. That challenge is to convince the rest of the land that this State law does not supplant the need for the Federal Earthquake Hazards Reduction Act, but rather complements it. Believe me, in Washington today where concerns about $200 billion-per-year budget deficits and required balanced budgets, the threat to research dollars is real. No matter how high the concern for earthquake safety may be in California, dollars normally provided by the Federal government will be severely challenged in the years ahead.

The challenge regarding California's Earthquake Hazards Reduction Act is to make sure that the expenditures of Federal dollars and state dollars are indeed complementary. I think it behooves the community represented at this workshop to see that those programs are integrated. I know I speak for the United States Geological Survey, and I believe I speak for the Federal community in challenging you to join us to make this an integrated, efficient, effective program that will result in genuine earthquake hazards reduction.

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APPENDIX B. — CONFERENCES AND WORKSHOPS TO DATE

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Conference I	Abnormal Animal Behavior Prior to Earthquakes, I Not Open-Filed
Conference II	Experimental Studies of Rock Friction with Application to Earthquake Prediction Not Open-Filed
Conference III	Fault Mechanics and Its Relation to Earthquake Prediction Open-File No. 78-380
Conference IV	The Use of Volunteers in the Earthquake Hazards Reduction Program Open-File No. 78-336
Conference V	Communicating Earthquake Hazard Reduction Information Open-File No. 78-933
Conference VI	Methodology for Identifying Seismic Gaps and Soon-to-Break Gaps Open-File No. 78-943
Conference VII	Stress and Strain Measurements Related to Earthquake Prediction Open-File No. 79-370
Conference VIII	Analysis of Actual Fault Zones in Bedrock Open-File No. 79-1239
Conference IX	Magnitude of Deviatoric Stresses in the Earth's Crust and Upper Mantle Open-File No. 80-625
Conference X	Earthquake Hazards Along the Wasatch and Sierra-Nevada Frontal Fault Zones Open-File No. 80-801
Conference XI	Abnormal Animal Behavior Prior to Earthquakes, II Open-File No. 80-453
Conference XII	Earthquake Prediction Information Open-File No. 80-843
Conference XIII	Evaluation of Regional Seismic Hazards and Risk Open-File No. 81-437
Workshop XIV	Earthquake Hazards of the Puget Sound Region, Washington Open-File No. 83-19
Workshop XV	A Workshop on "Preparing for and Responding to a Damaging Earthquake in the Eastern United States" Open-File No. 82-220
Workshop XVI	The Dynamic Characteristics of Faulting Inferred from Recording of Strong Ground Motion Open-File No. 82-591
Workshop XVII	Workshop on Hydraulic Fracturing Stress Measurements Open-File No. 82-1075
Workshop XVIII	A Workshop on "Continuing Actions to Reduce Losses from Earthquakes in the Mississippi Valley Area" Open-File No. 83-157
Workshop XIX	Active Tectonic and Magmatic Processes Beneath Long Valley Caldera, Eastern California Open-File No. 84-939
Workshop XX	The 1886 Charleston, South Carolina Earthquake and Its Implications for Today Open-File No. 83-843

Workshop XXI	A Workshop on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in the Northeastern United States" Open-File No. 83-844
Workshop XXII	A Workshop on "Site-Specific Effects of Soil and Rock on Ground Motion and the Implications for Earthquake-Resistant Design" Open-File No. 83-845
Workshop XXIII	A Workshop on "Continuing Actions to Reduce Potential Losses from Future Earthquakes in Arkansas and Nearby States" Open-File No. 83-846
Workshop XXIV	A Workshop on "Geologic Hazards in Puerto Rico" Open-File No. 84-761
Workshop XXV	A Workshop on "Earthquakes Hazards in the Virgin Island Region" Open-File No. 84-762
Workshop XXVI	A Workshop on "Evaluation of Regional and Urban Earthquakes Hazards and Risk in Utah" Open-File No. 84-763
Workshop XXVII	Mechanics of the May 1, 1983 Coalinga Earthquake Open-File No. 85-44
Workshop XXVIII	On the Borah Peak, Idaho, Earthquake Open-File No. 85-290
Workshop XXIX	A Continuing Action to Reduce Losses from Earthquakes in New York and Nearby States Open-File No. 85-386
Workshop XXX	Reducing Potential Losses from Earthquake Hazards in Puerto Rico Open-File No. 85-731
Workshop XXXI	A Workshop on "Evaluation of Regional Urban Earthquake Hazards and Risk in Alaska" Open-File No. 86-79
Workshop XXXII	Future Directions in Evaluating Earthquake Hazards of Southern California Open-File No. 86-401
Workshop XXXIII	A Workshop on "Earthquake Hazards in the Puget Sound, Washington Area" Open-File No. 86-253
Workshop XXXIV	Probabilistic Earthquake Hazards Assessment Open-File No. 86-185

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