Wasatch Front Seismic Risk Regional Seminar

Seminar 1: Economic Impacts of a Large Earthquake

A Seminar for Non-Technical Professionals

November 29, 1994
Salt Lake Airport Hilton
Salt Lake City, Utah

EERI Regional Seminar Series
Funded by the Federal Emergency Management Agency

Cosponsored by
Utah Seismic Safety Commission
Utah Geological Survey
Seismograph Stations at the University of Utah
Departments of Civil Engineering, and Geology and Geophysics, University of Utah
Department of Civil and Environmental Engineering, Utah State University (Logan)
Civil and Environmental Engineering Department, Brigham Young University
Utah Chapter of the American Planning Association

Wasatch Front Seismic Risk Regional Seminar

Seminar 1: Economic Impacts of a Large Earthquake

A Seminar for Non-Technical Professionals

EERI Regional Seminar Series Funded by the Federal Emergency Management Agency

Cosponsored by
Utah Seismic Safety Commission
Utah Geological Survey
Seismograph Stations at the University of Utah
Departments of Civil Engineering, and Geology and Geophysics, University of Utah
Department of Civil and Environmental Engineering, Utah State University (Logan)
Civil and Environmental Engineering Department, Brigham Young University
Utah Chapter of the American Planning Association

November 29, 1994
Salt Lake Airport Hilton
Salt Lake City, Utah

EERI REGIONAL SEMINAR SERIES

Regional seminars present the latest developments in earthquake engineering and research, and are tailored to meet the interests and needs of the region in which they are presented.

The Wasatch Front Seismic Risk Regional Seminars are designed to provide engineers, earth scientists, architects, and public officials in the western United States with state-of-the-art information on earthquake engineering, as well as provide the professional community with a better understanding of structural and non-structural earthquake damage mitigation techniques.

EERI

The Earthquake Engineering Research Institute is a national, non-profit, technical society of engineers, geoscientists, architects, planners, social scientists and public officials. The Institute is devoted to the advancement of the science and practice of earthquake engineering and the solution of national earthquake engineering problems to protect people and property from the effects of earthquakes. With FEMA support, EERI has developed this regional seminar to further the goals of NEHRP, and to provide the professional community in the western United States with innovative techniques to mitigate the risks of earthquakes.

FEMA

The Federal Emergency Management Agency (FEMA) is the Lead Agency of the National Earthquake Hazards Reduction Program (NEHRP). In fulfilling this role, FEMA supports conferences that enhance the effectiveness of earthquake hazard reduction science and technology, and that increase opportunities for participation by individuals who can then contribute to the advancement and progress of the Program.

499 14TH STREET, SUITE 320, OAKLAND, CALIFORNIA 94612-1902
☎ (510) 451-0905 FAX (510) 451-5411

EERI

WASATCH FRONT SEISMIC RISK REGIONAL SEMINARS

ORGANIZING COMMITTEE

Ann Becker, *Chair*
Woodward-Clyde Federal Services
Oakland, California
Member, EERI Seismic Risk Committee

Gary E. Christenson
Utah Geological Survey

Sue Nava
University of Utah Seismograph Stations

Stephen S. Weiser
Idaho Bureau of Disaster Services

SEMINAR COORDINATOR

Marjorie Greene
Special Projects Manager
Earthquake Engineering Research Institute

ACKNOWLEDGEMENTS

Our thanks to the following people for helping to make this program possible.

Federal Emergency Management Agency

Gina Higgs
Program Specialist
Mitigation Directorate

EERI Executive Committee

Lloyd S. Cluff, President
Christopher Arnold, Vice-President
Craig Comartin, Secretary/Treasurer
Loring Wyllie, Jr., President-Elect

Design

Wendy Warren

• EERI Regional Seminar Agenda

WASATCH FRONT SEISMIC RISK SEMINAR 1 • Economic Impacts of a Large Earthquake

TUESDAY, NOVEMBER 29, 1994

8:00 - 8:30 am	Registration
8:30 - 8:45 am	Introduction/Welcome Ann Becker, *Chair, Seismologist* *Woodward-Clyde Federal Services*
8:45 - 9:00 am	FEMA EARTHQUAKE HAZARD MITIGATION PROGRAM Michael Mahoney, *Geophysicist, Mitigation Directorate* *Federal Emergency Management Agency*
9:00 - 9:40 am	FUNDAMENTALS OF THE WASATCH FRONT EARTHQUAKE THREAT Walter Arabasz, *Research Professor* *Geology/Geophysics, University of Utah*
9:40 - 10:20 am	EARTHQUAKE GROUND SHAKING HAZARD IN UTAH Robert Youngs, *Vice President* *Geomatrix Consultants*
10:20 - 10:45 am	Break
10:45 - 11:25 am	OVERVIEW OF BUILDING CODE EARTHQUAKE PROVISIONS Susan Dowty, *Senior Staff Engineer* *International Conference of Building Officials*
11:25 am - 12:05 pm	ESTIMATES OF BUILDING PERFORMANCE IN A SALT LAKE CITY EARTHQUAKE Stephanie King, *Post-Doctoral Scholar* *John Blume Earthquake Center, Stanford University*
12:05 - 1:20 pm	Lunch
1:20 - 2:00 pm	TYPICAL NONSTRUCTURAL EARTHQUAKE LOSS PATTERNS Robert Reitherman, *President* *The Reitherman Company*
2:00 - 2:40 pm	REGIONAL ECONOMIC IMPACT OF A WASATCH FRONT EARTHQUAKE Harold Cochrane, *Professor* *Department of Economics, Colorado State University*
2:40 - 3:00 pm	Break
3:00 - 3:40 pm	RETROFIT COST EFFECTIVENESS William Holmes, *Structural Engineer, Rutherford and Chekene*
3:40 - 4:20 pm	INSURANCE COST EFFECTIVENESS Craig Taylor, *Executive Vice President, J. H. Wiggins Co.*
4:20 - 5:00 pm	ROUNDTABLE QUESTION AND ANSWER

Ann Becker
Chair, Organizing Committee

Ann Becker is a Project Seismologist with the Seismic Hazards Branch of Woodward-Clyde Federal Services based in Oakland, California. She has over twelve years of consulting experience in the fields of engineering seismology and earthquake engineering. Her professional experience includes performing numerous seismic hazards assessments, both site-specific and regional, at sites throughout the United States, the Pacific Rim, the Caribbean, and Europe.

Dr. Becker has made presentations in seismology and seismic hazards to non-technical audiences as well as at professional society meetings and seminars. She holds a bachelor's degree in civil engineering and a master's degree in structural engineering. She received her Ph.D. in seismology from the University of California, Berkeley, specializing in near-source directivity effects on earthquake ground motions. She was named the EERI/FEMA NEHRP Graduate Fellow in Earthquake Hazard Reduction for 1992-1993.

FEMA Earthquake Hazard Mitigation Program

presented by

MICHAEL MAHONEY

Michael Mahoney is a Senior Geophysicist with the Federal Emergency Management Agency's (FEMA) Mitigation Directorate, Program Development Branch, and its predecessor, the Office of Earthquakes and Natural Hazards. Since 1991, Mr. Mahoney has been responsible for all of FEMA's National Earthquake Hazards Reduction Program (NEHRP) technical activities relating to new construction. He is presently serving as Project Officer for the soon to be completed 1994 update and the recently contracted 1997 update of the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*. In addition, Mr. Mahoney has been named as Project Officer for FEMA's Program for Reduction of Earthquake Hazards in Steel Moment Frame Buildings. He is also serving as Project Officer for the Problem Focused Studies Project and the Home Builder's guides to Seismic-Resistant and Wind-Resistant Construction.

During this time, Mr. Mahoney also served as FEMA's representative on a Federal interagency report on the Northridge earthquake, initiated FEMA's Estimating Losses from Future Earthquakes Project, and served as a technical advisor to FEMA's Hurricane Program, and was its representative on the Hurricane Andrew Building Performance Assessment Report and the Federal Interagency Hazard Mitigation Team Report.

From 1984 to 1991, Mr. Mahoney was employed as a Physical Scientist with FEMA's Office of Loss Reduction, which was part of the National Flood Insurance Program. Mr. Mahoney was responsible for coordinating work with the nation's model building code groups, managing FEMA's Post Flood Damage Assessment Project, and was the Project Officer for several technical publications. During this time, Mr. Mahoney was recognized for his role in the Federal response after Hurricane Hugo.

From 1978 to 1984, Mr. Mahoney was employed by Factory Mutual Engineering as a Loss Prevention Consultant. He received his Bachelor of Science degree in physics from Grove City College and his Master's degree in physics from Kent State University.

TABLE OF CONTENTS

SEMINAR 1: ECONOMIC IMPACTS OF A LARGE EARTHQUAKE

1.

Fundamentals of the Wasatch Front Earthquake Threat

by

Walter Arabasz

Biosketch

— Walter J. Arabasz —

Dr. Walter J. Arabasz, a native of Massachusetts, received a bachelor of science degree in geology from Boston College in 1964, and his master of science and Ph.D. degrees in geology and geophysics from the California Institute of Technology in 1966 and 1971, respectively.

After completing his doctoral studies, which involved two years of geological and geophysical studies of the Atacama fault zone in northern Chile, he was awarded a post-doctoral fellowship from the New Zealand government for three years of earthquake research in New Zealand. Subsequently, he spent one year as a research scientist at the Lamont-Doherty Geological Observatory of Columbia University.

Dr. Arabasz joined the University of Utah as a research seismologist in 1974 and has been a member of the faculty since 1976. He is a research professor of geology and geophysics and has been director of the University of Utah Seismograph Stations since 1985. His current research focuses on earthquake hazard analysis, network seismology, and statistical patterns of earthquake occurrence in the Intermountain Seismic Belt.

He presently serves on the National Research Council's Committee on Seismology, its Panel on Seismic Hazard Evaluation, and on the Utah Seismic Safety Commission. He is also a member of the Board of Directors of the Seismological Society of America and is vice-chair of the Council of the National Seismic System.

Dr. Arabasz has provided professional consulting services on earthquake hazard evaluation for engineering firms, the International Atomic Energy Agency, the Department of Energy, the Soil Conservation Service, the Bureau of Reclamation, and the Electric Power Research Institute. He has had ongoing involvement in seismic hazard evaluations for the Jordanelle Dam in Utah and the Department of Energy's waste repository site at Yucca Mountain, Nevada.

Fundamentals of the Wasatch Front's Earthquake Threat

by
Walter J. Arabasz
Dept. of Geology and Geophysics, University of Utah
Salt Lake City, Utah 84112-1183

Summary

In Utah—and particularly in the Wasatch Front area—people and man-made structures are vulnerable to clearly identifiable earthquake dangers. Seismologists, geologists, and, engineers are in agreement about basic details of the earthquake threat—where, how big, how often, and what physically is going to happen. The only element of surprise that Mother Nature holds is the precise *when.*

My intention is to explain the basics of what we know about the earthquake threat, emphasizing that dangers arise from two sizes of earthquakes: (1) infrequent large surface-rupturing earthquakes (magnitude 6.5 to 7.5) and (2) more frequent moderate-sized, but potentially damaging, non-surface rupturing earthquakes (below about magnitude 6.5). The first occur on identifiable active faults—notably the Wasatch fault—which have evidence of geologically recent movement. The second can occur on "hidden" faults and can cause great damage if they occur beneath an urbanized area.

Non-technical decision-makers who must deal with Utah's earthquake threat need to do so in an informed way. Part of my purpose is to explain some key concepts and assumptions that underlie seismic hazard and risk analyses. My presentation is organized under the following topics (for which condensed summaries follow):

1. Earthquakes and faults (some basics)
2. Utah's earthquake environment (where? how big? how often?)
3. Quantifying the earthquake threat (hazard and risk analyses)
4. Dealing with the threat (crisis management)

1. Earthquakes and Faults (Some Basics)

An **earthquake** is the shaking or vibrating of the ground caused by the sudden release of energy stored in rock beneath the Earth's surface. Energy is a key word that relates to three basic parts of an earthquake's occurrence (**Figure 1**). First, energy that has been progressively built up and stored over hundreds or thousands of years is suddenly released in a matter of seconds from an earthquake source. Second, part of this suddenly-released energy radiates in all directions away from the source in the form of seismic waves. Third, the energy carried by seismic waves arrives at some site at the Earth's surface and produces ground motion, which must be predicted and characterized for safe earthquake engineering. The sources of earthquakes are in fact

faults, which are fractures in the earth along which the two sides have been displaced relative to one another (**Figure 2**).

The immediate local cause of an earthquake is the sudden frictional sliding of rocks on a fault due to a phenomenon called **elastic rebound**. Bruce Bolt (see bibliography) succinctly explains it this way: "Like a watch spring that is wound tighter and tighter, the more that crustal rocks are elastically strained, the more energy they store. When a fault ruptures, the elastic energy stored in the rocks is released, partly as heat and partly as elastic waves. These waves are the earthquake." **Figure 3** illustrates this phenomenon using the 1983 Borah Peak, Idaho, earthquake as an example.

The "size" of an earthquake can relate variously to the dimensions of the earthquake source, the amount of energy released as seismic waves, or potential effects. All of these, of course, are interrelated. The most common measure of earthquake size is **magnitude**, a number instrumentally determined from the recording of seismic waves on a seismograph, corrected for how far away the earthquake originated. Knowing the magnitude of an earthquake, one can infer the likely extent of fault slippage and the potential severity of ground shaking with varying distance.

The best known scale for estimating earthquake magnitude is the **Richter scale**. The "Richter scale" isn't a physical scale one can hold. Rather, it's a method of grading small to large earthquakes based on: (1) measurement of the maximum wave amplitude recorded on a standard seismograph, (2) correction for distance (because, for the same earthquake, amplitudes will be larger if the seismograph is close to the earthquake epicenter and smaller if farther away), and (3) use of a mathematical device (logarithms) to arrive at a compressed scale for handling differences in amplitude, from earthquake to earthquake, that can vary by factors of thousands.

At the same distance, the amplitude of earthquake waves increases by a factor of 10 for every 1 unit increase in magnitude. For example, compared to a magnitude 3.0 shock, the maximum wave amplitude for a magnitude 4.0 earthquake at the same distance would be 10 times greater, and that for a magnitude 7.0 earthquake would be 10,000 times greater than for the magnitude 3.0 shock. (Seismologists now know that the Richter scale underestimates the true size of earthquakes larger than about magnitude 6, and they prefer to use **moment magnitude** as a more reliable measure of size, taking into account the size of the fault that slipped and the amount of slip.)

Earthquakes of magnitude 2 are barely felt near the earthquake source; magnitude 3—felt as a sharp jolt or a rapid vibration; magnitude 4—may cause slight damage; magnitude 5—a moderate earthquake that can cause considerable damage to poorly built or badly designed structures; magnitude 6—a strong, moderately destructive earthquake; magnitude 7—a major earthquake; and magnitude 8+—a "great" earthquake.

The **energy** released from an earthquake source in the form of seismic waves goes up by a factor of about 32 for every 1 unit increase in magnitude, which leads to much faster multiplication than factors of 10. The seismic energy released in a magnitude 3.0 shock is equivalent to about one-half ton of TNT. Consider the atomic bomb blast at Bikini in 1946 (whose energy release was equivalent to the seismic energy of a magnitude 4.8 earthquake). A magnitude 7.5 earthquake—about the largest size expectable in Utah—will release seismic energy equivalent to about 10,000 such atomic bombs.

Only part of a fault slips or "ruptures" during an earthquake. The point where rupture initiates is called the **focus**, and the point on the surface of the earth above the focus is called the **epicenter (Figure 4)**. The area of the rupture and the amount of slip between the two blocks on opposite sides of the fault ultimately determines the "size" of the earthquake, and it's only during earthquakes of about magnitude 6.5 or greater that the rupture area reaches the surface and breaks the ground. The steep slope formed by displacing the ground surface along a fault is called a **scarp**.

In terms of **rupture area** and **amount of fault slip**, there's an enormous difference between earthquakes, say, of magnitude 3.0 and 7.5 (**Figure 5**). The magnitude 3.0 earthquake would have a fault rupture area of about one tenth of a square mile and an average slip of less than an inch. The magnitude 7.5 earthquake, on the other hand, would have a fault rupture area of about 350 square miles and a slip of about 10 to 15 feet. (The rupture area of one tenth of a square mile for a magnitude 3.0 earthquake may seem trivial, but that's the combined area of fifty American football fields.)

2. Utah's Earthquake Environment (Where? How big? How often?)

Utah is transected by the **Intermountain Seismic Belt (Figure 6)**, a northerly-trending belt of earthquake activity within the interior of western North America that extends at least 1,500 kilometers (900 miles) from southern Nevada and northern Arizona to northwestern Montana. The Intermountain Seismic Belt is characterized by geologically active normal faults and shallow earthquakes less than 25 kilometers (15 miles) deep.

The earthquake threat in Utah has a dual aspect, relating to (1) infrequent **large surface-rupturing earthquakes** (magnitude 6.5 to 7.5) and (2) more frequent **moderate-sized non-surface-rupturing earthquakes** (below about magnitude 6.5). The first occur on identifiable active faults—like the Wasatch fault—which have evidence of geologically recent movement. The second are not constrained to occur on faults which can be seen at the surface and can occur anywhere throughout Utah's main seismic belt. The latter earthquakes can cause great damage if the source of energy release is beneath an urbanized area.

Utah's largest historical earthquake was a magnitude 6.6 earthquake in 1934 in Hansel Valley, north of the Great Salt Lake—the only historical shock in the Utah region known to have produced surface faulting. Ground breaking with vertical displacements up to 1½ feet occurred over a zone several miles long. The largest historical shock in the Intermountain region was the 1959 Hebgen Lake, Montana, earthquake of magnitude 7.5—a magnitude which approximates the upper limit expectable in the Wasatch Front region. The Hebgen Lake earthquake caused 28 fatalities and produced dramatic geologic effects, including a catastrophic landslide into the Madison River and spectacular fault scarps up to 22 feet high over a zone 16 miles long. One other surface-rupturing earthquake has occurred historically in the Intermountain Seismic Belt. The magnitude 7.3 Borah Peak, Idaho, earthquake in 1983 (see Figure 3) produced 22 miles of surface faulting with scarps up to 9 feet high.

Figure 7 gives a graphic overview of Utah's main seismic belt, depicted by more than 16,000 earthquakes instrumentally located since 1962. The data come from the University of Utah's regional seismic network, outlined in **Figure 8**. On average, about 700 earthquakes (including aftershocks) are located in the Utah region each year, of which roughly 10 to 20 are felt. About 13 earthquakes of magnitude 3.0 or greater occur in the Utah region annually.

Two principal guides in judging where earthquakes are likely to occur in Utah are (1) the pattern of historical and instrumentally-located earthquakes and (2) the location of **active faults**—that is, faults that are considered likely to undergo renewed movements (and hence produce earthquakes) within a period of concern to humans. (A third guide is the location of human activities such as the impoundment of reservoirs, the injection of fluids into deep wells, or mining that have the potential for triggering natural earthquakes in areas where tectonic strain energy has already accumulated.) **Figure 9** shows the location of active faults and a representative sample of instrumentally located earthquake activity in the Wasatch Front area. As true for most of the Intermountain Seismic Belt, the small to moderate-sized earthquakes tend to be broadly scattered and are not simply associated with mapped active faults—emphasizing the danger of earthquake energy release on "hidden" faults, as occurred in the 1993 Northridge, California, earthquake.

Based on instrumentally-recorded earthquakes since 1962, potentially damaging earthquakes of magnitude 5.5 and greater are projected to occur, on average, somewhere in the Utah region about once every 7 years and in the Wasatch Front region about once every 24 years (**Figure 10**). Eleven mainshocks of magnitude 5.5 or greater have occurred in the Utah region since 1900, the most recent being a magnitude 5.8 earthquake near St. George in 1992. The last in the Wasatch Front region was a magnitude 6.0 shock along the Idaho-Utah border in 1975.

Instrumental seismicity is basic for estimating the frequency of earthquakes up to about magnitude 6½ in Utah—the upper size of historical shocks to date. Instrumental monitoring is also essential for identifying and characterizing the behavior of "hidden" faults that aren't simply recognizable from the surface geology. To estimate how often large surface-rupturing earthquakes occur, we rely on **paleoseismology**—the geologic study of the age, frequency, and size of prehistoric earthquakes. Although the data sets for historical seismicity and large prehistoric earthquakes are distinct, the respective rates of occurrence are in general agreement (see graph in Figure 10).

The greatest threat for large surface-rupturing earthquakes in the Wasatch Front region is posed by the **Wasatch fault zone**—despite the fact that it hasn't generated any earthquakes larger than magnitude 5 in historical time. The Wasatch fault zone is more than 230 miles long and is the longest continuous active normal fault in the United States. Detailed geological studies show that the fault is made up of ten **segments** or parts that tend to rupture independently of one another (**Figure 11, left**).

During the past 6,000 years, large earthquakes have occurred repeatedly on the Wasatch fault, on the average of once every 400 years somewhere along the fault's most active central portion between Brigham City and Nephi (**Figure 11, right**). Between about 400 and 1,500 years ago, at least six large surface-rupturing earthquakes occurred on the Wasatch fault with an average rate of occurrence of one event every 220 years. The average **recurrence interval** or repeat time for large surface-rupturing earthquakes on an individual active segment of the central Wasatch fault is roughly 2,000 years. The most recent large earthquakes on the Wasatch fault can only be dated with an uncertainty of hundreds of years, but probably occurred more than 400 years ago. A candidate for the next large earthquake on the Wasatch fault is the Brigham City segment, between North Ogden and Honeyville. Of all the Wasatch fault's central active segments, the Brigham City segment has gone the longest without a major rupture.

We pointed out in Figure 9 that there are many other known active faults in the Wasatch Front area, and indeed in other parts of Utah, that show evidence of prehistoric surface-rupturing and which may produce large earthquakes in the future. In general, the intervals between large earthquakes on those faults tends to be much longer than on active parts of the Wasatch fault.

When we consider how often earthquakes occur, we speak of <u>average</u> rates of occurrence. Such averages do not mean that events arrive uniformly spaced. On the contrary, earthquakes are generally part of a random process in which the spacing between occurrences in time is quite variable, leading to clusters and gaps (**Figure 12**)—even though the process involves an *average* long-term rate of occurrence. I'll return to this point again in the next section.

3. Quantifying the Earthquake Threat (Hazard and Risk Analyses)

Faced with the threat of earthquakes, there is a need to make informed decisions in an orderly way. Seismic hazard analysis and seismic risk analysis provide the information and the tools. For a start, let me explain some jargon (**Figure 13**). A **seismic hazard** is defined as "any physical phenomenon associated with an earthquake that may produce adverse effects on human activities." (The root word for *hazard* is the arabic *az-zahr*, "the die" or "dice" and implies "a source of danger.") The major seismic hazards are ground shaking, ground failure, surface faulting, tectonic deformation, and inundation. These hazards, of course, can produce many indirect hazardous effects such as fire, damaged structures, dam failure, chemical spills, and so on.

Seismic risk is "the probability that social or economic consequences of earthquakes will equal or exceed specified values at a site, at several sites, or in an area during a specified exposure time." (The root word for *risk* is the Italian *risco*, meaning "the chance of loss or injury.") In engineering practice, a **seismic hazard**

analysis focuses on and quantifies the hazard of earthquake ground shaking at a site due to future earthquakes. This is because ground shaking is the most widespread and damaging earthquake-related hazard. Predicting the character and severity of ground shaking is not only essential for defensive earthquake engineering but it also provides the basis for evaluating risk. In other words, forecasts of earthquake losses chiefly depend on knowing how severe ground shaking will be. A **seismic risk analysis** couples the output from a hazard analysis with information on the vulnerability of the built environment that experiences the ground shaking to estimate damage, losses, and casualties.

Hazard and risk analyses can be either **deterministic** or **probabilistic**. A deterministic analysis involves a "scenario" earthquake. The location and magnitude of an earthquake is specified—perhaps the closest largest earthquake expectable—and then the analysis answers the question, "What's going to happen?" A probabilistic analysis asks the additional question, "How likely?" and it considers the aggregate effect of many earthquakes over a time period of some interest called an **exposure period.**

As part of my outline here of "fundamentals," I'll describe the basic idea of a probabilistic seismic hazard analysis (**Figure 14**), for which another speaker (Robert Youngs, this volume) will give more detailed information for the Wasatch Front area, and I'll leave risk analysis to more qualified speakers. Recall that a seismic hazard analysis quantifies the hazard of earthquake ground motion. There are well-established methods for doing this. The most important elements address the following questions about future earthquakes: (1) Where? How far away? (Involves the depiction of seismic source zones, either as discrete faults or as areas within which earthquake epicenters are expected to lie.) (2) How big? How often? (Involves describing the size distribution and rate of occurrence of earthquakes within each source zone.) (3) How severe the effects? (Given an earthquake of a particular size and at a particular location, what will be the characteristics of ground motion at some site of interest?)

A key point of Figure 14 is that we want to calculate the mean number of times—annualized—in which a certain level of ground shaking at a site will expectedly be exceeded, and the graphical result is called a **seismic hazard curve (Figure 15**). As one wag puts it, we want to calculate how often "bad" happens. The inverse (that is, 1 divided by an annual frequency is called a **return period**, so a ground motion that occurs .002 times per year (annualized) simply occurs once every 500 years. Once we have a seismic hazard curve, we can use the Poisson random-arrival model (Figure 12) to answer the question, "What level of ground motion has a 10 percent probability of being exceeded in, say, 50 years?" This is equivalent to asking, "What level of ground motion has a 90 percent probability of not being exceeded during 50 years?" The answers for exposure periods of both 50 years and 250 years are shown in Figure 15.

An exposure period of 50 years generally forms the basis for seismic building codes, intended to ensure minimum standards for earthquake resistant design and to prevent life-threatening collapse of buildings. The level of ground shaking during a typical 50-year period will arise from moderate earthquakes. Ground shaking for a

250-year exposure period more closely approaches that expectable from a large surface-rupturing earthquake on the Wasatch fault.

Before ending this section, let me say a little bit about earthquake probabilities and offer some cautions. When we ask the question, "What's the chance of an earthquake in the next *x* years?" the answer (**Figure 16**) is, "It all depends." During some period of time there clearly are differences, for example, between how often earthquakes can be expected to occur on a particular segment of the Wasatch fault, anywhere on the Wasatch fault, or anywhere in the Wasatch Front area, where there are many other active faults. When the behavior of many faults or fault segments is considered, the Poisson model of random behavior gives a good approximation of earthquake occurrence. However, for a specific fault segment, which accumulates and releases strain energy as we described in Figure 3, the time since the last big earthquake should influence the likely timing of future rupture. So we expect that a "time-dependent" model may be more realistic than a random model.

If we accept that large surface-rupturing earthquakes occur *on average* about once every 400 years somewhere on one of the Wasatch fault's central active segments, we can use the Poisson model to estimate the probability that one or more such earthquakes will occur during some period of time. During a 50-year period, the probability (conventionally specified between 0 and 1.0) is 0.12; in other words, there is "a 12 percent chance" of such a happening. For a 100-year period, the probability rises to 0.22. Stuart Nishenko and David Schwartz (see bibliography), scientists with the U.S. Geological Survey, made a preliminary attempt in 1990 to estimate the probability of large surface-rupturing earthquakes on particular segments of the Wasatch faults using time-dependent models. Their results suggested that the 100-year probability of a large earthquake on any particular active segment of the Wasatch fault was less than 0.02, with the exception of the Brigham City segment, which had a 100-year probability of 0.07. (At a meeting of the National Earthquake Prediction Evaluation Council in 1991, Nishenko presented estimated 100-year probabilities for the Brigham City segment of 0.07 to 0.20, depending on the assumptions made. These estimates are being revised as scientists use more complete up-to-date information.)

Finally, let's consider the probability of a sizable earthquake somewhere in the Wasatch Front region during the next 50 years, assuming the Poisson random model. The instrumental seismicity data of Figure 10 indicates that the average return period for an earthquake of magnitude 6.5 or greater in the Wasatch Front area is 120 years. The probability of such an event during the next 50 years is 0.34. The geological data of Hecker, also shown in Figure 10, included her preferred estimate of 176 years for the average recurrence of surface-faulting earthquakes throughout the Wasatch Front region in the past 15,000 years. That rate would give a probability of 0.25 for such an earthquake somewhere in the Wasatch Front region during the next 50 years.

4. Dealing with the Threat (Crisis Management)

Despite all that is known about earthquake dangers in the Wasatch Front region, psychological "denial" is common (**Figure 17**). The antidote is sensible **crisis management**—using timely and reliable information to take effective actions before, during, and after a crisis. In dealing with earthquakes, information is essential:

- to understand the earthquake threat
- to characterize earthquake hazards so they can be anticipated
- to quantify risk for decision-making
- to be prepared to withstand (earthquake engineering)
- to be prepared to respond (emergency management)
- to be prepared to recover (social and economic survival)

In earthquake-prone regions like Utah, where large earthquakes are infrequent, there has to be a balanced posture that recognizes both the constancy of the threat and the possibility that a threatening catastrophic event may be decades away. Actions ideally should include (1) immediate attention to critical vulnerabilities, (2) progressive transformation to reduce vulnerabilities, and (3) persistent, long-term attention to the problem.

The Wasatch Front area is a classic example of a seismically active region having only moderate historical seismicity but high catastrophic potential from infrequent large earthquakes. Devastation caused by the magnitude 6.9 earthquake in Armenia in December 1988 gives a real-world lesson for such situations.

Acknowledgments

I am indebted to many colleagues whose ideas and data form parts of this overview. My ongoing research relating to Utah's earthquake threat has been funded by the U.S. Geological Survey, under the National Earthquake Hazards Reduction Program, and by the state of Utah, through a line-item appropriation to the University of Utah Seismograph Stations.

Cited References & Selected Bibliography

Adan, S.M., and Rollins, K.M., 1993, Damage potential index mapping for Salt Lake Valley, Utah: Utah Geological Survey Miscellaneous Publication 93-4, 64 p.

Arabasz, W.J., ed., 1991, A guide to reducing losses from future earthquakes in Utah—"Consensus Document": Utah Geological and Mineral Survey Miscellaneous Publication 91-1, 30 p.

Arabasz, W.J., Pechmann, J.C., and Brown, E.D., 1992, Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah, *in* Gori, P.L., and Hays, W.W., eds., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah, U.S. Geological Survey Professional Paper 1500-A–J, D1–D36.

Bolt, B.A., 1993, Earthquakes (revised edition): New York, W.H. Freeman and Company, 331 p.

Hecker, S., 1993, Quaternary tectonics of Utah with emphasis on earthquake hazard characterization: Utah Geological Survey Bulletin 127, 157 p.

Lund, W.R., series editor, 1991– , Paleoseismology of Utah [multivolume series]: Utah Geological Survey.

Machette, M.N., Personius, S.F., Nelson, A.R., Schwartz, D.P., and Lund, W.R., 1991, The Wasatch fault zone, Utah—segmentation and history of Holocene earthquakes: Journal of Structural Geology, v. 13, p. 137-149.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1992, Paleoseismology of the Wasatch fault zone: A summary of recent investigations, interpretations, and conclusions, *in* Gori, P.L., and Hays, W.W., eds., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah, U.S. Geological Survey Professional Paper 1500-A–J, A1–A59.

McGuire, R.K., and Arabasz, W.J., 1990, An introduction to probabilistic seismic hazard analysis, *in* Ward, S.H., ed., Geotechnical and Environmental Geophysics, Vol. 1, Review and Tutorial: Society of Exploration Geophysicists, Investigations in Geophysics No. 5, p. 333-353.

Nishenko, S.P., and Schwartz, D.P., 1990, Preliminary estimates of large earthquake probabilities along the Wasatch fault zone, Utah (abstract), Eos, Transactions, American Geophysical Union, v. 71, no. 43, p. 1448.

Smith, R.B., and Arabasz, W.J., 1991, Seismicity of the Intermountain Seismic Belt, *in* Slemmons, D.B., Engdahl, E.R., Zoback, M.D., and Blackwell, D.D., eds., Neotectonics of North America: Boulder, Colorado, Geological Society of America, Decade Map Volume 1, p. 185-228.

Utah Geological Survey, 1991, Earthquakes [special issue devoted to Utah's earthquake problems]: Survey Notes, v. 24, no. 3, 32 p.

Wong, I.G., and Silva, W.J., 1993, Site-specific strong ground estimates for the Salt Lake Valley, Utah: Utah Geological Survey Miscellaneous Publication 93-9, 34 p.

Youngs, R.R., Swan, F.H., Power, M.S., Schwartz, D.P., and Green, R.K., 1987, Probabilistic analysis of the earthquake ground-shaking hazard along the Wasatch Front, Utah, *in* Gori, P.L., and Hays, W.W., eds., Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah, U.S. Geological Survey Open-File Report 87-585, M1–M110.

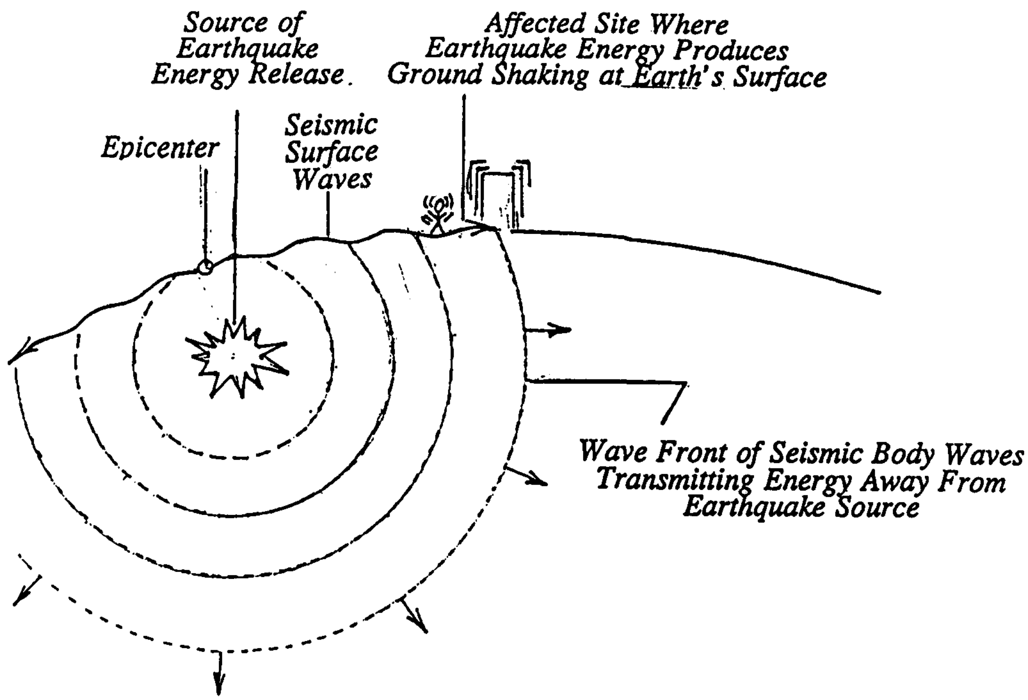


Figure 1. Three basic parts of an earthquake's occurrence—a source of earthquake energy release, seismic waves, and an affected site at the surface of the earth.

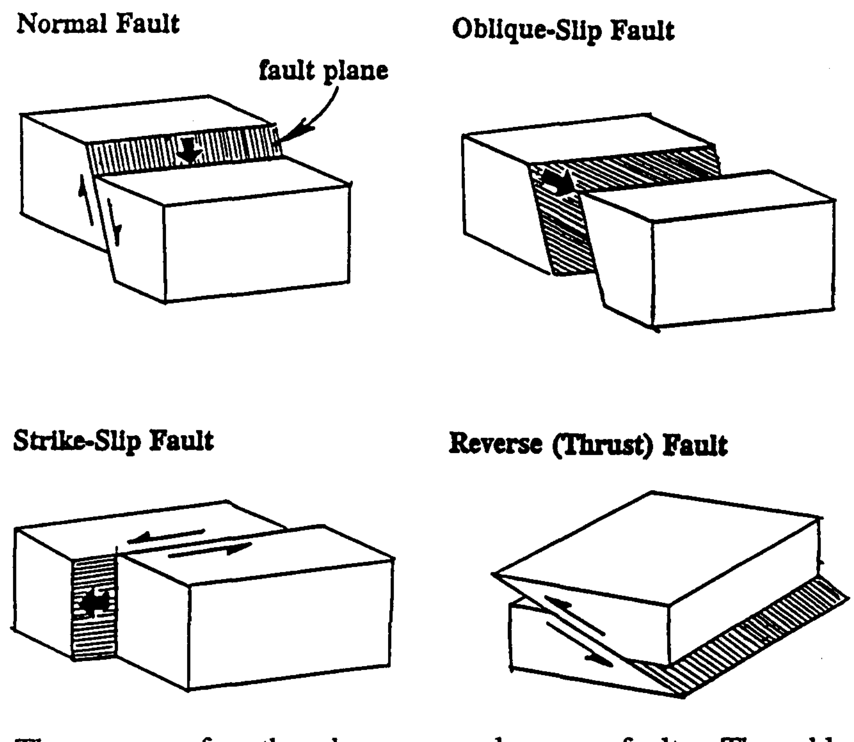


Figure 2. The sources of earthquake energy release are faults. These block diagrams illustrate different kinds of faults, defined by the relative motion of the rocks on opposing sides of the faults. Faults that produce earthquakes in Utah and the Intermountain region are mostly normal faults, which involve the down-dropping of a valley block and the relative uplift of a mountain block.

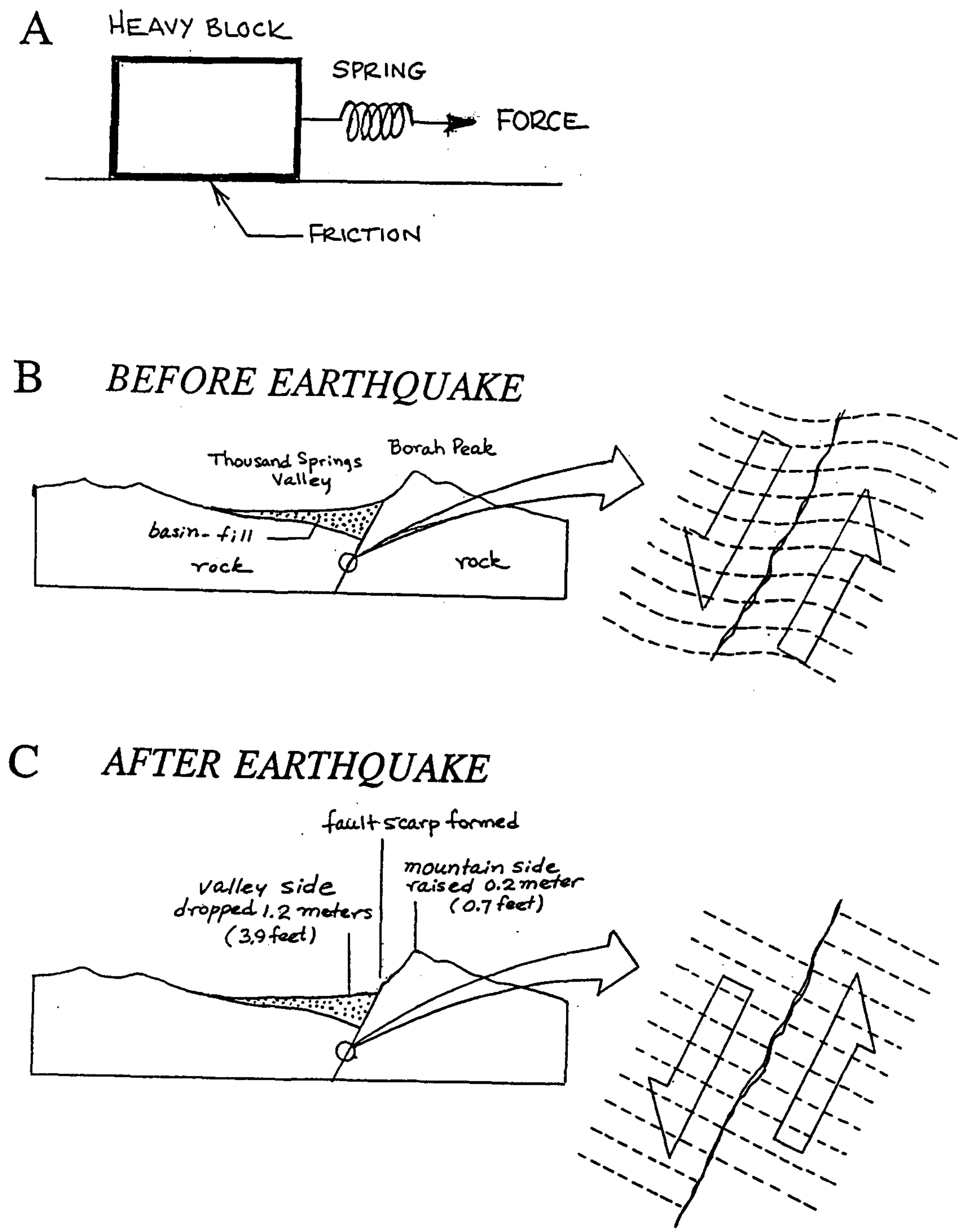


Figure 3. (A) Block and spring illustrating strain accumulation and elastic rebound as a simple model of an earthquake. Spring accumulates and stores elastic strain energy until frictional resistance at the base of the block is overcome. Then the block suddenly slides, the spring is relaxed, and a new cycle begins. Schematic cross sections of the Borah Peak, Idaho, area showing (B) a locked fault and the accumulation of strain before the 1983 earthquake of magnitude 7.3, and (C) results after the large surface-rupturing earthquake.

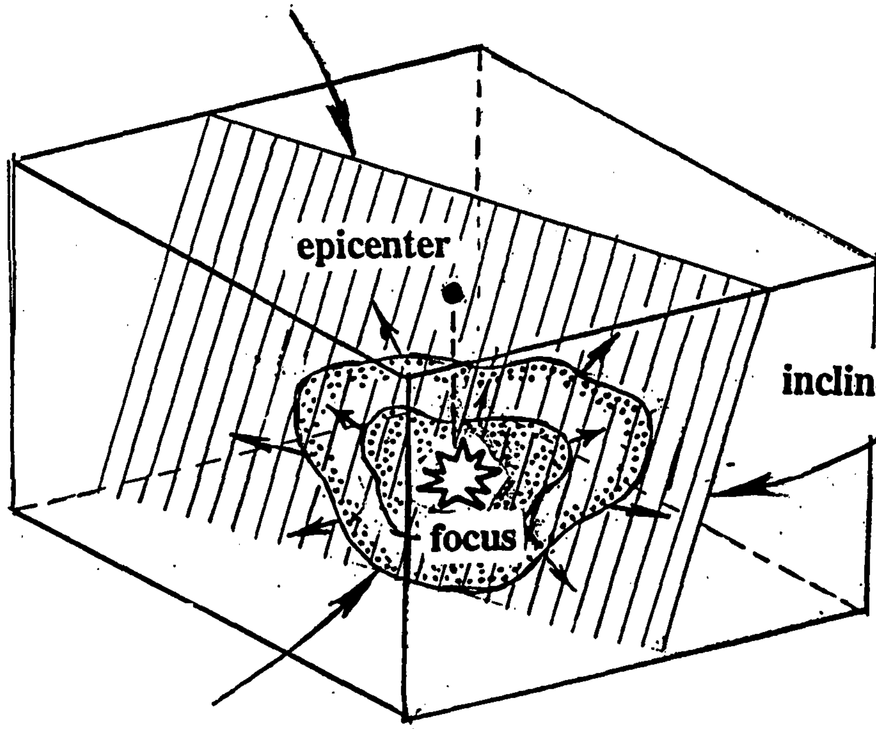
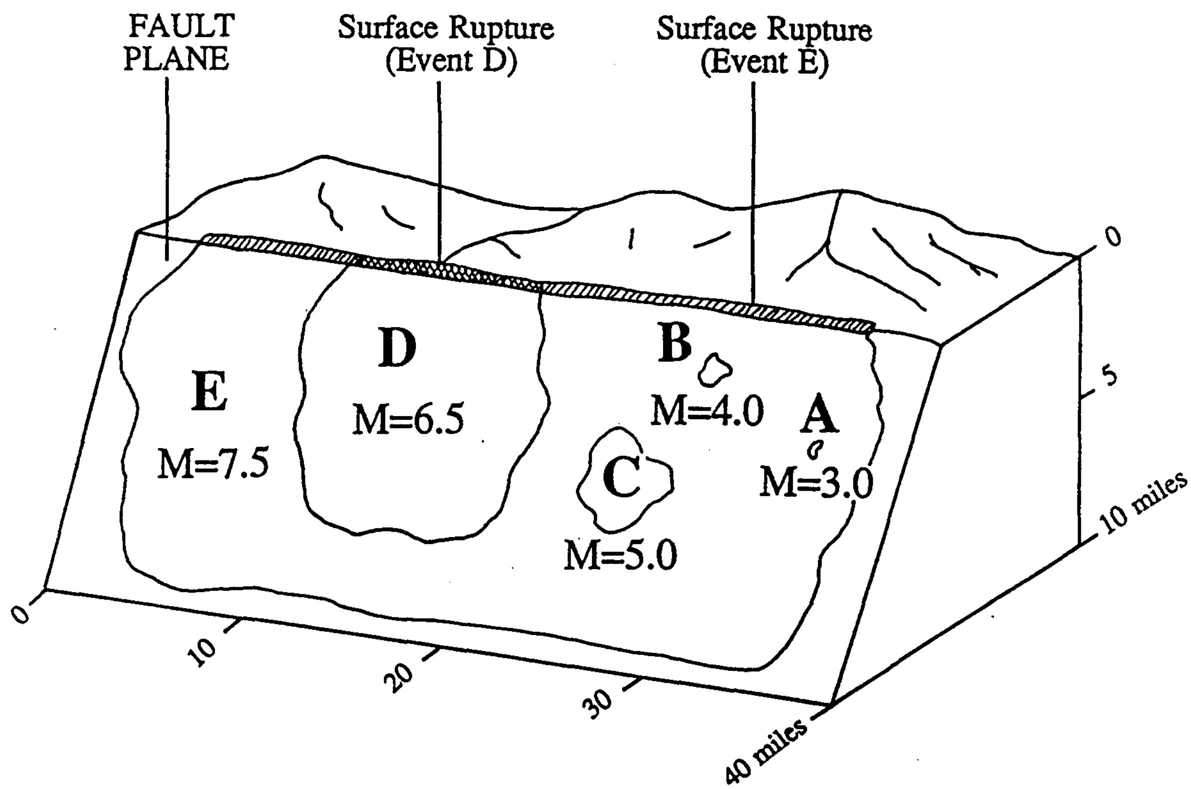


Figure 4. Block diagram showing the geometry of slip on a fault that produces an earthquake. The focus (or hypocenter) is the point at which rupture begins and then spreads on the fault. The rupture only reaches the ground surface during large earthquakes. The epicenter is the point on the surface vertically above the focus.



EVENT	MAGNITUDE	APPROXIMATE RUPTURE AREA (square miles)	APPROXIMATE SLIP
A	3.0	0.1	< ½ inch
B	4.0	0.4	< 1 inch
C	5.0	4	2 inches
D	6.5	60	1-3 feet
E	7.5	350	10-15 feet

Figure 5. Schematic diagram showing how earthquake magnitude relates to the dimensions of an earthquake source. For five events (A-E), ranging in magnitude from 3.0 to 7.5, the approximate size of the corresponding rupture patch is shown above and tabulated below, together with the approximate slip that takes place for the given size earthquake. Surface rupture occurs only for earthquakes of about magnitude 6.0 to 6.5 and greater in the Utah region.

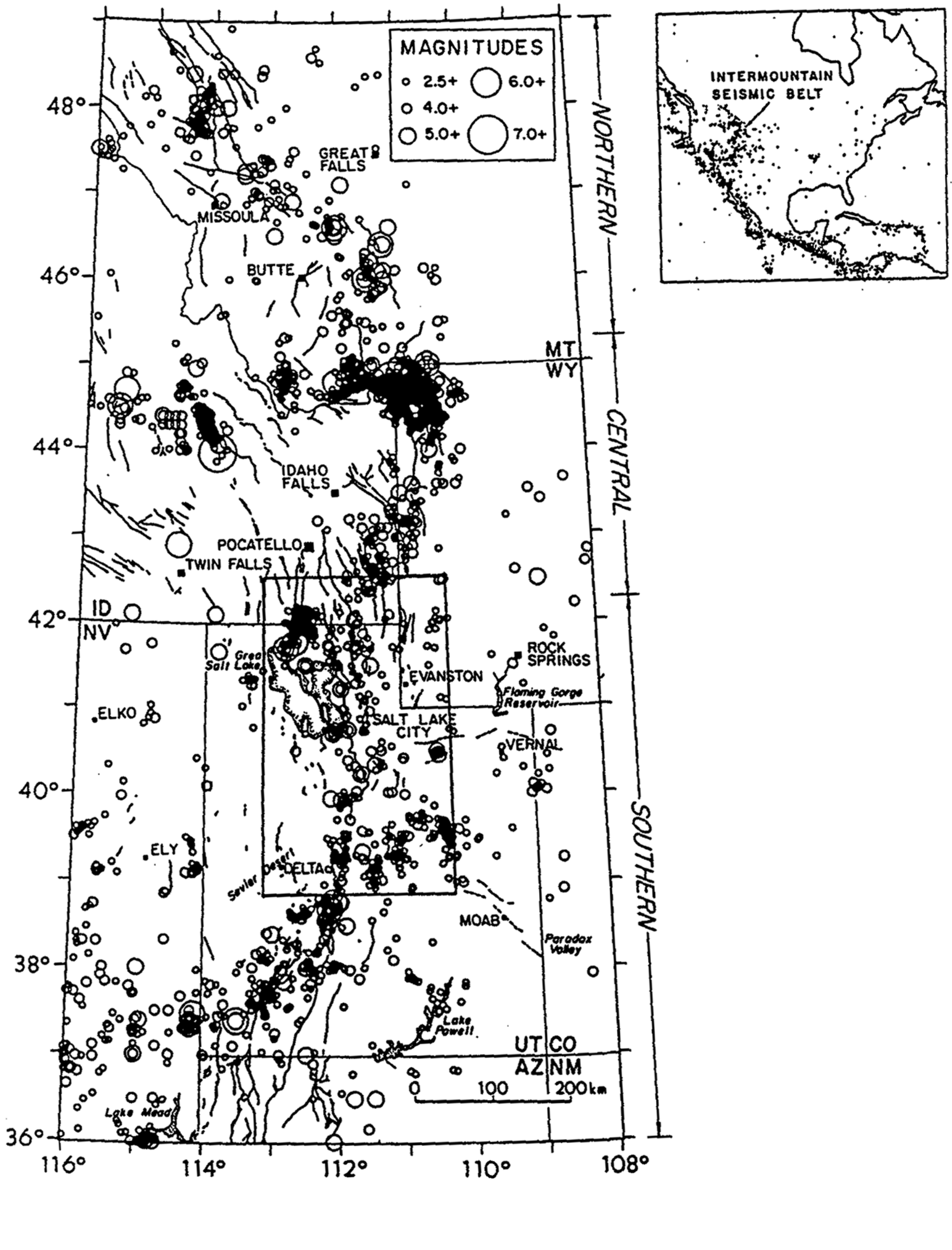


Figure 6. Map showing the setting of the Wasatch Front area of northern Utah (inset rectangle) with respect to the Intermountain Seismic Belt, 1900-1985 (from Smith and Arabasz, 1991).

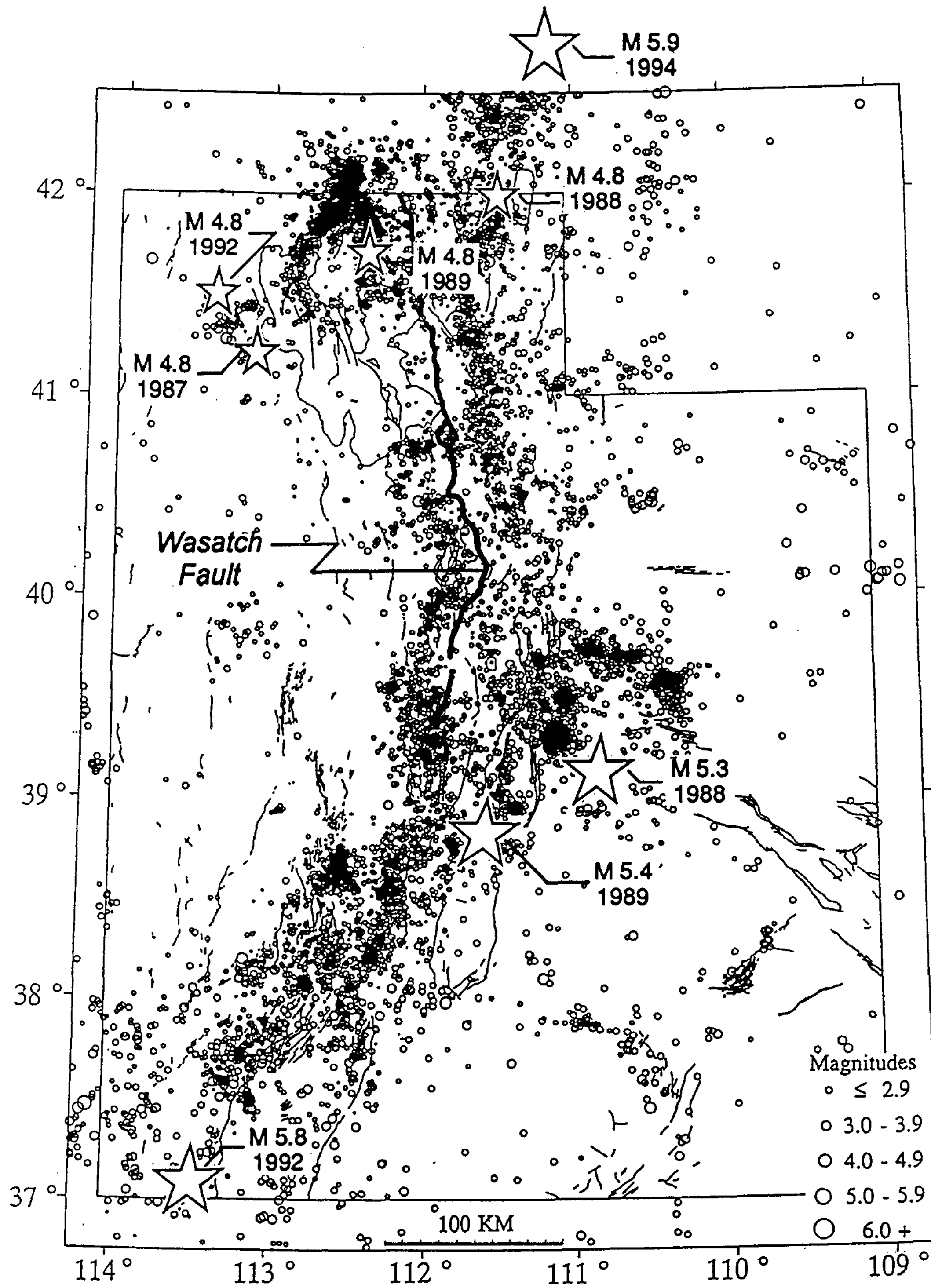


Figure 7. Map of Utah region showing the epicenters of more than 16,000 earthquakes located by the University of Utah Seismograph Stations from 1962 through 1993. Earthquakes of magnitude 4.8 and larger since 1987 shown as stars. The base map showing geological young faults was compiled by the Utah Geological Survey.

University of Utah
Regional Seismic Network
1993

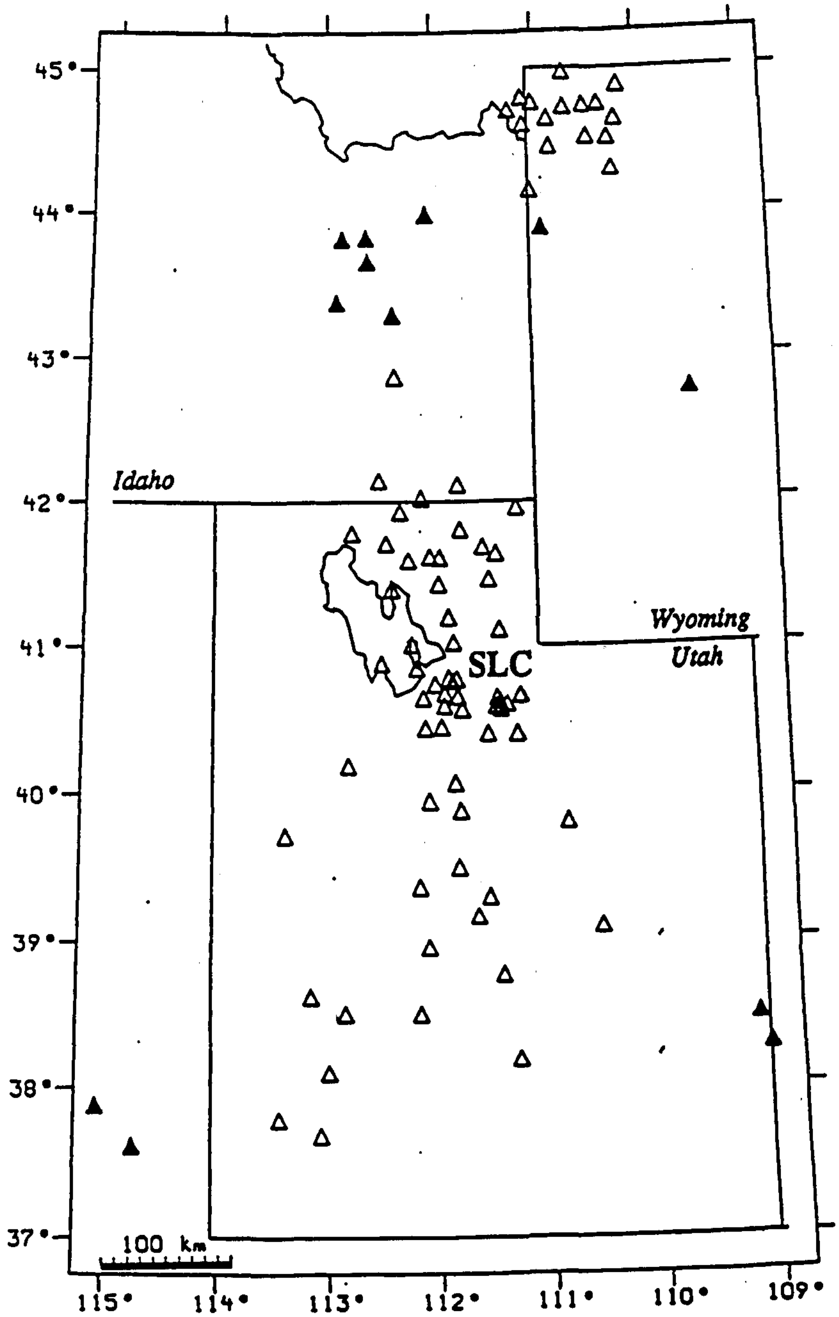


Figure 8. Map of remote seismograph stations making up the University of Utah's regional seismic network. Seismic data from each station are transmitted continuously by radio, telephone, and/or microwave and are centrally recorded on the University campus in Salt Lake City (SLC). The open triangles indicate stations maintained and operated by the University of Utah; the filled triangles, stations owned and operated by other agencies.

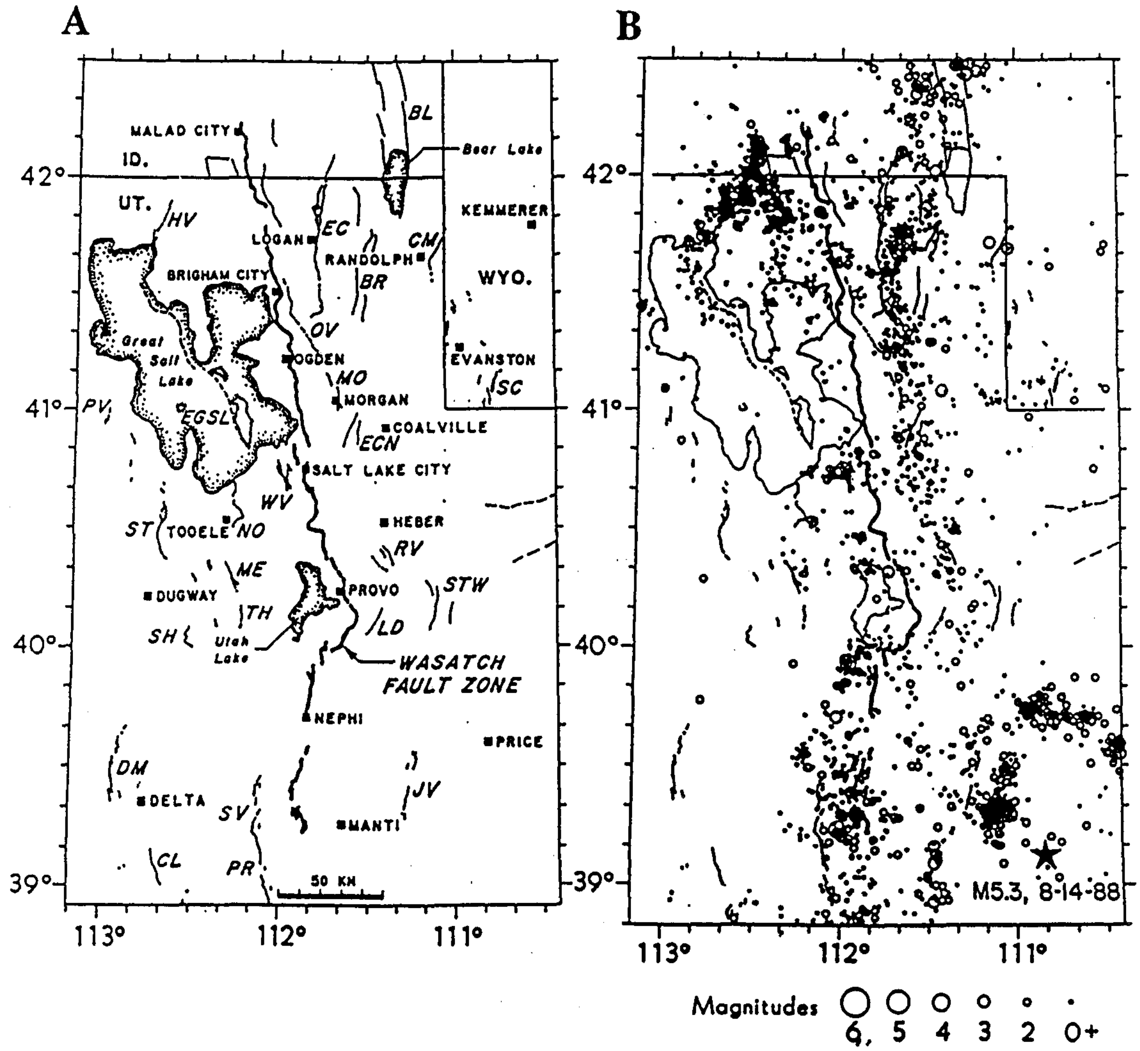
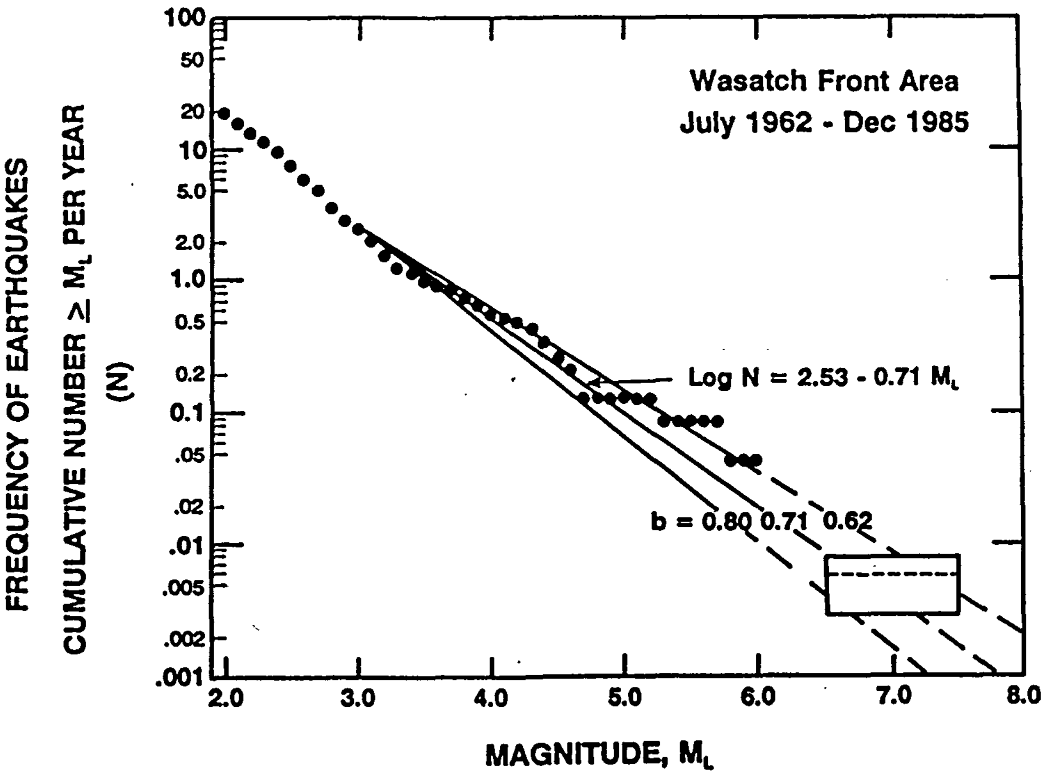


Figure 9. Active faulting and seismicity in the Wasatch Front area, outlined in Figure 6. The left side (A) shows the traces of geologically young (late Quaternary) faulting; the right side (B), shows a representative sample of earthquake activity instrumentally located by the University of Utah Seismograph Stations from July 1, 1978, through December 31, 1986. (Figures taken from Arabasz and others, 1992.) For a more comprehensive depiction of active faulting in this area, see Hecker (1993).



M_L	Average Return Period (years) Preferred Estimate	Range of Estimates
≥3.0	0.40	
≥3.5	0.90	0.81 - 1.0
≥4.0	2.0	1.7 - 2.5
≥4.5	4.6	3.4 - 6.3
≥5.0	10	7 - 16
≥5.5	24	14 - 40
≥6.0	54	29 - 100
≥6.5	120	60 - 250
≥7.0	280	120 - 630
3.0 - 3.5	0.71	.66 - .78
3.5 - 4.0	1.6	1.6 - 1.7
4.0 - 4.5	3.7	3.3 - 4.2
4.5 - 5.0	8.3	6.6 - 10
5.0 - 5.5	19	14 - 26
5.5 - 6.0	42	28 - 66
6.0 - 6.5	96	57 - 170
6.5 - 7.0	220	120 - 420
7.0 - 7.5	490	240 - 1000

Figure 10. Frequency of occurrence of mainshocks in the Wasatch Front area, in graphical form (left) and table form (right), based on instrumentally recorded seismicity, 1962-1985 (after Arabasz and others, 1992). For comparison, the small box in the graph is from Hecker (1993) and shows the estimated combined rate with which large surface-faulting earthquakes (magnitude 6.5–7.5) have occurred on active faults throughout the Wasatch Front area in the past 15,000 years.

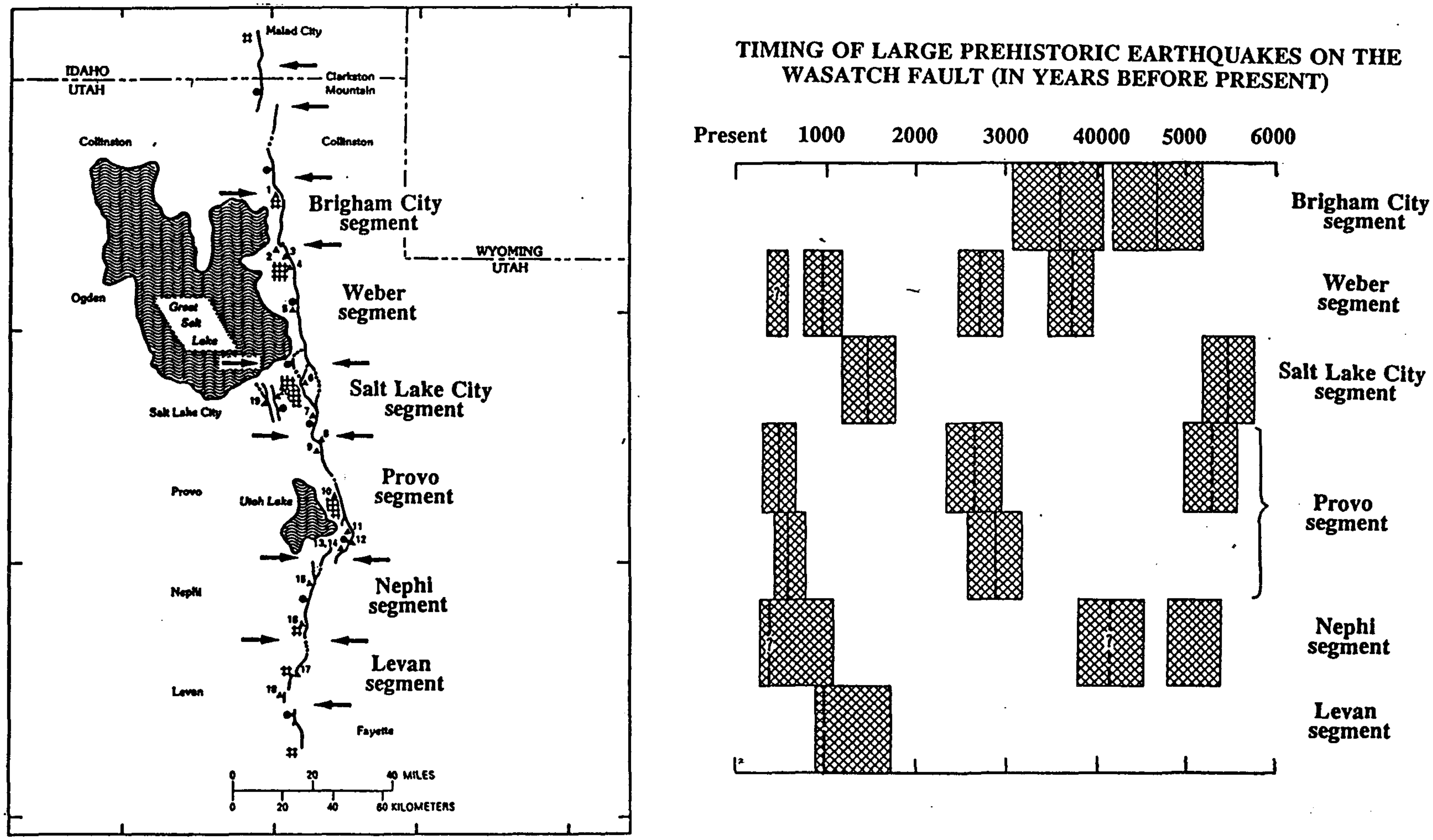
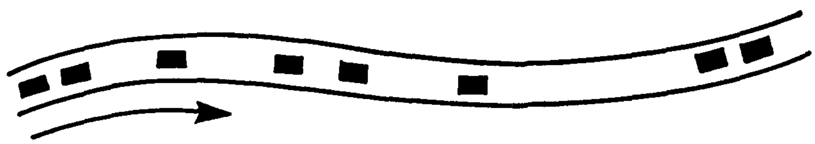


Figure 11. Map of the Wasatch fault zone (left) showing the boundaries of its major segments (large type) together with a diagram (right) indicating the estimated timing of large surface-rupturing earthquakes on those segments during the past 6,000 years (the hachured pattern shows the uncertainty bounds). Both figures are adapted from Machette and others (1992).

EXAMPLES OF A RANDOM ARRIVAL PROCESS



CAR TRAFFIC ON A ONE-WAY ROAD

UTAH EARTHQUAKES
OF MAGNITUDE 5 OR GREATER

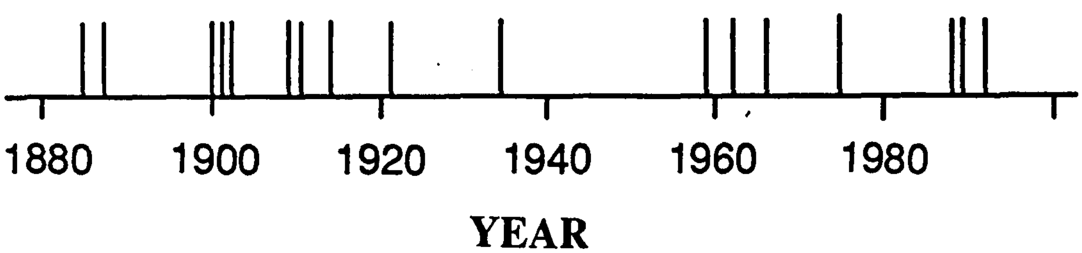


Figure 12. Examples of variable interevent spacing (clusters and gaps) due to a random arrival process called a "Poisson" process, named after a French mathematician and physicist. Such a process involves an *average* long-term rate of occurrence—say the arrival of an average number of cars per hour at some point, or the occurrence of an average number of earthquakes per decade. Because of randomness, the "events" are not uniformly spaced. By knowing the average long-term rate of occurrence, one can calculate the probability that zero, one, or some number of events will occur in a specified time interval.

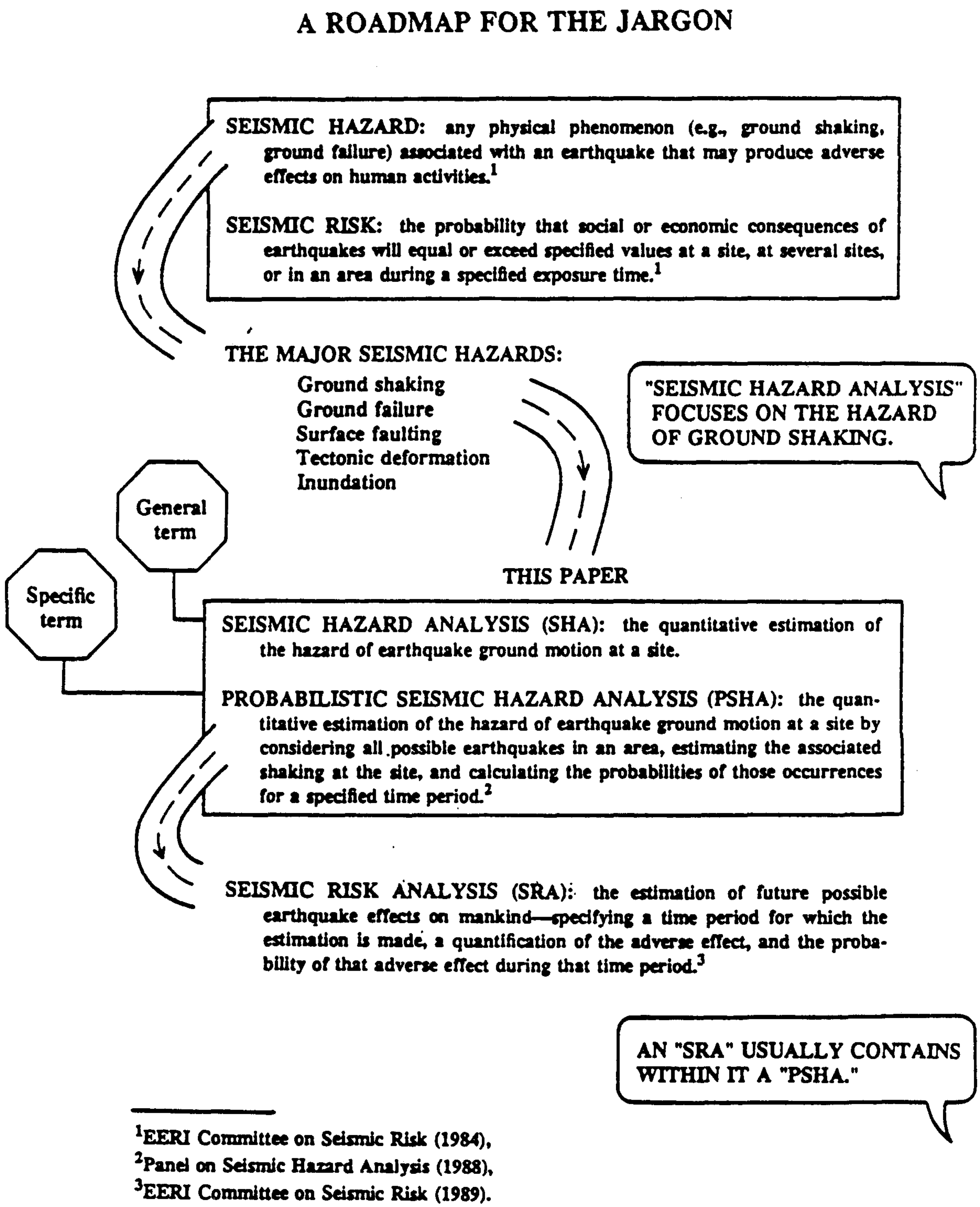
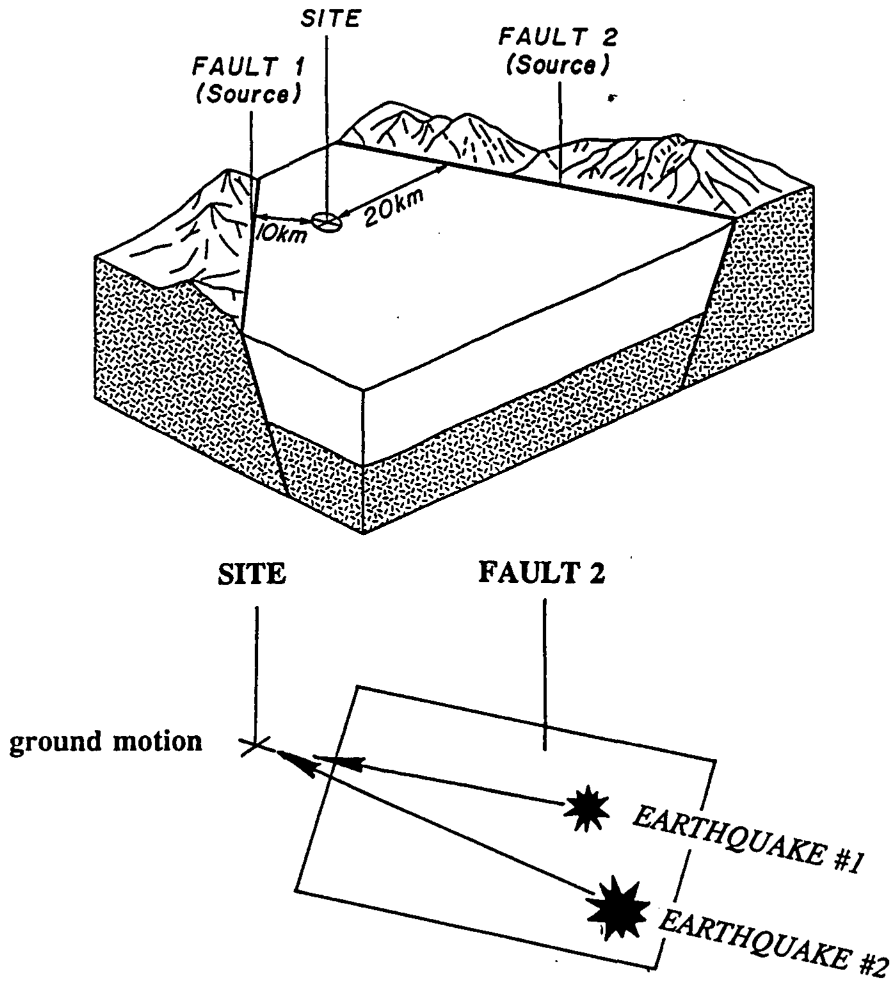


Figure 13. Outline of some basic terms and concepts for seismic hazard and risk analysis (from McGuire and Arabasz, 1990).



Probabilistic seismic hazard analysis (PSHA) basically involves a mathematical process to calculate the mean number of events per year in which the level of ground motion at a site exceeds some specified value.

Sum over all magnitudes and all locations within each source zone—and sum over all possible source zones—to get a Seismic Hazard Curve.

Figure 14. The basic idea of a probabilistic seismic hazard analysis for strong ground shaking (adapted, in part, from McGuire and Arabasz, 1990). Once the location and geometry of all sources of potential earthquakes are identified (as in the upper block diagram), the analysis proceeds as described in the lower part of the figure. Note that Earthquake #1 and Earthquake #2 are potential earthquakes.

SEISMIC HAZARD CURVE

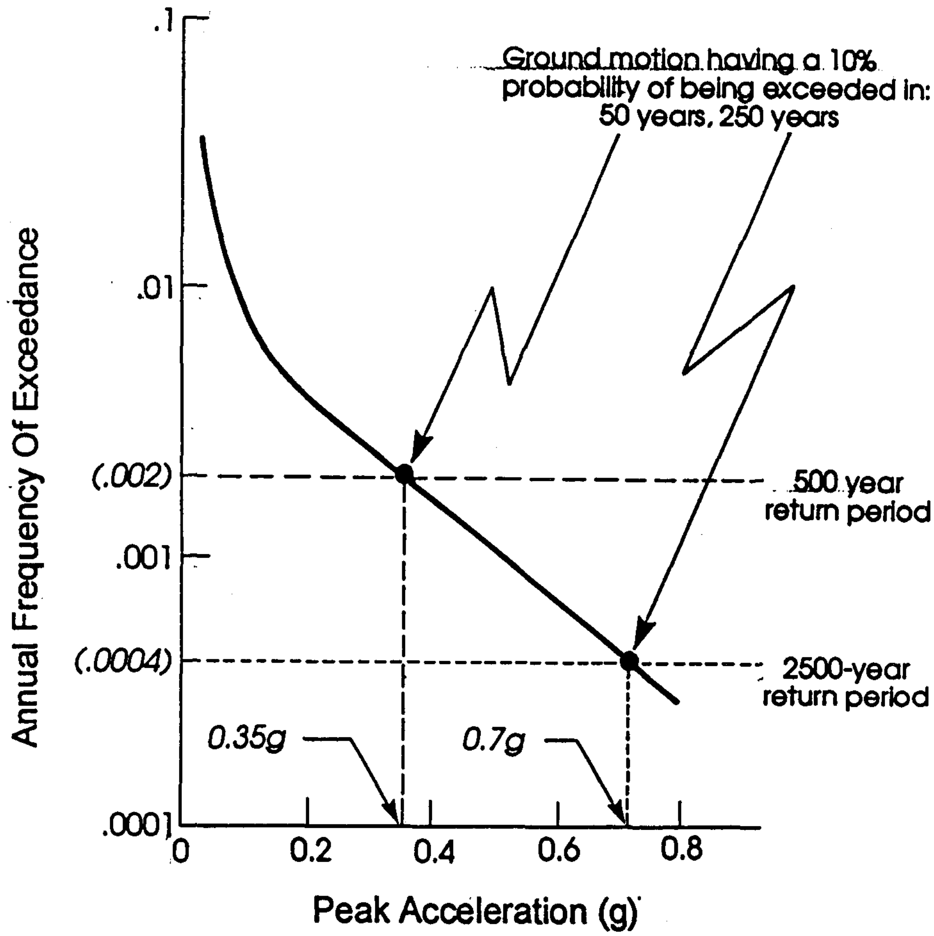
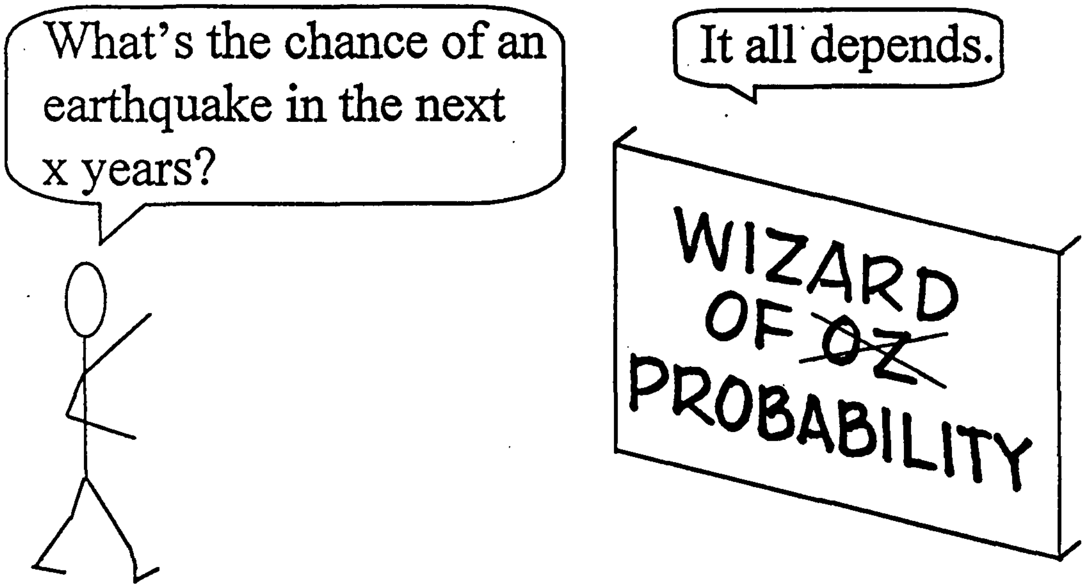


Figure 15. Graph of a simplified seismic hazard curve for a hypothetical site. From the procedure outlined in Figure 14, the curve gives the mean annual number of times (vertical axis) that a certain level of ground shaking (horizontal axis) is expected to be exceeded. The inverse (i.e., 1 divided by) an annual frequency is called a "return period." The ground motions having a 10 percent probability of being exceeded (or equivalently a 90 percent probability of <u>not</u> being exceeded) for some specified "exposure periods" are based on the Poisson model for random occurrence of events.



- What size earthquake?
- Anywhere in the Wasatch Front area? In Utah?
- On the Wasatch fault?
- Anywhere on the Wasatch fault?
- On a specific segment of the Wasatch fault?
- Assuming a Poisson (random, memoryless) model?
- Assuming a time-dependent model?

Figure 16.

"A disaster will not happen."

"A disaster will not happen to me."

"If a disaster does happen and it happens to me, it won't be that bad."

"If a disaster does happen to me and it is that bad, I can't do anything about it anyway."

— Anon., *Natural Hazards Observer*, Nov. 1991

Figure 17. Symptoms of a "disease" for which crisis management is the "cure."

2.

Earthquake Ground Shaking in Utah

by

Robert Youngs

PAPER NOT AVAILABLE AT TIME OF PRINTING

3.

Overview of Building Codes Earthquake Provisions

by

Susan Dowty

Susan M. Dowty

Susan Dowty is a Registered Civil and Structural Engineer in California. She obtained her Master of Science in Civil Engineering in 1990 at California State University Long Beach. She has ten years of experience in plan checking and administering the Uniform Building Code and handicap and energy regulations. Currently she is Senior Staff Engineer in the Codes and Engineering Department of the International Conference of Building Officials. Her duties include code development and interpretation tasks, processing of code changes and representing ICBO on a number of committees, including the Structural Engineers Association of Southern California's Anchorage-to-Concrete and Wood subcommittees, Building Seismic Safety Council committees, and the Advisory Panel for the National Association of Home Builders/FEMA Homeowner's Guide to Earthquake Safety.

Previously, she spent six years as Senior Staff Engineer in the Plan Review Services of ICBO, and two years as Assistant Structural Engineer with the County of San Diego Building Department. She is a member of the Structural Engineering Association of California and the American Society of Civil Engineers.

Overview of Building Code Earthquake Provisions
November 29, 1994
Susan Dowty, P.E., S.E.
Senior Staff Engineer, ICBO

The Uniform Codes address seismic design for existing and new construction. The history of how the seismic design provisions were incorporated into the code provides an insight into the underlying philosophies behind the provisions. The provisions were primarily developed to protect life, not to limit damage. In addition to the *Uniform Building Code* provisions, there is a national effort to develop seismic design provisions through the National Earthquake Hazards Reduction Program. This presentation will address these subjects as well as review the fundamental principles of the seismic provisions.

UNIFORM CODES AND LIMITATIONS (Slides 2 and 3)

The *Uniform Building Code* has contained seismic design provisions for new construction since its first edition in 1927. The provisions have been based on the Structural Engineer's Association of California's (SEAOC) *Recommended Lateral Force Requirements*, commonly referred to as the Blue Book, since 1959. With each major earthquake, the provisions have been revised through the code change process to reflect lessons learned. Many proposed revisions to the *1994 Uniform Building Code* have been submitted as a result of studies made after the 1994 Northridge earthquake.

The seismic provisions of the building code were not developed to create an earthquake-proof structure, if there is such a thing. Rather the provisions take into consideration the economical and practical limitations involved with building construction. The Blue Book specifically states in the recommendations that the recommendations are primarily intended to safeguard against major failures and loss of life; not to limit damage, maintain functions, or provide for easy repair.

The *Uniform Code for Building Conservation* establishes life-safety requirements for existing buildings that undergo alteration or a change in use. Its provisions offer alternative methods of achieving safety so that the inventory of existing buildings can be preserved. Appendix Chapter 1 contains seismic strengthening provisions for unreinforced masonry bearing wall buildings. Section A101 specifically states that the provisions are established primarily to reduce the risk of life loss or injury and do not necessarily prevent loss of life or injury or prevent earthquake damage to rehabilitated buildings.

STRUCTURAL OBSERVATION (Slides 4 through 6)

Structural observation was first introduced into the *1988 Uniform Building Code* as a result of a code change proposed by the Structural Engineer's Association of California. Structural observation, as defined in the code, means the visual observation of the structural system, for general conformance to the approved plans and specifications, at significant construction stages and at completion of the structural system. Structural observation is cheap insurance to ensure a building is built in accordance with the plans. Plans can become very complicated very quickly, and as a result, key features in the vertical and lateral load resisting paths can be missed resulting in what can be catastrophic consequences.

Currently in the 1994 U.B.C., Section 1702 requires structural observation in Seismic Zones 3 and 4 for buildings which pose a higher than normal risk either due to use, occupant load or hazardous contents. This grouping includes:

ESSENTIAL FACILITIES

1. Group I, Division 1 Occupancies having surgery and emergency treatment areas.
2. Fire and police stations.
3. Garages and shelters for emergency vehicles and emergency aircraft.
4. Structures and shelters in emergency-preparedness centers.
5. Aviation control towers.
6. Structures and equipment in government communication centers and other facilities required for emergency response.
7. Standby power-generating equipment for Category I facilities.
8. Tanks or other structures containing housing or supporting water or other fire-suppression material or equipment required for the protection of Category I, II or III structures.

HAZARDOUS FACILITIES

9. Group H, Divisions 1, 2, 6 and 7 Occupancies and structures therein housing or supporting toxic or explosive chemicals or substances.
10. Nonbuilding structures housing, supporting or containing quantities of toxic or explosive substances which, if contained within a building, would cause that building to be classified as a Group H, Division 1,2 or 7 Occupancy.

SPECIAL OCCUPANCY STRUCTURES

11. Group A, Divisions 1, 2 and 2.1 Occupancies.
12. Buildings housing Group E, Divisions 1 and 3 Occupancies with a capacity greater than 300 students.
13. Buildings housing Group B Occupancies used for college or adult education with a capacity greater than 500 students.

14. Group I, Divisions 1 and 2 Occupancies with 50 or more resident incapacitated patients, but no included in Category I.
16. Group I, Division 3 Occupancies.
15. All structures with an occupancy greater than 5,000 persons.
16. Structures and equipment in power-generating stations; and other public utility facilities not included in Category i or Category II above, and required for continued operation.

HIRISE GROUP B OFFICES AND GROUP R, DIVISION 1 OCCUPANCIES

17. Group B office buildings and Group R, Division 1 Occupancies having floors used for human occupancy located more than 74 feet above the lowest level of fire department vehicle access.

Also, Section 1702 gives the architect, engineer and building official the authority to require structural observation when determined necessary.

An additional requirement which pertains to essential and hazardous facilities is that these structures need to be designed for a 25 percent increase in design load due to their critical occupancy use in the event of an earthquake.

ORGANIZATION OF THE U.B.C. SEISMIC DESIGN PROVISIONS (Slides 7 through 13)

Note: Chapter references are based on the 1994 U.B.C.

The general seismic design provisions which pertain to all structures, regardless of material of construction, are found in Chapter 16. The seismic load for which a structure is designed depends on its location in the United States with respect to seismic activity. Figure 16-2 provides the seismic zoning of the United States. Seismic zones vary from 0 to 4 with zone 0 assigned to those regions with no seismic activity to zone 4 which is considered to be the most seismically active region. The design coefficient designated for each seismic zone reflects the effective peak ground acceleration on rock with a 10 probability of being exceeded in 50 years. The State of Utah has been mapped seismic zones 1, 2B and 3.

Specific seismic detailing requirements for the materials of construction are included in the material chapters. Wood construction provisions are contained in Chapter 23. Wood construction is somewhat unique in that a design completed by an engineer or architect is not always required. The chapter contains prescriptive measures by which box-type wood-framed structures may be constructed. These prescriptive provisions are based on experience gained over the last 60 years. ICBO has recently released a video and workbook, *Bolt-It-Down, A Homeowner's Guide to Earthquake Protection* which provides a homeowner with the necessary information to strengthen their home against earthquake damage.

Masonry and concrete seismic detailing requirements are found in Chapters 21 and 19 respectively. The most common form of seismic load resisting systems in these types of construction are shear walls and moment resisting frames. Steel seismic detailing requirements are found in Chapter 22, and the most common form of seismic load resisting systems for steel construction are moment resisting frames and braced frames.

Seismic-isolated structures are gaining in popularity and provisions for these type of structures are found in Appendix Chapter 16. Seismic-isolated structures are essentially placed on "shock absorbers" so that the energy imposed by the earthquake is absorbed by the isolators rather than the building construction.

NEHRP RECOMMENDED PROVISIONS (Slides 14 and 15)

The U.B.C. is used predominately west of the Mississippi. Two other codes are used in the United States: (1) the National Building Code (NBC) published by Building Officials and Code Administrators, International (BOCA) and (2) the Standard Building Code, published by Southern Building Code Congress International (SBCCI). Both of these codes base their seismic design requirements on the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings.* These provisions were developed by a large number of volunteer experts and the Building Seismic Safety Council (BSSC) Board of Direction and staff. As is evident from reading the purpose of the provisions (see Slide 15), the primary goal of the provisions is to protect life.

KEY ELEMENTS IN QUAKE RESISTANT CONSTRUCTION (Slide 16)

It is the project team's responsibility to ensure the structure is designed and built in accordance with the code, and this can be a tall order to fill. The five key elements in quake-resistant construction are as follows:

1. **Plan Review/Peer Review.** It is critical that the structure undergo a design review by an independent party to ensure that code requirements have been met.

2. **Redundancy and Ductility.** The structure should be designed so that there are multiple lines of defense. If one seismic load resisting element fails, there should be a backup system. Also, materials should be utilized in the design so that they can absorb the energy imparted by the earthquake.
3. **Connection Details.** Connections are the critical element in putting the structure together and it is imperative connections are adequately detailed.
4. **Complete Load Path.** The seismic loads must have a path to reach the foundation and that path should be defined, designed, detailed and reviewed.
5. **Quality Control.** Inspections, special inspections and structural observation should be provided as necessary to ensure the structure is built in accordance with the plans.

LOOKING INTO THE FUTURE (Slide 17)

It appears that the direction of future seismic code provisions is to develop performance based criteria for seismic design. In many cases, the design community is being requested to design for more than life-safety and to limit the amount of damage suffered by a structure in a major seismic event. Design provisions for varying degrees of protection are being discussed. Categories such as risk reduction, collapse prevention, substantial life-safety, damage control and immediate occupancy have been suggested.

Overview of Building Code Earthquake Provisions

November 29, 1994

Susan Dowty, P.E., S.E.

ICBO

INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS · 1922 ·

UNIFORM BUILDING CODE

3 – 6

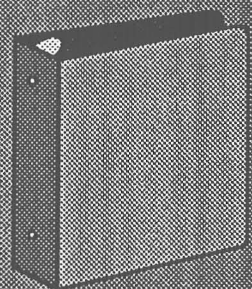
International Conference of Building Officials

Uniform Building Code

Uniform Code for Building Conservation

Appendix Chapter 1 - Seismic Strengthening Provisions for Unreinforced Masonry Bearing Wall Buildings

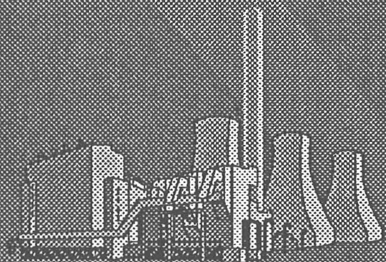
Structural Engineers Association of California - (SEAOC)



Blue Book

Recommended Lateral Force Requirements and Commentary

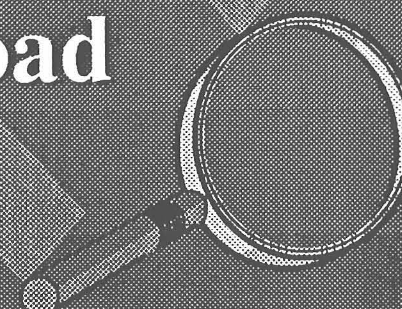
"These recommendations primarily are intended to safeguard against major failures and loss of life, not to limit damage, maintain functions, or provide for easy repair"



<u>Essential Facilities:</u> **Structures necessary for emergency operations subsequent to a natural disaster.**

<u>Hazardous Facilities:</u> **Structures housing, supporting or containing sufficient quantities of toxic or explosive substances to be dangerous to the safety of the general public if released.**

- **25% increase in design load**
- **Structural Observation**



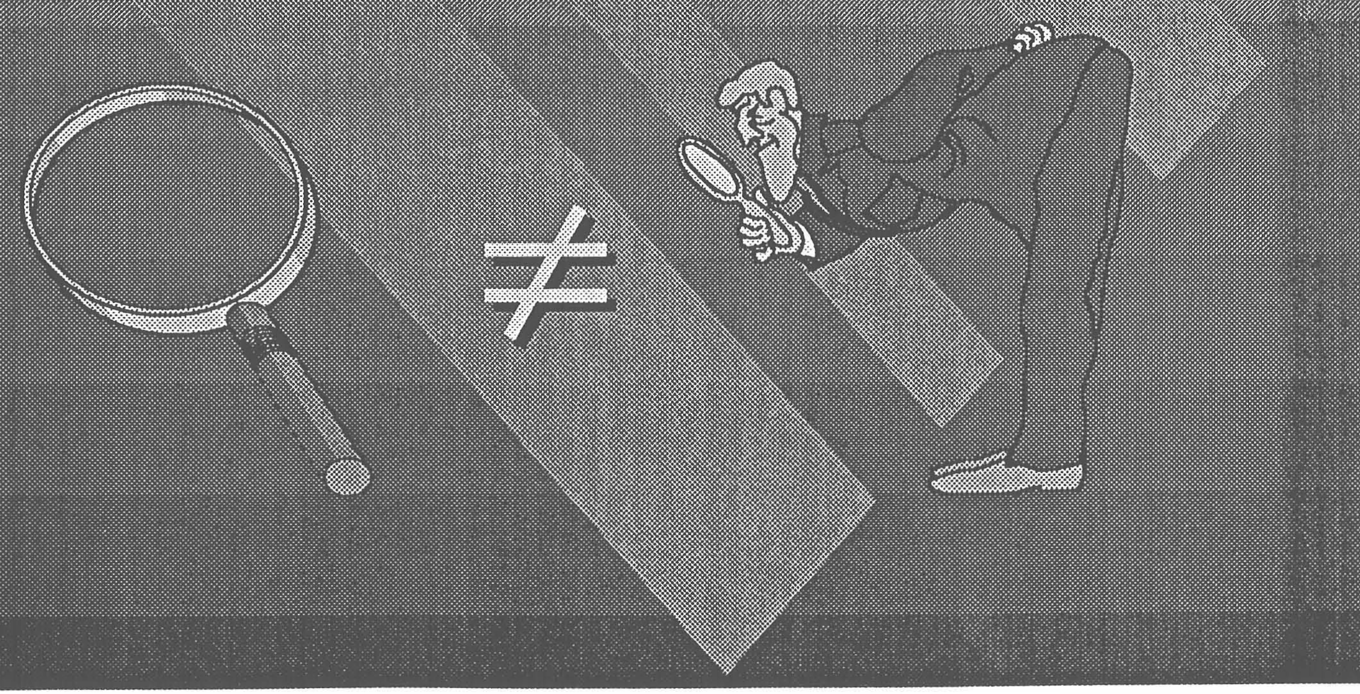
3-8

Structural Observation Shall Also Be Provided In Seismic Zones 3 & 4 Per Section 1702 For:

1. Special Occupancy Structures
2. Highrise Structures
3. When Required by the Architect, Engineer or Building Official

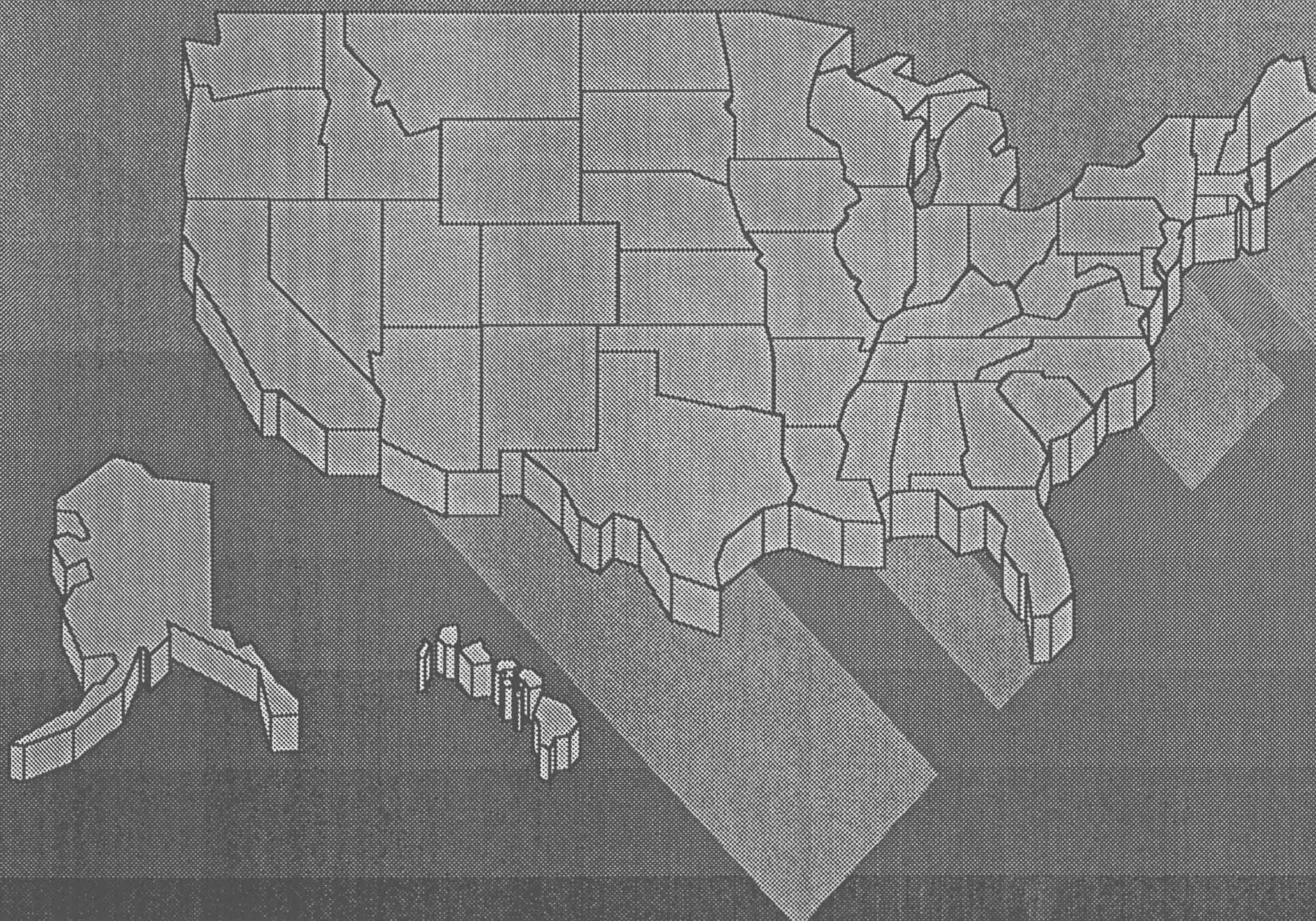
Structural Observation ≠ Inspection

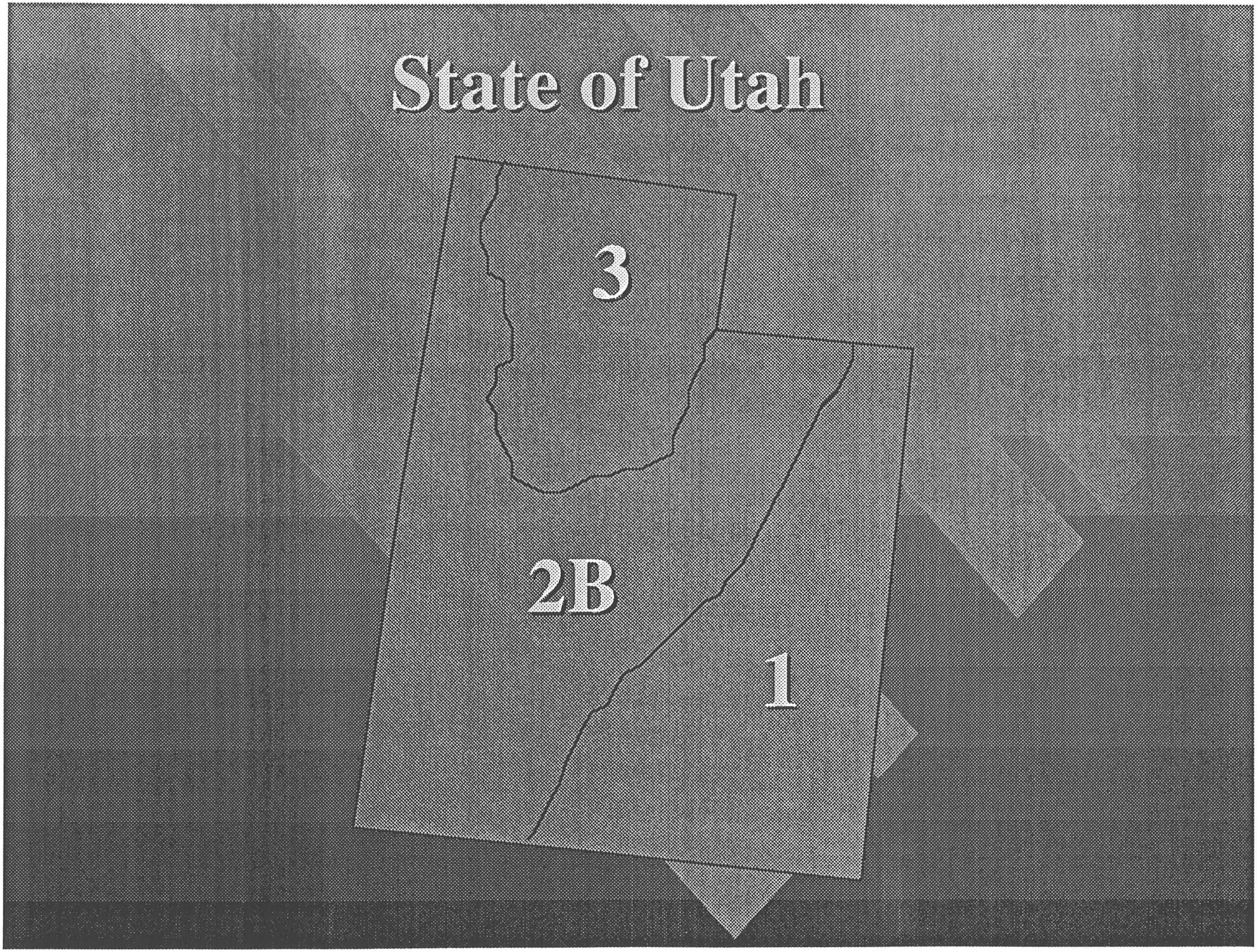
"Structural Observation means the visual observation of the structural system, for *general conformance* to the approved plans and specifications, at *significant construction stages* and at completion of the structural system. Structural Observation does not include or *waive the responsibility for the inspections* required by Sections 108, 1701 or other sections of this code."



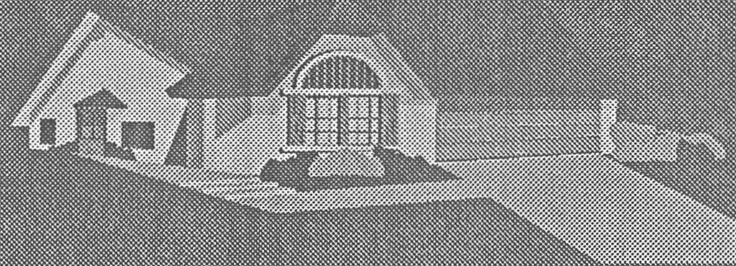
	91 UBC	94 UBC
Loads (10% probability of exceedance in 50 years)	Ch. 23	Ch. 16
Masonry	Ch. 24	Ch. 21
Wood	Ch. 25	Ch. 23
Concrete	Ch. 26	Ch. 19
Steel	Ch. 27	Ch. 22
Seismic-Isolated Structures	Appendix Ch. 23	Appendix Ch.16

Figure No. 16-2
Seismic Zone Map of the U.S.

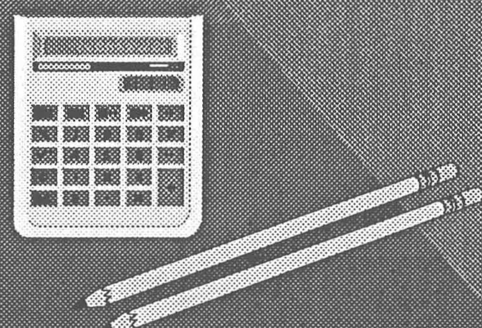



State of Utah
3
2B
1

Wood Construction

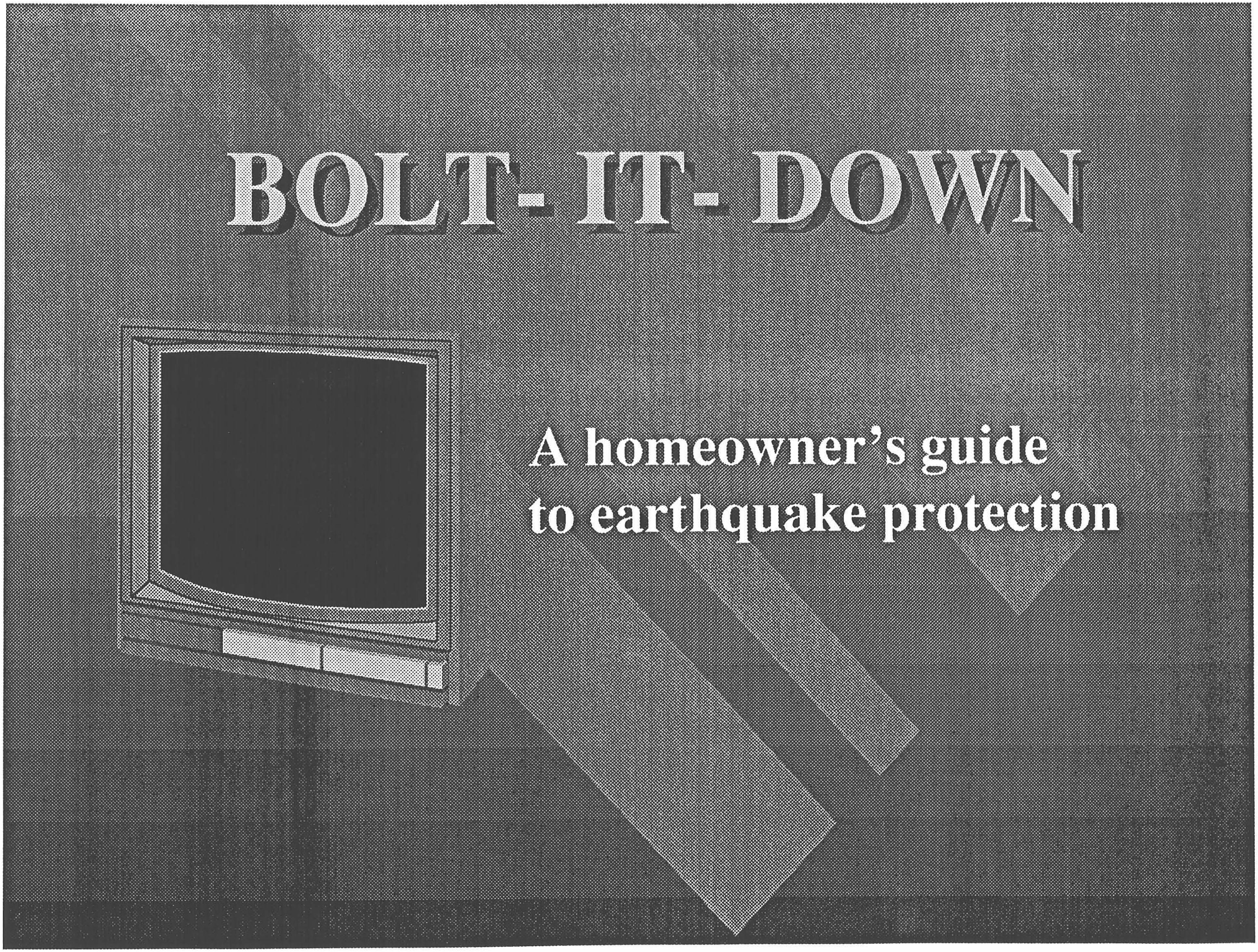


Design or Prescriptive



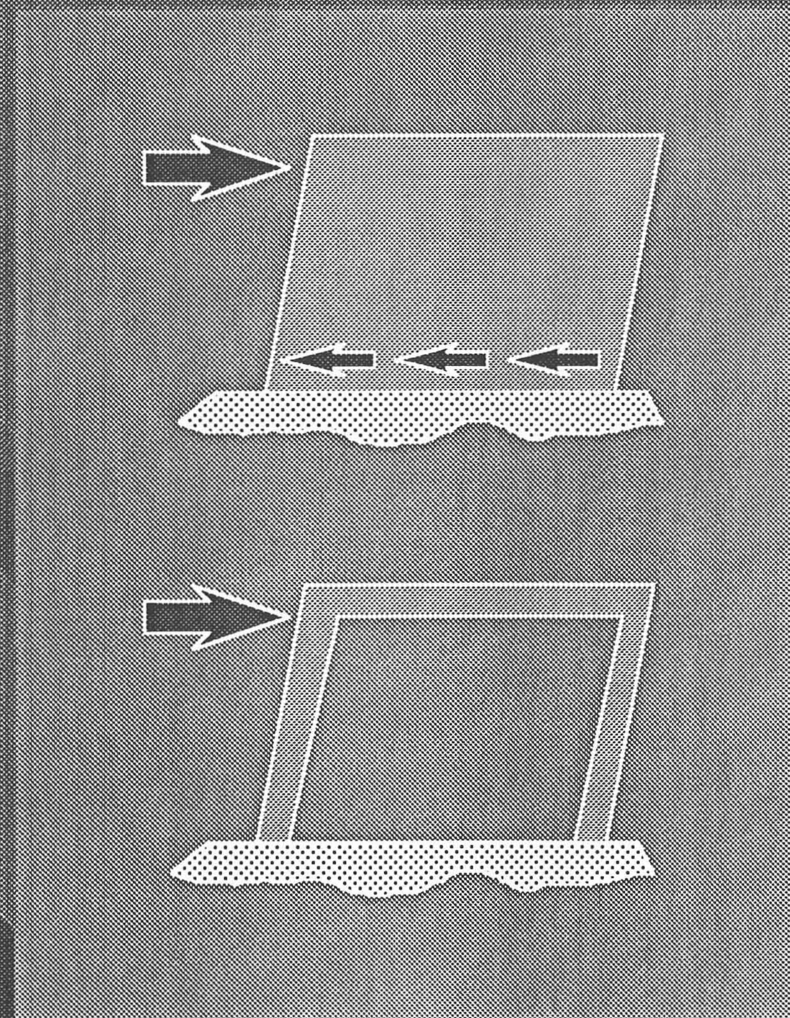
2517
91 UBC

2326
94 UBC


BOLT- IT- DOWN
A homeowner's guide
to earthquake protection

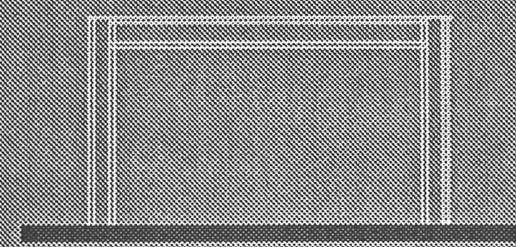
Masonry and Concrete

- Shear Walls
- Moment Resisting (wall) Frame

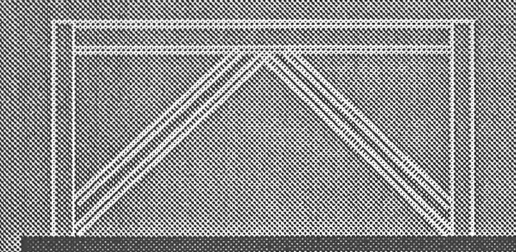


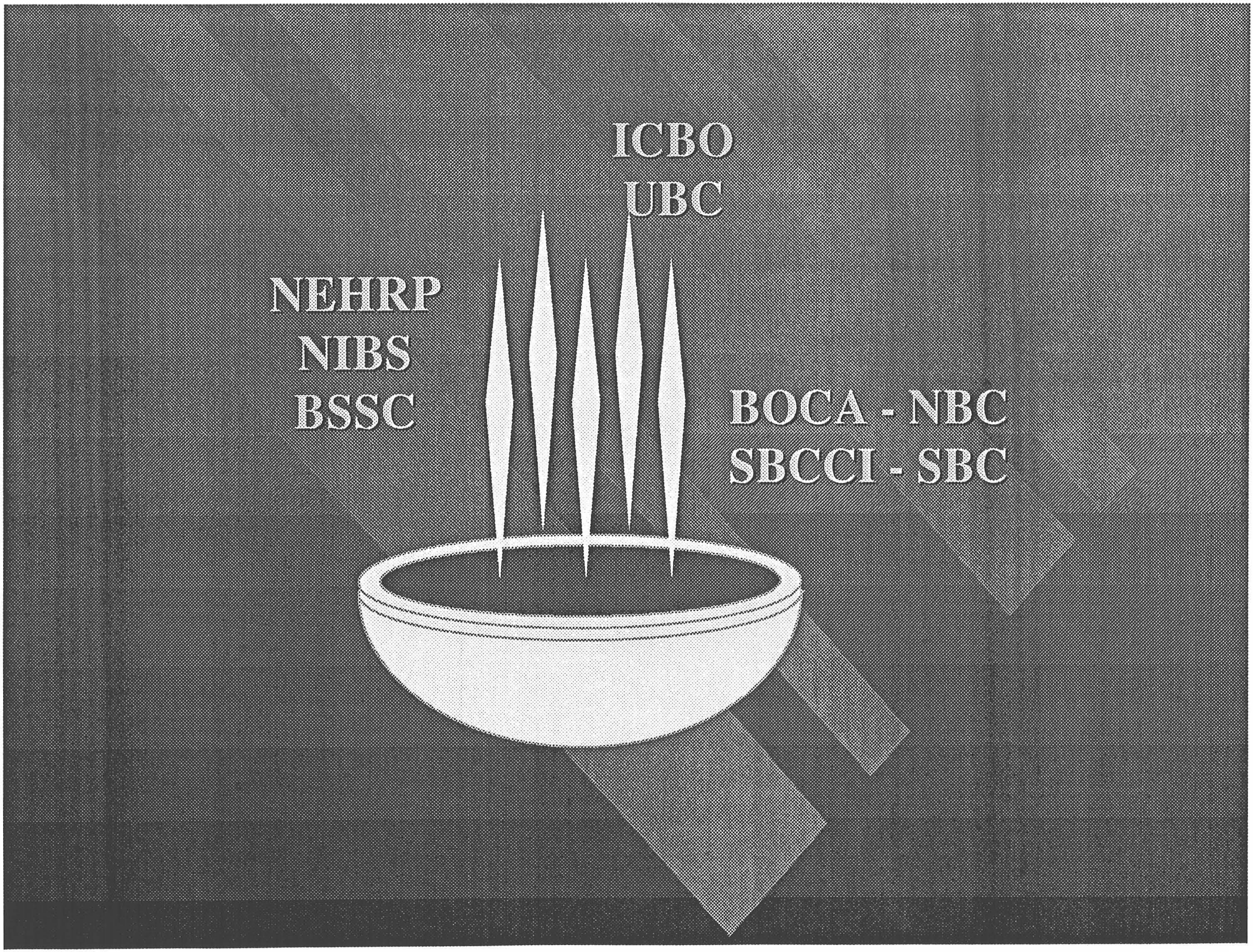
Steel

- Moment Resisting Frames



- Braced Frames




ICBO
UBC
NEHRP
NIBS
BSSC
BOCA - NBC
SBCCI - SBC

1994 NEHRP Recommended Provisions

1.1. Purpose: . . .The "design earthquake" ground motion levels specified herein may result in both structural and nonstructural damage. For most structures designed and constructed according to these provisions, it is expected that structural damage from even major earthquakes would likely be repairable; however, this would depend upon a number of factors including the structural framing type, materials and details of construction actually used. For ground motions larger than the design levels, the intent of these provisions is that there be a low likelihood of building collapse.

Key Elements In Quake Resistant Construction

1. Plan Review / Peer Review
2. Redundancy and Ductility
3. Connection Details
4. Complete Load Path
5. Quality Control

Looking Into the Future:

Performance Based Criteria

4.

Estimates of Building Performance in a Salt Lake City Earthquake

by

Stephanie King

Stephanie A. King

Dr. King has recently completed her doctoral work in the area of geographic information system (GIS) applications in seismic hazard and risk analysis and provides state-of-the-art knowledge in this field. She has completed regional earthquake damage and loss studies for various municipalities, including 200,000 buildings in Salt Lake County, Utah and 22,000 buildings in the City of Palo Alto, California. She has also been involved in nationwide earthquake risk assessment projects for the U.S. Postal Service and the Federal Emergency Management Agency. Dr. King has extensive skills in the implementation of geographic information systems, relational database management systems, and knowledge based expert systems for the purposes of regional as well as site specific seismic hazard and risk assessment. Dr. King has also provided investigation and expert witness testimony for residential earthquake damage and geotechnical effects in the northern California area. She obtained her Ph.D. in civil engineering from Stanford University in 1994.

ESTIMATES OF BUILDING PERFORMANCE IN A SALT LAKE CITY EARTHQUAKE

Stephanie A. King

John Blume Earthquake Engineering Center
Stanford University
Stanford, CA 94305-4020
e-mail: sking@blume.stanford.edu

BACKGROUND AND OVERVIEW

In November 1992, the Applied Technology Council (ATC) of Redwood City, California entered into a cooperative agreement with the Federal Emergency Agency (FEMA) to develop the methodology and associated databases for evaluating the damage and loss associated with a scenario earthquake in Salt Lake County, Utah (see Applied Technology Council, ATC-36, in progress). ATC engaged a project team consisting of consultants with experience in earthquake damage and loss estimation studies and local experts with knowledge of the earthquake hazards and the structural engineering practice in Salt Lake County. The purpose of the project is to develop a better understanding of the impact on areas such as the built environment, the population, and the economy in Salt Lake County due to future earthquakes. **SLIDE 1** summarizes the ATC-36 project and its participants.

The methodology and associated databases developed as part of the ATC-36 project are designed for implementation in a geographic information system (GIS). A GIS can best be described as a graphical database tool for the storage, manipulation, analysis, and display of both spatial and tabular data. By overlaying maps that represent regional information such as expected ground shaking, soil conditions, lifeline facilities, building inventory, and population statistics, the impact in the region due to various earthquake scenarios can be displayed in several formats. This type of GIS-based analysis is useful for emergency response planning, seismic retrofit legislation, land use planning, prioritization for seismic upgrade of facilities, and other earthquake hazard mitigation purposes. **SLIDE 2** illustrates the GIS map overlay process for earthquake damage and loss estimation.

The work presented here is a sub-set of the ATC-36 project and focuses on the development of the building inventory in Salt Lake County, and the estimation of damage and loss to this inventory for a scenario earthquake event. The results of the earthquake damage and loss analysis are of course a function of the models that are used to characterize parameters such as the various types of buildings, the relationship between shaking and damage for each building type, the use and replacement cost of each building, and the estimated ground shaking at each building site. These models, developed specifically for Salt Lake County as part of the ATC-36 project, are briefly discussed below followed by the results of the building performance analysis.

BUILDING INVENTORY

A detailed inventory of nearly 200,000 residential and commercial buildings in the region was developed from the 1993 Salt Lake County Tax Assessor Database. **SLIDE 3** lists the data attributes associated with each building in the inventory. Some of the attributes were obtained directly from the Tax Assessor Database, but several had to be inferred from available information and expert opinion. The inferred attributes include the following:

> *Longitude/latitude and Census tract/block locations.* Buildings were addressed matched to US Census data to translate street address locations to longitude/latitude and Census tract/block locations for implementation in the GIS.
>
> *ATC-36 earthquake engineering class(es).* 16 model building types were defined for Salt Lake County. An expert system was used to assign each building to one of the 16 classes based on the available information in the Tax Assessor Database. In some cases, buildings were assigned to more than one class in a probabilistic manner.
>
> *ATC-36 social function class(es).* 50 social function or use classes were defined for Salt Lake County. Each building was assigned to one or more social function classes based on the 3-digit use codes provided by the Tax Assessor Database.
>
> *Replacement cost.* The replacement cost (in 1993 dollars) was estimated for each building as a function of the social function class and the square footage.
>
> *Day and night occupancy.* The day and night occupancy of each building were also estimated as a function of the social function class and the square footage, but included input from US Census population data.

SLIDES 4 and 5 show examples of the rules used for inferring data attributes during the development of the building inventory.

After the building inventory was developed and stored in the GIS, several summary tables and maps describing the inventory were created. **SLIDE 6** shows a table of summary statistics for the nearly 200,000 residential and commercial buildings in the inventory. The building stock in Salt Lake County has an estimated replacement cost of about 31.4 billion dollars (1993 dollars), an average design date of 1960, and it covers roughly 593 million square feet. The ratio of residential to commercial buildings is nearly 10 to 1. Over half of the buildings are of wood frame construction, a typically good performer in earthquakes, and roughly one quarter are of unreinforced masonry construction, a typically bad performer in earthquakes. **SLIDE 7** shows the percentage of buildings in each Census tract that are of unreinforced masonry construction, illustrating the concentration of potentially hazardous buildings in and around downtown Salt Lake City. **SLIDE 8** shows the average design date of buildings in each Census tract, again illustrating the concentrations of older potentially more hazardous buildings.

EARTHQUAKE DAMAGE TO BUILDINGS

There are several terms used to describe earthquake damage to an individual structure and to an entire region or group of structures. The most widely used measure of earthquake damage is an expression of damage in terms of percent financial loss that can be applied to both individual buildings and an entire inventory of buildings. This measure is typically called a "damage factor" and is defined as the ratio of dollar loss to replacement cost of the building (see Applied Technology Council, ATC-13, 1985). In this work, earthquake damage is expressed in terms of the expected damage factor, E[DF], with a measure of the uncertainty in the estimate given by the standard deviation of the damage factor, SD[DF]. When characterizing earthquake damage in this format, the expected loss, E[loss], and the standard deviation of the loss, SD[loss], are easily computed by multiplying the E[DF] and SD[DF] values by the replacement cost.

There are several forms of motion-damage relationships for estimating the earthquake damage for a given building type due to various levels of ground shaking. (see King and Kiremidjian, 1994). These relationships, also known as vulnerability functions, are typically derived from empirical data, computational structural analysis, or expert opinion survey. The motion-damage relationships used in this work are in the form of curves relating expected damage factor to ground shaking intensity for each of the 16 model building types defined for Salt Lake County. The curves were developed from expert opinion survey, primarily through the modification of curves commonly used in California (see Applied Technology Council, ATC-13, 1985) to reflect the building construction practices and materials found in Utah. **SLIDE 9** illustrates the development of the expected damage factor curve for one class of buildings. For a given building, the curve may be shifted up or down as a function of the specific data attributes, such as design date, height, and seismic retrofit.

ESTIMATION OF GROUND SHAKING

Although previous earthquakes have shown that structural damage can be caused not only by strong ground shaking but also by secondary effects such as liquefaction and landslide, the earthquake damage estimation presented in this work is limited to ground shaking alone in order to simplify the analysis. The ATC-36 damage and loss estimation methodology for Salt Lake County includes a thorough treatment of the combination of expected damage due to ground shaking and the various secondary effects.

The scenario earthquake for the building performance analysis is a magnitude 7.5 event on the Salt Lake City Segment of the Wasatch Fault Zone. Surface ground shaking in Salt Lake County was estimated by first postulating a length of rupture along the Wasatch Fault Zone that is capable of generating a magnitude 7.5 earthquake. An empirical attenuation relationship that estimates the surface ground shaking as a function of distance to the rupture zone and magnitude of the earthquake was used to produce a map showing the distribution of ground shaking intensity in the region. **SLIDE 10** shows the approximate location of faults in the Wasatch Fault Zone and **SLIDE 11** shows the estimated ground shaking intensity used in the analysis of building performance.

The ground shaking intensity is expressed in terms of Modified Mercalli Intensity (MMI) to correspond with the expected damage factor curves discussed above. The use of other motion-damage relationships might require the characterization of surface ground shaking in terms of different parameters, such as peak ground acceleration or spectral velocity. The utility of the GIS-based earthquake damage and loss estimation methodology developed in the ATC-36 project is that once the extremely time-consuming and expensive task of compiling the required data (e.g., inventory of structures, geotechnical and geologic maps, population statistics) is completed, any number of different analysis models can typically be implemented and updated as more current information becomes available. **SLIDE 12** shows an example GIS map overlay, combining building inventory data with surface ground shaking.

BUILDING PERFORMANCE

As discussed earlier, the results of an earthquake damage and loss study are influenced by the characterization of input data and the assumptions in the analysis models. The previous sections discuss some of these influencing factors in an attempt to illustrate the limitations and utility of the results presented here. The performance of Salt Lake County buildings in a magnitude 7.5 earthquake on the Wasatch Fault Zone is measured in terms of expected damage factor and expected loss to each of the nearly 200,000 records in the building inventory. The results are aggregated for buildings of the same construction type and for buildings located in the same Census tract. Results for individual buildings, as well as information about the owners and street locations, are stored in the database but never reported. The expected damage factor curves are based on expert opinion survey and represent the average response of a large sample of buildings of the same engineering class. These curves are not intended to predict the performance of an individual building; this is the goal of a detailed dynamic structural analysis. Legal and political concerns also preclude the reporting of results for specific buildings, as well as the owner name and address information.

SLIDES 13 and 14 illustrate building performance in the magnitude 7.5 earthquake aggregated at the Census tract level. **SLIDE 13** shows the expected damage factor, E[DF], averaged for all buildings in each Census tract, and **SLIDE 14** shows the percentage of the buildings in each Census tract with an E[DF] that is greater than 60%.

Maps such as these are useful for quickly identifying regions that might be targeted for seismic hazard mitigation studies. **SLIDE 15** illustrates the performance of buildings in the earthquake in terms of total expected loss, E[loss], summed over each Census tract. The most vulnerable regions, in terms of economic loss, are easily identified with this type of map.

In addition to zonation maps, tables describing the earthquake performance of buildings in terms of expected damage and loss are also useful for hazard mitigation purposes. **SLIDE 16** presents a summary of building performance in Salt Lake County by type of construction material. Wood frame buildings have an expected average damage factor of about 11%, resulting in a total expected loss of about 1.4 billion dollars or about $12,500 per building. Unreinforced masonry buildings have an expected average damage factor of about 56%, resulting in a total expected loss of about 4.2 billion dollars or about $80,000 per building. The buildings of concrete and steel construction are few in number, but are typically larger with high replacement costs. Steel buildings are expected to perform better than concrete with an average damage factor of about 12% and a total expected loss of about 64 million dollars. Concrete buildings have an expected average damage factor of about 25%, resulting in a total expected loss of about 148 million dollars or about $948,000 per building. The results for the roughly 30,000 buildings of other or mixed construction include several types of building classes (e.g. steel frame with concrete shear walls, concrete frame with unreinforced masonry infill, reinforced masonry) and should be broken down further by class so that meaningful conclusions can be made.

SUMMARY

The work presented here is part of an Applied Technology Council project that involves the development of an earthquake loss evaluation methodology and the associated databases for estimating the effects of future earthquakes in Salt Lake County. The performance of the nearly 200,000 residential and commercial buildings in the region was investigated for a given earthquake scenario, a magnitude 7.5 event on the Salt Lake City segment of the Wasatch Fault Zone. The models and analysis assumptions used in the GIS-based damage and loss study are discussed to indicate the limitations and utility of the results. Damage and loss to the building stock in Salt Lake County is summarized by location (i.e. Census tract) and by type of construction. **SLIDE 17** shows a final summary of the analysis results discussed earlier. For the given scenario earthquake, the expected damage to the Salt Lake County building stock due to ground shaking alone is about 28%, resulting in an expected total loss of about 8.5 billion dollars (plus or minus 2.4 billion dollars). The maps and tables showing the breakdown of expected damage and loss by location and construction type provide a useful tool for emergency response planning, seismic retrofit legislation, land use planning, prioritization for seismic upgrade of buildings, and other earthquake hazard mitigation purposes.

REFERENCES

Applied Technology Council (1985). *Earthquake Damage Evaluation Data for California, ATC-13.* Redwood City, California.

Applied Technology Council (in progress). *Earthquake Loss Evaluation Methodology and Databases for Utah, ATC-36.* Redwood City, California.

King, S.A. and A.S. Kiremidjian (1994). "Regional Seismic Hazard and Risk Analysis Through Geographic Information Systems." *The John Blume Earthquake Engineering Center Report No. 111.* Department of Civil Engineering, Stanford University. Stanford, California.

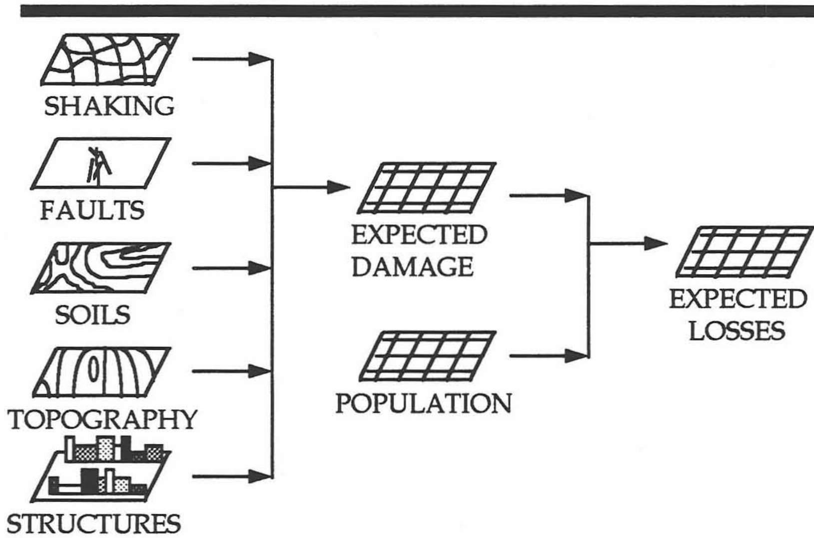
SLIDE 1

ATC-36 PROJECT

- EQ Loss Evaluation Methodology and Databases for Utah
  - *Development of building and lifeline inventory database*
  - *M 7.5 scenario earthquake study (shaking and secondary hazards)*
  - *Losses - repair and replacement cost, loss of business use*
  - *Other effects - lifeline loss of function, casualties, earthquake induced fire*
- Management
  - *Chris Rojahn (PM), Roger Scholl (PD), Bob Wilson (PO)*
- Consultants
  - *UTAH - Lawrence Reaveley*
  - *CALIF - Roger Scholl, Stephanie King, Anne Kiremidjian*
- Advisory Panel
  - *UTAH - Gary Christensen, Fred May, Newland Malmquist, Les Youd*
  - *CALIF - Weimin Dong, Ron Eguchi, Charles Scawthorn, Roland Sharp*

SLIDE 2

GIS MAP OVERLAY PROCESS



SLIDE 3

BUILDING DATA ATTRIBUTES

- Location Information
  - *street address, city, county, state, zip code*
  - *longitude and latitude*
  - *US Census tract*
- Social and Economic Information
  - *facility use*
  - *replacement cost, contents value, sales*
  - *number of occupants*
- Structural Information
  - *construction material*
  - *type of framing system*
  - *year designed*
  - *height, square footage*

SLIDE 4

DATA INFERENCE EXAMPLES

- Longitude and Latitude (Address Matching)

TAX ASSESSOR DATABASE	→	US CENSUS TIGER FILE	→	BUILDING INVENTORY
street address		*street name* *to/from address* *to/from long.* *to/from lat.* *Census tract*		*street address* *longitude* *latitude* *Census tract*

- ATC-36 Earthquake Engineering Class

IF year built < *1961* **AND** exterior wall type = *stucco*
THEN class(1) = *1* **AND** P[class(1)] = *.75*
class(2) = *15* **AND** P[class(2)] = *.25*

SLIDE 5

DATA INFERENCE EXAMPLES

- ATC-36 Social Function Class

  IF year built > *1980* **AND** use code = *500* **AND** material = *light metal*
  THEN SF class = *12*

- Replacement Cost

  IF SF class = *12* **AND** number of stories < *3*
  THEN replacement cost = *$50 / square foot*

- Day and Night Occupancy

  IF SF class = *12*
  THEN day occupants = *5.0 / 1000 square feet*
  night occupants = *0.3 / 1000 square feet*

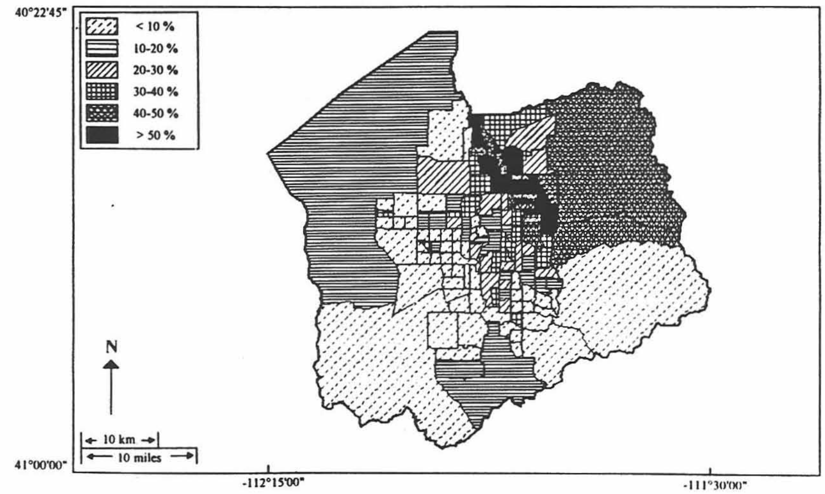
SLIDE 6

BUILDING INVENTORY SUMMARY

TOTAL NUMBER OF BUILDINGS	195,785
RESIDENTIAL BUILDINGS	176,657 (90.2%)
COMMERCIAL BUILDINGS	19,128 (9.8%)
AVERAGE DESIGN DATE	1960
TOTAL SQUARE FOOTAGE	593,088,274
AVERAGE REPLACEMENT COST (1993 $)	160,466
TOTAL REPLACEMENT COST (1993 $)	31,416,939,684
WOOD FRAME CONSTRUCTION	111,732 (57.1%)
UNREINFORCED MASONRY CONSTRUCTION	52,519 (26.8%)
STEEL CONSTRUCTION	555 (0.27%)
CONCRETE CONSTRUCTION	156 (0.08%)
OTHER/MIXED CONSTRUCTION	30,823 (15.7%)

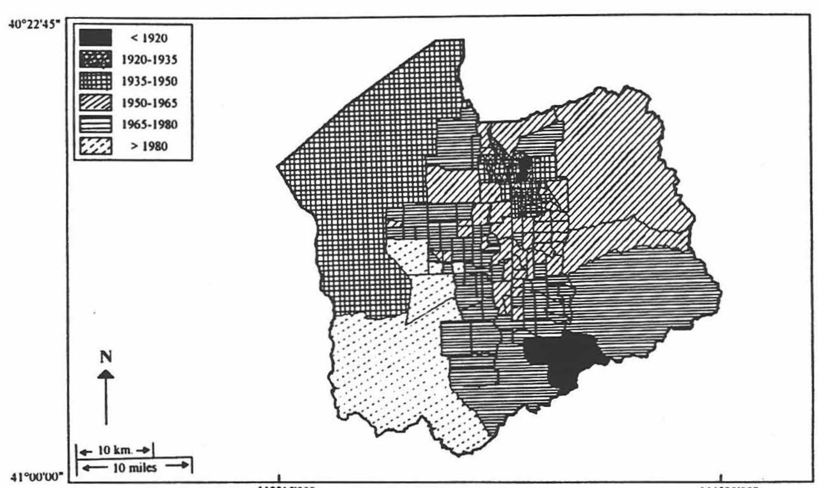
% UNREINFORCED MASONRY BUILDINGS IN SALT LAKE COUNTY

SLIDE 7



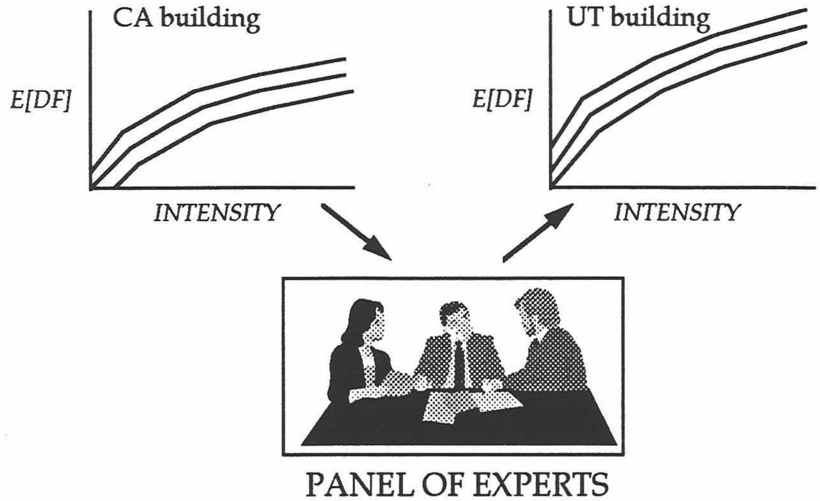
AVERAGE DESIGN DATE OF BUILDINGS IN SALT LAKE COUNTY

SLIDE 8



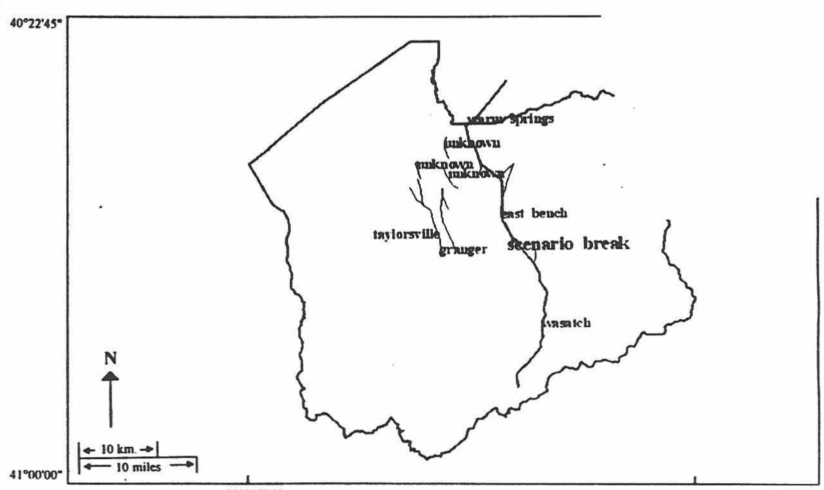
DEVELOPMENT OF EXPECTED DAMAGE FACTOR CURVES

SLIDE 9



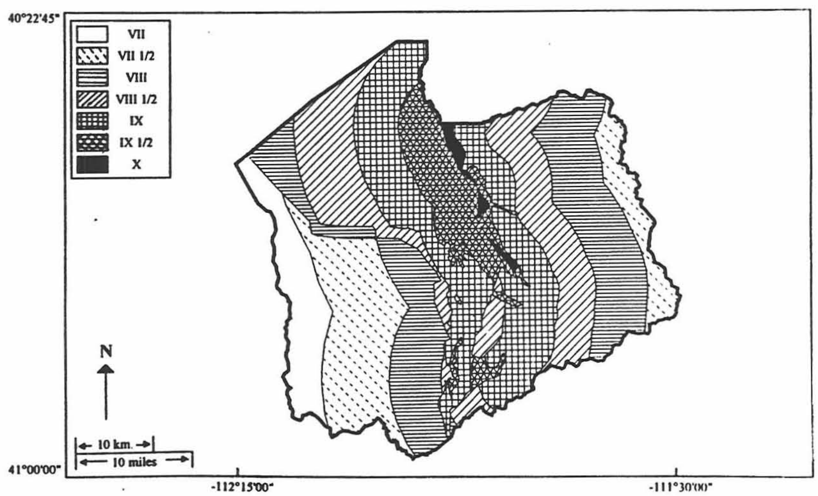
APPROXIMATE LOCATIONS OF FAULTS IN SALT LAKE COUNTY

SLIDE 10



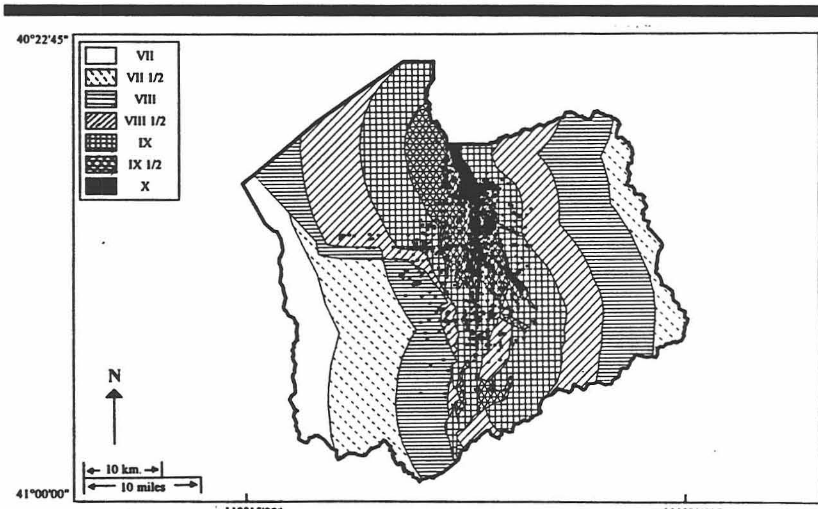
ESTIMATED GROUND SHAKING INTENSITY IN SALT LAKE COUNTY

SLIDE 11



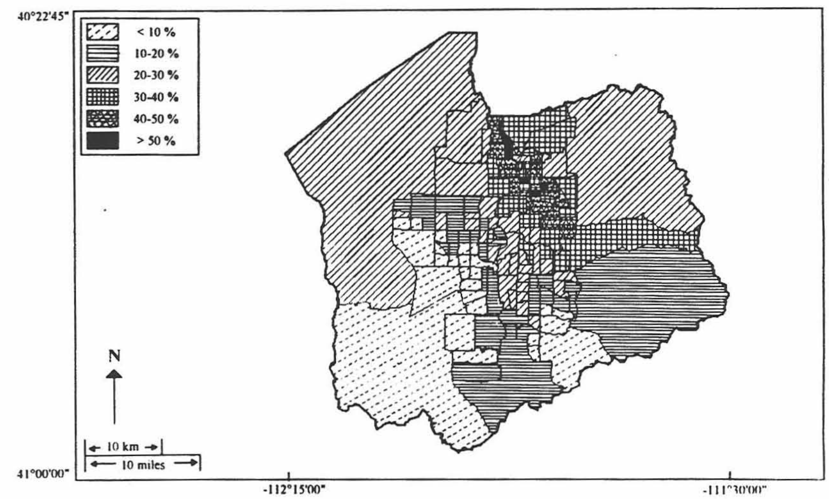
EXAMPLE GIS OVERLAY OF BUILDINGS

SLIDE 12



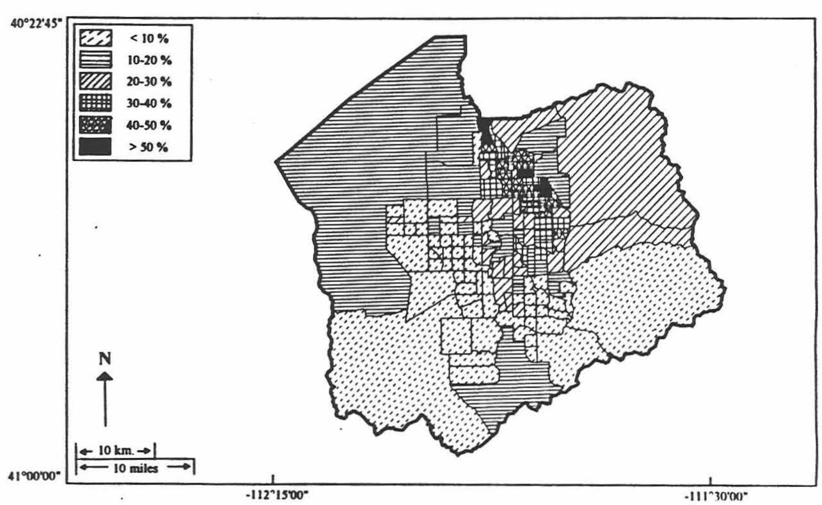
AVERAGE EXPECTED DAMAGE FACTOR FOR BUILDINGS

SLIDE 13



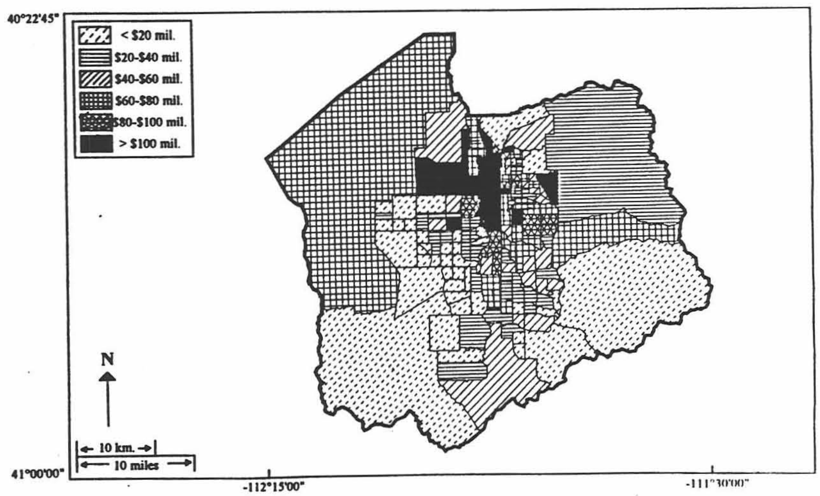
% OF BUILDINGS WITH EXPECTED DAMAGE FACTOR > 60%

SLIDE 14



TOTAL EXPECTED LOSS BY CENSUS TRACT (1993 $)

SLIDE 15



SUMMARY OF BUILDING PERFORMANCE BY MATERIAL

SLIDE 16

	Wood Frame Construction Buildings	URM Construction Buildings	Steel Construction Buildings	Concrete Construction Buildings	Other/Mixed Construction Buildings
Total number of buildings	111,732	52,519	555	156	30,823
Average replacement cost (1993 $)	111,849	140,690	933,727	3,828,976	346,315
Total replacement cost (1993 $)	12,497,119,279	7,388,896,656	518,218,820	597,320,254	10,674,462,124
Average E[DF] (%)	11.19	56.42	12.34	24.77	25.63
Average SD[DF] (%)	4.97	11.61	4.33	7.66	8.22
Average E[loss] (1993 $)	12,514	79,383	115,252	948,286	88,774
Average SD[loss] (1993 $)	5,555	16,339	40,438	293,220	28,471
Total E[loss] (1993 $)	1,398,207,580	4,169,106,764	63,964,785	147,932,626	2,736,266,350
Total SD[loss] (1993 $)	620,681,177	858,119,685	22,443,298	45,742,386	877,566,153

SLIDE 17

SUMMARY OF ANALYSIS

- Building Inventory
  - *200,000 buildings, $31.4 billion value*
  - *50% wood frame, 25% unreinforced masonry*
- Scenario Event
  - *Magnitude 7.5 on Wasatch Fault Zone*
  - *Ground shaking only (no secondary effects)*
- Building Performance
  - *Wood Frame: E[DF] = 11.19%, E[loss] = $1.40 billion*
  - *Unreinforced Masonry: E[DF] = 56.42%, E[loss] = $4.17 billion*
- Building Performance (all materials)
  - *Average E[DF] = 27.27%, SD[DF] = 7.45%*
  - *Total E[loss] = $8.52 billion, SD[loss] = $2.42 billion*
  - *Average E[loss] = $43,493, SD[loss] = $12,384*

5.

Typical Nonstructural Earthquake Loss Patterns

by

Robert Reitherman

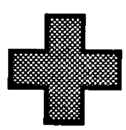
Bob Reitherman has conducted consulting and research projects on the architectural aspects of earthquakes, and in particular has written about and studied the problem of nonstructural earthquake damage. He has recently helped coordinate EERI's efforts to collect and publish information on the 1994 Northridge Earthquake. He conducts his consulting work through the Reitherman Company in Half Moon Bay, in the San Francisco Bay area, and is project manager of a Northridge Earthquake Research Coordination Project for California Universities for Research in Earthquake Engineering at the Earthquake Engineering Research Center in Richmond (also in the San Francisco area).

Typical Nonstructural Earthquake Loss Patterns

Bob Reitherman

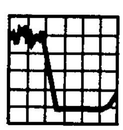
The nonstructural features of a building (ceilings, computers, air conditioning, elevators, etc.) have typical patterns of damage depending upon their precise characteristics, as well as the nature of the earthquake and the structure of the building. The January 17, 1994 Northridge or Los Angeles earthquake provided a "full-scale test" of a large urban region--the region of the United States where earthquake codes have been adopted and enforced for the longest period of time. Even with this relatively high level of earthquake resistance, the resulting nonstructural damage was extensive. Comparisons with possible future Salt Lake City earthquake losses must involve adjustments for differences in the earthquake: Salt Lake City "on average" will experience less severe ground shaking, but there is also the geologically credible very large Wasatch Fault earthquake that could cause even more severe or longer-duration shaking. The other basic correction involves the degree of earthquake resistance of nonstructural features, and while selected recently built buildings in Utah have incorporated high levels of protection for data processing or other vital nonstructural features, on average the typical Salt Lake City building has less nonstructural protection than its Los Angeles counterpart.

The basic issue concerning nonstructural earthquake protection in the Salt Lake City, in the context of lessons from the Northridge earthquake, thus simpifies to: How much risk are you (or your organization) willing to accept, compared to the sometimes significant costs of reducing those risks?



SAFETY

PROPERTY

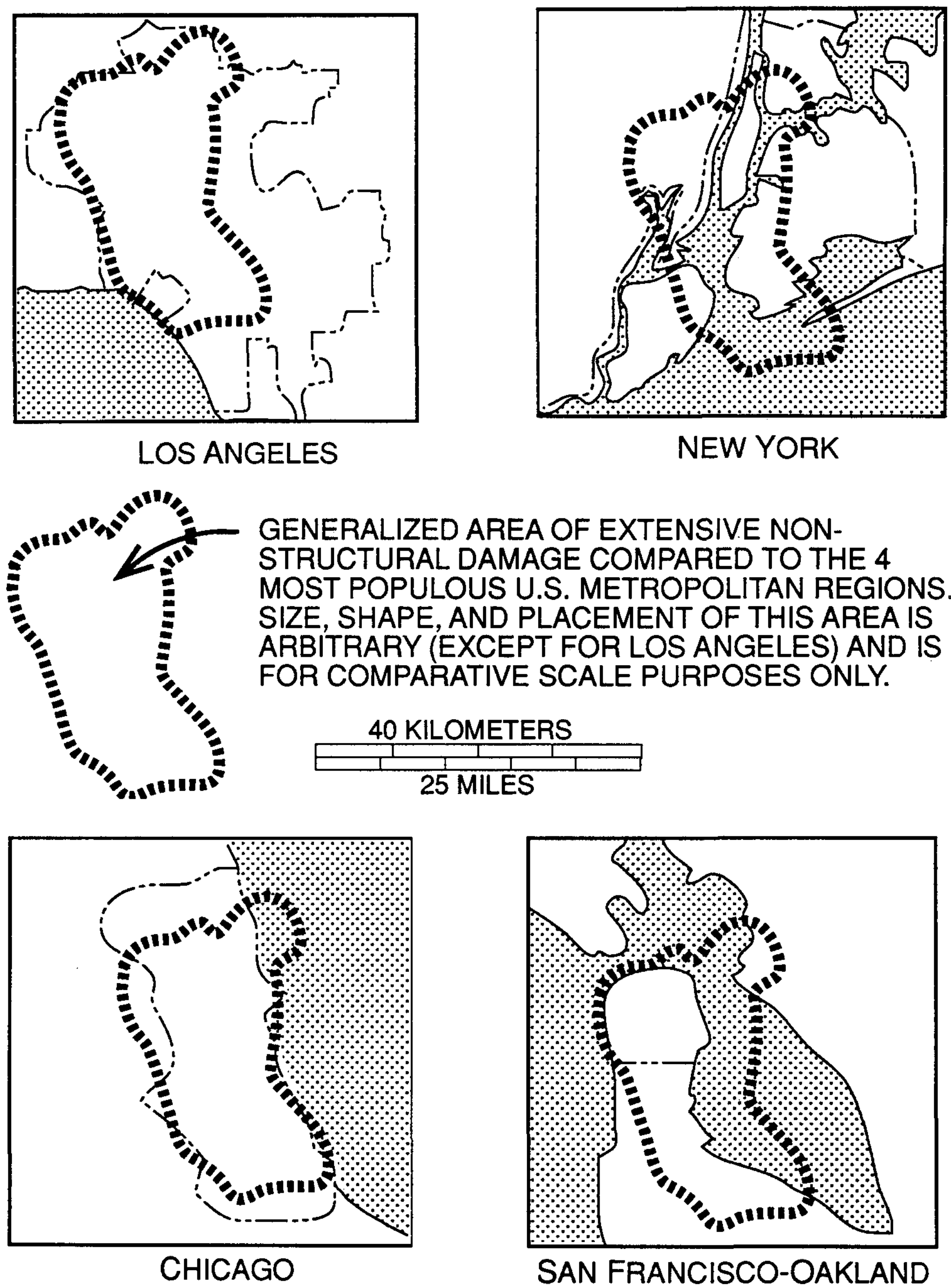


FUNCTION

Intelligently reducing risks to safety, property, and essential functions is reasonable and advisable; eliminating risk by preventing 100% of all possible damage isn't.

Even in areas of California where the probability of strong ground shaking is higher than in the Salt Lake City area, no organization anchors everything or protects every nonstructural feature up to the best available state-of-the-art, regardless of cost.

Examples of damage from the recent Northridge earthquake help illustrate how these three distinct kinds of risk must be considered to decide which potential problems are small enough, or improbable enough, to disregard, and which are important enough to do something about.



(source: forthcoming EERI *Spectra* Northridge Earthquake report)

Damage to Types of Nonstructural Components

Architectural
Mechanical
Electrical
Contents, Misc. Equip.

Mechanical

sprinkler & other water lines
HVAC equipment
elevators

Electrical

transformers, switchgear
outage vs. damage

Architectural

ceilings & soffits
glass
shelving
veneer
roof tiles

Contents, Misc. Equipment

computers
museums
hazardous materials

6.

Regional Economic Impact of a Wasatch Front Earthquake

by

Harold Cochrane

Hal Cochrane -- Professor of Economics and
Director of the Hazards Assessment Laboratory

Hal Cochrane received his B.S. in Industrial Engineering from Penn State and his Ph.D. in Economics from the University of Colorado. He is currently Director of the Hazards Assessment Laboratory, a university center for the study of the economic consequences of catastrophic geophysical events. Dr. Cochrane is the author of numerous articles and research reports on subjects including: the economics of unreinforced masonry buildings, the impact of earthquakes and risk information on housing markets, loss accounting principles for performing damage assessments, the economic consequences of earthquake predictions, the economic consequences of limited nuclear war, optimal strategies for coping with dam failure, option value in the context of global warming, and the impact of catastrophic events on the growth path of developing countries. Dr. Cochrane is currently directing three projects: 1) an assessment of how banks and financial markets would be impacted by a catastrophic earthquake; 2) an assessment of insurance markets in the wake of several catastrophic events; 3) the development of an expert system for determining the magnitude of regional economic dislocations stemming from highly destructive geophysical events. He has served on a number of National Research Council panels and has been called on to assess losses from high profile events such as the Exxon Valdez oil spill.

Regional Economic Impact of a Utah Earthquake

Hal Cochrane
Professor of Economics
and
Director of
the Hazards Assessment Lab
Colorado State University

Introduction

There are numerous potential economic repercussions stemming from a major Wasatch Fault earthquake. Economic dislocations could spell a sharp rise in unemployment. Taxable sales might suffer, thereby undercutting local governments' ability to provide post disaster services. Housing markets might deteriorate producing a wave of financial dislocations and bank failures. Local price increases might result. This, of course, is too lengthy a list of topics to cover in a short seminar, but I will provide a brief summary of what is known about each.

Financial Repercussions

Direct and indirect losses are borne in part by the homeowners, workers, corporate shareholders, bond holders, factory owners, banks, and the general taxpayer. The value of stocks and bonds should decline as a result of the disaster by at least the amount of damages sustained. Smaller banks and insurance companies may be forced into bankruptcy. What is at stake in each instance is the distribution of losses, not their magnitude. The magnitude is determined by simply summing the direct and indirect damages. This leads to an important consideration -- **financial damages are a mirror image of the real losses and as a result it would be incorrect to count them as part of the total.** Financial losses do become relevant, however, when and if bank and insurance company failures produce a reverse ripple effect triggering a second wave of economic dislocations. It would be proper to account for these as a separate and additive disaster cost. The following are some relevant observations.

1. It is highly unlikely that national interest rates would rise as a result of a catastrophic earthquake. The existence of national capital markets permit the free flow of funds. Investment opportunities in the effected region that remain profitable would be financed by external sources. The magnitude of the financial crisis, although possibly staggering from the effected region's vantage point would prove to be relatively small when scaled against the national stock of financial assets.

2. On a regional level, however, interest rate changes might slow recovery and future growth. The sudden loss of a region's capital base would produce two effects. First, the shock would increase the area's indebtedness relative to its ability to repay. Put simply, the effected region's creditworthiness would suffer. As a result, it would be forced to pay higher interest on new loans (aside from those backed by federal guarantees). These higher rates would slow the pace of rebuilding and reduce the rate of capital accumulation, thereby ratcheting the economic growth path downward. An accurate accounting of losses should include both direct damages to the capital stock plus secondary employment losses, plus a percentage of the **shadow costs** stemming from additional indebtedness.

3. So called "credit crunches" which appear after disaster are really "profits crunches". The limited availability of credit in a depressed economy reflects limited investment opportunities. There is little evidence to support the contention that financial losses produce additional real losses for the economy.

4. It has been argued that a catastrophic earthquake would force insurance companies to liquidate $30 to $50 billion in municipal bonds thereby depressing bond prices and raising interest rates. It is claimed that this would make it more costly for municipalities trying to raise funds and thereby delay the completion of planned public projects. The insurance industry may well incur capital losses. However, they are likely to be marginal at best. Municipal bond yields rise and fall with the Treasury Bill rate and the anticipated tax advantages municipals offer. Destabilizing events such as New York's fiscal crisis (June 1975 to December 1976) had no impact on this market.

Possible Regional Economic Consequences a Major Wasatch Fault Earthquake for Salt Lake County

The regional economic consequences of a major Wasatch earthquake has been modeled using a newly developed procedure for rebalancing post disaster interindustry trade flows. The procedure is based on a transactions matrix which is a double-entry accounting device to keep track of how an economy operates. One important fact about this device is that it must "balance." This means that the sum of any industry's inputs must equal its output. An earthquake disturbs this balance such that firms may no longer be able to acquire adequate supplies and/or may lose the market for their product. Table 1 provides a brief description of how the procedure works.

A variety of scenarios (differing in terms of damage patterns and amount of reconstruction) were explored to clarify how the Salt Lake economy would be impacted by a major Wasatch earthquake. Two loss patterns were assumed. 1) all economic sectors lose 10 percent of their capacity (e.g., one in ten structures is rendered uninhabitable). 2) 10 percent of manufacturing capacity is lost while all other sectors are unaffected. Roughly $5 billion in direct dollar damages would result from the first scenario. This is almost 10 times (when scaled for the size of the Salt Lake economy) the loss sustained in Northridge. The first column in Table 2 shows the economic ramifications of such an event. Since all sectors shrink proportionately, the economy is not unbalanced and income losses are approximately 10 percent. Total losses shrink slightly when the rebuilding occurs. However, supply constraints still limit the extent to which the economy can expand.

A highly concentrated shock yields the most interesting scenario. Column 3 shows the impact of 10 percent loss of manufacturing facilities (roughly $750 million). This produces severe bottlenecks, resulting in almost $790 million in indirect loss. In this instance the cost of economic bottlenecks is at least as great as the direct damage. The reason is simple -- the high concentration of damage is highly destabilizing. Shortages and surpluses ripple through the region, causing shutdowns in plants not directly damaged by the earthquake. The effect of rebuilding is just as interesting. Column 4 shows that these indirect losses can be eliminated through reconstruction spending. In this scenario the $790 million in indirect losses turn into $286 million in indirect **gains**. Spending on rebuilding can produce a short term boom, providing no other constraints prevent idled capacity from being utilized during the reconstruction period. What is not shown in Table 2 is a potential negative effect on future spending if rebuilding is financed through new debt or savings.

Table 1
Procedure for Deriving Estimates
of Regional Economic Consequences

1) A set of direct losses are imposed on the system. This causes the transactions table to be unbalanced, since some industries are either no longer able to supply as much as other industries require, or are producing more than other industries can purchase.

2) Alternative outlets for excess production are explored. These include:

- Other industries in the local economy;
- Finished goods inventories;
- Exports;
- Consumer demand not met by other firms in the industry;
- Reconstruction demand.

3) Alternative sources for lost supplies are explored. These include:

- Supply inventories;
- Imports;
- Increased production by unaffected firms in the industry.
- Supplies made available by reduced production in directly affected firms.

4) If some firms are still unable to find outlets for their output, they must reduce production accordingly. These impacts are referred to as forwardly linked losses.

5) If some firms are still unable to acquire supplies they require to continue producing, they must reduce production accordingly. These impacts are referred to as backwardly linked losses.

6) If some firms have the capacity to increase production, and the reconstruction process can utilize some of their output, they will increase production accordingly. These impacts are referred to as reconstruction gains.

7) Steps 3 through 6 are repeated until the system reaches a reasonably stable equilibrium (supplies equal demands).

Table 2

Regional Losses
Due to a Wasatch Front Earthquake

SALT LAKE COUNTY				
	IMPACT OF HAZARD EVENT			
LOSS	10% LOSS ALL SECTORS UNEMPLY=0% NO REBUILDING	10% LOSS ALL SECTORS UNEMPLY=5% REBUILDING	10% MFG LOSS UNEMPLY=0% NO REBUILDING	10% MFG LOSS UMEMPLY=5% REBUILDING
%TOTAL LOSS	9.878%	9.309%	9.964%	+1.170%
%DIRECT LOSS	9.173%	9.173%	1.790%	1.780%
%INDIRECT LOSS	0.706%	0.136%	8.174%	+2.961%
$TOTAL LOSS	$955,232,000	$908,128,000	$963,548,000	+$113,279,700
$DIRECT LOSS	$887,021,000	$894,860,688	$173,069,000	$173,066,400
$INDIRECT LOSS	$68,233,000	$13,267,312	$790,420,000	+$286,346,500

Evidence of Regional Economic Consequences: Hurricanes Hugo and Andrew, and the Loma Prieta Earthquake

Taxable sales (deseasonalized) provide an indication of how disaster stricken economies have been impacted by past natural disasters. As can be observed in Figures 1 through 7, in some instances the stimulus from rebuilding tends to dominate the effects of economic dislocation. This is evident in Charleston and in Dade counties (Hurricanes Hugo and Andrew respectively). In others, the post disaster economy seems to be unaffected or suffers a decline. This appears to be the case in San Francisco, Oakland and Santa Cruz. It is interesting to note that whatever Santa Cruz lost in taxable sales, Capatola, a neighboring community undamaged by the earthquake, gained.

Despite press coverage about instances of price gouging after disaster, abnormal price increases do not appear to be a problem. To use Hurricane Andrew as an example, the post disaster Consumer Price indices (Bureau of Labor Statistics) for Miami-Fort Lauderdale and Florida as a whole are virtually identical.

Impact of Earthquake Risk/damage on Housing Markets

I will now turn attention to two studies which assessed the extent to which housing markets responded to risk information (either in the form of maps, regulations or the occurrence of an earthquake).

Single family residential study. Nearly one million real estate transactions were obtained and analyzed to determine whether earthquake risk altered the market for single family residential structures. Care was taken to normalize for housing characteristics, pollution, nearness to transportation, income, racial mix, among other factors.

Findings

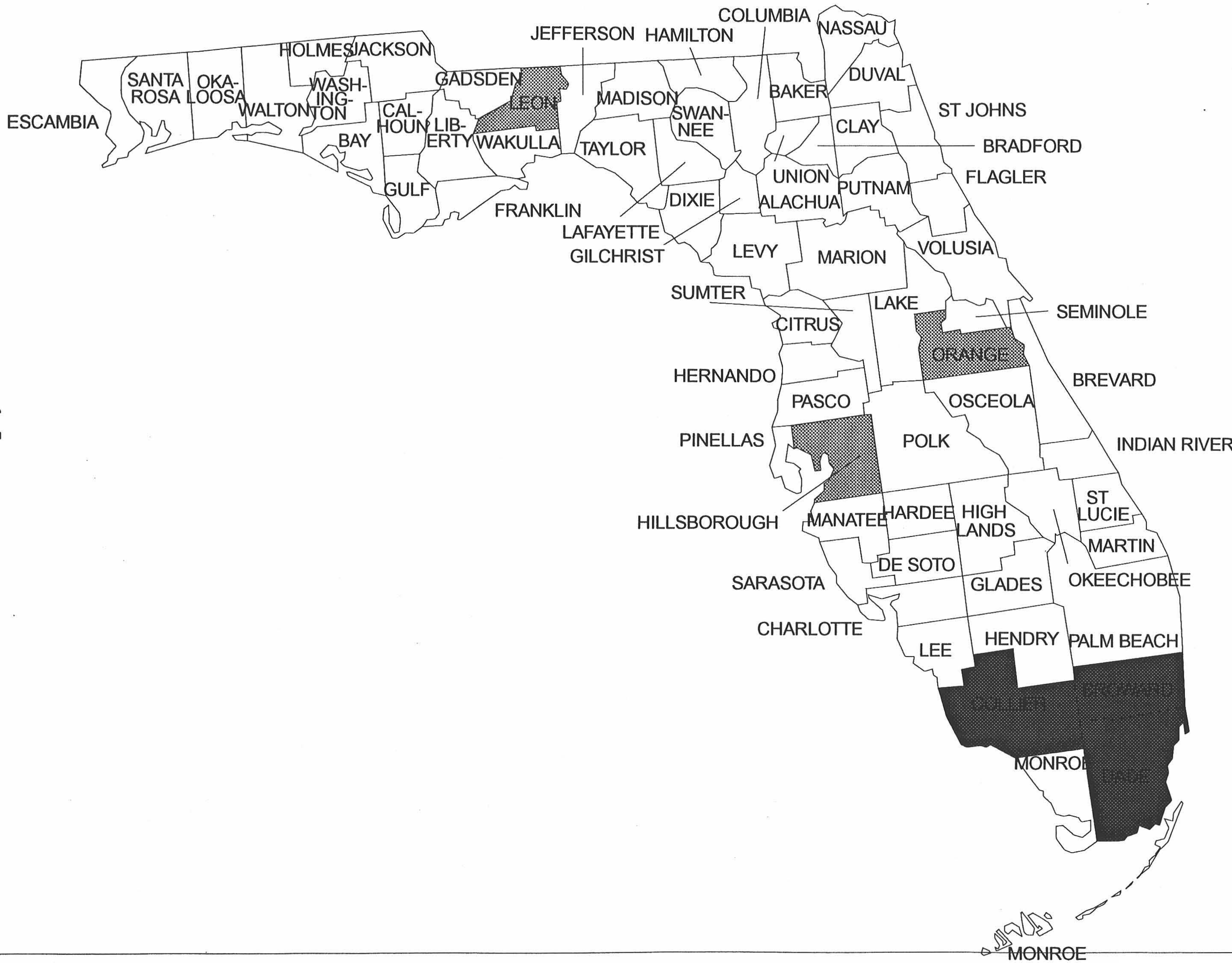
1. The sales price of properties located in special study zones is **no different** than for properties located outside these zones. This conclusion held regardless of year (1977 to 1990) or location (Los Angeles, Alameda County).
2. Proximity to damage in San Francisco's Marina district (Loma Prieta, 1989) did not influence property values.

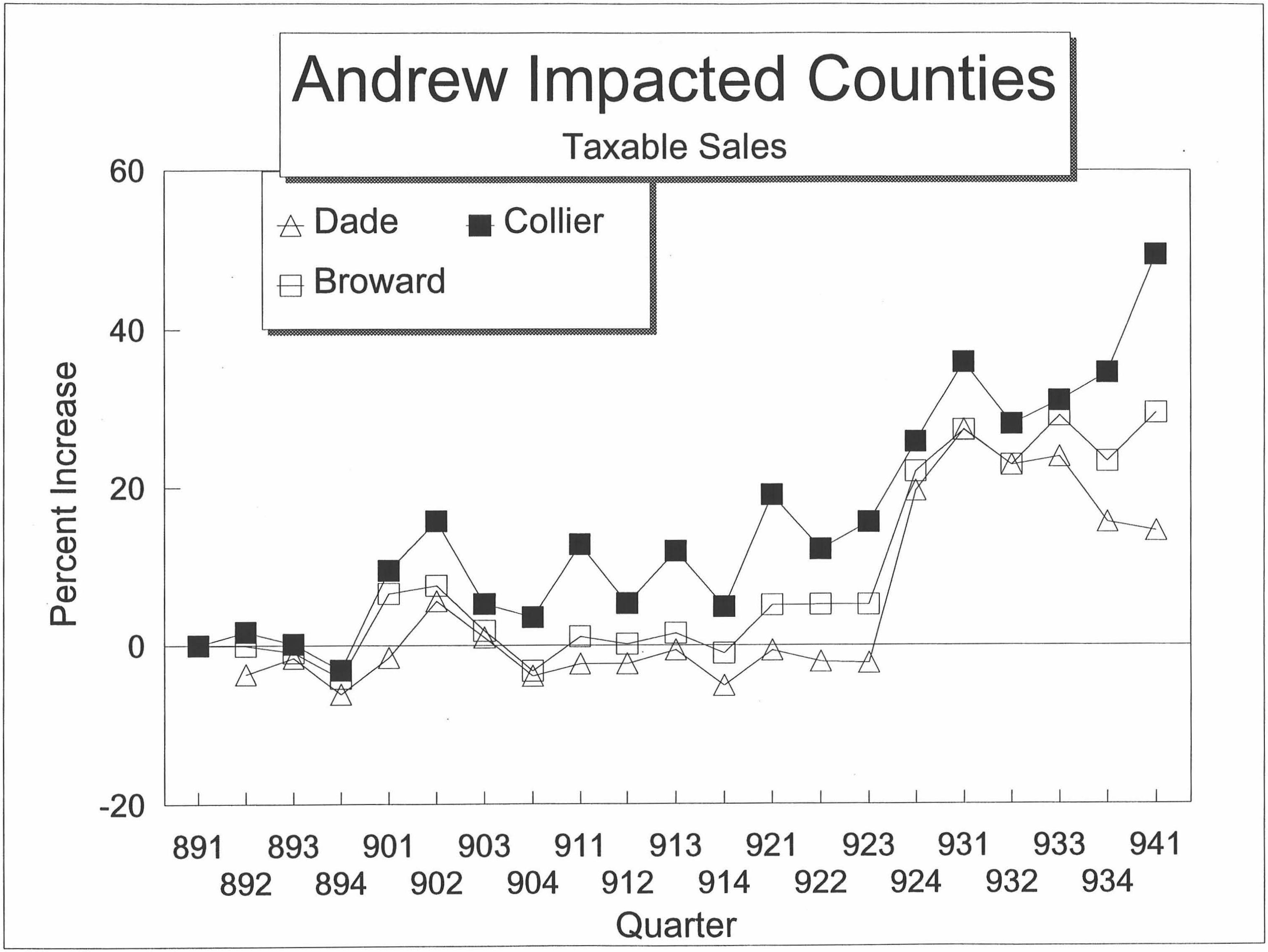
URM study. A simple investment model was constructed to show how a typical building owner (or prospective owner) would react to the City of Los Angeles' procedure for notifying and mandating the seismic upgrading of the city's 6,633 URMs. Information on each building (when notified, complied, or vacated), obtained from the Department of Building and Safety, was analyzed to derive a decision tree. The data were then merged with sales information to assess whether notification and compliance altered the price of a typical URM. Additional tests were conducted to determine whether the market for rent controlled apartment buildings responded differently than that for uncontrolled commercial and industrial buildings.

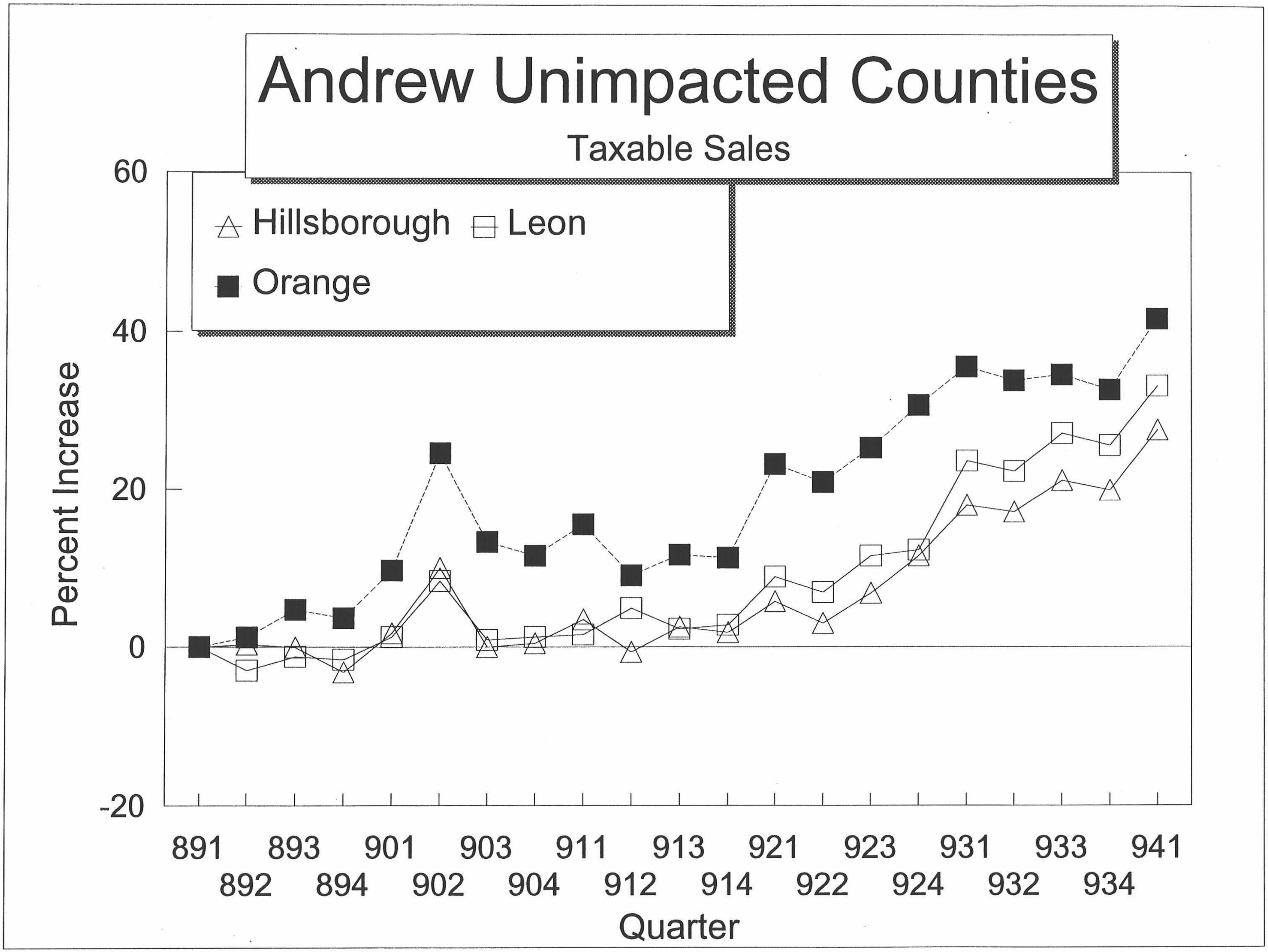
Findings

1. Identifying URMs **did not** detract from their marketability, particularly for those buildings that sold shortly after notification and long before compliance. A retrofitted building sold for a premium.

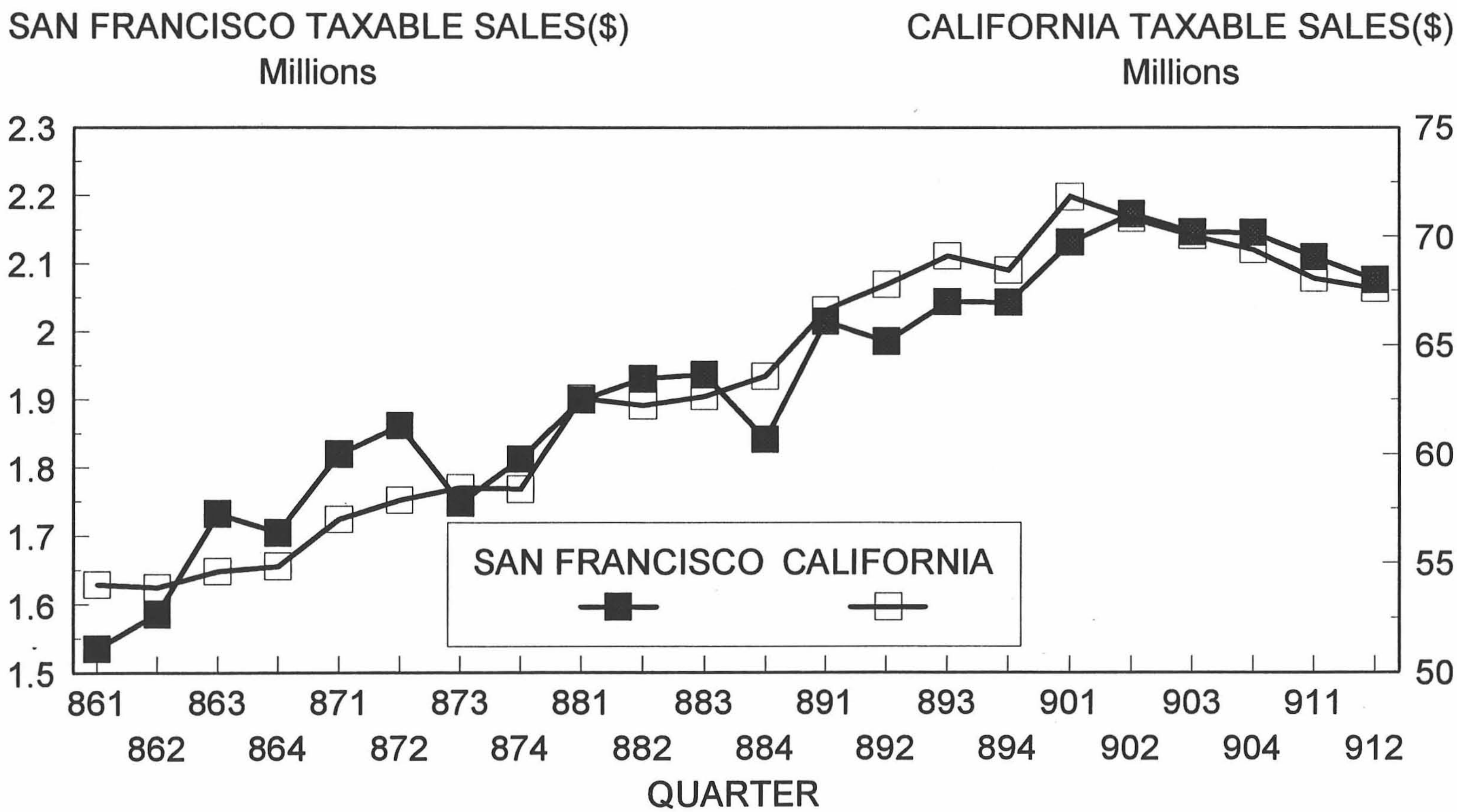
Counties Analyzed



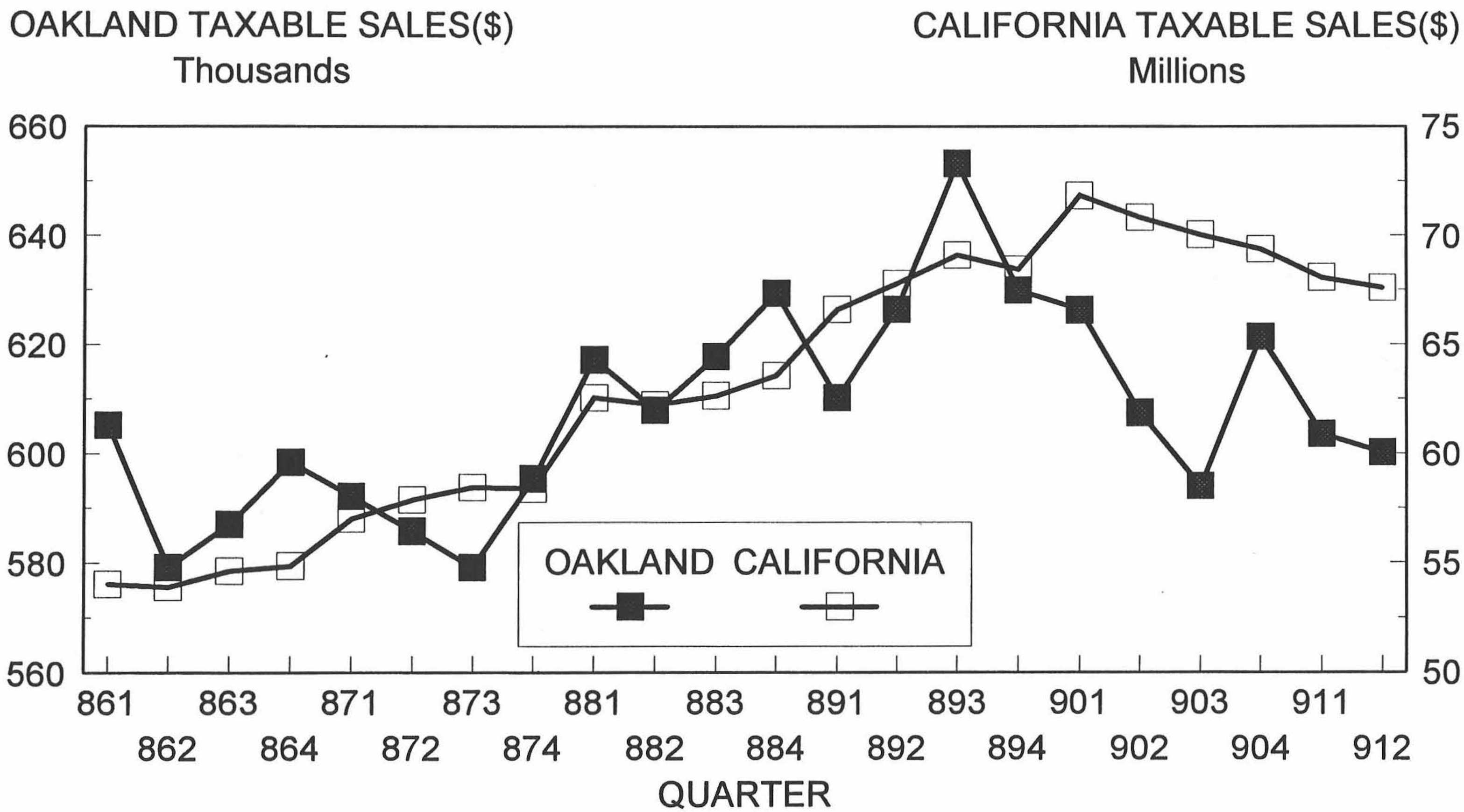

Andrew Impacted Counties
Taxable Sales
Dade
Collier
Broward
60
40
20
0
-20
Percent Increase
891
892
893
894
901
902
903
904
911
912
913
914
921
922
923
924
931
932
933
934
941
Quarter


Andrew Unimpacted Counties
Taxable Sales
Hillsborough
Leon
Orange
Percent Increase
60
40
20
0
-20
891
892
893
894
901
902
903
904
911
912
913
914
921
922
923
924
931
932
933
934
941
Quarter

TAXABLE SALES IN SAN FRANCISCO

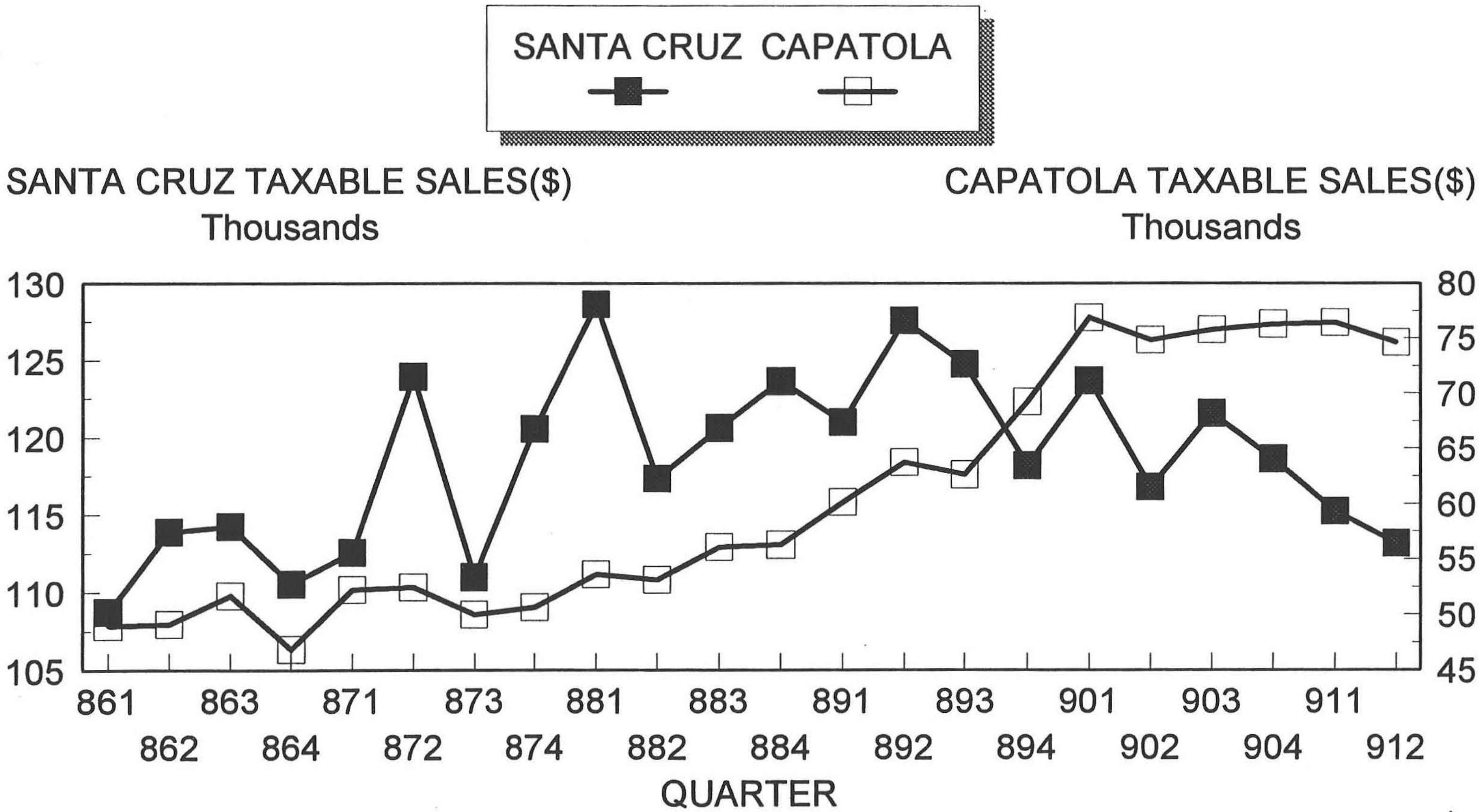


OAKLAND TAXABLE SALES

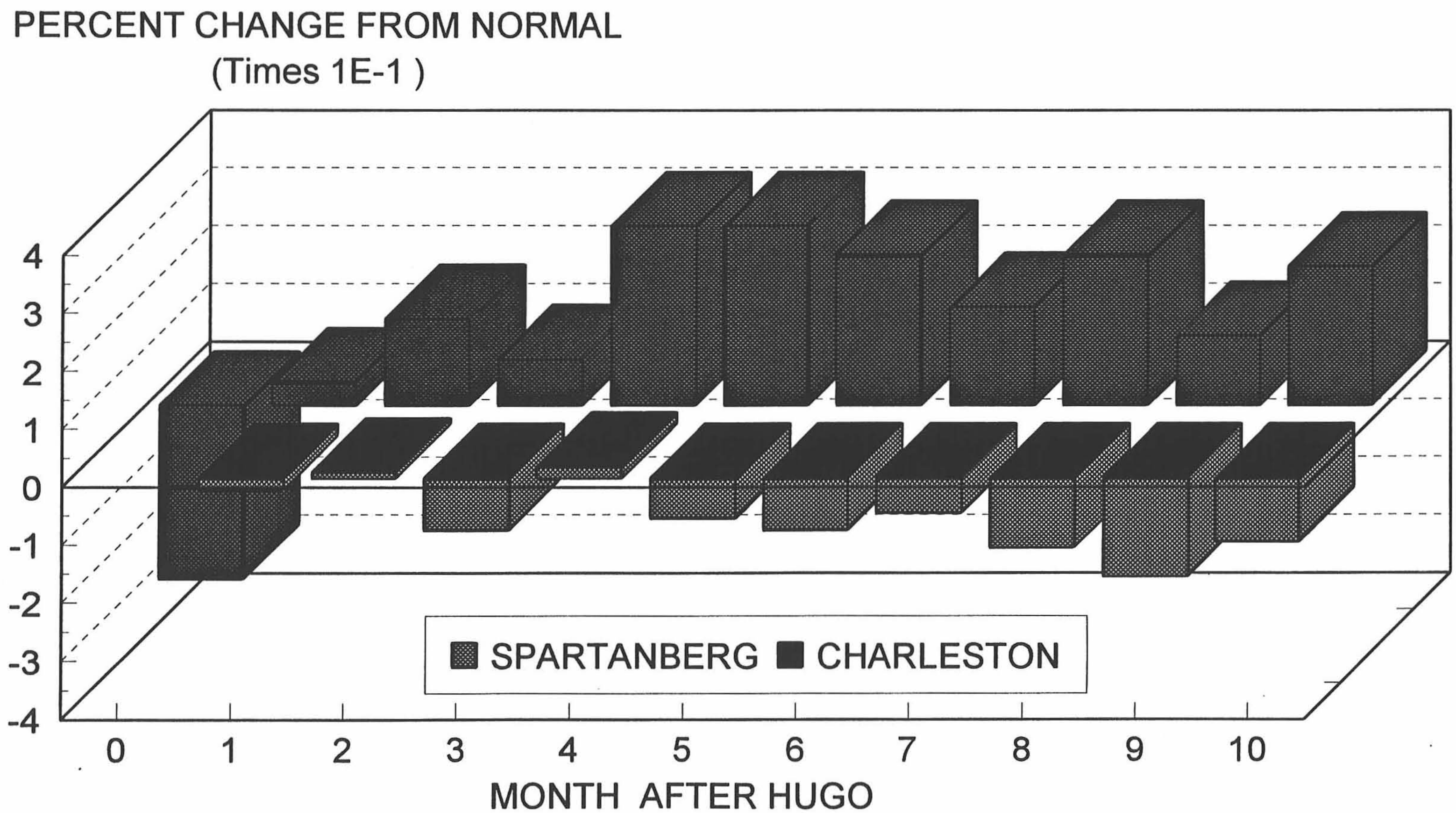


6-11

SANTA CRUZ AND CAPATOLA



PERCENT CHANGE IN NORMAL TAXABLE SALES



7.

Retrofit Cost Effectiveness

by

William Holmes

William T. Holmes

William Holmes is Vice President of Rutherford & Chekene, a consulting engineering firm in San Francisco. He has 29 years experience in the design of new buildings and seismic retrofit of existing structures.

Mr. Holmes is a Registered Structural Engineer in California and other states. He is a past president of the Structural Engineers Association of Northern California and the Applied Technology Council, and a past vice-president and Board member of the Earthquake Engineering Research Institute. He is currently Chair of the California Hospital Building Safety Board.

Mr. Holmes served as the Co-Team Leader for Buildings for EERI's Reconnaissance of the Northridge earthquake of January 17, 1994. He is the Buildings Consultant to California's Seismic Safety Commission for their *Report to the Governor* on the Northridge earthquake.

COST EFFECTIVENESS OF SEISMIC RETROFIT

William T. Holmes
Vice President
Rutherford & Chekene
San Francisco, Ca.

INTRODUCTION

It is generally conceded that the largest seismic risk in this country is created by the enormous existing stock of buildings built without provision for seismic loads. Although the risk to life safety has historically commanded the most attention, the Loma Prieta and Northridge earthquakes have shown that the economic losses from direct damage and resulting business interruption must also be considered.

Reduction of this risk can be accomplished by minimizing important occupancies in seismically poor buildings, by outright replacement, or by seismic retrofit. Seismic retrofit is accomplished by physical modification of the structural and nonstructural systems in buildings that are vulnerable to damage.

The retrofit process can be piecemeal or comprehensive and often is done in conjunction with nonseismic improvements. In general, there are no standard techniques or criteria for retrofit, including terminology. The retrofit process is sometimes called seismic strengthening, seismic upgrade, or seismic rehabilitation. The federal government has adopted the term *rehabilitation* and would discourage use of other terms. The term *retrofit* has been adopted at this seminar.

Structural retrofit consists of modifications (usually additions) to the existing structural system (beams, columns, walls, etc.) primarily to reduce the possibility of overall collapse or of dangerous wall collapses onto the street; structural retrofit can also be done with the intent of controlling structural damage to a point it is economically repairable or so the building remains safe to occupy. *Nonstructural retrofit* consists of replacement or strengthening of ceilings, light fixtures, mechanical and electrical systems, etc. either to minimize the hazard to occupants, or to control economic damage.

It is becoming increasingly common, for both retrofit and the design of new buildings, to designate a seismic *performance objective* for each project. A performance objective specifies a desired seismic performance level for a given earthquake of level of shaking. Although it is not possible to guarantee a given performance for a building, there will be an obvious difference between the performance of a building designed with the intention of only providing life safety and one designed with the intent of allowing immediate occupancy after an earthquake. Performance objectives have begun to become standardized into the following categories:

- *Spot Hazard Reduction*: A range of risk reduction without overall consideration of all characteristics of the building or without setting a standard goal as described below. Elimination of parapet falling hazards is a common example. This performance level is also known as *limited safety*.

- *Collapse Prevention:* Prevention of global collapse of the structure. Concentration is placed on the stability of the primary structure rather than protection of occupants from falling hazards or ensuring immediate egress.

- *Standard Safety:* Formally commonly known as life-safety. A level of safety for occupants and passersby that is considered generally "acceptable" considering all risks from seismic damage. This is normally associated with an earthquake expected to occur, on average, every 500 years. This level is not currently formally defined, but is often thought of as being similar to the safety provided by new buildings, but allowing more damage.

- *Damage Control:* A range of performance that includes Standard Safety but also considers control of damage for purposes other than life safety, primarily economic.

- *Immediate Occupancy:* A level of performance intended to limit damage to the extent that the building could be occupied immediately after the earthquake. All facilities needed to <u>function,</u> such as provision of power, water, communication, or functionality of specialty equipment are not included in this level of performance because many of these systems are independent of the performance of the individual building. However, if full functionality is desired, the necessary systems can be considered as an add-on to this level.

COSTS AND BENEFITS

The cost effectiveness of seismic retrofit can refer to the answer to a layperson's informal question, "Is it worth it?" or to the results of a formal benefit/cost analysis. The term *cost effective* is used in the Stafford Act, which governs FEMA's post earthquake emergency assistance activity and therefore has a significant formal meaning in that context. Whether formal or informal, the costs and benefits of seismic retrofit must be understood to determine its effectiveness.

Costs and benefits of seismic retrofit can generally be categorized as follows:

<u>COSTS</u>	<u>BENEFITS</u>
Construction Costs	Lives/injuries saved
Lost Business/Rentals during construction	Reduction of direct damage
Permanent loss of building efficiency	Reduction of business interruption
	Increase in value of building (or salvage)

Cumulative effect on local economy

Construction Costs

- Unreinforced masonry: $5-20/sf
- Tilt-ups: $2-4/ sf
- Other: Varies widely. Recent FEMA publication uses 2000 data points to estimate typical structural costs. See attached tables. Note large expected variation due to unique characteristics of each building.

TABLE 1.6.1 TYPICAL STRUCTURAL COSTS FOR VERY HIGH SEISMICITY AND LIFE SAFETY ($/sq. ft.)

BUILDING GROUP	MODEL	FEMA BUILDING TYPES	AREA			
			SMALL	MEDIUM	LARGE	V-LARGE
1	URM	Unreinforced Masonry	18.22	18.04	17.14	14.43
2	W1 W2	Wood Light Frame Wood (Commercial or Industrial)	14.07	14.79	18.56	23.78
3	PCI RM1	Precast Concrete Tilt Up Walls Reinforced Masonry with Metal or Wood Diaphragm	18.69	17.70	15.52	9.43
4	C1 C3	Concrete Moment Frame Concrete Frame with Infill Walls	25.75	25.04	23.86	19.84
5	S1	Steel Moment Frame	25.82	25.37	24.26	18.47
6	S2 S3	Steel Braced Frame Steel Light Frame	10.07	9.56	7.68	4.35
7	S5	Steel Frame with Infill Walls	29.47	29.18	28.05	24.65
8	C2 PC2 RM2 S4	Concrete Shear Wall Precast Concrete Frame with Concrete Shear Walls Reinforced Masonry with Precast Concrete Diaphragm Steel Frame with Concrete Walls	22.67	22.06	20.83	16.95

TABLE 4.3.7 CONFIDENCE LIMITS FOR OPTION 1 COST ESTIMATES

NUMBER OF BUILDINGS	CONFIDENCE LIMITS					
	90%		75%		50%	
	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}
1	0.18	5.57	0.27	3.69	0.40	2.48
2	0.38	2.63	0.51	1.97	0.67	1.49
5	0.54	1.84	0.65	1.53	0.78	1.29
10	0.64	1.54	0.73	1.35	0.84	1.19
50	0.82	1.21	0.87	1.15	0.92	1.08
100	0.87	1.15	0.90	1.10	0.95	1.06
500	0.94	1.06	0.96	1.04	0.96	1.03
1000	0.96	1.04	0.97	1.03	0.98	1.02

Notes:

1. Costs in 1993 dollars. Construction in state of Missouri.
2. Very high seismicity roughly equivilent to UBC zones 3 and 4: high similar to zone 2B.
3. C_{CRL} and C_{DRU} of Table 4.3.7 can be multiplied times typical costs to determine the range of probable costs based on the database used for analysis.

Source: *Typical Costs of Seismic Rehabilitation of Buildings, Volume 1 (Prepublication Edition, July, 1994)*, Hart Consultant Group, FEMA, Wash. DC.

TABLE 1.6.2 TYPICAL STRUCTURAL COSTS FOR HIGH SEISMICITY AND LIFE SAFETY ($/sq. ft.)

BUILDING GROUP	MODEL	FEMA BUILDING TYPES	AREA			
			SMALL	MEDIUM	LARGE	V-LARGE
1	URM	Unreinforced Masonry	13.74	13.61	12.93	10.89
2	W1 W2	Wood Light Frame Wood (Commercial or Industrial)	10.61	11.16	14.00	17.94
3	PCI RM1	Precast Concrete Tilt Up Walls Reinforced Masonry with Metal or Wood Diaphragm	14.10	13.35	11.48	7.11
4	C1 C3	Concrete Moment Frame Concrete Frame with Infill Walls	19.42	18.89	18.00	14.97
5	S1	Steel Moment Frame	19.47	19.14	18.30	13.93
6	S2 S3	Steel Braced Frame Steel Light Frame	7.59	7.21	5.79	3.28
7	S5	Steel Frame with Infill Walls	22.22	22.01	21.16	18.59
8	C2 PC2 RM2 S4	Concrete Shear Wall Precast Concrete Frame with Concrete Shear Walls Reinforced Masonry with Precast Concrete Diaphragm Steel Frame with Concrete Walls	17.10	16.64	15.71	12.79

TABLE 4.3.7 CONFIDENCE LIMITS FOR OPTION 1 COST ESTIMATES

NUMBER OF BUILDINGS	CONFIDENCE LIMITS					
	90%		75%		50%	
	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}	C_{CRL}	C_{CRU}
1	0.18	5.57	0.27	3.69	0.40	2.48
2	0.38	2.63	0.51	1.97	0.67	1.49
5	0.54	1.84	0.65	1.53	0.78	1.29
10	0.64	1.54	0.73	1.35	0.84	1.19
50	0.82	1.21	0.87	1.15	0.92	1.08
100	0.87	1.15	0.90	1.10	0.95	1.06
500	0.94	1.06	0.96	1.04	0.96	1.03
1000	0.96	1.04	0.97	1.03	0.98	1.02

Notes:

1. Costs in 1993 dollars. Construction in state of Missouri.
2. Very high seismicity roughly equivilent to UBC zones 3 and 4: high similar to zone 2B.
3. C_{CRL} and C_{DRU} of Table 4.3.7 can be multiplied times typical costs to determine the range of probable costs based on the database used for analysis.

Source: *Typical Costs of Seismic Rehabilitation of Buildings, Volume 1 (Prepublication Edition, July, 1994)*, Hart Consultant Group, FEMA, Wash. DC.

Other Construction Costs

- Nonstructural: Depends on associated remodeling and amount of nonstructural seismic mitigation included in the project. Following table is from FEMA document *Typical Costs of Seismic Rehabilitation of Buildings, Volume II, Draft in Progress, Sep 28,1994:*

TABLE 1.1 NONSTRUCTURAL COST ALLOWANCES FOR ALL BUILDING TYPES

NONSTRUCTURAL SEISMIC MITIGATION	NONSTRUCTURAL REMODELING			
	None	Minimal	Moderate	Complete
	Useful only to find costs solely attributable to seismic work	Minimal costs for cover-up of structural work	"Logical" associated remodel	Gutted building
None	N/A	$3*/SF	$13/SF	N/A
Light	$3/SF	$6/SF	$16/SF	N/A
Complete	$7/SF	$10/SF	$20/SF	$50/SF

N/A = Not applicable

- Disabled Access Requirements: Seismic retrofit work will trigger partial or complete compliance. Maximum improvements limited to 20% of construction costs.

- Hazardous Material Removal: Hazardous materials may be encountered. Costs associated with safe removal and disposal vary widely. Probabilities of finding such materials should be considered. Premium could be as high as $5/sf.

- Design, Testing and Inspection, and Management Costs: Design and Inspection may be 10-15%. Full-time management assistance could increase this "overhead" factor to a total of 30%.

Costs: Lost Business/Rents, etc.

- Partially of completely close building during construction
- Inconvenience, dirt, or noise can reduce business
- Permanent change in configuration may reduce rentable space or otherwise reduce value.

Benefits: Lives/Injuries Saved

- If life-safety is the only goal, and risk is obvious, cost effectiveness often not considered.
- If combined with dollar losses
  - ◊ Controversial
  - ◊ Done in other areas (autos or airline travel)
  - ◊ Values used from $300,000 to $1,700,000 per life
  - ◊ Injuries more difficult to value, but may be important

Benefits: Reduction in Repair Costs

- Usually cannot eliminate damage, just reduce
- Expensive finishes or contents important consideration
- Other special consideration
  - ◊ Damage (of unretrofit building) may require retrofit in addition to repair, increasing the cost of repair
  - ◊ Repair costs at or above about 50% may be equal to total loss (uneconomical to repair)

Benefits: Reduction of Business Interruption

- Often important consideration
- Recognized more after Loma Prieta and Northridge as important consideration
- Small business: could bankrupt if federal assistance not available
- Large business:
    - ◊ Competitive edge
    - ◊ Effects on time-to-market
    - ◊ Ability to invoice
    - ◊ Lost business

Benefits: Increase in Value of Building

- Change in salvage at end of 20-30 year period is small
- If retrofit is required, change in value is significant.

Damage/Loss Expectations

Any given performance objective will have different damage levels for different earthquakes: For example:

Performance Level		Earthquake	
	Moderate	Large(500y)	Major
Spot Hazard Reduction	Some	None	None
Collapse Prevention (CP)	DC	CP	ineffective
Standard Safety	DC	DD	CP
Damage Control (DC)		DC	
Immediate Occupancy (IO)	DC	IO	LS

Benefit/cost analysis must consider performance considering all events, not just one.

Calculation of Future Benefits

		Earthquake	
	Moderate	Large	Major
Existing Condition	$$	$$$$	$$$$$
Retrofit	$	$$	$$$$
Improvement	$	$$	$
Probability of occurrence	high	moderate	low
Numerical per year	1%/year	.5%/year	.1%/year
Savings	.01x$	.005x$$	.001x$

Annual Savings = .01$ + .005$$ + .001$

Discount Future Savings to Present Worth

Discount Rate		Period	
	10 years	25 years	50 years
2 %	90%	78%	63%
5 %	77%	56%	36%
8%	67%	43%	24%

Discounting future savings has significant affect on results, particularly using high discount rates.

Benefit/Cost Ratio

Benefit / Cost Ratio = Present Worth of all losses saved / (Construction + others) Costs

If the ratio is greater than 1.0, the benefits are greater than the costs.

Life Cycle Costs

Life cycle costing is a similar concept. The total cost (immediate plus future) of various alternatives is estimated and compared. In the case of seismic retrofit, the life cycle cost of the as-is condition (no retrofit) is simply the present worth of future damages. The life cycle cost of the retrofit building would be the sum of the retrofit cost and the present worth of future damages (these damages presumably would be smaller than the no-retrofit case). The two life cycle costs could then be compared; if the life cycle cost of the retrofit case is smaller, the savings in damage is offsetting the cost of retrofit. This is precisely the same as a benefit cost ratio greater than 1.0.

An example of life cycle cost comparison of three different retrofit schemes is shown below:

Cost Item	**Base-Isolated Scheme**		**Repairable-Damage Fixed-Base Scheme**		**Life-Safety Fixed-Base Scheme**	
Non-Structural Rehabilitation	$38,000,000		$38,000,000		$38,000,000	
Seismic And Structural Upgrade	$12,200,000		$13,000,000		$5,600,000	
Total Rehabilitation And Seismic Upgrade	**$50,200,000**		**$51,000,000**		**$43,600,000**	
Earthquake Loss Scenario	**Probable Case**	**Worst Case**	**Probable Case**	**Worst Case**	**Probable Case**	**Worst Case**
Structural And Non-Structural Losses	$1,409,000	*$2,997,000*	$1,794,000	*$4,405,000*	$3,903,000	*$13,044,000*
Contents Losses	$508,000	*$682,000*	$759,000	*$1,575,000*	$838,000	*$1,976,000*
Collateral Losses	$3,000	*$10,000*	$45,000	*$159,000*	$801,000	*$2,216,000*
Total Value Of Earthquake Losses	**$1,920,000**	***$3,689,000***	**$2,598,000**	***$6,139,000***	**$5,542,000**	***$17,236,000***
Total Life-Cycle Cost	**$52,120,000**	***$53,889,000***	**$53,598,000**	***$57,139,000***	**$49,142,000**	***$60,836,000***

Table 3: Summary Of Life-Cycle Costs For The State Of California Justice Building

Conclusions

The cost effectiveness of retrofit schemes and performance objectives selected can be estimated. The accuracy of such calculations is not high, and sensitivity studies of various parameters should be run. The parameters that most influence results are the following:

- The seismic risk at the site (the probability of various seismic events)
- The initial cost of retrofit
- The reduction in losses (particularly casualties)
- The cost of business interruption

Unless retrofit is a community policy (for life-safety or to protect the local economy), normally two or more of these parameters must be particularly favorable to yield a positive benefit cost ratio.

8.

Insurance Cost Effectiveness

by

Craig Taylor

CRAIG E. TAYLOR, Ph.D.
Professional Biography

SUMMARY

For sixteen years, Dr. Taylor has provided consulting and performed research in earthquake risk analysis. His emphases have been on critical systems analysis, financial risk analysis, and technical policy analysis. He has been the Principal Investigator on four projects for the United States Geological Survey (USGS), two projects for the National Science Foundation (NSF), and one project for the Federal Emergency Management Agency (FEMA), and has worked on many other projects for USGS, NSF and FEMA.

Many of his projects have covered earthquake risk issues in Utah. Beginning with nine reports to the Utah Seismic Safety Advisory Council, he continued his Utah investigations (along with D. Ward) with two USGS projects on potable water and natural gas systems and state building evaluations. More recently, with Dr. L. Reaveley, he completed an NSF project pertinent to the seismic zone 4 issue.

In the areas of insurance and financial risk analysis, he has also worked for many insurers and financial companies, including FGIC, Reliance National Risk Specialist, Factory Mutual Services, GEICO, Skandia America, American Home Assurance, Bear Stearns, and Standard and Poors. With the Universities of Pennsylvania and Wisconsin, he recently completed an NSF project on small business and earthquake insurability. He was also the principal investigator/project director on a two-year FEMA/Federal Insurance Administration project to evaluate the feasibility of incorporating loss-reduction provisions into a federal earthquake insurance program, should one be created by Congress. This project was a primary source for at least three bills that have subsequently been introduced by Congress in order to deal with the effects of natural disasters on the nation.

Dr. Taylor belongs to five professional societies, is a member of about ten subcommittees, and is currently Chair, Seismic Risk Committee, Technical Council on Lifeline Earthquake Engineering (TCLEE) of the American Society of Civil Engineers (ASCE). He was recently awarded the TCLEE/ASCE Recognition Award.

Two of his more noteworthy publications, as primary author, have included Loss Reduction Provisions of a Federal Earthquake Insurance Program (FEMA-200 and its summary FEMA-201) and Seismic Loss Estimates for a Hypothetical Water System (ASCE/Technical Council of Lifeline Earthquake Engineering, Monograph No.2)

INSURANCE COST-EFFECTIVENESS

by Craig Taylor
J.H. Wiggins Company
1650 South Pacific Coast Highway
Redondo Beach, CA 90277

A dilemma faces Utahns who seek to anticipate financing of losses after a moderate-to-major earthquake along the Wasatch Front [1, 2, 3]. Past studies have shown that these losses could exceed a billion dollars and perhaps stretch into the tens of billions of dollars. Although federal disaster relief funds might currently be anticipated for damage to public works, insurance coverage of private sector losses would be a smaller share than Californians received after the 1994 Northridge earthquake. Even in that earthquake, much of the losses (over a third) were financed out-of-pocket or through special loans. How can this situation be remedied? Is increased insurance coverage a major part of the solution?

POST-DISASTER FINANCING: THE DILEMMA

After the Northridge earthquake, almost a third of all losses (in excess of $30 billion) were covered by insurers [4]. Almost an additional third of all losses were covered by federal disaster assistance programs. These programs included cost-sharing with state and local governments and non-profit organizations for damage to their buildings. Low-interest loans and occasional small grants to homeowners and small businesses comprise additional smaller volume subsidies. The remainder of losses (over a third) was absorbed by individuals, businesses, lenders, investors, and state and local governments.

Barring major changes in federal disaster relief policy, damages to Utah's public works after a moderate-to-major earthquake would still probably be amply funded by federal disaster relief funds. Past studies have shown that Utah's highway bridge structures, culinary water system facilities, vitrified clay sewage pipes, schools, hospitals, and state and local buildings are in many cases seismically vulnerable [5, 6, 7, 8, 9]. Nonetheless, current federal post-disaster subsidy programs provide no-cost peace-of-mind for government officials. Even so, state and local governments will need to raise capital to pay their portions of this federal cost-sharing program, and government officials cannot ignore life-safety, health, and secondary economic risks attendant to a seismically vulnerable infrastructure.

Partly as a result of large losses in the past five-to-seven years, changes in the property and casualty insurance market have diminished the expected post-earthquake financing through insurance in California [10, 11]. Insurance losses from Hurricane Andrew in 1992 and from the Northridge earthquake this year have made insurance industry decision-makers even more suspicious that the catastrophe perils of hurricane and quake are uninsurable.

One area of concern to big businesses is the current confused evolution of national account or Fortune 1000 catastrophe insurance markets [12, 13, 14]. If these markets fail to maintain international support, then big businesses will need to seek alternative markets including self-retention funds, financial reinsurance, and other non-traditional post-loss financing techniques. Earthquake risk-reduction measures generally become more attractive as earthquake insurance acceptance guidelines tighten.

For homeowners and small businesses, the current Utah picture for post-loss financing looks bleak [15]. If national statistics are valid as applied to Utah, then a very low percentage (less than 5 percent?) of Utah homeowners and small businesses have earthquake insurance coverage. (In contrast, about 30 percent of homeowners in the Northridge area had earthquake insurance coverage). Moreover, whereas at least most California dwellings and small offices have a significant degree of earthquake resistance, many Utah homes and small offices are of unreinforced masonry or other seismically vulnerable construction.

The only current positive signs for post-loss financing for homeowners and small businesses are: (a) the fact that some small portion of overall post-earthquake losses are covered even without earthquake endorsements [16] and (b) limited low-interest loans and grants are available through the federal government after a Presidentially declared disaster.

POSSIBLE REMEDIES

Candidate remedies for Utah's post-disaster financing dilemma include (1) measures to assure economic vitality in general, (2) broad-based support for cost-effective earthquake loss reduction measures, (3) increased expansion of the use of insurance markets, including alternative markets, and (4) government insurance programs.

The first two remedies are primary [17]. A plausible hypothesis is that regions attract post-disaster financing much more if they provide a potentially healthy economy for investors. Many factors in developing a healthy economy lie far outside the scope of the discussions today.

Besides benefitting building occupants, cost-effective seismic loss reduction measures will:

- signal to insurers and bond investors that at least some significant portion of Utah's building stock is insurable for earthquake risks,
- imply decreased mortgage default risks for primary lenders and secondary mortgage portfolio investors,
- indicate to big businesses and large institutional investors that they are not overexposed in Utah because negative impacts of potential Utah earthquakes on their businesses or funds are being

mitigated,

- reduce the total capital that state and local governments need to contribute to post-disaster financing, and

- reduce post-disaster out-of-pocket expenses and emergency loans required by individuals and businesses [18].

Insurance, whether private or public, forms a second line of defense. Insurers in general are not enforcers of loss-reduction measures. This is a government role. However, confidence in Utah's building and land-use practices can encourage insurers to target Utah as a niche market and provide post-loss remedies through either traditional insurance mechanisms or alternative markets (financial insurance devices are increasing, as are alternative markets and as self-retention funds). Ideally, if insurance underwriters (and underwriters for loans, bonds, and other financial instruments) distinguish good from bad earthquake risks, price signals will alert individuals, businesses, and politicians as to what earthquake risk reduction measures will result in savings to individuals and businesses. Risk-takers themselves will pay for their lack of caution [19].

Government catastrophe insurance programs have sprung up in California (the now defunct California Residential Earthquake Recovery Program), Hawaii, and Florida. State proposals generally suffer severe financial (or actuarial) weaknesses. Either the state surplus must be huge to cover potential catastrophes, premiums must be very high, or partial paybacks must be employed in large disasters. Government premiums that are not risk-based can reward risk taking (e.g., shoddy construction) [20].

In 1990, the federal administration outlined six general principles that must be met for any federal program:

- correction of a market failure
- actuarial fairness
- hazard mitigation
- federal oversight and control
- deficit neutrality, and
- risk sharing [21].

These principles conform to the standard set by a late renowned Utah banker who maintained that increased federal liabilities should involve increased federal controls.

From 1990 through 1992, Congressional proposals for a national earthquake insurance program approached these principles, especially through the increased role of cost-effective loss-reduction measures tied to risk-based premiums. In 1994, expansion of proposed legislation to cover other perils (an expansion of liabilities) also coincided with a weakening of federal controls [22].

SUMMARY

Today, Utahns face the dilemma of how refinancing may occur should a moderate-to-large earthquake cause billions of dollars of damage within the Wasatch Front. Federal disaster relief policy provides a safety net for public and private non-profit entities. However, homeowners and businesses could pay a heavy price. The only obvious remedies are the long-term commitment to prudent seismic risk reduction measures. Insurance and other financial mechanisms are secondary lines of defense, themselves strengthened if the primary line of defense is broadly supported. Government catastrophe insurance proposals require establishment of controls commensurate with expanded liabilities [23].

[1]

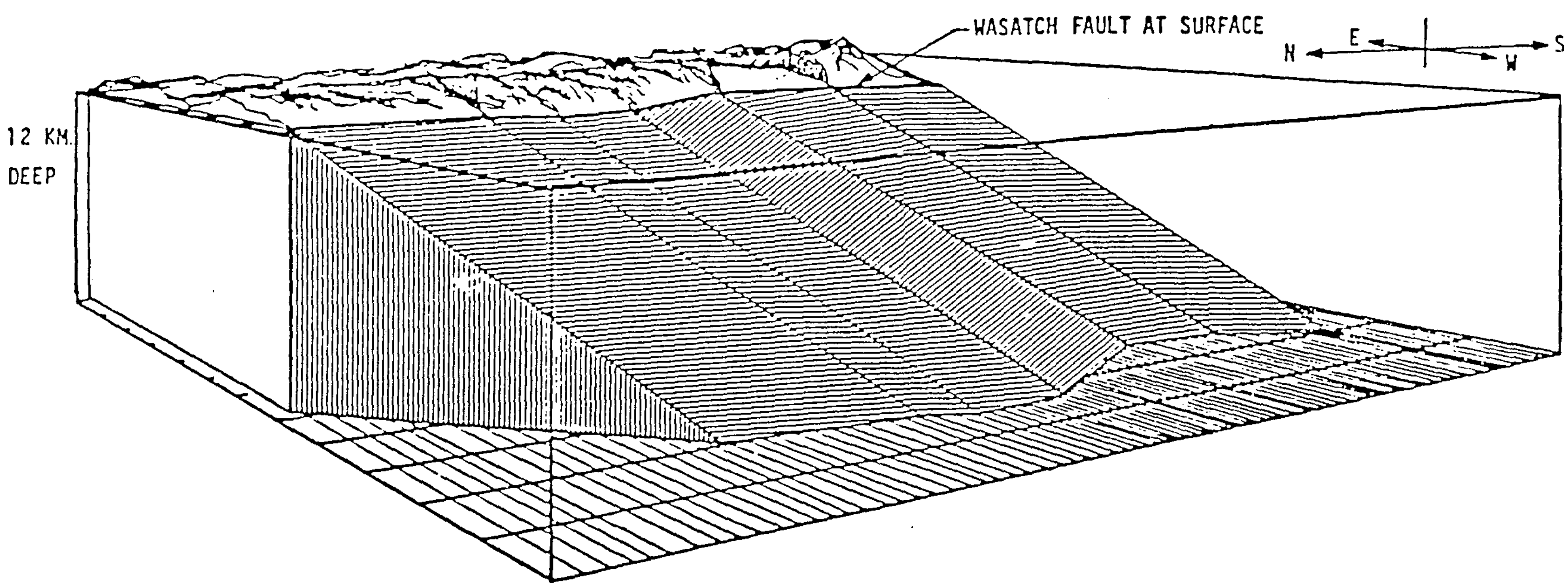
INSURANCE COST-EFFECTIVENESS

Craig Taylor
J.H. Wiggins Company
Redondo Beach, California

[2]

UTAH'S DILEMMA:

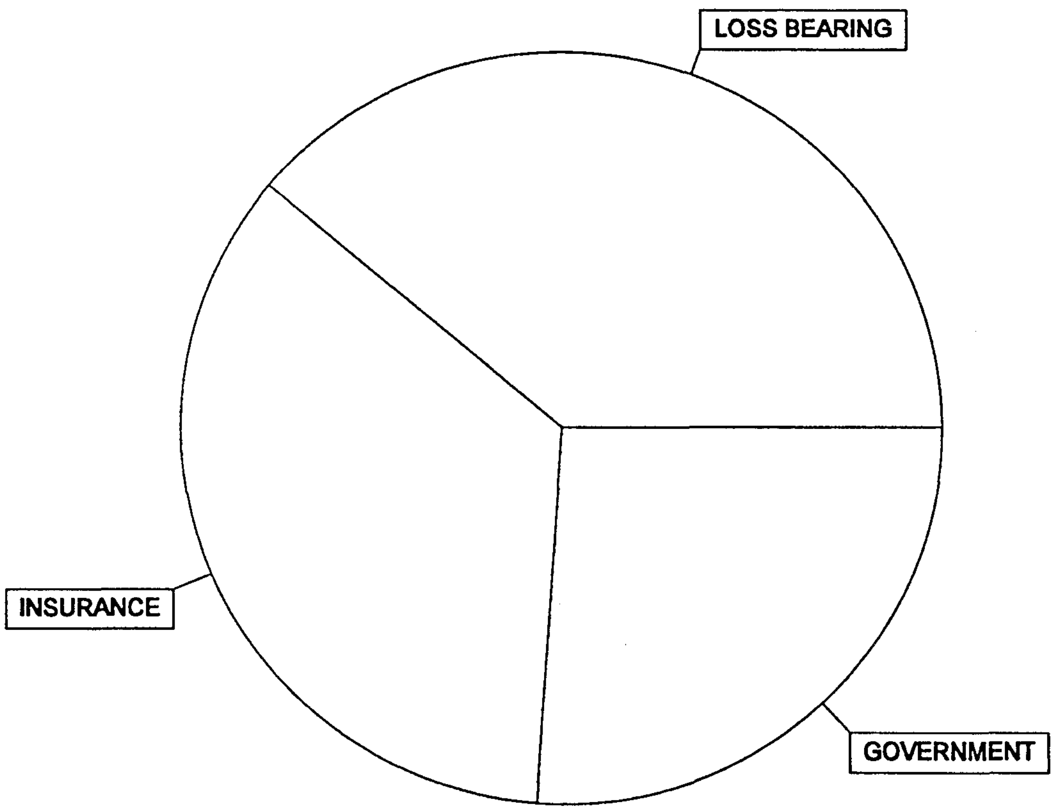
- **A DIRECT HIT: Billions of Dollars of Losses**
- **Less Private Sector Post-Loss Financing Than After The 1994 Northridge Earthquake**



The Wasatch Fault in Three Dimensions

[4]

POST-FINANCING: THE NORTHRIDGE EARTHQUAKE ($30+ BILLION)



[5]

FACILITIES COVERED BY CURRENT FEDERAL DISASTER RELIEF PROGRAMS

- State Offices and Universities
- Public Water Supply and Distribution Systems
- Sewage Systems
- Primary and Secondary Schools
- Highway Bridges
- Non-Profit Facilities

[6]

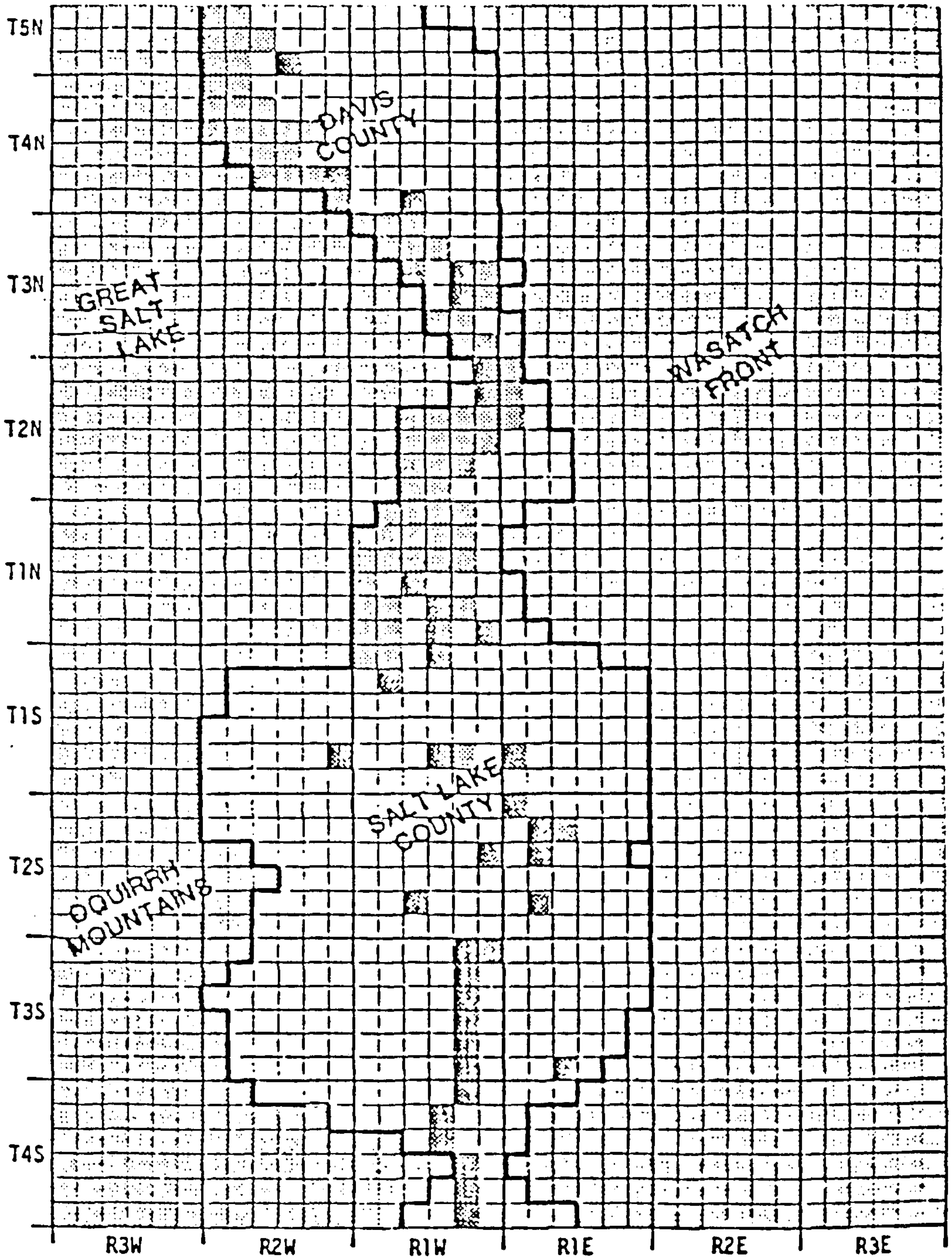
UTAH'S INFRASTRUCTURE IS SEISMICALLY VULNERABLE

- 1996 Study: $ 260 in Losses to State Buildings (Excluding Downtime)

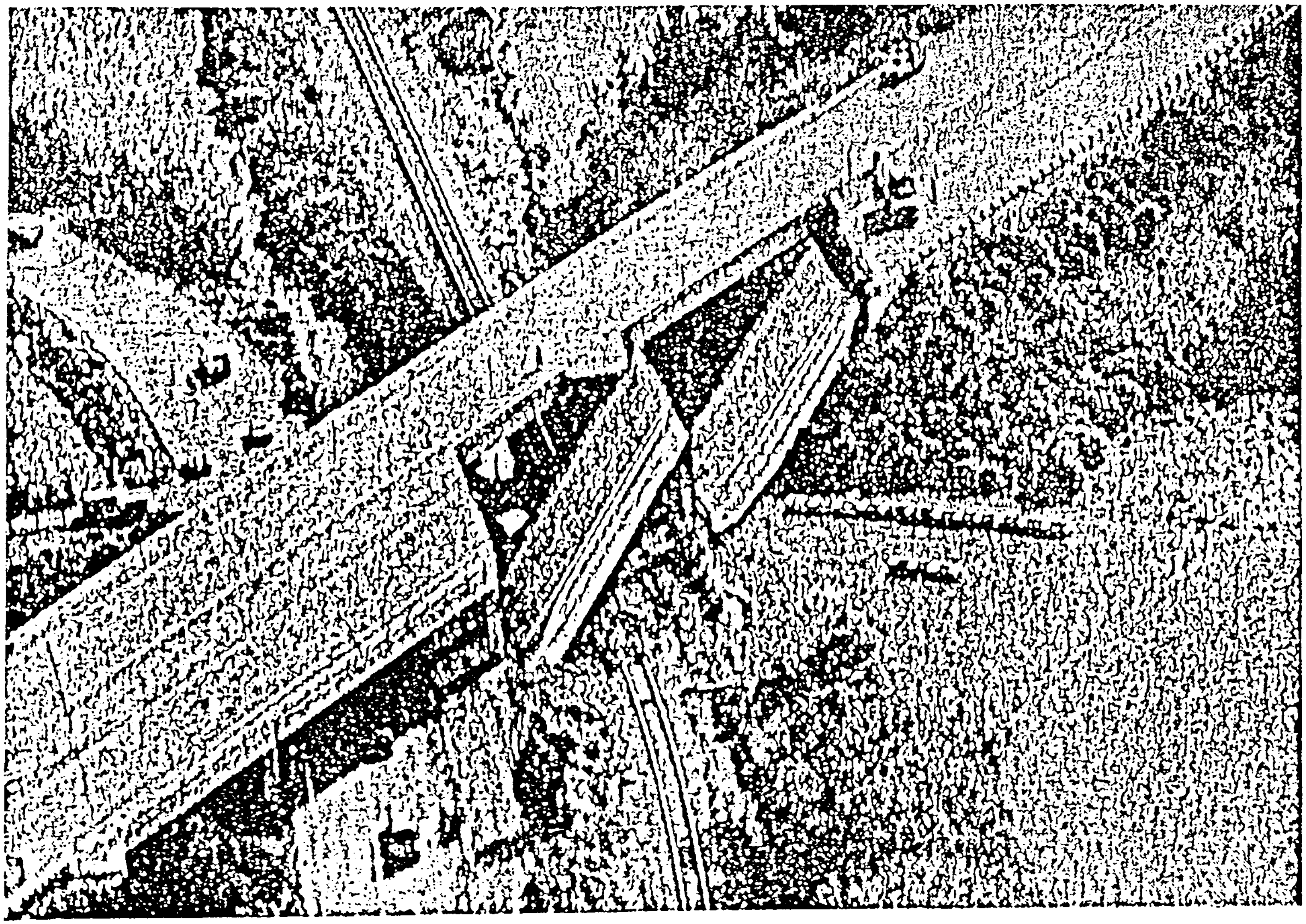
- 1980, 1981 Studies: Utah's Highway Bridge Structures Are Seismically Vulnerable

- Many Studies: Both Water Supply and Water Distribution Systems Have Many Seismic Vulnerabilities

[7]



High Liquefaction Zones



COLLAPSE OF THE U.S. 101 OVERPASS NEAR EUREKA, CALIFORNIA ON NOV. 8, 1980
(AP Photo, Los Angales Times, Nov. 9, 1980)

[9]

CURRENT FEDERAL DISASTER RELIEF PROGRAM BAILS OUT GOVERNMENT OFFICIALS, EXCEPT FOR

- **Cost-sharing Requirement**
- **Lives, Injuries, Illness**
- **Higher Order Economic Consequences of Highway, Water System, Personal Losses**

[10]

SAMPLE WORLDWIDE INSURANCE LOSSES (1988-PRESENT)

	$ Billions
• Piper Alpha	1
• Phillips Refinery	1
• European Hurricanes	2
• Hurricane Hugo	4
• Loma Prieta Earthquake	1
• Exxon Valdez	3
• Hurricane Andrew	15
• Hurricane Omar	1
• Hurricane Iniki	$1^1/_2$
• Northridge Earthquake	10
• Others	20
• Total	60

[11]

THE LEAST INSURABLE PERILS

- Environmental Impairment Liability
- Earthquake
- Severe Wind (Hurricane)
- (Third-Party Automobile Liability)
- (Flood--Before the Federal Program)
- Landslide

[12]

BIG BUSINESS

RISK TRANSFER

- National Accounts (Fortune 1000). Are They Insurable?
- Highly Protected Risks (HPR)
- Excess and Surplus Lines
- Financial Insurance

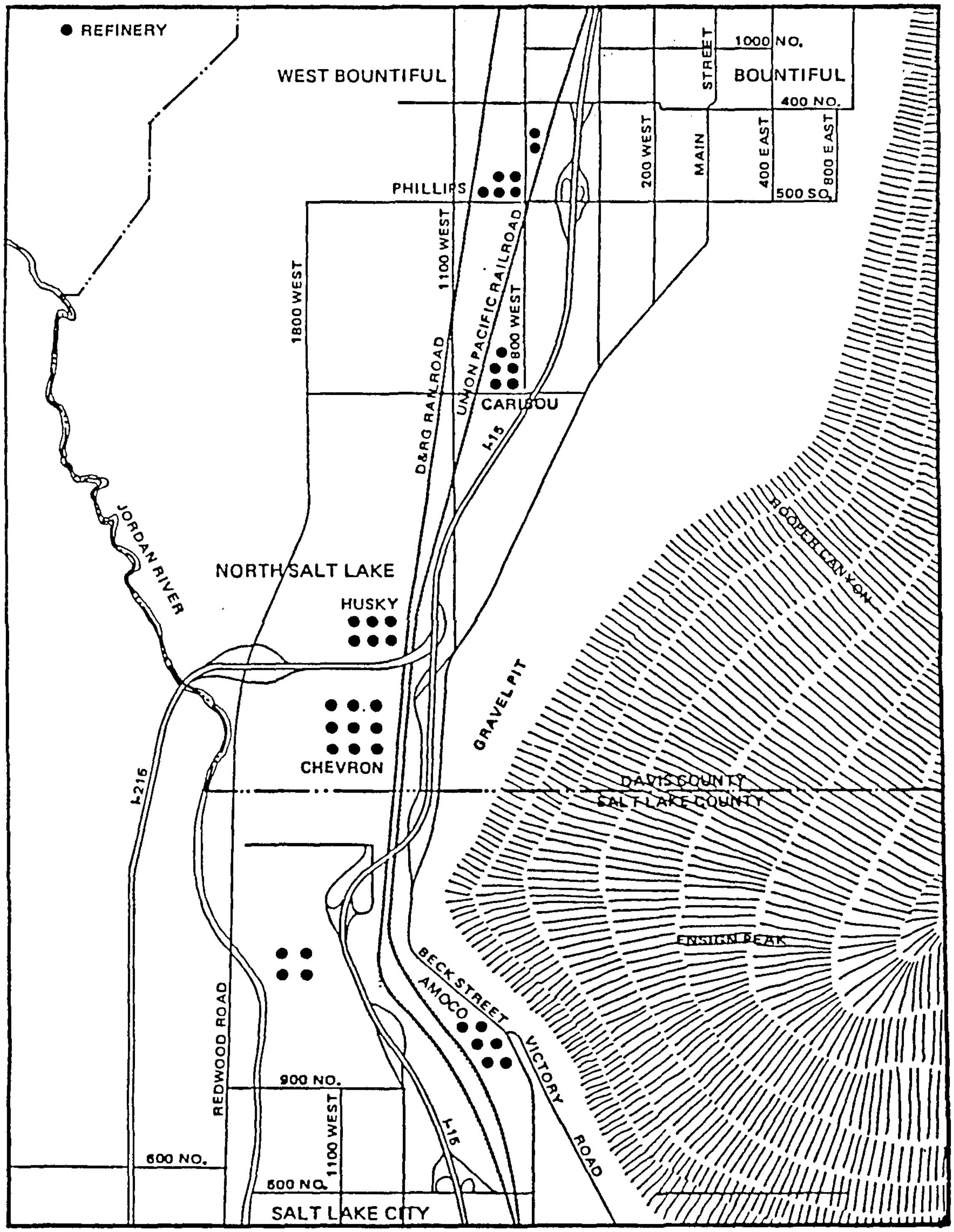
RISK RETENTION/RESERVING

- Self-Retention Pools
- Wholly Owned Captives

RISK REDUCTION

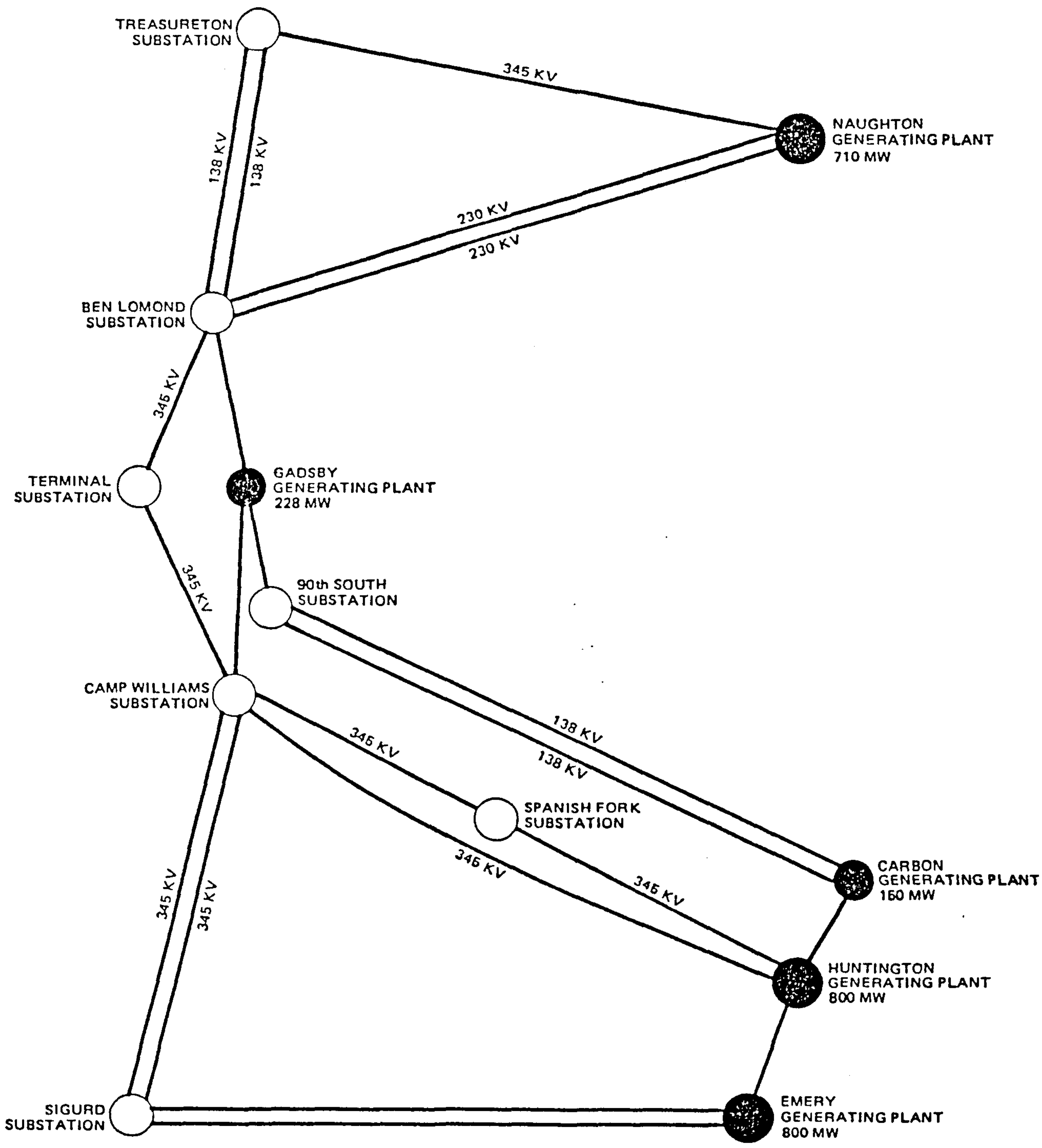
EMERGENCY PREPAREDNESS

[13]



REFINERIES

[14]



SCHEMATIC DIAGRAM OF THE UTAH POWER & LIGHT COMPANY TRANSMISSION SYSTEM

DWELLINGS/SMALL BUSINESS

CONTRAST TO CALIFORNIA

- Low Percentage of Earthquake Coverage
- No Mandatory Offer
- Low Seismic Quality (Pre-1960)
- Less Leverage in State Owing to Smaller Population (But Also Less Perceived Overregulation)

[16]

SOME LOSSES AFTER EARTHQUAKES ARE COVERED BY NON-EARTHQUAKE LINES

INSURANCE	EARTHQUAKE		
	1971 San Fernando Valley	1987 Whittier	1989 Loma Prieta
• Earthquake, Inland Marine	68%	43.7%	56.3%
• Farmowners, Homeowners, Commercial MP	15.1%	33.7%	31.5%
• Fire	4.4%	9.8%	3.5%
• Life, Accident & Health, Workers Compensation	Not Recorded	0.5+%	0.9%
• Auto, Glass, Boiler & Machinery	2.0%	1.3%	1.0%
• Other	1.4%	0.7%	0.8%
• TOTAL	100%	100%	100%

[17]

CANDIDATE REMEDIES

FIRST LINES OF DEFENSE

- Healthy Economy, Attractive to Investors After a Disaster
- Cost-Effective Loss Reduction Measures

COST-EFFECTIVE RISK REDUCTION

- Creates Insurability (Insurance/Bonds/Stocks)
- Reduces Mortgage Default Risks (Lenders/Investors/Insurers)
- Justifies Business Exposures in Utah (Stocks)
- Reduces Total Cost-Sharing (Government/Non-profit Entities)
- Reduces Out-of-Pocket Expenses and Emergency Loans (Individuals/Business/Lenders)
- Protects Lives

[19]

INSURANCE PROVIDES INCENTIVES

- Risk Based Underwriting
- Risk Takers Themselves Pay
- Risk-Averse Save

[20]

STATE INSURANCE PROGRAMS: DANGERS

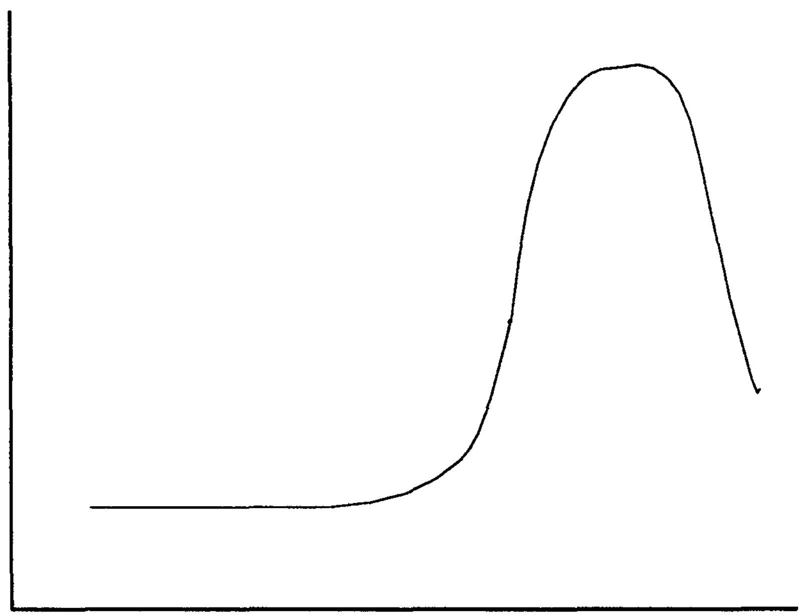
- **Fiscally Very Liberal (Actuarial Problems)**
- **Subsidized Rates Can Have Perverse Incentives**

FEDERAL ADMINISTRATION (1990) PRINCIPLES FOR GOVERNMENT INSURANCE:

- Correction of Market Failure
- Actuarial Fairness (Risk-Based Rates)
- Hazard Mitigation
- Federal Oversight and Control
- Deficit Neutrality, and
- Risk Sharing

(Controls Commensurate with Expanded Liabilities)

[22]



PROGRESS IN FEDERAL BILLS

[23]

SUMMARY

- **Private Sector Losses After Potential Utah Direct Hits are Mainly Unfunded**
- **The First Line of Defense: Cost Effective Risk Reduction**
- **Second Lines of Defense: Evolving Insurance Markets/Sound Government Insurance**