A GUIDE TO REDUCING LOSSES FROM FUTURE EARTHQUAKES IN UTAH "CONSENSUS DOCUMENT"

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Editor

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A Guide to Reducing Losses from Future Earthquakes in Utah

"Consensus Document"

Editorial Note: This document represents a consensus view of scientists, engineers, planners, emergency management officials, and others involved in a five-year program (1983-1988) as part of the National Earthquake Hazards Reduction Program focusing on earthquake hazards and risk in Utah. It was developed in connection with the "Fifth Annual Workshop on Earthquake Hazards and Risk Along the Wasatch Front, Utah" (January 31-February 2, 1989, Salt Lake City). —WJA

July 1989

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FOREWORD

(Purpose and Contents)

The purpose of this document, as originally conceived, was to motivate and guide actions that will reduce losses from future moderate-to-large (magnitude 5.5 to 7.5) earthquakes in Utah, with primary emphasis on Utah's densely populated Wasatch Front region. In its present form, this document is viewed as an "intermediate-stage" product.

Public officials and decisionmakers in Utah need understandable and reliable information about Utah's earthquake threat. To meet their needs, it seems inescapable that one or more derivative documents—illustrated and simplified to meet the particular needs at hand—will have to be created. For example, Appendix B is a pamphlet entitled "Utah's Earthquake Threat" prepared in February 1990 for an earthquake-preparedness exposition at the Salt Palace (attended by more than 10,000 people). A book for the general public entitled "The Earthquake Threat—and Challenge—in Utah," currently being written by W. J. Arabasz and D. R. Mabey and sponsored by the U.S. Geological Survey, will be published in 1991 by the Utah Geological and Mineral Survey. The consensus view of scientists and engineers summarized in this document provides underpinnings for the book.

There are three basic parts to *this* document. Part One considers the question whether Utah is ready to take action to reduce its earthquake risk—and it is argued that seven key ingredients now exist for timely action in Utah. In Part Two, four basic strategies are outlined for communities in Utah to reduce earthquake losses. In Part Three, information is presented summarizing the nature and extent of the physical effects and losses that can be expected from earthquakes in Utah. This summary is based on up-to-date information and represents the consensus judgment of scientific and engineering experts involved in studies of Utah's earthquake problems. Technically-worded statements prepared by the scientists and engineers are presented in the Appendix A. A "layman's distillation" of those statements appearing in Part Three was written by S. J. Nava and W. J. Arabasz.

Walter J. Arabasz
Salt Lake City
June 1990

PART ONE

IS UTAH READY TO TAKE ACTION TO REDUCE ITS EARTHQUAKE RISK?

by
Genevieve Atwood[1] and Walter W. Hays[2]

YES—focused efforts during the last five years have achieved several successes including an adequate scientific and engineering base upon which to take action; a general willingness of public and private leaders to act responsibly relative to the earthquake risk; a general willingness of the public to accept actions to reduce the risk; and a willingness of a few key leaders—but not yet many elected officials—to provide leadership to bring about actions.

Key ingredients that now exist for future success in implementing earthquake hazard reduction include:

1. **A High Level of Concern**—Technically-trained public officials have an understanding of the earthquake hazards in Utah and realize that actions taken now can mitigate the hazard and reduce losses. The Wasatch Front news media is remarkably well-informed and has played a major role in enlightening the public to earthquake risks. Opinion polls show that the general public recognizes the potential for earthquake disasters and will support the adoption of a number of earthquake mitigation measures.

2. **Reliable Information**—Scientists, engineers, planners, and emergency response officials have amassed a substantial body of technical information about the Wasatch fault and other active faults in Utah—their location and geometry, the hazards associated with them, the recurrence of large earthquakes, and what actions will be effective in reducing the risk. New hazard maps and recent loss studies show the nature and extent of the earthquake threat along the Wasatch Front. This information clearly demonstrates the vulnerability of the region's economy to earthquake losses.

3. **User-Friendly Products**—A wide range of data, reports, maps, guidelines, and digitized information has been translated into plain wording to answer the basic questions asked by planners, emergency managers, and public officials—i.e., Where? How often? What effects? "Translated" hazard maps have been developed specifically for technical users and disseminated through the cooperative effort of federal, state, and local governments working together with the academic and private sectors. The county geologist program has been exceptionally effective in bridging the gap between information producers and information users in local government.

1. former Utah State Geologist, currently with Atwood & Mabey, Inc.
2. U. S. Geological Survey

4. **Professional and Institutional Support**—A core group of individuals believes the earthquake threat is real, and these individuals are trained and committed to devising effective and appropriate hazard reduction techniques for the Wasatch Front. This group includes social scientists, architects, planners, civil engineers, structural engineers, earth scientists, public decisionmakers, public-safety professionals, and business people. These individuals provide leadership within their own groups and exert influence beyond their organizations.

5. **Policy Champions**—Dedicated proponents of earthquake safety both within and outside Utah have promoted specific earthquake safety policies in Utah. Past experience has taught many lessons in how to succeed with decisionmakers, business people, and the public. Although Utah lacks sufficient public concern to force action and compel elected officials at all levels of government to make a crusade of the issue, decisionmakers do recognize earthquake hazard reduction as part of their responsibility for the public health, safety, and economic well-being of their communities.

6. **Information Exchange**—A network of information exchange links seismologists, structural engineers, and land-use planners. New findings in seismology, geology, and engineering can be readily transferred for incorporation into local hazard mitigation policies. Conversely, special needs in local policy can be readily addressed by experts drawing on an existing knowledge base. The network of information exchange enhances the credibility of mitigation policy even when implemented in a context of changing needs and expanding knowledge. New information can be incorporated into existing siting design, construction, retrofitting, and land-use practices by redefining map boundaries and refining existing concepts about the hazard without jeopardizing the fundamental credibility of the program.

7. **Window of Opportunity**—Will it take a major destructive earthquake before Utah takes significant actions to reduce its earthquake risk? Not now! Significant steps already have been taken (e.g., hospital construction standards, enactment of zoning ordinances), and other steps are ready to be taken. The damage caused by the 1982-86 wet cycle significantly increased (1) the level of awareness and (2) the commitment of public officials to make the state less vulnerable to geologic hazards.

The "window of opportunity" during which communities can accelerate the adoption of seismic safety measures is wide open in Utah. The most recent, comprehensive five-year effort, involving several hundred worker-years and more than 15 million dollars of federal, state, and local resources, was built upon the legacy of Utah's Seismic Safety Advisory Council and earlier regional seismological research. Now that most of the technical and societal information is in place, Utah is ready to take political and policy actions to reduce its earthquake risk.

PART TWO

BASIC STRATEGIES FOR LOSS REDUCTION

by
M. Lowe[1], G.E. Christenson[1], C.V. Nelson[2],
R.M. Robison[3], and J. Tingey[4]

To reduce its vulnerability to earthquakes, a community must adopt four basic strategies to keep expected losses within acceptable limits. These strategies necessarily involve an understanding of the earthquake threat, a knowledge of what actions will be effective in reducing risk, and an appreciation of the willingness and ability of the people involved to take action. The four basic strategies, which can be adopted and tailored to local needs, are: (1) improved development and construction practices; (2) public education concerning earthquake hazards and how to respond during a hazard event; (3) disaster-response plans; and (4) post-earthquake recovery plans.

Improvement of development and construction practices is primarily the responsibility of state, county, and municipal government agencies through adoption and enforcement of building codes and subdivision zoning, and retrofit ordinances. When faced with earthquake hazards, communities have five possible alternative actions: (1) ignore the hazard; (2) avoid the hazard; (3) modify the hazard (reduce the likelihood or severity of the hazard); (4) modify what is at risk (strengthen structure to withstand the hazard event); and (5) understand the hazard and accept the risk (usually involves disclosure of the hazard to potential owners and occupants) (Anderson, 1987).

Ignoring the hazard is not an acceptable action as it does not fulfill government's mandate to protect the health, safety, and welfare of its citizens and may lead to governmental liability for damages and/or loss of life accompanying earthquakes. In determining which of the other alternative actions is most appropriate, the risk, in terms of both economic and life loss, should be considered along with the cost of avoiding or mitigating the hazard and the type of facility which is being considered. Table 1 lists typical hazard-reduction techniques for some of the more widespread types of earthquake hazards. Which techniques are most appropriate for a particular development must generally be determined by a site-specific study.

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One of the more serious problems in promoting earthquake-hazard reduction is convincing the public that there is indeed a hazard. (Only a few of Utah's urban areas have been damaged historically by close earthquakes of Richter magnitude 5.5 or larger [Richfield, magnitude 6½, 1901; Elsinore, two shocks of magnitude 6, 1921; Logan, magnitude 5.7, 1962].) In order to show the need for taking steps to reduce earthquake hazards, technical information must be translated so that it may be understood by the layman. This translated information must identify the likelihood of occurrence, location, severity in terms of what will happen when the event occurs, and what steps may be taken to reduce the risk. This consensus document is one attempt to provide translated information about earthquake hazards to the layman.

The purpose of disaster-response plans is to identify: (1) the types of decisions that are likely to be needed when the expected earthquake event occurs, (2) who will make the decisions, and (3) how the decisions will be transmitted to the public and emergency-response personnel so that they may be implemented. Disaster-response exercises are conducted so that implementation of disaster-response plans will occur in the fastest, most efficient manner possible.

Recovery plans are designed to anticipate and meet the time-varying needs of the community as the post-earthquake recovery period unfolds over a period of 5 to 10 years. These plans will help ensure that the community quickly returns to cultural and economic viability following an earthquake.

Basic products are now, or soon will be, available to develop and carry out these strategies for earthquake-loss reduction in Utah. They include: (1) maps showing susceptibility to earthquake hazards such as ground shaking, surface rupture, slope failure, and liquefaction, and depicting either explicitly or implicitly the affected area, severity of impact, frequency of occurrence, impact time, duration, and the potential for triggering secondary effects; (2) loss studies identifying the distribution and nature of the damage and losses expected in the realistic scenario of one or more earthquakes; and (3) risk-reduction studies based on experience in Utah communities and elsewhere describing which risk-reduction actions are likely to be most effective.

TABLE 1

PRINCIPAL EARTHQUAKE HAZARDS, EXPECTED EFFECTS, AND COMMONLY-APPLIED TECHNIQUES TO REDUCE HAZARDS

Hazard	**Expected Effects**	**Commonly Used Hazard-Reduction Techniques. Other Mitigation Techniques May Be Used Which Are Not Listed Here.**
Surface-Fault Rupture	Rupture of ground with relative displacement of surface up to 20 feet along main trace of fault. Tilting and ground displacements may occur in a zone of deformation up to several hundred feet wide, chiefly on the downthrown side of the main fault trace.	Avoid active fault traces by setting structure back a safe distance from fault.
Ground Shaking	Vertical and horizontal movement of the ground as seismic waves pass. Damage or collapse of man-made structures can result, depending on the amplitudes, frequencies, and duration of ground motions. Horizontal motions generally cause greatest damage. Damaging ground motions can occur as far as 60 miles from the earthquake source, depending on source, path, and site conditions.	Design and build new structures to meet or exceed the seismic provisions in the current Uniform Building Code. Replace or retrofit older structures (especially unreinforced masonry buildings) to strengthen them so they meet current UBC requirements. Tie down water heater and secure heavy objects inside buildings.
Tectonic Subsidence	Regional tilting of valley floor toward fault causing flooding near lakes and in areas of shallow ground water. May cause loss of head in gravity-flow structures (for example, sewer systems).	Increase tolerance for tilting in gravity-flow structures; design structures for releveling. Buffer zones or dikes around lakes or impounded water to limit flood hazard; prohibit basements in shallow ground-water areas.
Liquefaction	Water-saturated sandy soils may liquefy (become like quicksand) causing differential settlement, ground cracking, subsidence, lateral downslope movement of upper soil layers on gentle slopes, and flow failures (landslides) on steep slopes.	Improve soil-foundation conditions by removing susceptible soils, densification of soils through vibration or compaction, grouting, dewatering with drains or wells, and loading or buttressing to increase confining presures. Structural solutions include use of end-bearing piles, caissons, or fully compensated mat foundations.
Earthquake-Induced Rock Fall	Downslope movement of bedrock fragments and boulders causing damage due to impact.	Avoidance. Remove or stabilize potential rock-fall sources by bolting, cable lashing, burying, or grouting. Protect structures with deflection beams, slope benches, or catch fences.
Earthquake-Induced Landslides	Downslope movement of earth material causes damage to structures below the landslide due to impact and/or burial. Differential displacement of scarps and movement in both vertical and horizontal directions causes loss of foundation support for structures within and adjacent to the central mass of the landslide.	Avoidance. Remove landslide-prone material. Stabilize slopes by dewatering, retaining structures at toe, piles driven through landslide into stable material, weighting, or buttressing slopes. Bridging.
Earthquake-Induced Seiches	Earthquake-generated water waves causing inundation around shores of lakes and reservoirs. Loss of life due to drowning. Damage due to flooding, erosion, and pressures exerted by waves.	Avoidance. Flood-proofing and strengthening to withstand wave surge. Diking. Elevate buildings.

PART THREE

THE EARTHQUAKE THREAT IN UTAH

A Consensus on the Expected Physical Effects and Potential Losses Associated With Future Earthquakes

As early as 1883, the eminent geologist G.K. Gilbert recognized and warned of the serious earthquake threat posed by the Wasatch fault and other active faults in Utah despite the absence up to that time of any large earthquakes in the region since settlement by Mormon pioneers in 1847. In modern times, seismologists, geologists, and engineers, have amassed a large body of technical information and have reached fundamental agreement about Utah's earthquake dangers. That consensus was arrived at as part of a special five-year focus (1983-1988) on the Wasatch Front region under the National Earthquake Hazards Reduction Program. The technical "consensus" statements of the scientists and engineers are presented verbatim in the Appendix of this document. A "layman's distillation" of the technical information is summarized here. Numbered references appearing in the margins are keyed to the Appendix. It should be noted that the following summary and appended statements reflect a general agreement on what to expect, even though some scientific and technical issues may not be fully resolved.

Our understanding of earthquake danger in Utah is based on earthquakes experienced in Utah, earthquakes that have occurred elsewhere in the western United States, our knowledge of the geology of Utah, and research on earthquake mechanisms and effects. This understanding has led most, if not all, scientists who have studied the problem to conclude that the Wasatch Front area, where 90 percent of Utah's population resides, is an active seismic zone with earthquake dangers that demand the attention of officials and the general public. Although a destructive earthquake could occur anywhere in Utah, the primary focus of this discussion—because of the large population at risk—will be a large surface-faulting earthquake on the Wasatch fault and physical effects that are expected in the eleven counties within or adjacent to the Wasatch Front: Salt Lake, Davis, Juab, Weber, Wasatch, Summit, Morgan, Cache, Utah, Tooele, and Box Elder. However, many of the general statements presented in this document are also applicable for earthquakes occurring elsewhere in Utah than on the Wasatch fault. Utah's earthquake problems emphatically are not restricted to the Wasatch fault.

Reference (Keyed to Appendix)	**General Statements**

The state of Utah is transected by the Intermountain seismic belt, a coherent northerly-trending belt of **earthquake** activity extending at least 1,500 kilometers (900 miles) from southern Nevada and northern Arizona to northwestern Montana. The Intermountain seismic belt is characterized by shallow scattered earthquakes less than 25 kilometers (15 miles) deep, geologically active **normal faults**, and high **seismic risk** associated with episodic **surface-faulting** earthquakes of about **magnitude** 6.5 to 7.5.

[1.2] **Seismic hazards** in the Wasatch Front arise from the potential for two different types of earthquake occurrence: (1) Moderate-sized earthquakes that are not constrained in location to mapped faults and that may occur anywhere throughout the region, and (2) infrequent large surface-faulting earthquakes on identifiable faults having evidence of geologically recent movement.

[1.2.2] Moderate but potentially damaging non-surface-faulting earthquakes (magnitudes 5.5 to 6.5) may occur anywhere within the Wasatch Front region. These earthquakes may occur on either known or unknown faults. Unknown faults include buried faults which cannot be seen at the surface. Based upon instrumentally-
[1.3.2] recorded earthquakes since 1962, potentially damaging earthquakes of magnitude 5.5 and larger are expected to occur in the Wasatch Front region about once every 14 to 40 years. Eight earthquakes with measured or estimated magnitudes of 5.5 or greater occurred in this region from 1850 through 1988, the most recent being the 1975 Pocatello Valley earthquake near the Utah-Idaho border.

Moderate-sized earthquakes have the potential to produce substantial damage in the Wasatch Front urban corridor. A "direct-hit" to one of the Wasatch Front's

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earthquake: A sudden trembling in the earth caused by slippage on a fault (fracture) accompanied by the abrupt release of slowly accumulated strain energy.
fault: A fracture or fracture zone along which there has been displacement of the sides relative to one another along the surface of the fracture.
normal fault: A fault whose movement is primarily in a vertical direction. The Wasatch fault is an example of a normal fault with the mountain block rising relative to the valley floor.
seismic risk: The social or economic consequences of future possible earthquakes. Risk may be expressed as the probability that adverse effects will equal or exceed specified values in an area during a specified interval of time.
surface faulting (surface rupture): Displacement of the ground surface by a fault movement. Surface faulting is expected to occur in Utah only in earthquakes of magnitude 6.3 or larger. The majority of small to moderated-sized earthquakes in Utah occur on faults whose rupture does not reach the surface.
magnitude: A number that characterizes the size of an earthquake from measurable motions recorded by a seismograph, corrected for the distance to the source of the earthquake.
seismic hazard: Any physical phenomenon (e.g., ground shaking, ground failure, surface-faulting) associated with an earthquake that may produce adverse effects on human activities.

major cities could result in more than $2.3 billion for a magnitude 6.5 earthquake—and more than $830 million for a magnitude 5.5 earthquake. A magnitude 6.5 [2.1.4] earthquake is expected to produce ground motions on soils within 10 kilometers (6 miles) of the fault that range from at least 0.25 to 0.5g. [The force of gravity is 1.0g.] At 20 kilometers (12 miles) from the fault, corresponding ground motion estimates on soil are 0.15 to 0.25g. The greater ground shaking will tend to occur at sites underlain by unconsolidated alluvium and lake deposits, and lesser ground [2.3.3] shaking will tend to occur at sites underlain by rock. Ground motion levels at soft sediment sites are expected to be 6 to 10 times greater than at rock sites.

[3.1.3] Earthquakes of magnitudes less than 6.5 could cause rock falls, rock slides, and other slope instabilities within a few miles of the earthquake source. Such [3.1.1] earthquakes also could trigger **liquefaction** locally.

Earthquakes of about magnitude 6.3 and greater occurring along the Wasatch [1.5.1] Front are expected to produce surface-faulting. Since 1850, there have been three historical earthquakes in the Intermountain seismic belt that were associated with documented surface-faulting:

Year	Magnitude	Location	Maximum Surface Displacement
1934	6.6	Hansel Valley, Utah	0.5 meters (1.6 feet)
1959	7.5	Hebgen Lake, Mont.	5.5 ± 0.3 meters (18.0 ± 1.0 feet)
1983	7.3	Borah Peak, Idaho	2.7 meters (8.9 feet)

[1.4.1] Future large earthquakes on the Wasatch fault and other major faults in Utah are expected to have characteristics similar to those of large normal faulting earthquakes occurring in nearby states. These include: the 1959 Hebgen Lake, Montana, earthquake; the 1983 Borah Peak, Idaho, earthquake; and earthquakes up to magnitude 7.7 that have occurred in this century in Nevada.

The greatest threat for large surface-faulting earthquakes in Utah is posed by the Wasatch fault zone—despite the fact that it has not generated any earthquakes larger [1.2.1] than magnitude 5 in historical time. There are many other known active faults in Utah that show evidence of prehistoric surface-faulting and that may produce large-surface-faulting earthquakes in the future. In general, the intervals between larger earthquakes on these faults tends to be considerably longer than for repeat ruptures along the most active parts of the Wasatch fault.

liquefaction: The process by which water-saturated, unconsolidated sediments subjected to shaking in an earthquake temporarily lose strength and behave like a fluid. The lower areas of many of western Utah's valleys are susceptible to liquefaction.

The Wasatch fault zone follows the base of the western edge of the Wasatch
Range, from Malad City, Idaho, southward to Fayette, Utah, for a distance of
[1.4.4] 380 kilometers (240 miles). The Wasatch fault is made up of as many as 12
independent **segments**. Each segment is expected to rupture independently, although
rupturing on one segment may be followed closely in time by rupture on another
segment. This pattern of more-frequent-than-average rupturing is termed temporal
[1.1.1] clustering. The central 6 to 8 segments of the Wasatch fault zone (from Brigham
City to Levan)—based on trenching and dating studies—have repeatedly produced
magnitude 7.0 to 7.5 earthquakes during the past 6,000 years. The timing pattern of
[1.1.2] such large surface-faulting earthquakes on the Wasatch fault during the past 6,000
years is complicated. For the segments between Brigham City and Nephi, the
[1.3.1, composite recurrence interval—the average time between two faulting events
1.1.2] anywhere on this central part of the fault zone—ranges from a maximum of 415
years to a minimum of 340 years.

Based upon studies of **fault scarps** and the ages and timing of fault offsets, the
[2.1.1] probability of a large surface-faulting earthquake on the Wasatch fault in the next 50
years has been estimated to be between 4 and 20 percent. However, because of the
variability of the data used in this analysis and the possibility of multiple interpreta-
tions, it should be noted that a higher probability of occurrence in 50 years cannot
be ruled out.

Surface-faulting accompanying a magnitude 7.0 to 7.5 earthquake on the
Wasatch fault zone can be envisioned as follows. The fault rupture would likely
[1.4.2] extend beneath the valleys adjacent to the fault, probably to depths of 10 to 20
kilometers (6 to 12 miles). The length of the surface rupture would range from 20
to 70 kilometers (12 to 44 miles), depending upon the fault segment involved. A
[1.5.2, complex zone of faulting could be formed up to 500 meters (1640 feet) wide. Fault
1.4.2] scarp heights could be as much as 5 to 6 meters (16.5 to 19.5 feet).

The hazard from surface-faulting will be localized along a single segment of the
[1.5.4] fault—as opposed to the associated ground shaking and ground failure, which will
affect a much larger area and may be most intense away from the fault.

[2.1.3] The severity of ground shaking expected within urban areas adjacent to the rup-
tured fault segment (within 10 kilometers) roughly corresponds to a Modified

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segment: Portion of a fault that ruptures as a unit during an earthquake.
fault scarp: The cliff or steep slope formed by a fault that breaks the earth's surface.

Mercalli Intensity (MMI) of VIII on firm sediments and Modified Mercalli X or greater on soft sediments (0.4 to 0.6g). Modified Mercalli Intensity VIII is

[2.1.2, 2.1.3] characterized by: partial collapse of weak masonry walls; fall of chimneys, factory stacks, towers, elevated tanks; frame houses moved on foundations if not bolted down. Modified Mercalli Intensity X is characterized by: most masonry and frame structures destroyed with their foundations; some well-built wooden structures destroyed; serious damage to dams, diking and embankments; rails bent; and large landslides.

[3.1.1] Large earthquakes of magnitude 7.0 and greater are likely to trigger liquefaction and destructive ground failures in the sediments that lie beneath many areas in the

[3.1.2] lower parts of valleys along the Wasatch Front. The most common consequence of liquefaction along the Wasatch Front is expected to be **lateral spreading**. Lateral spreads would cause ground displacements of up to several feet, along with fracture of buildings, roads, and other surface works located on the unstable ground.

[3.1.3] Major damage from rock falls, rock slides, and other slope instability should be expected on steep slopes (such as within canyons and along mountain fronts) over a wide area.

In a magnitude 7.5 earthquake on a central part of the Wasatch fault, Utah

[2.4.1] should expect damage to buildings to exceed $4.5 billion in Davis, Salt Lake, Utah and Weber counties. This may represent only 20 percent of the total economic loss. Unreinforced masonry buildings (for example, brick homes built before 1960) are

[2.4.2] particularly vulnerable to ground shaking and are expected to account for 75 percent of the building losses. The Wasatch Front area has a sizable inventory of other structures not built with earthquake-resistant design that will be seriously damaged.

Surface-faulting, and other ground failures due to ground shaking during a large earthquake, will cause major disruption of lifelines (utilities, water, sewer), transportation systems (highways, bridges, airports, railways), and communication systems.

[2.4.4] As a result of the geographical concentration of state-owned buildings—and their limited seismic resistance—losses from a large Wasatch fault earthquake could easily reach 30 or 40 percent of replacement value. (Schools, hospitals, and fire stations were not studied.)

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lateral spreading: Landslides that form on gentle slopes as the result of liquefaction of a near-surface layer from ground shaking in an earthquake.

[2.4.3] A 1976 study by the U.S. Geological Survey for a worst-case earthquake on the central Wasatch fault estimated 2,300 fatalities (assuming no dam failures), 9,000 injured, and 30,000 homeless. The number could be as high as 14,000 if deaths from dam failure are included in the casualty total. The experience of the 1988 Armenian earthquake—and more up-to-date engineering judgment about the collapse potential of many structures in the Wasatch Front area—suggests the 1976 fatality estimate is low.

[2.4.6] There may be losses relating to disturbance of the Great Salt Lake and Utah Lake from a major earthquake. The magnitude of the losses would be dependent upon such factors as lake elevation and the amount of downward tilting of a valley floor toward the fault scarp. Rapid inundation of developed areas adjacent to lakes could result in large losses of life and property. **Seiches** may cause the Great Salt Lake and Utah Lake to oscillate for many hours, temporarily raising and lowering the water level. Additional losses could be expected from flooding due to possible failures of dams or other water impoundment structures and from fires.

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seiche: Oscillations (standing waves) of the surface of a closed body of water when the surface is disturbed by wind or an earthquake.

APPENDIX A

Editorial Note: The summary statements that follow were written by small working groups formed during a planning meeting in Salt Lake City on November 9, 1988. A draft of the statements was distributed—and revised in response to group discussion—at the "Fifth Annual Workshop on Earthquake Hazards and Risk Along the Wasatch Front, Utah" (January 31-February 2, 1989, Salt Lake City). Sections 2.1 through 2.3 here, prepared by A. M. Rogers and others, consist of revised text written in September 1989. —WJA

1.0 HAZARDS ASSOCIATED WITH EARTHQUAKES AND SURFACE-RUPTURING FAULTS

1.1 The Wasatch Fault Zone (M.N. Machette, W.R. Lund, D.P. Schwartz, R.L. Bruhn)

1.1.1 Trenching and dating studies indicate that the southern 220 km (Brigham City to Levan) of the 343-km-long Wasatch fault zone is made up of 6 to 8 independent fault-rupture segments that have repeatedly produced M 7-7.5 earthquakes during the past 6,000 years (Machette and others, 1987). Siting and design criteria should be based on the expectation that the next large earthquake on the Wasatch fault will occur on one of these segments. (The next large earthquake in Utah, however, may not necessarily occur on the Wasatch fault; see 1.2.1.)

1.1.2 The pattern of timing of large surface-faulting earthquakes (M 7-7.5) on the Wasatch fault during the past 6,000 years is complicated. For the segments between Brigham City and Nephi, the *composite* recurrence interval—the average time between two faulting events anywhere on this central part of the fault zone—ranges from a maximum of 415 years to a minimum of 340 years (Machette and others, 1989).

1.1.3 Of the 6 to 8 active fault-rupture segments, the elapsed time since the last large earthquake has been longest on the Brigham City and Salt Lake City segments (3,600 and 1,500 years, respectively; Machette and others, 1989). However, the recurrence intervals for faulting on any one segment are usually quite variable (Machette and Scott, 1988, fig. 6).

1.1.4 Each segment of the Wasatch fault zone is expected to exhibit independent movement, although rupturing on one segment may be followed closely in time by rupture on another segment (Schwartz and Coppersmith, 1984; Machette and others, 1987). This pattern of more-frequent-than-average rupturing is termed temporal clustering. During an earthquake, most of the rupturing will be concentrated on the causative segment.

1.2 Sources of Seismic Hazard (J.C. Pechmann, M.N. Machette, W.J. Arabasz, K.M. Shedlock)

Seismic hazards in the Wasatch Front region arise from two different classes of earthquakes (Arabasz and others, 1987):

1.2.1 Large (M 6.3±0.2 to 7.5±0.2) earthquakes, accompanied by surface rupture, will occur in the future on the Wasatch fault as well as on a number of other known active faults in the region showing evidence of prehistoric surface faulting.

1.2.2 Moderate but potentially damaging earthquakes without surface rupture (M 5.5 to 6.5) may occur anywhere within the Wasatch Front region on either known or unknown faults. Unknown faults include buried faults which cannot be seen at the surface.

1.3 Frequency of Earthquake Occurrence (J.C. Pechmann, M.N. Machette, W.J. Arabasz, K.M. Shedlock)

1.3.1 Large surface-faulting earthquakes occur somewhere along the Wasatch fault on the average of once every 340 to 415 years (Machette and others, 1989). Large earthquakes are known to occur less frequently on other faults in the region for which information on earthquake recurrence is available (e.g., Youngs and others, 1987).

1.3.2 Analysis of the instrumental earthquake catalog from July 1962 through 1985 indicates the likelihood that potentially damaging earthquakes of M 5.5 or greater will occur on the average of once every 14 to 40 years in the Wasatch Front region. Eight earthquakes with measured or estimated magnitudes of 5.5 or greater occurred in this region from 1850 through 1988, the most recent being the 1975 M 6.0 Pocatello Valley earthquake near the Utah-Idaho border (Arabasz and others, 1987).

1.4 Characteristics of Future Large Earthquakes (J.C. Pechmann, M.N. Machette, W.J. Arabasz, K.M. Shedlock)

1.4.1 Future large earthquakes on the Wasatch fault and other major faults in Utah are expected to have characteristics similar to those of large normal faulting earthquakes that have occurred in nearby states. These earthquakes include: the 1959 M 7.5 Hebgen Lake, Montana, earthquake; the 1983 M 7.3 Borah Peak, Idaho, earthquake; and earthquakes of up to M 7.7 that have occurred this century in Nevada.

1.4.2 Future large Wasatch Front earthquakes could break sections of fault up to 70 km long and produce maximum vertical displacements at the surface of up to about 6 m. (Schwartz and Coppersmith, 1984; Machette and others, 1987; Arabasz and others, 1987). The fault ruptures will extend beneath the valleys adjacent to the faults, probably to depths of 10 to 20 km (Smith and Richins, 1984).

1.5 Surface Faulting (W.R. Lund, M.N. Machette, D.P. Schwartz)

1.5.1 Earthquakes having magnitudes of 6¼ (±¼) and greater along the Wastach Front are expected to produce surface faulting.

1.5.2 Surface faulting accompanying a magnitude 7.0-7.5 earthquake on the Wasatch fault zone will likely be characterized by:

(a) Rupture patterns that are expressed as a single fault trace or as several sub-parallel or branching traces that form a complex zone of faulting up to 500 m (1,650 ft) wide.

(b) Length of surface rupture 20-70 km (12.5-44 mi)

(c) Net tectonic displacement 2-5 m (6.5-16.5 ft)

(d) Scarp heights that can be as much as 5-6 m (16.5-19.5 ft) high with associated antithetic faulting, graben formation, and backtilting. The zone of intense ground deformation along *individual* fault traces can be as much as 50 m (165 ft) wide.

1.5.3 Surface faulting will destroy or severely damage lifelines (roads, utilities, pipelines, communication lines) that cross the fault as well as any structures built in the fault zone.

1.5.4 The hazard from surface faulting will be localized along a single segment of the fault—as opposed to associated ground shaking and ground failure, which will affect a much larger area and may be most intense away from the fault.

2.0 HAZARDS ASSOCIATED WITH GROUND SHAKING

2.1 Ground Motions for the Maximum Earthquake on the Wasatch Fault (A.M. Rogers, S.T. Algermissen, K.W. Campbell, D.M. Perkins, J.C. Pechmann, M.S. Power, J.C. Tinsley, T.L. Youd)

2.1.1 Rupture of one of the longer segments of the Wasatch fault could produce an earthquake as large as M = 7.5. Based on the studies of fault scarps and the ages and timing of fault offsets (Machette and others, 1989), the probability of such an event somewhere on the Wasatch fault in the next 50 years has been estimated to be between 4 and 20 percent (Perkins, personal comm.; Youngs and others, 1987); however, because of the variability of the data used in this analysis and the possibility of multiple interpretations, one should note that a higher probability of occurrence in 50 years cannot be ruled out at present.

2.1.2 For a M = 7.5 earthquake, urban areas adjacent to the ruptured segment (within 10 km) are expected to experience peak horizontal accelerations on soil sediments ranging from at least 0.4 to 0.6 g and peak horizontal velocities ranging from at least 50 to 100 cm/s. This zone includes most of the incorporated region of Salt Lake City, for example. At 20 km from the rupture, corresponding ground motion estimates on soil sediments are 0.2 to 0.3 g for peak acceleration and 25 to 50 cm/s for peak velocity (Campbell, 1987; Youngs and others, 1987; M.S. Power, written comm.)[1]. The motions on soft soil

1. It should be noted that the ground motion values quoted are based on data recorded primarily in California and are representative of ground motions from strike-slip faults. The Wasatch fault is a normal fault; theoretical studies suggest that a normal fault that dips underneath Salt Lake Valley would act to focus more energy in the urban area than might be expected from a strike-slip fault (Benz and Smith, 1988). This focusing is due both to the fact that the fault dips underneath the urban area and to the nature of rupture propagation on the fault.

sediments[2] will tend to be larger than on firm sediments, especially in terms of peak velocities[3].

2.1.3 The estimated values of ground motion for the hypothesized M = 7.5 earthquake roughly correspond to a Modified Mercalli Intensity (MMI) of VIII on firm sediments and X or greater on soft sediments. Modified Mercalli Intensity VIII is characterized by: partial collapse of weak masonry; damage to ordinary masonry; some damage to reinforced masonry; fall of some masonry walls; fall of chimneys, factory stacks, towers, elevated tanks; frame houses moved on foundations if not bolted down. Modified Mercalli Intensity X is characterized by: most masonry and frame structures destroyed with their foundations; some well-built wooden structures destroyed; serious damage to dams, dikes, and embankments; rails bent, and large landslides.

2.1.4 Smaller but more frequent earthquakes are expected to occur in the region that could also produce substantial damage in the Wasatch Urban Corridor (see the section on losses, this report). For example, M = 6.5 events are expected to produce ground motions on soil within 10 km of the fault that range from at least 0.25 to 0.5 g (25 to 75 cm/s). At 20 km from the rupture, corresponding ground motion estimates on soil are 0.15 to 0.25 g (15 to 35 cm/s) (Campbell, 1987; and Youngs and others, 1987; M.S. Power, written comm.). Again, the motions on soft soil sites will tend to be at the higher end of these ranges, especially for peak velocity.

2.2 **Probabilistic Ground Motion Hazard** (A.M. Rogers, S.T. Algermissen, K.W. Campbell, D.M. Perkins, J.C. Pechmann, M.S. Power, J.C. Tinsley, T.L. Youd)

2.2.1 In any 50-year time period, there is a 10 percent probability that the levels of peak horizontal ground acceleration and velocity at sites underlain by firm sediments will exceed the range 0.20 to 0.35 g and 20 to 50 cm/s, respectively, along the Wasatch Front (Algermissen and others, in preparation; Youngs and others, 1987; M.S. Power, written comm.). These values are most likely to occur within a 10-km zone located to the west of the surface trace of the Wasatch fault. These values are based on the contemporary Wasatch Front region seismic record and evidence of large earthquakes in the recent geologic past. The estimates incorporate the effects of earthquakes on the Wasatch fault, as well as more distant earthquakec. The ground motions cited correspond

2. The term "soft sediments" is used collectively to refer to sediments of low near-surface shear velocity, high near-surface shear velocity gradients, and high shear velocity contrast at the base of the sediments, which tend to occur in those parts of Salt Lake Valley underlain by deep sediments.

3. One should also note that studies by Benz and Smith (1988) indicate that at least half the spectral amplification observed in Salt Lake Valley, at periods greater than about 0.7 seconds, can be attributed to the velocity contrast between basin sediments and crystalline basement as opposed to amplification associated with near-surface soft sediments.

roughly to Modified Mercalli Intensity VIII to IX. It is likely that at this same probability level some sections of the urban areas near the epicenter would experience ground motions larger or smaller than these values, reflected by intensities one to two units above or below VIII. Higher ground motions and damage will tend to occur at sites underlain by unconsolidated alluvium and lake deposits, and lower damage levels will tend to occur at sites underlain by rock.

2.2.2 In any 10-year time period, there is a 10 percent probability that the levels of peak horizontal ground acceleration and velocity at sites underlain by firm sediments will exceed 0.06 to 0.08 g and 5 to 9 cm/s, respectively, along the Wasatch Front (Algermissen and others, in preparation; Youngs and others, 1987; M.S. Power, written comm.). These values are likely to occur anywhere within the Ogden-Salt Lake-Provo corridor. These ground motions correspond roughly to Modified Mercalli Intensity IV to VI.

2.2.3 In any 250-year time period, there is a 10 percent probability that the levels of peak horizontal ground acceleration and velocity at sites underlain by firm sediments will exceed 0.5 to 0.7 g and 55 to 110 cm/s, respectively, along the Wasatch Front (Algermissen and others, in preparation; Youngs and others, 1987; M.S. Power, written comm.). These values are most likely to occur within a 10-km zone located to the west of the surface trace of the Wasatch fault and correspond roughly to Modified Mercalli Intensity IX to X or greater.

2.2.4 Neither the deterministic ground-motion values based on maximum magnitude, the probabilistic ground-motion values, nor the intensities cited above are necessarily intended to be the design motions for this region. The choice of design ground motions should be based on the level of risk deemed appropriate for a given level of design motion. That is, a level of risk should be chosen that is acceptable to the engineering community and public officials for various classes of structures. Nevertheless, at 50-year exposure time, 10 percent probability of exceedance description of ground motion is consistent with that used by the Applied Technology Council (1978) for design ground-motion maps included in their proposed seismic regulations for buildings. The same specifications for ground motion are used in the National Earthquake Hazards Reduction Program "NEHRP Recommended Provisions for the Development of Seismic Regulations for Buildings" (Building Seismic Safety Commissions, 1985) and are the basis for the new 1988 Uniform Building Code (UBC). Thus, the probabilistic ground-motion values quoted above can be compared directly with ground-motion maps used nationally for the development of seismic provisions of building codes. The 10-year exposure period ground motions have not been used as design motions in the past, but are cited here to convey the short-term hazard, which is mostly due to intermediate-sized earthquakes. The 250-year exposure period ground motions have been used in the past as design values for critical facilities, such as hospitals, power plants, etc. For this exposure, the probabilistic ground motions convey the hazard due to the occurrence of large earthquakes, which are also more likely to occur over a 250-year exposure period compared to shorter intervals.

2.3 The Effect of Site Conditions on the Ground Motions of Distant Earthquakes (A.M. Rogers, S.T. Algermissen, K.W. Campbell, D.M. Perkins, J.C. Pechmann, M.S. Power, J.C. Tinsley, T.L. Youd)

2.3.1 Based on recordings of distant nuclear explosions in Nevada, it is known that sediment properties in Salt Lake Valley can produce substantial geographical variation in the level of ground motions (Hays, 1987; King and others, 1987). Theoretical studies of ground motion in Salt Lake Valley qualitatively support this observation (Benz and Smith, 1988; Schuster and others, 1990). The data collected by Hays and King, and others suggest that mean spectral estimates of low-amplitude ground-motion values are increased by factors of 6 to 10 or more in some sections for the valley, compared to hard rock, for the period range 0.2 to 3.0 seconds[1]. The effects noted are about a factor of 1.5 to 2 greater than have been observed in Los Angeles (Rogers and others, 1985), but are comparable to amplifications observed in the damaged zone of Mexico City (Singh, and others, 1988). The implication of such large site factors is that an earthquake of a given size at any given distance is likely to be more destructive in the Salt Lake area than in, say, the Los Angeles area.

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1. Considerable controversy continues in the scientific and engineering communities concerning the response of alluvium under conditions of strong shaking such as occurs in the near-field of a large earthquake. The amplification factors that are quoted for Salt Lake Valley are based on the measurements of distant Nevada Test Site underground nuclear tests, and strict application of these measurements to predict the response of alluvium under conditions of strong earthquake shaking represents an extrapolation. This extrapolation was shown, however, to approximate the measured response of alluvium in Los Angeles during the San Fernando earthquake (Rogers and others, 1985). The alluvium site-response issue continues to be discussed in connection with two questions, 1) is ground shaking greater on alluvium compared to rock at the same distance from a fault rupture; 2) are peak accelerations greater on alluvium compared to rock, all else equal? These questions are fundamentally related to how the alluvium shear velocity and attenuation parameters change under strong shaking. Clearly, low-amplitude site response factors cannot be applied to all levels of rock motion to estimate corresponding levels on alluvium. At some level of ground shaking and for some ground motion periods, the non-linear behavior of alluvium acts to limit the upper level of shaking. Nonetheless, the reader should be aware that large damaging levels of ground shaking are sustainable on some types of alluvium, as demonstrated clearly in the 1985 Mexico City and Chile events. In Chile, peak accelerations at several sites underlain by alluvium reached levels in the 0.6-0.7g range while the levels at sites underlain by rock at equivalent distances from the fault reached levels of only 0.15-0.25g. Continued research is required to fully understand the response characteristics of alluvium under strong ground shaking conditions, the situations under which site factors determined from low-level motions apply, and the specific behavior of the types of alluvium found along the Wasatch Front. At present, there is no information which would prevent us from erring on the side of safety, that is, that large low-amplitude site response measurements indicate the potential for relatively high ground shaking values, particularly for taller buildings and earthquakes that are some distance from the site under consideration.

2.3.2 Generally, individual buildings respond to narrow ranges of ground-motion periods (spectral ground motions) in a manner that is strongly dependent on building height; a general rule of thumb is that the period to which a building is most sensitive, i.e., its fundamental period, is equal to the number of stories divided by 10. For example, a 9-story building would have a fundamental period of about 0.9 seconds and be most sensitive to damage from ground motions of about 0.9 seconds. Thus, the effects noted by Hays and King, and others (see section 2.3.1) would have the greatest effect on structures with heights between 2 to 30 stories.

2.3.3 Moderate-to-large earthquakes at some distance could also cause more damage to high-rise structures located on deep sediment sites than might be expected from our extensive California experience. In particular, because of the nature of geologic site conditions in Salt Lake Valley, the ground-shaking hazard to high-rise structures sited over deep and soft valley sediments (fine sand and lake-clay deposits) are likely to be enhanced compared to the hazard at sites underlain by coarse sand and gravel, especially for distant earthquakes. For distant earthquakes, the ground motion levels that occur at the soft sediment sites are expected to be 6 to 10 times greater than at rock sites, for periods greater than about 0.2 s. For this reason, high-rise structures constructed on soft deep valley sediments may require special design to accommodate exceptionally large expected ground motions.

2.4 Losses from Ground Shaking and Other Effects (E.V. Leyendecker, S.T. Algermissen, L.M. Highland, D. Mabey, A.M. Rogers, C.M. Taylor, L. Reaveley)

2.4.1 **Effect of Magnitude and Location of Rupture on Economic Loss.**—North-central Utah should expect direct economic losses to reach $4.5 to $5.5 billion for a magnitude 7.5 earthquake occurring on the Wasatch fault zone. Losses in the four-county area of Davis, Salt Lake, Utah, and Weber counties could be as large as 23 percent of the $23.7 billion building inventory due to the effects of ground shaking and fault rupture. Losses in the same four counties range from $2.3 billion to $4.0 billion for a magnitude 6.5 earthquake and $830 million to $1.9 billion for a magnitude 5.5 earthquake. These estimates of losses due to ground shaking and fault rupture in the immediate vicinity of the Wasatch Fault have been made by Algermissen and others (1988) for a series of simulated earthquakes treated both as scenario (deterministic) and probabilistic. The scenario studies included earthquakes of different magnitudes occurring one at a time on the Provo, Salt Lake, or Weber segments of the Wasatch fault and an earthquake on a hypothetical fault west of Salt Lake City. The smallest losses result from rupture on the Provo segment while the largest losses result from rupture on the Salt Lake segment.

2.4.2 **Effect of Construction Type.**—Buildings and other structures that do not consider modern design requirements appropriate to the hazard can contribute greatly to the losses in an area. Unreinforced masonry buildings are particularly vulnerable to ground shaking. These are a large percentage of the building inventory in the four-county study area and contribute significantly to the losses. Other structural types likely to experience a large percentage of loss include reinforced concrete frame construction that has not been designed to resist earthquake ground motion.

2.4.3 **Effect on Deaths and Injuries.**—Rogers and others (1976) included estimates of deaths and injuries in a study of earthquake losses in the same four counties included in the economic loss study. Analysis of the events indicates that under the worst condition as many as 2,300 people would die, and 9,000 additional persons would suffer injuries requiring hospitalization or immediate medical treatment. The number of deaths could be as high as 14,000 if deaths from dam failure are included in the casualty total.

2.4.4 **Effect on State-Owned Buildings.**—As a result of the geographical concentration of the wealth of State-owned buildings, and of the limited seismic resistance of many of them, losses in a major Wasatch fault earthquake could easily reach 30 or even 40 percent of replacement value (Taylor and others, 1986).

2.4.5 **Effect on Lifelines.**—Liquefaction-induced ground failure along with other localized effects are likely to disrupt Wasatch Front water and natural gas systems. Except for the natural gas systems in Utah and Weber Counties, no service should be expected following a major localized earthquake. Thousands of water pipe breaks may occur and hundreds of natural gas main breaks may occur (Taylor and others, 1988; Highland, 1986). Rogers and others (1976) also examined effects on different types of lifelines. They concluded that there would be at least temporary disruption to the transportation systems—including highways, bridges, airports, and railways. There would be collapses of some structures due, in part, to earthquake resistance not being included in their design requirements.

2.4.6 **Effect on Water Impoundment Systems.**—There may be losses relating to the Great Salt Lake and Utah Lakes from a major earthquake. These losses will vary depending on factors such as lake elevations and tectonic deformation. The lake beds are areas of high liquefaction potential and dikes constructed on the lake beds are likely to be damaged and may fail in a major shaking event. Seiches may cause the Great Salt Lake and Utah Lake to oscillate for many hours, temporarily raising and lowering the water level, compounding the problem. Dike failure and or tectonic deformation of the lake beds could result in rapid inundation of some developed areas adjacent to the lakes with large losses of life and property. The study by Rogers and others (1976) examined possible dam failures. They concluded that there would be at least one dam failure and examined its effects.

2.4.7 **Other Loss Effects.**—Except for fault rupture, economic losses from liquefaction, landslides, and other ground failures have not been estimated in the Algermissen and others (1988) study. These would only increase the losses. Additional losses could be expected from factors such as fire and flooding due to dam or other water impoundment failure.

3.0 HAZARDS ASSOCIATED WITH GROUND FAILURE

3.1 Ground Failure Hazard (T.L. Youd, L. Anderson, C. Taylor)

3.1.1 Sediments susceptible to liquefaction lie beneath many areas in the lower parts of the valleys along the Wasatch Front. Large earthquakes (magnitude greater than 7) are likely to trigger liquefaction and destructive ground failures in many of these sediments. Small to moderate earthquakes (magnitude 5 to 7) are likely to trigger liquefaction locally with less severe effects.

3.1.2 The most common consequences of liquefaction along the Wasatch Front are expected to be lateral spreads. These ground failures, which occur on gentle slopes, would cause ground displacements of up to several feet along with fracture of buildings, roads, and other surface works located on the unstable ground. Pipelines and other buried facilities passing through the spreads would likely be broken or severed. Displacements capable of causing damage in the most susceptible sediment might be expected locally on the average of once in a hundred years. Larger and more widespread displacements would be associated with the more infrequent large earthquakes.

3.1.3 Major damage from rock falls, rock slides, and other slope instability should be expected on steep slopes such as within canyons and along mountain fronts. For earthquakes larger than magnitude 6.5, these failures would be distributed over a rather wide area. Smaller earthquakes could cause similar failures, but only within a few miles of the earthquake source. Facilities most commonly disrupted by these types of failures are lifelines such as pipelines, powerlines, and roads.

4.0 REFERENCES

Algermissen, S.T., Arnold, E.P., Steinbrugge, K.V., Hopper, M.G., and Powers, P.S., 1988, Earthquake losses in central 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 88-680, v. III, p. X1-X62.

Algermissen, S.T., Thenhaus, P.C., Hanson, S.L., Perkins, D.M., and Bender, B.L., 1989, Earthquake hazard in Utah: U.S. Geological Survey Professional Paper (in preparation).

Applied Technology Council, 1978, Tentative provisions for the development of seismic regulations for buildings: National Science Foundation Publication 78-8, 505 p.

Arabasz, W.J., Pechmann, J.C., and Brown, E.D., 1987, 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 Open-File Report 87-585, p. D1-D39 [edited version in press, 1991, U.S. Geological Survey Professional Paper 1500].

Benz, H.M., and Smith, R.B., 1988, Elastic-wave propagation and site amplification in the Salt Lake Valley, Utah, from simulated normal faulting earthquakes: Bulletin of the Seismological Society of America, v. 78, p. 1851-1874.

Building Seismic Safety Council, 1985, NEHRP recommended provisions for the development of seismic regulations for new buildings: Federal Emergency Management Agency, Washington, D.C.

Campbell, K.W., 1987, Predicting strong ground motion in 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, v. II, p. L1-L90 [edited version in press, 1991, U.S. Geological Survey Professional Paper 1500].

Hays, W.W., 1987, Site amplification in the Salt Lake City-Ogden-Provo, Utah, corridor and the implication for earthquake-resistant design, *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, v. II, p. K1-K69 [edited version in press, 1991, U.S. Geological Survey Professional Paper 1500].

Highland, L.M., 1986, Earthquake hazards to domestic water distribution systems in Salt Lake County, Utah, *in* Proceedings of the Distribution System Symposium, September 8-11, 1985: Seattle, Washington, American Water Works Association.

King, K.W., Williams, R.A., Carver, D.L., 1987, Relative ground response in Salt Lake City and areas of Springville-Spanish Fork, 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, v. II, p. N1-N48 [edited version in press, 1991, U.S. Geological Survey Professional Paper 1500].

Machette, M.N., Personius, S.F., and Nelson, A.R., 1987, Quaternary geology along the Wasatch fault zone: Segmentation, recent investigations, and preliminary 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 Open-File Report 87-585, p. A1-72 [edited version in press, 1991, U.S. Geological Survey Professional Paper 1500].

Machette, M.N., and Scott, W.E., 1988, Field trip introduction *in* Machette, M.N., ed., In the footsteps of G.K. Gilbert—Lake Bonneville and neotectonics of the eastern Basin and Range Province: Geological Society of America Guidebook to Field Trip 12, Utah Geological and Mineral Survey Miscellaneous Publication 88-1, p. 7-16.

Machette, M.N., Personius, S.F., Nelson, A.R., Schwartz, D.P., and Lund, W.R., 1989, Segmentation models and Holocene movement history of the Wasatch fault zone, Utah, *in* Schwartz, D.P., and Sibson, R.H., eds., Proceedings of Conference XLV, Fault segmentation and controls of rupture initiation and termination: U.S. Geological Survey Open-File Report 89-315, p. 229-242.

Rogers, A.M., Algermissen, S.T., Hays, W.W., and Perkins, D.M., 1976, A study of earthquake losses in the Salt Lake City, Utah, area: U.S. Geological Survey Open-File Report 76-89, 357 p.

Rogers, A.M., Tinsley, J.C., Borcherdt, R.D., 1985, Predicting relative ground response, *in* Ziony, J.I., ed., Evaluating earthquake hazards in the Los Angeles region: U.S. Geological Survey Professional Paper 1360, p. 221-248.

Schuster, G., Benz, H., Murphy, M., Hill, J., Sikorski, C., Tsay, C., 1990, Prediction of seismic ground amplification by forward modeling techniques, *in* Ward, S.H., ed., Geotechnical and environmental geophysics, Volume 1: Review and tutorial: Society of Exploration Geophysics, in press.

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

Singh, S.K., Mena, E., Castro, R., 1988, Some aspects of source characteristics of the 19 September 1985 Michoacan earthquake, and ground motion amplification in and near Mexico City from strong motion data: Bulletin of the Seismological Society of America, v. 78, p. 451-477.

Smith, R.B., and Richins, W.D., 1984, Seismicity and earthquake hazards of Utah and the Wasatch front: Paradigm and paradox, *in* Hays, W.W., and Gori, P.L., eds., Proceedings of Conference XXVI, A workshop on evaluation of regional and urban earthquake hazards and risk in Utah: U.S. Geological Survey Open-File Report 84-763, p. 73-112.

Taylor, C.E., Wiggins, J.H., Haber, J.M., and Ward, D.B., 1986, A systems approach to Wasatch Front seismic risk problems: Long Beach, California, NTS Engineering under USGS Contract No. 14008-001-G1394.

Taylor, C.E., Salmon, M., Eguchi, R., Campbell, R., and Tillman, C., 1988, Continuing investigations of earthquake risks to Utah water and gas systems: Long Beach, California, NTS Engineering under USGS Contract No. 14008-001-G1394.

Youngs, R.R., Swan, F.H., Power, M.S., Schwartz, D.P., and Green, R.K., 1987, Probabilistic analysis of 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, p. M1-M110 [edited version in press, 1991, U.S. Geological Survey Professional Paper 1500].

APPENDIX B

UTAH'S EARTHQUAKE THREAT

THE UNIVERSITY OF UTAH

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As early as 1883, the eminent geologist G.K. Gilbert recognized and warned of the serious earthquake threat posed by the Wasatch fault and other active faults in Utah despite the absence up to that time of any large earthquakes in the region since settlement by Mormon pioneers in 1847.

The Wasatch Front area is a classic example of a seismically active region having only moderate historical seismicity but high catastrophic potential from future large earthquakes. Devastation caused by the magnitude 6.9 earthquake in Armenia on December 7, 1988, gives a real-world lesson for such situations. The high death toll of at least 30,000 people in the Armenian earthquake, due primarily to the collapse of modern buildings, emphasizes the price for not heeding the threat of infrequent large earthquakes. According to Peter Yanev (an American earthquake engineering specialist), "Rarely has the importance of systematic risk identification and proper seismic design and construction in earthquake-prone areas been more apparent (than in the Armenian earthquake)" (*EPRI Journal*, June 1989, p. 24).

Seismologists, geologists, and engineers are in fundamental agreement about technical details of the earthquake threat in Utah—where, how big, how often, and what's going to happen. That consensus, summarized below, was arrived at as part of a special five-year focus (1983-1988) on the Wasatch Front region under the National Earthquake Hazards Reduction Program.

• When and where do large earthquakes occur in Utah?

— Large earthquakes (magnitude 6.5 to 7.5) can occur on any of several active segments of the Wasatch fault between Brigham City and Levan (see Figure on right). Such earthquakes can also occur on many other recognized active faults in Utah.

— During the past 6,000 years, large earthquakes have occurred on the Wasatch fault on the average of once every 400 years, somewhere along the fault's central active portion between Brigham City and Levan.

— The chance of a large earthquake in the Wasatch Front region during the next 50 years is about 1 in 5.

• What would happen if a magnitude 7.5 earthquake occurs along the Wasatch fault?

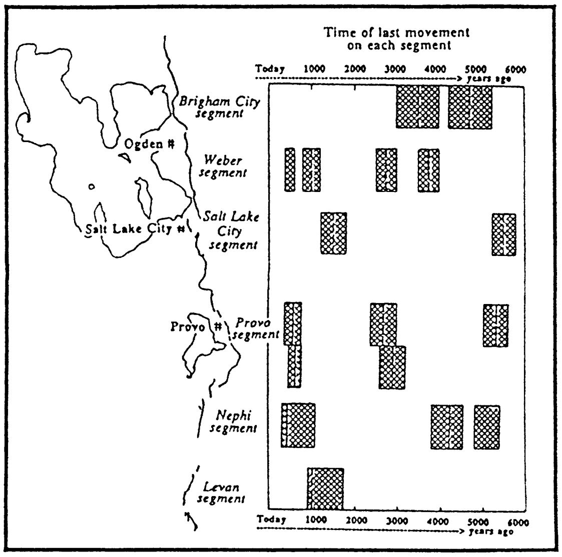
— Future large earthquakes will break segments of the fault about 20 - 40 miles long and produce displacements at the surface of up to 10 - 20 feet.

— Strong ground shaking could produce considerable damage up to nearly 50 miles from the earthquake.

—The strong ground shaking may be amplified by factors up to 10 or more on valley fill compared to hard rock.

—Also possible are soil liquefaction, landslides, rock falls, and broad permanent tilting of valley floors possibly causing the Great Salt Lake or Utah Lake to inundate parts of Salt Lake City or Provo.

Prehistoric Earthquakes on Segments of the Wasatch Fault



Timing of large prehistoric earthquakes on the central part of the Wasatch fault during the past 6,000 years. Note the irregular pattern of occurrence. Heavy dashed lines are best estimates of faulting and cross-hachure pattern represents likely limits for timing as determined by radiocarbon and thermoluminescence dating. Adapted from *Segmentation models and Holocene movement history of the Wasatch fault zone, Utah*, by Machette and others, 1989, U.S. Geological Survey Open File Report 89-315, pp. 229-245.

• How much damage would be caused by a large earthquake on the Wasatch Front?

— If the earthquake were to occur on a central part of the Wasatch fault, Utah should expect damage to buildings to exceed $4.5 billion in Davis, Salt Lake, Utah and Weber counties. This may only represent 20% of the total economic loss.

— A 1976 study by the U.S. Geological Survey for a worst case earthquake on the central Wasatch fault estimated 2,300 casualties (assuming no dam failures), 9,000 injured and 30,000 homeless. The experience of the 1988 Armenian earthquake—and engineering judgment about the collapse potential of many Wasatch Front structures—suggests the 1976 fatality estimate is low.

— Unreinforced masonry buildings (for example, brick homes built before 1960) are particularly vulnerable to ground shaking and are expected to account for 75% of the building losses.

— Surface faulting and ground failures due to shaking during a large earthquake will cause major disruption of lifelines (utilities, water, sewer), transportation systems (highways, bridges, airports, railways), and communication systems.

"It is useless to ask when this [earthquake] disaster will occur. Our occupation of the country has been too brief for us to learn how fast the Wasatch grows; and, indeed, it is only by such disasters that we can learn. By the time experience has taught us this, Salt Lake City will have been shaken down..."

– G. K. Gilbert, 1883

"Whatever the earthquake danger may be, it is a thing to be dealt with on the ground by skillful engineering, not avoided by flight...."

– G. K. Gilbert, ca. 1906

• Do we need to worry only about large earthquakes causing damage?

— No. A moderate-sized earthquake that occurs under an urbanized area can cause major damage.

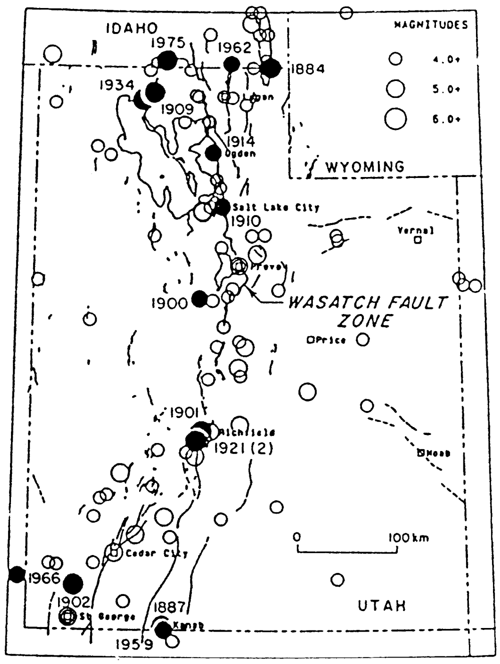
— Magnitude 5.5 - 6.5 earthquakes occur somewhere in Utah on the average of once every 7 years.

— Estimates of damage from a "direct hit" to one of the Wasatch Front's major metropolitan areas reach $2.3 billion for a magnitude 6.5 earthquake, and more than $830 million for a magnitude 5.5 earthquake.

— Since 1850, at least 15 independent earthquakes of magnitude 5.5 and larger have occurred in the Utah region (see Figure at right).

Recent magnitude 5.0 and larger earthquakes in the Utah region include:

Local Date	Magnitude	Location
Jan. 29, 1989	5.4	16 miles SE of Salina
Aug.14, 1988	5.3	Central Emery County
Mar. 27, 1975	6.0	Pocatello Valley (Utah - Idaho border)
Oct. 14, 1967	5.2	Marysvale
Aug. 16, 1966	5.6	Utah-Nevada Border
Sep. 5, 1962	5.2	Salt Lake Valley
Aug.30, 1962	5.7	Cache Valley



Epicenter map of all earthquakes of magnitude 4.0 and larger, (excluding foreshocks and aftershocks), in the Utah region from 1850 through 1989. Earthquakes of estimated magnitude 5.5 and greater are indicated by solid circles and labeled with date. Adapted from *Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch Front area, Utah,* by Arabasz and others, 1989, U.S. Geological Survey Professional Paper.

• When were the largest historical earthquakes in Utah?

Since settlement in 1847, Utah's largest earthquakes were the 1934 Hansel Valley earthquake, north of the Great Salt Lake, magnitude 6.6, and the 1901 earthquake near the town of Richfield, estimated magnitude 6.5

• How often do earthquakes occur in Utah?

About 700 earthquakes (including aftershocks) are located in the Utah region each year. Approximately 2% of the earthquakes are felt. An average of about 13 earthquakes of magnitude 3.0 or larger occur in the region every year. Earthquakes can occur anywhere in the state of Utah.

• How many earthquakes occur in the Wasatch Front region?

About 500 earthquakes are located in the Wasatch Front region each year. About 60% of the earthquakes of magnitude 3.0 and larger in Utah occur in the Wasatch Front region.

• When was the last earthquake?

Worldwide: In the last minute, somewhere in the world.
Utah: Within the past 24 hours, somewhere in the state.
(The last *large* earthquake in Utah occurred on the Wasatch fault north of Nephi about 400 years ago.)

• When were seismographs first installed in Utah?

In 1907, by James Talmage at the University of Utah. A skeletal statewide network began in 1962. Modern seismographic surveillance in the Wasatch Front began in 1974. Computerized recording of earthquake data began in 1981.

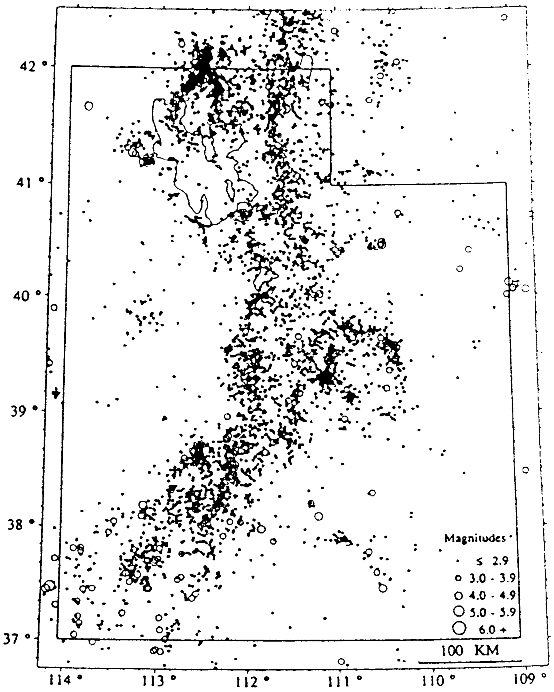
• Do earthquakes occur only on visible faults?

No. Many of the active faults in Utah are deep below the earth's surface, and are not visible to us.

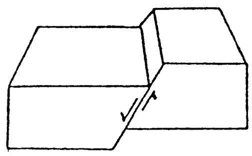
• Is the Wasatch fault the same type of fault as the San Andreas fault in California?

No. The San Andreas fault slips horizontally with little vertical movement. This is called a strike-slip fault. The Wasatch fault slips in a primarily vertical direction, with the mountains rising relative to the valley floor. The Wasatch fault is a so-called normal fault. All earthquakes produce both vertical and horizontal ground shaking. Usually the horizontal shaking is more energetic and more damaging because structures generally resist vertical loads, like gravity, more easily.

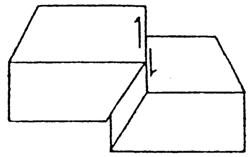
Seismicity of Utah



Each dot represents one earthquake located by the University of Utah Seismograph Stations from July 1962 through December 1989 (11,285 earthquakes).



Normal fault
(Wasatch fault type)



Strike-slip fault
(San Andreas fault type)

General Earthquake Information

• What is an earthquake?

A trembling or shaking of the ground caused by the sudden release of energy stored in the rocks below the surface, radiating from a fault along which movement has just taken place.

• How long do earthquakes last?

Generally, only seconds. Strong ground shaking during a moderate to large earthquake typically lasts about 10 to 30 seconds. Readjustments in the earth cause more earthquakes (aftershocks) that can occur intermittently for weeks or months.

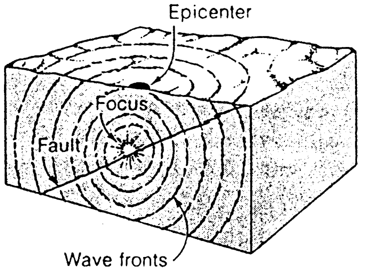


Diagram showing the focus and epicenter of an earthquake. The focus is the site of initial slip on the fault. The epicenter is the point on the surface above the focus. Also shown are seismic waves radiating from the focus.

• Is there an '*earthquake season*' or '*earthquake weather*'?

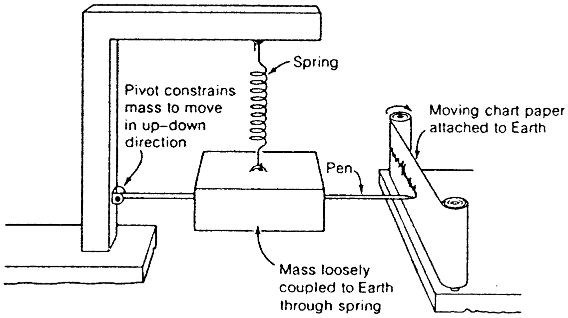
No. Earthquakes can occur at any time of the year and at any time of the day or night. Earthquakes occur under all weather conditions, sunny, wet, hot, or cold–without special tendency.

• Where is the safest place to be in an earthquake?

In an open field, where nothing can fall on you. Earthquakes do not injure or kill people; buildings and falling objects do. If you are indoors, when you feel the ground start to shake, take cover immediately under a table or sturdy piece of furniture, placing a barrier between falling objects and yourself. Do not attempt to use the stairs or an elevator or run out of the building.

• Will the ground open up during an earthquake?

The ground does not open up and swallow people (a commonly feared myth). Open ground cracks may form during an earthquake–related, for example, to landsliding or ground slumping. But such fissures are open gaps (they don't "swallow") that a person could stand in.



Cartoon depicting a seismograph that records vertical ground motion.

• What is a seismometer, seismograph, and a seismogram?

A seismometer is an sensor placed in the ground to detect vibrations of the earth. A seismograph is an instrument that records these vibrations. A seismogram is the recording (usually paper or film) of the earth's vibrations made by a seismograph.

• When was the seismograph invented?

In 1880. The earliest seismographs in the U.S. were installed in 1887, in California. (In 132 A.D. a Chinese scholar, Chang Heng, made a mechanical device to detect the first main impulse of ground shaking.)

• What is the Richter Scale?

A scale for determining the size of an earthquake from the recording of earthquake waves made on a seismograph. The maximum height of the visible recording is adjusted for the distance from the instrument to the earthquake. This is not a physical scale (in other words, one cannot look at or hold the "Richter Scale"). Each 1-unit increase in the Richter Scale roughly corresponds to a 30-fold increase in energy release and a 10-fold increase in ground motion at any site.

The Richter magnitude is the number generally reported in the press, and in principle the value should be the same at all recording locations (though natural variations and the use of diverse scales may lead to reported numbers that slightly differ). Due to the earth's physical limitations, the largest earthquakes have Richter magnitudes in the upper 8 range.

Magnitude	Energy equivalence
-2	100 watt light bulb left on for a week
-1	Smallest earthquake detected at Parkfield, CA
0	Seismic waves from one pound of explosives
1	A two-ton truck traveling 75 miles per hour
2	
3	Smallest earthquakes commonly felt
4	Seismic waves from 1,000 tons of explosives
5	
6	
7	1989 Loma Prieta ,CA earthquake (magnitude 7.1)
8	1906 San Francisco earthquake (magnitude 8.3)
9	Largest recorded earthquake (magnitude 8.9)

• Do many small earthquakes prevent larger earthquakes?

No. Observed numbers of small earthquakes are too few to equal the amount of energy released in one large earthquake. (It would take roughly 24 million earthquakes of magnitude 2 to release the same energy as one earthquake of magnitude 7.)

• Can we predict earthquakes?

No. We cannot predict the precise time, location, and size of earthquakes in the U.S. (except in special study areas, such as Parkfield, CA). In order to predict earthquakes there has to be an adequate history of repeated earthquake cycles and/or extraordinary instrumental observations. Long-term forecasts (on scales of years or decades) are becoming common for well-studied earthquake zones. The Chinese have correctly predicted some earthquakes, evacuated cities and saved lives. They have also had large earthquakes occur with no predictions and have predicted earthquakes that never occurred.

Magnitude	Energy released (millions of ergs)
-2	600
-1	20000
0	600000
1	20000000
2	600000000
3	20000000000
4	600000000000
5	20000000000000
6	600000000000000
7	20000000000000000
8	600000000000000000
9	20000000000000000000

• What is liquefaction?

Water-saturated sands, silts, and other very loosely compacted soils, when subjected to earthquake motion, may be rearranged, thereby losing their supporting strength. When this occurs, buildings may partly sink into the ground and sand and silts may come to the surface to form sand flows. In effect, the soils behave as dense fluids when liquified.