WASATCH FRONT FORUM

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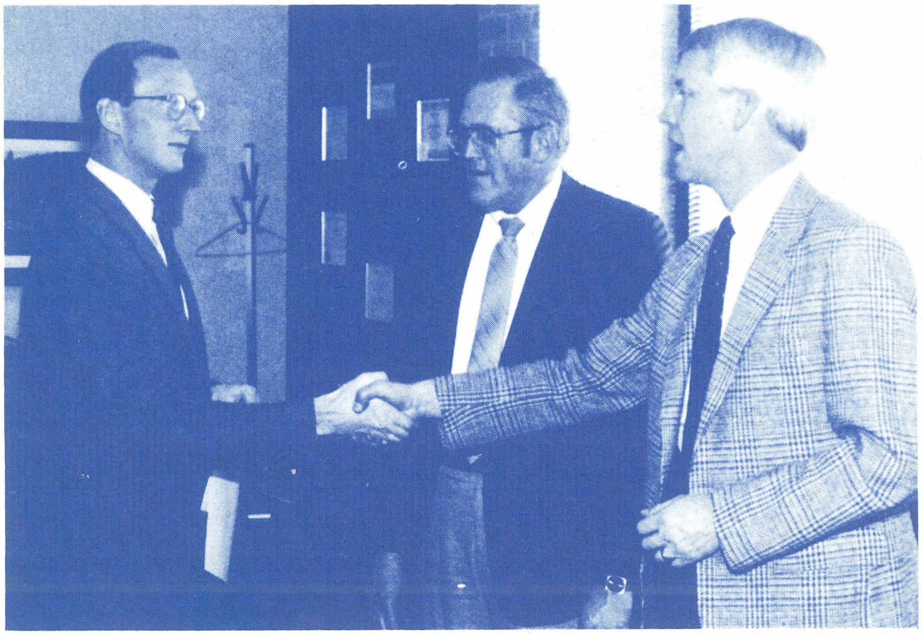
EARTHQUAKE HAZARDS PROGRAM

JIM TINGEY HITS THE ROAD

James Tingey, long-time co-editor of the Wasatch Front Forum (WFF) and Manager of CEM's Earthquake Preparedness Information Center (EPICENTER), resigned in August (coincidentally the week before the St. George earthquake) to accept a position as a risk analyst with the Los Alamos National Laboratory in New Mexico. The earthquake community in Utah has lost one of its "most valuable players" in Jim, and will miss his vision and abilities as a leader, advocate, coordinator, facilitator, and planner. Jim has been "Mr. Earthquake" in Utah since starting CEM's earthquake-planning program in 1984. He was instrumental in establishing the CEM/FEMA Comprehensive Cooperative Agreement during the NEHRP years (1983-1988) and beyond, and was recognized by the NEHRP cooperating agencies in 1988 with a Certificate of Appreciation in recognition of his accomplishments.



Jim Tingey (left) is recognized in 1986 by then-Commissioner of Public Safety Loren Nielson (right) and present Commissioner Douglas Bodrero (center), for his meritorious service in fostering earthquake preparedness.

He is the architect of the State's earthquake emergency response and preparedness plan, and he established lines of communication and cooperation for federal-state-local government interaction during a major earthquake disaster. In 1991, he founded the EPICENTER at CEM, and was instrumental in establishing and defining the goals of the Utah Earthquake Advisory Board that same year. He was a dynamic, sought-after spokesperson on earthquake issues throughout Utah.

We at the WFF have worked with Jim for many years on a variety of projects, and wish to thank him for his tireless efforts on behalf of public safety, earthquake preparedness, and the WFF. We'll miss you Jim!

Bob Carey and Fred May will be taking over Jim's duties at CEM and EPICENTER. Bob has replaced Jim as coeditor of the WFF.

Earthquake Activity in the Utah Region

January 1 – March 31, 1992

Susan J. Nava, University of Utah Seismograph Stations
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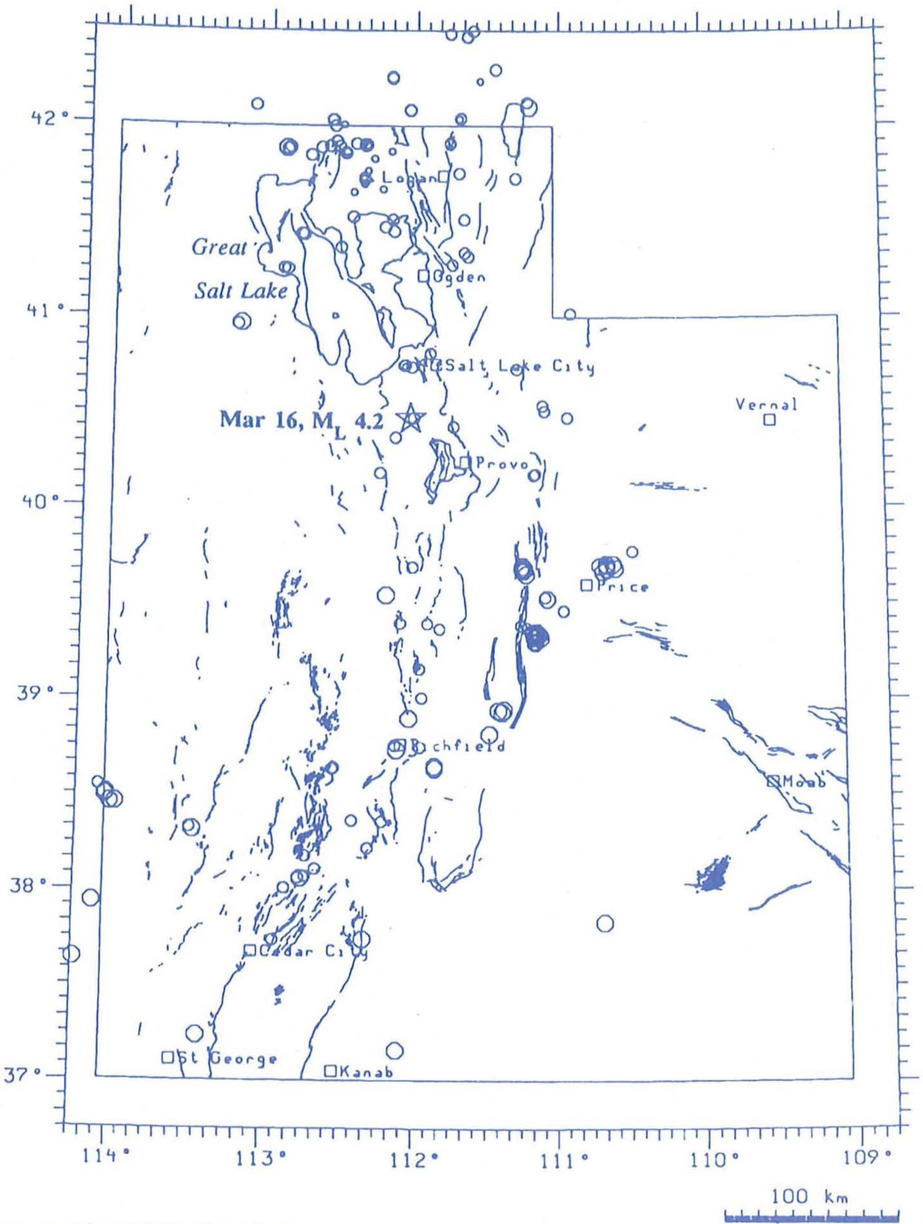

During the three-month period January 1 through March 31, 1992, the University of Utah Seismograph Stations located 180 earthquakes within the Utah region. The total includes one earthquake in the magnitude 4 range, specifically labeled on the epicenter map, and 64 in the magnitude 2 range. (Note: Magnitude indicated is either local magnitude, M_L, or coda magnitude, M_C. All times indicated are local time, which was Mountain Standard Time).

Larger and/or Felt Earthquakes

• M_C 2.5	February 12	7:54 p.m.	8 miles WNW of Orangeville; felt at Cottonwood Creek Mine
• M_L 2.4	March 4	7:41 a.m.	5 miles WNW of Sigurd; felt in Aurora and Sigurd
* • M_L 4.2	March 16	7:42 a.m.	6 miles SW of Riverton; felt in Salt Lake Valley and Utah Valley

*More information on this earthquake is available in, "The March 16, 1992, M_L 4.2 Western Traverse Mountains earthquake, Salt Lake County, Utah," G.E. Christenson, compiler, Utah Geological Survey Open-File Report 255, 1992.

Significant Clusters of Earthquakes

- Southwest and northeast of Price (coal-mining related): Three clusters of earthquakes (magnitude 1.5 to 2.9) make up 24% of the shocks that occurred in the Utah region during the report period.

Additional information on earthquakes within the Utah region is available from the University of Utah Seismograph Stations.

THE ST. GEORGE (WASHINGTON COUNTY), UTAH EARTHQUAKE OF SEPTEMBER 2, 1992

by Walter J. Arabasz,
James C. Pechmann, and
Susan J. Nava
University of Utah Seismograph Stations

OVERVIEW

A moderate earthquake occurred 5 miles southeast of St. George in the southwestern corner of Utah at 04:26 a.m. MDT (local time) on Wednesday morning, September 2, 1992. The local or Richter magnitude (M_L) of 5.8 assigned by the University of Utah Seismograph Stations makes it the largest earthquake in the Utah region since the magnitude 6.0 Pocatello Valley (Idaho-Utah border) earthquake of March 1975. Eight main shocks of magnitude 5.0 or greater have now been instrumentally located in the Utah region since 1962. The largest prior historical earthquake in the immediate vicinity of St. George was a shock of estimated magnitude 6.0 that occurred on November 17, 1902, about 32 km (20 mi) north of St. George in Pine Valley, Utah.

In this preliminary report, we emphasize seismological data relating to the earthquake of September 2, 1992. We summarize information

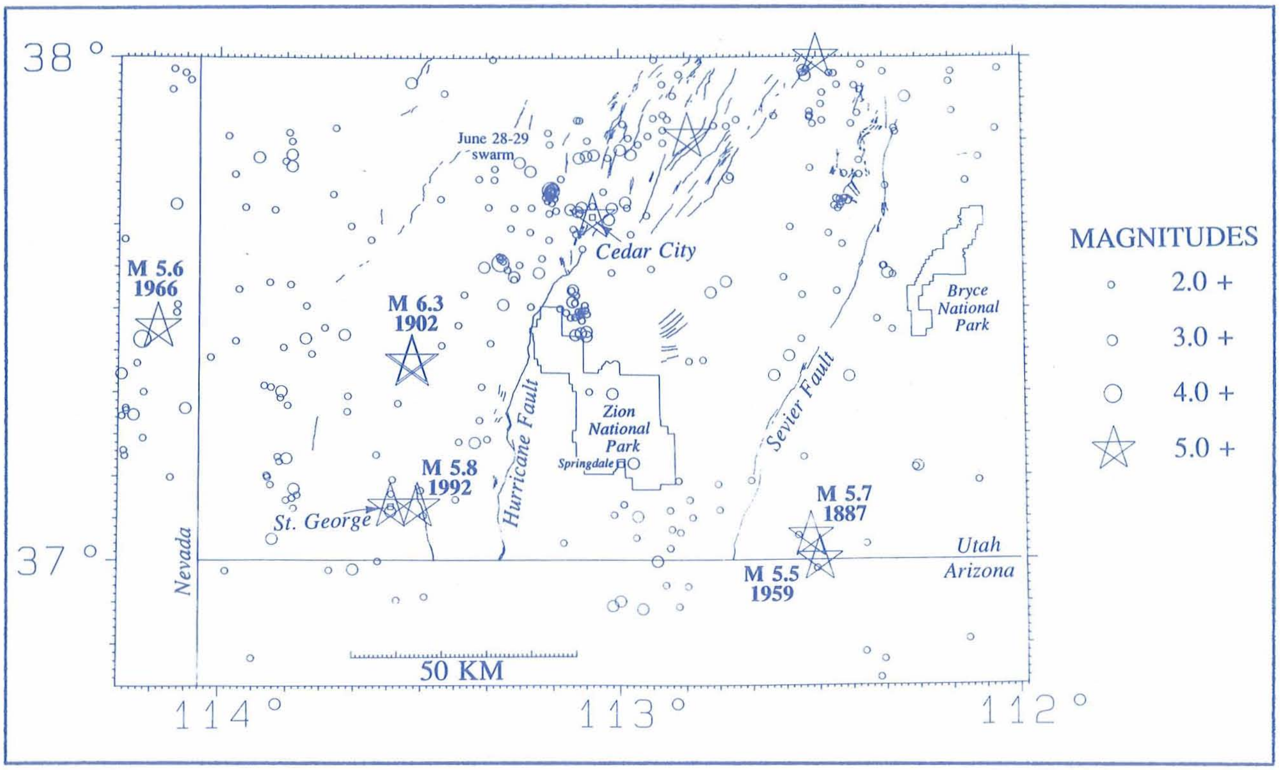

Figure 1. Map showing the epicenters (circles) of earthquake in southwestern Utah, June 1 through September 5, 1992. Earthquakes of special interest—including the magnitude 5.8 earthquake on September 2—are labeled. Also shown are the locations of geologically young faults (after Hecker, in press). Despite coincidence of its epicenter with the Washington fault, the magnitude 5.8 earthquake possibly originated on a subsurface projection of the Hurricane fault.

compiled to date by staff of the University of Utah Seismograph Stations—augmented by important contributions from seismological colleagues at other earthquake research centers in the western United States (see Acknowledgments).

In terms of the human impact of the earthquake, briefly, the main shock was reported felt over a widespread area in southwestern Utah and as far away as Richfield, Utah, Flagstaff, Arizona, and Las Vegas, Nevada. Early reports in the news media and from the Utah Division of Comprehensive Emergency Management and the Utah Geological Survey indicate: (1) no deaths or serious injuries; (2) structural damage in Hurricane, New Harmony, and Springdale (see figure 1); (3) massive, destructive landslide in Springdale, 48 km (30 mi) northeast of the epicenter; and (4) minor damage in St. George and other communities within about 56 km (35 mi) of the main shock.

BACKGROUND INFORMATION

Southwestern Utah lies within the Intermountain seismic belt (e.g., Smith and Arabasz, 1991), within which small earthquakes (less than magnitude 4) are relatively frequent. Although historical earthquakes haven't exceeded magnitude 6½ in southwestern Utah, geological studies of faulting and evidence of prehistoric earthquakes indicate that this region has the potential for earthquakes in the magnitude 7 to 7½ range (Anderson and Christenson, 1989; Christenson and Nava, 1992). Figure 1 shows the distribution of earthquakes located in the southwestern corner of Utah from June 1 through September 5, 1992. Notable earthquake activity in recent months, prior to the September 2 earthquake, included an earthquake swarm south of Panguitch in July (July 20-26; largest magnitude = 2.9) and another swarm sequence near Cedar City in late June (June 28-29; largest magnitude = 4.1). An earthquake swarm is a series of shocks occurring closely together in time and space that doesn't have one outstanding main shock, but instead peaks with a cluster of roughly similar size events. Small earthquakes have occurred episodically in the general area of the September 2 earthquake; five prior shocks of magnitude 2.0 to 3.1 had occurred within 25 km (16 mi) of its epicenter since January 1990.

PRELIMINARY SEISMOLOGICAL INFORMATION

September 2, 1992, Main Shock. Basic seismological parameters for the St. George earthquake are summarized in table 1. The earthquake occurred beyond the southern limit of the University of Utah's regional seismic network. The closest station to the main-shock epicenter was station CCU, 74 km (46 mi) to the NNE in Cedar City (figure 1). Arrival times of seismic waves at stations from other seismic networks have helped constrain a reliable epicenter, which is given in table 1. In terms of the main shock's size, the local magnitude (M_L) of 5.8, is estimated from an azimuthally weighted average of readings from 9 stations located throughout the western United States, and is consistent with the moment magnitude (M_W) of 5.7, based on a moment-magnitude relation for the Intermountain seismic belt developed by Shemeta and Pechmann (1989, and subsequent unpublished work).

Main-Shock Focal Mechanism and Nearby Faults. Figure 2 shows a preliminary focal mechanism for the main shock determined from first motion data recorded by the University of Utah regional seismic network, supplemented with data from seismograph stations operated by other institutions in Utah, Arizona, California, New Mexico, and Nevada. The hypocenter used to determine this focal mechanism (table 1) was computed using velocity models given in Bjarnason and Pechmann (1989) and a fixed focal depth of 15 km (9 mi), the source depth determined by Terry C. Wallace of the University of Arizona from analysis of teleseismic waveform data. The first motion data indicate normal faulting on a north-south-striking fault which dips moderately to either the west or to the east (solid nodal planes, figure 2).

We believe that the west-dipping plane of the focal mechanism represents the fault plane which broke during the earthquake. The surface projection of this nodal plane lies very close to the surface trace of the Hurricane fault (figure 1), a major westward-dipping late Quaternary normal fault which strikes north-south in the vicinity of the main shock epicenter (Anderson and Christenson, 1989). This observation suggests, but does not prove, that the St. George earthquake occurred on the Hurricane fault. With the information at hand, we cannot rule out the possibility that the earthquake occurred on a

Table 1. Seismological parameters for main shock.

Origin Time & Date:	September 2, 1992 $04^h 26^m$ (MDT, local time) $10^h 26^m 20.93^s$ (GMT)
Epicenter:	lat. N = 37° 04.96' ± 1 km, long. W = 113° 29.65' ± 12 km [University of Utah]
Focal Depth:	depth = 15 ± 2 km [T.C. Wallace, University of Arizona; based on distant earthquake recordings]
Magnitude:	Local (Richter) magnitude, $M_L = 5.8$ [based on azimuthal averaging of readings from 9 stations] Moment magnitude, $M_W = 5.7$ [T.C. Wallace, University of Arizona]
Seismic Moment:	$M_O = 3.9 \times 10^{24}$ dyne-cm [T.C. Wallace, University of Arizona]
Focal Mechanism:	Nodal plane 1: strike = 190° ± 12°, dip = 46° ± 06° W, rake = -84° + 10°, - 18° Nodal plane 2: strike = 02° + 11°, - 4°, dip = 46° ± 05° E, rake = -96° + 16°, - 13° [University of Utah; from P-wave first motions]

buried or unrecognized fault oriented parallel to either of the two nodal planes. The main shock's focal mechanism, in combination with its epicenter, appears to be incompatible with slip on the Washington fault.

Aftershock Activity. No foreshocks preceded the main shock; the last prior shock within 25 km (16 mi) was a magnitude 2.8 event on January 7, 1992. The University of Utah's regional seismic network detection threshold for earthquakes in the main-shock epicentral area is estimated to be approximately magnitude 2.0.

To supplement its regional-network coverage, the University of Utah Seismograph Stations sent a field crew with a variety of portable seismographs, including one digital seismograph, into the epicentral area on September 2 after the main shock. The first portable seismograph began on-site recording about 18 hours after the main shock. The epicentral area is being instrumented on a temporary basis with five seismographs capable of transmitting data directly to the University of Utah through a state microwave link. Remote recording from the first two of these instruments began at 9:00 p.m. on September 4.

Since the occurrence of the St. George main shock, only one earthquake in the magnitude 2 range has been detected and located in the area of the September 2 shock. During the two months following the September 2 earthquake, the University of Utah has recorded only 20 locatable aftershocks.

Implications of Weak Aftershock Activity. The absence of sizable aftershocks following the St. George earthquake is clearly unusual for a main shock of magnitude 5.8, based on worldwide seismological experiences. Again, some aftershocks are occurring at the microearthquake level, but more than four days after the main shock, not a single aftershock above about magnitude 2.0 had occurred. Using average parameters for California aftershock sequences, one would expect a magnitude 5.9 main shock to be followed by about 15 aftershocks of magnitude 3.0 or larger during the first 24 hours; further, the probability of having one or more aftershocks of magnitude 5.0 or larger would be 20% during the first day and about 30% during the following few weeks (Paul Reasenberg, U.S. Geological Survey, personal communication, September 3, 1992). For comparison, the 1975 Pocatello Valley earthquake of magnitude (M_L) 6.0, comparable in size to the St. George earthquake, was followed by 17 aftershocks of magnitude 3.0 or larger during the first 24 hours; the total number of such aftershocks during the first four days was 32, including a magnitude 4.7 aftershock (the largest aftershock), which occurred 35 hours after the main shock.

Regarding the implication of moderate-sized earthquakes with few aftershocks, Paul Reasenberg of the U.S. Geological Survey, who has been studying the statistics of aftershock sequences in California, has told us that he is not aware of any example where such behavior was an immediate precursor to a larger earthquake (personal communication, September 3, 1992). Some examples of moderate-sized main shocks with unusually weak aftershock behavior are known in California, but their predictive implications are uncertain. Examples include: (1) a magnitude 5.5 main shock in February 1980 within "the Anza seismic gap" (Sanders and Kanamori, 1984), a part of the San Jacinto fault zone in southern California recognized as a likely candidate for producing a magnitude 6½ or larger earthquake; and (2) the magnitude 4.9 Pasadena, California, earthquake of December 1988 (Jones and others, 1990). Neither of these events has yet been followed by a larger earthquake. Another example is: (3) a magnitude 5.0 shock near Lake Elsman, California, in June 1988, which preceded the 1989 magnitude 7.1 Loma Prieta, California, earthquake by about 16 months (Paul Reasenberg, U.S. Geological Survey, personal communication, September 3, 1992). In the latter case, Reasenberg notes that a subsequent main shock of magnitude 5.2 in August 1989 preceded the Loma Prieta earthquake more directly (by about two months) and that this main shock produced a vigorous aftershock sequence—but one which is unusual in that its aftershocks decayed in an unusually slow way.

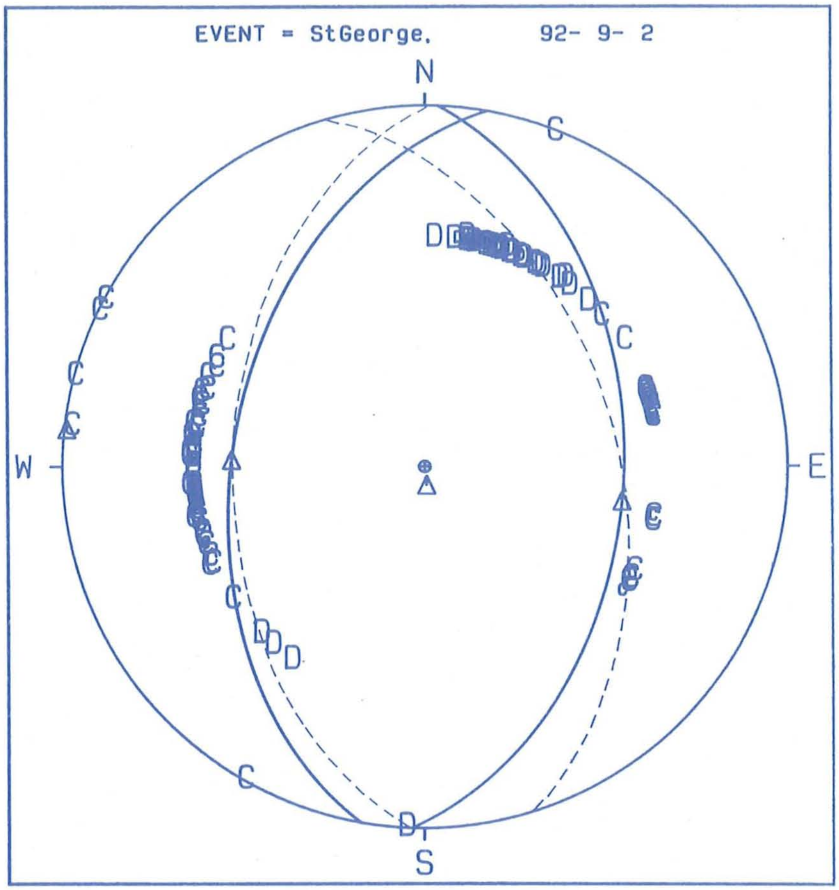

Figure 2. Focal mechanism for the M_L 5.8 St. George earthquake of September 2, 1992. P-wave first motions are plotted on a lower hemisphere equal area projection, with compressions shown as C's and dilatations as D's. Smaller letters indicate readings of lower confidence. The solid nodal planes are fit to the first motion data. The triangles on these planes show slip vectors and P and T axes. For comparison, the dashed nodal planes show the focal mechanism determined by Terry C. Wallace of the University of Arizona from inversion of broadband waveform data.

Weak aftershock behavior in fact has occurred a number of times in parts of the Wasatch Front area since 1962 (Veneziano and others, 1987)—most recently in the case of a magnitude 4.2 earthquake that occurred near the southwestern edge of the Salt Lake Valley on March 16, 1992. That earthquake was followed by only a single aftershock of magnitude 1.2. In sum, it is uncertain whether weak aftershock activity is simply characteristic of particular earthquake source regions or whether it might indicate an increased or decreased likelihood of a following larger earthquake.

GEOLOGIC EFFECTS

Contributed by Gary E. Christenson
Utah Geological Survey

Geologic effects of the earthquake, other than ground shaking, included rock falls, liquefaction, and landslides. Rock falls were common because the earthquake occurred in an area of steep cliffs and canyons. Local roads were temporarily closed as rocks were cleared, and a rock fall in St. George damaged a car. Otherwise, little rock-fall damage was reported, principally because the areas where rock falls were most common are remote and sparsely populated.

Liquefaction occurred near the epicenter along the Virgin River. Numerous small sand blows were found along the channel, and ground cracks, indicating lateral spreading, were common along channel banks (figure 3). No damage to structures from liquefaction has been documented.

The most damaging geologic effect was a large landslide (termed the Balanced Rock Hills landslide) in Springdale (45 km (28 mi) east of the epicenter) which temporarily closed State Highway 9, the entrance to Zion National Park (figure 4). The main scarp is about 12 m (39 ft) high, and the volume of material has been estimated to be about 20 million cubic meters (26 million cubic yards). The landslide, which is believed to be one of the largest in the world caused by a M_L 5.8 earthquake, is much further from the epicenter than would be expected for a landslide of this type (Randy Jibson, U.S. Geological Survey, verbal communication, September 15, 1992; Keefer, 1984). Although movement was initiated by the earthquake, the landslide moved slowly and significant movement continued for many hours after the earthquake. The landslide destroyed three homes, disrupted utilities along Highway 9, and threatens several businesses, the highway, and a condominium complex.

Figure 3. Lateral spread cracks and caved stream banks resulting from liquefaction along the Virgin River near St. George. Photo by W.E. Mulvey, UGS.

Figure 4. Aerial photo of the Balanced Rock Hills landslide (arrows indicate main scarp) in Springdale, view to east. Photo by B.J. Solomon, UGS.

The two major potentially active faults near the epicenter are the Hurricane and Washington faults. Both were searched for evidence of surface rupture, but no scarps, ground cracks, or obvious surface deformation were found. Of these two faults, the focal mechanism indicates that the earthquake was more likely on the Hurricane fault. Paleoseismic data, chiefly late Quaternary slip rates, indicate that the Hurricane fault is one of the most active faults in southern Utah.

EFFECTS ON BUILDINGS

Contributed by Larry Reaveley
Reaveley Engineers and Associates

The earthquake ground motion in St. George was intense according to many people who experienced it. The individuals who were there and are experienced in building design expected to find considerable structural and nonstructural damage. The magnitude and location of the earthquake should have produced ground shaking that would cause significant nonstructural damage and structural damage to buildings not constructed in compliance with earthquakes codes. Detailed observations of many buildings failed to verify the expected damage.

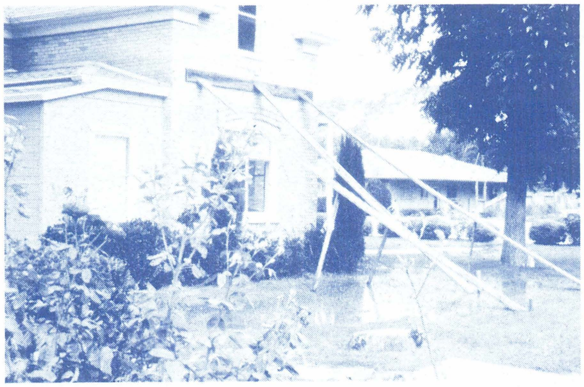

Figure 5. House in Hurricane damaged by ground shaking. Photo by B.D. Black, UGS.

The only buildings structurally damaged were constructed utilizing massive stone walls or adobe bricks (figure 5). There were no reports of observations of collapsed elements. Minor hairline cracks were observed in unreinforced concrete masonry partition walls. There were a few cases where light ceiling systems were damaged. Ceiling tile and gridwork were dislodged in grocery stores and gymnasiums. There were relatively few items dislodged from shelves. There were no reports of any water heaters overturning.

These observations raise the question of why there was so little damage. There were no instruments in the epicentral area, therefore no strong motion records exist. However, it appears to this observer that the duration may have been very short and the vertical motion may have been much greater than the horizontal motion. Similar motions were created following the 1983 Borah Peak earthquake. Perhaps the ground motion created by normal faults in the intermountain west is different from ground motions produced by other mechanisms.

ACKNOWLEDGEMENTS

We are indebted to seismological colleagues who contributed important data and information incorporated in this report. We thank David Brumbaugh of Northern Arizona University and George Zandt of Lawrence Livermore National Lab for their rapid responses to our request for data. Terry Wallace of the University of Arizona provided us with the preliminary results of his study of the main shock and graciously allowed us to include his results in this report. Paul Reasenberg of the U.S. Geological Survey supplied calculations and information that helped put the lack of aftershocks into perspective. Linda Hall and Paula Oehmich helped compile the seismological information contained in this report. Peter Fivas, Gerhard Henschel, Erwin McPherson, and Ken Whipp deployed portable seismographic instruments in the epicentral area of the September 2 earthquake for improved earthquake recording. Financial support for earthquake monitoring in Utah is provided to the University of Utah Seismograph Stations by the U.S. Geological Survey, the state of Utah, and the U.S. Bureau of Reclamation. Sections on geologic effects and effects on buildings were taken from the Earthquake Engineering Research Institute Newsletter (v. 26, no. 10, p. 6-7) Special Earthquake Report.

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THE SEPTEMBER 2, 1992 ST. GEORGE EARTHQUAKE AND DAM SAFETY

by Joe Borgione
Utah Division of Water Rights
Dam Safety Section

Subsequent to the 5.8 Richter magnitude St. George earthquake on September 2, 1992, noticeable changes in two significant dams were observed. In a post-earthquake inspection, engineers from the Utah Division of Water Rights Cedar City office noted what was thought to be a sand boil near the downstream toe of the Ivins Bench Dam. Such an occurrence is considered symptomatic of internal erosion or piping within the dam. A number of piezometers in the Quail Creek main dam near Leeds, Utah experienced sudden and abrupt increases or decreases in water levels following the earthquake. Changes of this nature can possibly mean internal structural deficiencies. However, no increases in drain flows were recorded, a sign that no serious problems occurred.

Ivins Bench Dam is a sluice-fill structure, originally built prior to 1920. Its location is 14.5 miles (23.3 km) from the epicenter. A later inspection of the dam early in October revealed cracks and settlement along the embankment. The sand boil was determined to be an engineered drain, buried by surface erosion not associated with the earthquake. An engineering study of the dam is necessary and needed repairs must be completed before the State Engineer will allow water to be stored again at the site.

An embankment instrumentation monitoring program is part of the standard operating procedures at the zoned earthfill Quail Creek main dam, located 7.9 miles (12.7 km) from the epicenter. To better monitor the situation, scheduled biweekly readings of piezometers and drains were increased to daily readings. Drain discharges remained constant. None of the piezometer levels exceeded critical design parameters, and have returned to a state of near equilibrium, similar to pre-earthquake conditions.

CHANGING OF THE GUARD AT SALT LAKE COUNTY

Craig Nelson, Salt Lake County geologist, resigned his position in September to take a new position as Senior Engineering Geologist and Business-Marketing Manager for

Delta Geotechnical Consultants in Salt Lake City. Craig began as county geologist in 1985 under a 3-year USGS NEHRP grant. The county geologist program was a pilot project to demonstrate the effectiveness of geologic expertise at the local government level, and as Salt Lake County's first geologist, Craig was responsible for establishing the position as a viable one and setting its goals and responsibilities. He was instrumental in helping develop and enforce Salt Lake County's Natural Hazards Ordinance adopted in 1989. He is well-known and well-respected for his technical ability, strength of character, and no-nonsense approach in reviewing geologic reports.

Much of Craig's work at Salt Lake County involved earthquake hazards. He was a strong advocate of earthquake issues and routinely made presentations to civic groups and local governments, both city and county. His pioneering work in the county geologist program was recognized with a Certificate of Appreciation from the NEHRP cooperating agencies in 1989.

Craig has had a significant impact in fostering loss-reduction measures in Salt Lake County. We applaud his efforts and hope to continue interacting with him in his new position at Delta.

We welcome Craig's replacement, Brian Bryant, formerly a geologist with the U.S. Army Corps of Engineers at Little Dell Dam. Brian graduated from San Diego State University in 1986 with a Master's degree in geology, and worked for 6 years as a consulting geologist in southern California. He is a certified engineering geologist in California and Oregon. Brian started work at Salt Lake County on October 16, 1992.

UTAH EARTHQUAKE ADVISORY BOARD NEWS

The streamlined Utah Earthquake Advisory Board (UEAB) (see WFF, v.8, no. 2, p. 7-8) met August 20, 1992 and October 13, 1992. Current issues and actions are summarized below.

The Board recommended establishing an Earthquake Evaluation Team to respond after smaller Utah events like the March 16th, 1992 Western Traverse Mountains earthquake. The Team would coordinate the collection of geologic data, perform damage estimates or obtain damage reports for earthquake events in Utah, and measure and document earthquake mitigation progress in Utah. The Team would include representatives from the UGS, the Seismic Committee of the Structural Engineers Association of Utah, and CEM.

Beginning this year, the Utah Legislature authorized $75,000 per year to the UGS to implement a strong-motion instrumentation program. In a Memorandum of Understanding with the University of Utah Seismograph Stations (UUSS), the Utah Strong-Motion Instrumentation Program (USMIP) was established as a joint venture composed of a UGS component and a UUSS component. The UGS made a proposal to the UEAB to form a Strong-Motion Instrumentation Advisory Committee (SMIAC). The purpose of the SMIAC would be to (1) help ensure that the UGS component fulfills user's needs to collect and provide earthquake ground-shaking information that can be used to improve earthquake-resistant design of structures, (2) provide engineering and seismological expertise and perspective, (3) suggest sources of additional funding, (4) help educate the user community and disseminate information to them, and (5) act as a forum to coordinate UGS component activities with other USMIP components and other operators of earthquake instrumentation in Utah. The Board passed the proposal unanimously and appointed Les Youd as the UEAB's representative to the SMIAC. He will serve as acting Chair of the Committee. SMIAC will hold its first meeting in January 1993.

Members of the UEAB will conduct a critical analysis of the Federal Earthquake Insurance legislation (H.R. 2806, H.R. 4792, and S. 2533) that will come before Congress next year. An ad hoc committee was formed and will make a presentation at the next UEAB meeting. The UEAB will then decide what action is appropriate with regard to recommendations to the State Legislature and the federal government.

Other issues that the Board will be considering in the future include continuing evaluations of earthquake predictions, creation of a policy for releasing post-earthquake statements, and a pro-active commitment to a long-term planning document for Utah similar to "California at Risk" by the California Seismic Safety Commission.

UTAH DAM SAFETY IMPLEMENTS GIS

by Joe Borgione
Utah Division of Water Rights
Dam Safety Section

The Utah Division of Water Rights Dam Safety Section is implementing the geographic information system ARC/INFO. The data base includes 660 dam entries, each with 60 fields of attributes. These dams represent a subset of another data base containing over 1600 dams. The 660 dams are those which the Dam Safety Section routinely inspect, monitor, and regulate, and others which fall under the jurisdiction of agencies such as the Bureau of Reclamation.

The Dam Safety Section is responsible to inspect dams for damage following an earthquake. The definition of the impacted area is established by policy: the size of the area affected by a given seismic event is a function of the magnitude of the event. In other words, a circle of given radius, centered on the epicenter of the earthquake, and based on the Richter magnitude of the event is drawn. Any dams which lie within this circle must be inspected. The basic concept was recently written into an interactive program using Arc Macro Language (AML).

Conceptually, the program is simple. A basic scenario is as follows. An earthquake occurs. The University of Utah Seismograph Station alerts the Dam Safety Section of the latitude and longitude of the epicenter in degrees and decimal minutes, and the magnitude of the event. Before the AML program was written, staff personnel using a hand held compass and a best guess estimate of the epicenter, drew a circle of the prescribed radius on a 1:250,000 scale wall mounted map. Dam locations that fell within the circle got inspected.

With the AML called QUAKES, personnel input the needed data at the initiation of the program. Internally, a file for the locational data is opened and they are then projected to a Universal Transverse Mercator format, consistent with the operational dam inventory data base. A coverage containing the properly projected epicenter location is created, and a search of the data base begins using the pre-determined radius constraints. An output file is created containing the names and hazard ratings of the dams within the affected area, and is printed. For archival purposes, the output file is also stored electronically.

As the list of dams is coming from the printer, an outline of the state is drawn on the screen, along with the Division's jurisdictional drainage area boundaries. A primary inspection circle is drawn about the epicenter with dam locations appearing as red squares. At the user's request, a secondary inspection circle is drawn and dams within that circle are graphically depicted as well. The secondary circle is useful for those dams that may fall just outside the primary area and really should be inspected as well. The printed list contains dams from both circles and is sorted based on mileage from the epicenter in ascending order.

QUAKES has already proven itself useful. A 4.5 Richter magnitude earthquake occurred in a remote area of the state while the program was being written. The mechanical compass/map procedure missed a dam that the program, once finished, found. (see also related article, this issue.) As a simulation tool QUAKES is useful as well. A 7.5 magnitude earthquake centered on the Wasatch Front has just over 300 dams in the primary circle, and another 100 in the secondary circle.

The Dam Safety Section has plans to broaden this GIS application to include probable maximum flood (PMF) studies, dam failure inundation mapping, and routine inspection scheduling. Those readers interested in obtaining further information can contact Joe Borgione at (801) 538-7377.

NEW INFORMATION ON TIMING OF LARGE EARTHQUAKES ON THE SALT LAKE CITY SEGMENT OF THE WASATCH FAULT ZONE:

IMPLICATIONS FOR INCREASED EARTHQUAKE HAZARD ALONG THE CENTRAL WASATCH FRONT

by William R. Lund
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The Salt Lake City segment of the Wasatch fault trends through the most populated part of the Wasatch Front. Fault trenching studies by Woodward-Clyde Consultants in 1979 at the mouth of Little Cottonwood Canyon and by the Utah Geological Survey and U.S. Geological Survey in 1985 at South Fork Dry Creek (figure 1) provide the basis for our current understanding of the size, timing, and recurrence of surface-rupturing earthquakes on this segment of the Wasatch fault. Results of those studies indicated that the Salt Lake City segment experienced three large-magnitude, surface-faulting earthquakes in the past 8000-9000 years. One shortly after 8000-9000 years B.P., one shortly after 5500-6000 years B.P., and the most recent shortly after 1100-1800 years B.P. Accounting for uncertainties in timing associated with those events, an average recurrence interval of 4000±1000 years was considered characteristic of large (M 7+) earthquakes on this part of the Wasatch fault zone.

New information from a trench excavated across the Wasatch fault a few hundred meters south of the South Fork Dry Creek site, indicates that a previously unrecognized surface-rupturing earthquake occurred on the Salt Lake City segment about 2400 years ago. The new trench

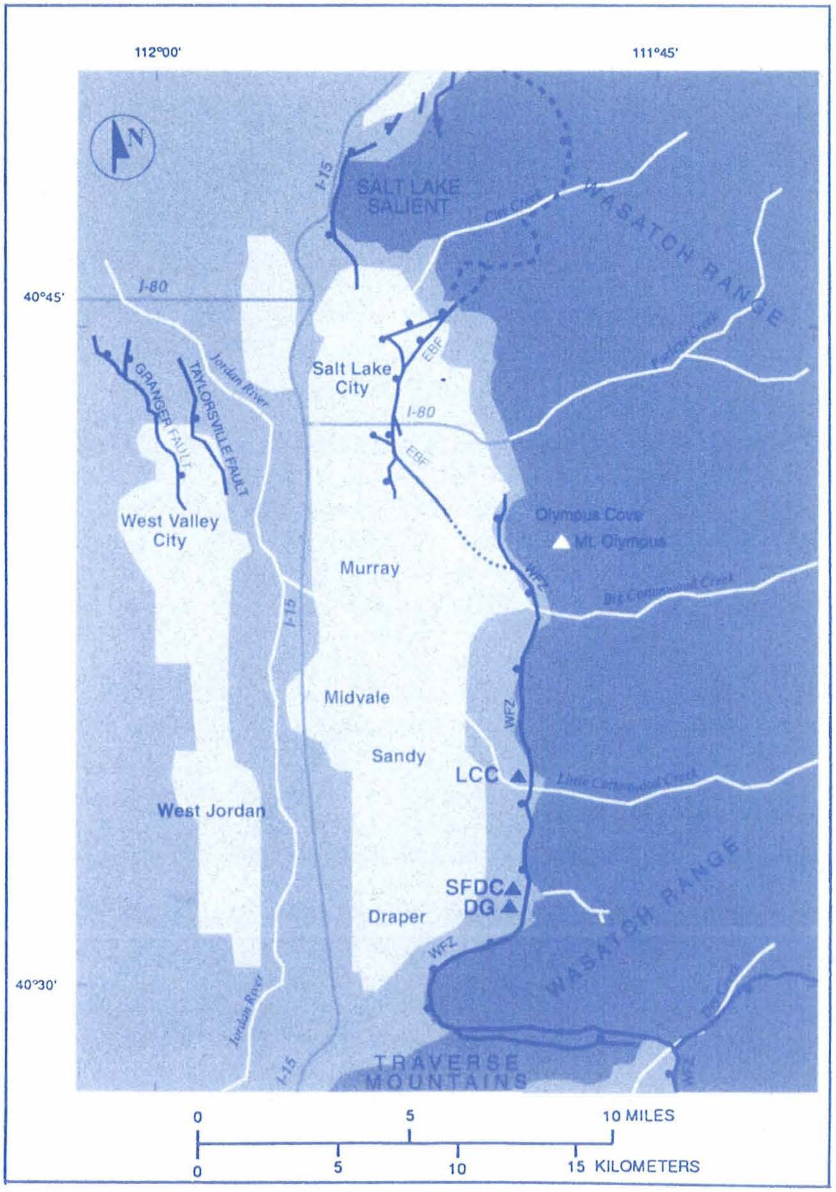
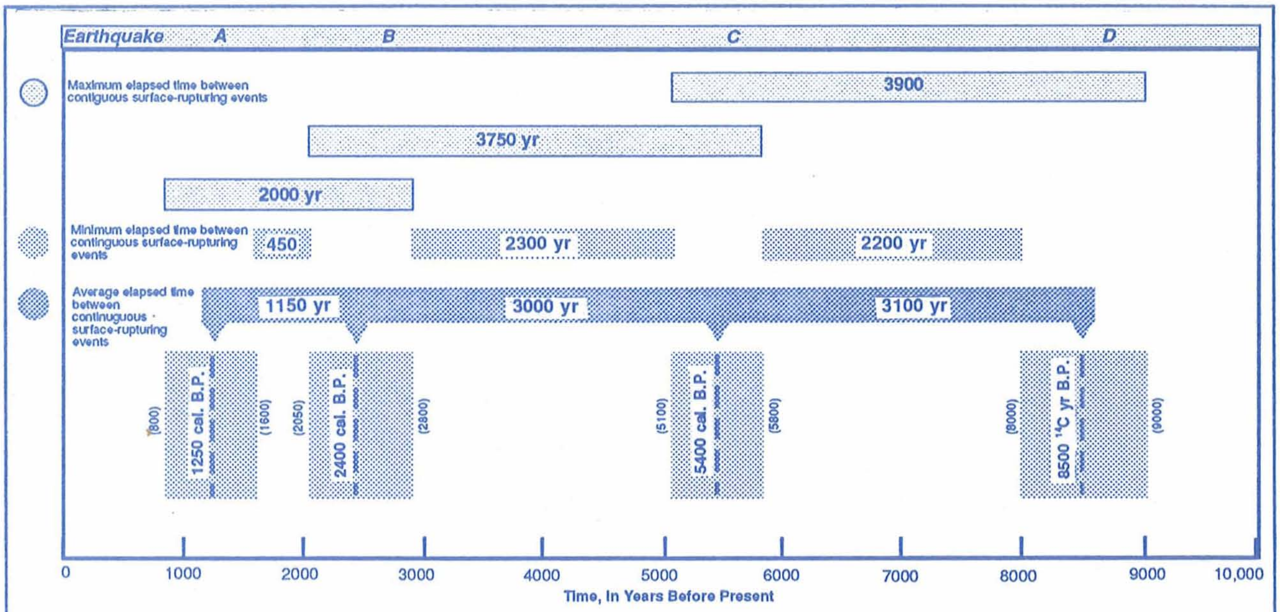


Figure 1. Salt Lake City segment of the Wasatch fault zone showing Little Cottonwood Canyon (LCC), South Fork Dry Creek (SFDC), and Dry Gulch (DG) trench sites.

exposed a pair of stacked colluvial wedges and buried paleosols adjacent to a fault trace. The stratigraphic relations were similar to those seen in trenches excavated across multiple-event scarps at South Fork Dry Creek. Radiocarbon ages from bulk organics in the buried paleosols showed that the timing of the most recent event (1600 cal B.P.) generally coincides with that determined from previous studies. However, the penultimate event occurred shortly after 2400 years B.P. rather than 5500-6000 years B.P. expected from the earlier studies. Resampling and testing confirmed these results. Subsequent trenching and resampling at South Fork Dry Creek confirmed the 5000 year plus age for the penultimate event at that location.

The new radiocarbon ages provide strong evidence that at least four surface-rupturing earthquakes have occurred on the Salt Lake City segment in the past 8000-9000 years. The addition of a fourth event within that time frame shows that large earthquakes are irregularly spaced in time on the Salt Lake City segment, and occur more frequently (average recurrence about 2400±500 years rather than 4000±1000 years) than previously suspected (figure 2). This new information demonstrates that the danger to the heavily urbanized Salt Lake Valley from large, surface-rupturing earthquakes is greater than estimated in current hazard assessments.



Four surface-rupturing earthquakes in the past 9000 years create three intra-event intervals. Current best estimates for the length of those intervals are: Interval A-B, 1150 yr; Interval B-C, 3000 yr; Interval C-D, 3100 yr.
The average recurrence interval for the past 9000 years ((1150 + 3000 + 3100)/3) is 2400 years with an assigned uncertainty of plus-minus 500 years.

The average recurrence interval for the past 6000 years (time period for which radiocarbon ages can be dendrocorrected) is 2150 years with an assigned uncertainty of plus-minus 400 years.

Figure 2. Temporal distribution of Salt Lake City segment surface-rupturing earthquakes and their associated uncertainty limits.

PREHISTORIC EARTHQUAKES ON THE OQUIRRH FAULT ZONE, TOOELE COUNTY

by Susan S. Olig
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How big? When? How often? The Utah Geological Survey is looking for answers to these questions about large (surface-rupturing, probably greater than magnitude 6.5) earthquakes on the Oquirrh fault zone in eastern Tooele County (figure 1). Our ongoing study involves investigating the geomorphology along the fault and excavating trenches across fault scarps to examine the earthquake-related deposits. William Lund, Bill Black, and I are conducting the one-year study with partial funding from the U. S. Geological Survey under the National Earthquake Hazards Reduction Program.

The Oquirrh fault zone is a normal fault that bounds the east side of Tooele Valley, dipping to the west underneath the valley. It generally extends along the base of the Oquirrh Mountains from northeast of Lake Point to southeast of Tooele (figure 1). The fault zone has long been recognized as a potential source for large earthquakes (Everitt and Kaliser, 1980) that would not only affect the city of Tooele and Tooele Army Depot, but also the more populous central Wasatch Front. Even though downtown Salt Lake City is over 20 miles away, a large earthquake on the Oquirrh fault zone could cause strong shaking (ground acceleration over 0.2 g) and liquefaction, which could severely damage older buildings and bridges. Although the fault zone was mapped by Barnhard and Dodge in 1988, little is known about the occurrence of large prehistoric earthquakes on the fault. Consequently, studies of the ground-shaking hazard in north-central Utah had to make assumptions with large uncertainties about how large and how often large earthquakes occur on the Oquirrh fault zone.

So far we have excavated and logged three trench exposures at a site near the mouth of Big Canyon (figures 1 and 2). Here, the fault offsets Lake Bonneville deposits about 200 feet below the Provo shoreline (Solomon, in preparation). There is a wide graben formed by a single large main fault scarp (about 50 feet high) that faces west and a smaller antithetic fault scarp (about 5 feet high) that faces east.

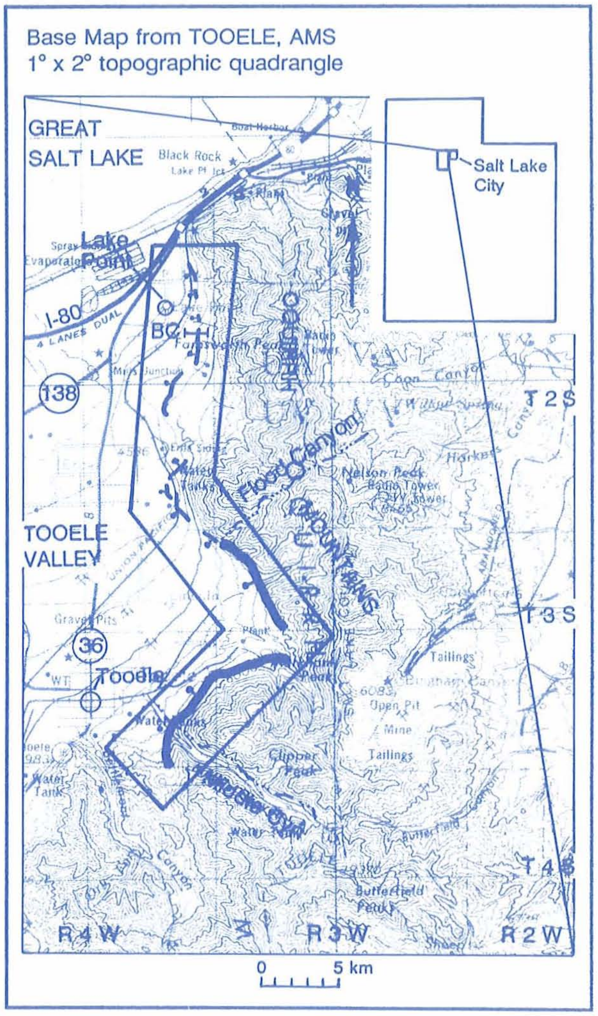

Figure 1. Map of the Oquirrh fault zone (after Barnhard, 1988). Thinner lines in boxed area are fault scarps in alluvium with bars and balls on downthrown side. Heavy lines are fault traces at the bedrock-alluvium contact. BC marks the Big Canyon trench site.

The two southern trenches exposed similar stratigraphy with Lake Bonneville transgressive beach and deep-water sediments overlain by a debris-flow deposit on the downthrown side of the fault, and pre-Bonneville alluvial-fan deposits on

Figure 2. Officials from Tooele County, local cities, Tooele Army Depot, and Dugway Proving Ground examine a trench exposure at the Big Canyon site.

the upthrown side of the fault. A thick colluvial wedge (6 to 10 feet) overlies the debris-flow deposit on the downthrown side. This wedge was derived from sediment eroded off the crest of the fault scarp and deposited at the base of the scarp after the earthquake. Samples collected from the debris-flow deposit, directly under the colluvial wedge, yeild radiocarbon ages of 6840 ± 100 yr B. P. and 7650 ± 90 yr B. P. These ages indicate the most recent surface-rupturing earthquake occurred during the last 7000 years and is much younger than previous geomorphic studies estimated (Barnhard, 1988). To better constrain the minimum age of this event, we excavated another trench to the north across unfaulted alluvial-fan sediments that bury the fault. Radiocarbon-age estimates are still pending for samples collected from this northernmost trench.

Trenching at another site south of Big Canyon will hopefully answer questions regarding the timing of the penultimate surface-rupturing earthquake (the event prior to the most recent event) and the recurrence interval of surface-rupturing earthquakes on the Oquirrh fault zone. We expect to be done with the project by next summer.

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ACCEPTABLE DAMAGE IN LOW AND MODERATE SEISMIC ZONES

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INTRODUCTION

The definition of acceptable earthquake damage in regions of low and moderate seismicity is closely related to the characteristics of the seismic hazard and the economic and social costs and benefits of mitigating measures. United States seismic design provisions, such as the Uniform Building Code (UBC) and the 1988 National Earthquake Hazards Reduction Program (NEHRP) document have been modified over the last 10 years to include detailing requirements for non-structural elements, in order to limit damage and facilitate post-earthquake resumption of functions. The economic impact of the 1989 Loma Prieta earthquake will undoubtedly lead to further modifications in that direction.

In low and moderate seismic zones (L/MSZ), where there have not been many, or any damaging earthquakes in the recent past, the general thrust of seismic provisions should be, for most buildings, toward the prevention of building collapse and life threatening damage - i.e. "life safety." The application of those provisions of the UBC and NEHRP that limit loss of function and cost of repair may not be appropriate in L/MSZ. On the other hand as the understanding of the nature of the seismic hazard has evolved in L/MSZ, it has become apparent that the acceleration levels that serve as a basis for code designs, substantially underestimate what may actually occur in an infrequent but credible event.

The problem of seismic design in L/MSZ is therefore related to the definition of acceptable damage through the following two issues:

1. How can one design structures to provide a consistent level of safety across different seismic zones given the limitations of economy, ductility, or energy dissipation capacity and the variation in ratio of constant design basis accelerations (e.g. 10 percent probability of exceedance in 50 years) to maximum credible earthquake (MCE) accelerations?

2. How does one focus the benefits of seismic design in L/MSZ on only life safety aspects and prepare the public for the economic losses associated with the damage thereby deemed acceptable in the very infrequent MCE?

This paper discusses these issues in the context of Salt Lake City and New York City.

THE NATURE OF THE SEISMIC HAZARD

Current design practice in the United States is based upon design ground motions that are expressed as seismic coefficients for various zones (UBC 88) or as coefficients for effective peak accelerations (NEHRP).

These two different

approaches reflect the influence of the original maps created by the committees that prepared the original ATC 3 documents. These maps were based on the best scientific knowledge available in 1976. The Commentary to the 1988 NEHRP provisions, a revised and updated version of the ATC-3 document, states that,

> "It was expected, however, that the maps and coefficients would change with time as the profession gained more knowledge about earthquakes and their resulting ground motions and as society gained greater insight into the process of establishing acceptable risk."

The ground shaking regionalization maps are based on several policy decisions. The 1988 NEHRP commentary gives those decisions as:

> "The first decision was that the distance from anticipated earthquake sources should be taken into account. This decision reflects the observation that the higher frequencies in ground motion attenuate more rapidly with distance than the lower frequencies. Thus, at distances of 10 km or more from a major earthquake, flexible buildings may be more seriously affected than stiff buildings. To accomplish the objective of this policy decision, it proved necessary to use two separate ground motion parameters and, therefore, to prepare a separate map for each."
>
> "The second policy decision affecting the maps was that the probability of exceeding the design ground-shaking should be roughly the same in all parts of the country. Thus, the NEHRP Recommended Provisions maps are different from other zoning maps used in the United States that have been based on estimates of the maximum ground-shaking experienced during the recorded historical period without consideration of how frequently such motions might occur. There is not unanimous agreement in the profession with this policy decision. In part, this lack of agreement reflects doubt as to how well the probability of ground motion occurrence can be estimated with today's knowledge and disagreement with the specific procedures used to make the estimates rather than any true disagreement with the goal."
>
> "The third important policy decision, which also is not new, was that the regionalization maps should not attempt to microzone (i.e., there was to be no attempt to locate actual faults on the regionalization maps, and variations of ground-shaking over short distances - on a scale of about 10 miles or less - were not to be considered). Such micro-zoning must be done by experts who are familiar with localized conditions, and there are many local jurisdictions that should undertake it, a point that is discussed further below."

The second policy decision is based upon a laudable position, but, is questionable because of the lack of specific data that exists in much of the United States outside of California, and due to the fact that the degree of additional severity is not quantified.

The Commentary further states that it is undesirable for economic reasons to design structures for extreme ground motion. Buildings properly designed for a particular ground motion are expected to provide considerable protection to the lives of occupants during a more sever ground motion. Also,

> "Even if it were desirable to design for the "extreme" or "maximum credible" ground motion, it is not yet possible to get agreement on how intense this motion might be. This is specially true for the less seismic portions of the country."

There is a paucity of ground shaking data in areas such as Charleston, Memphis, Boston, New York City, and Salt Lake City. Few historical earthquakes have occurred upon which decisions could be based. Recent ground trenching studies conducted by the USGS have added greatly to the data base for the Wasatch fault zone in Utah. These studies indicate that 17 major earthquakes of Richter Magnitude 7.0 to 7.5 have occurred along a 100 mile stretch of this fault.

The record of known earthquakes in the general New York City region goes back to the 1638 St. Lawrence River

(Canada) and 1755 Cape Ann, Massachusetts events. In 1884, an earthquake with an estimated Richter magnitude of 5.0 to 5.5 occurred near New York City. In response to a query from the Nuclear Regulatory Commission, the USGS has stated that:

> "Because the geologic and tectonic features of the Charleston region are similar to those in other regions of the eastern seaboard, we conclude that although there is no recent or historical evidence that other regions have experienced strong earthquakes, the historical record is not of itself sufficient ground for ruling out the occurrence in these other regions of strong seismic ground motions similar to those experienced near Charleston in 1886 (R_m7). Although the probability of strong ground motion due to an earthquake in any given year at a particular location on the eastern seaboard may be very low, deterministic and probabilistic evaluations of the seismic hazard should be made for individual sites in the eastern seaboard to establish the seismic engineering parameters for critical facilities."

Additional studies similar to the work done in Salt Lake City are currently being done in the Seattle, Washington area, and it is anticipated that other areas in the country will be studied in the future.

Various cities and regions in the United States have recently been studied in a comparison of the maximum expected ground motion (USGS Open-File Report 88-669). The ground accelerations for 10, 50, and 250 years were plotted. The values shown in figure 1 are from this paper and have a 10 percent chance of being exceeded in the time periods shown.

The design codes and maps have been based on the ground accelerations associated with the values that have a 10 percent chance of being exceeded in a 50 year period. Figure 1 shows the danger of this practice. The values of acceleration were scaled from figure 1 for three different time periods. The value at 50 years for a city or region was divided into the value for that region at 150 years and 50 years. The results are given in table 1.

Figure 1 and table 1 clearly demonstrate that for the three California cities, the earthquake accelerations that might occur over a long period are not overwhelmingly bigger than those that are expected at 50 years. Conversely, the use of the 50 year interval for most of the other areas greatly underestimates the eventual ground motion. The values shown for Boston would apply for New York City The consequence of the decision to base design codes on a uniform probability of exceeding the specified ground shaking for a short period of time has not been understood. The Mexico earthquake of 1985 demonstrated the effects of ground shaking on structures that were designed for force levels well below that which they were called on to resist.

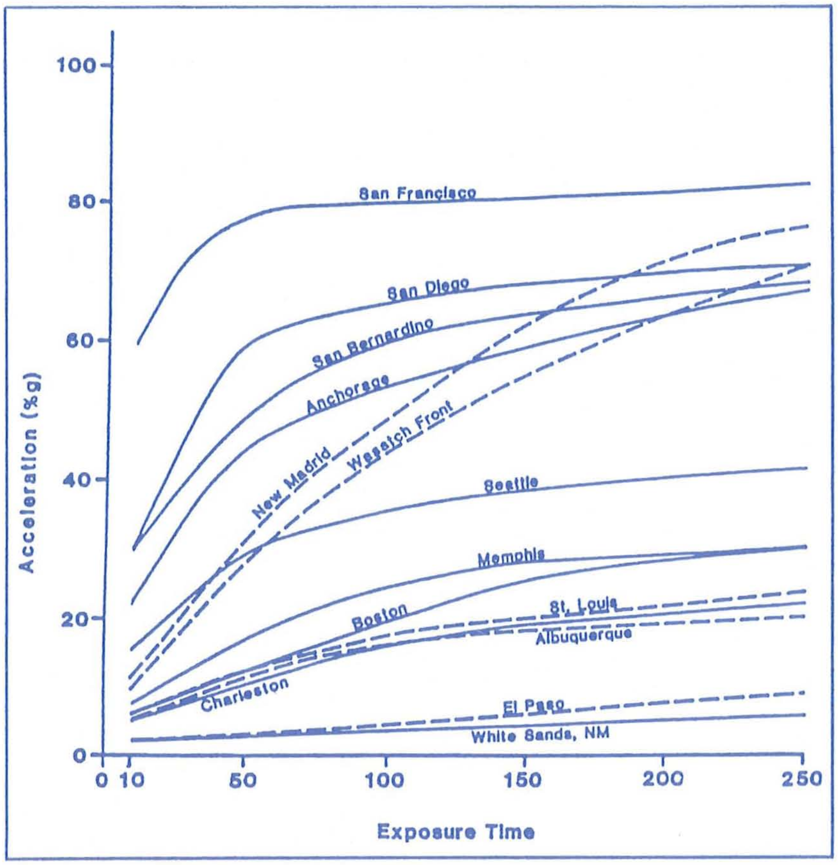

Figure 1. Comparison of the maximum expected ground acceleration in 10, 50, and 250 years at a number of sites in the United States. The ground accelerations shown have a 10 percent chance of being exceeded in the time periods shown.

U.S. ENGINEERING PRACTICE AND LIMITS OF SYSTEM BEHAVIOR

Implicit in all U.S. design codes is the understanding that the force used for the design is less than that which an expected earthquake will produce. This is thought to be acceptable because well designed structures are supposed to possess the following qualities:

- Redundancy
- Ductility
- Energy dissipation capabilities
- Unaccounted for over strength

There is, therefore, a high probability that there will be permanent deformations in buildings following a large earthquake.

By allowing the structure to experience inelastic deformations, there is a great advantage in that the accelerations and therefore, the later force on that structure are reduced below that which it would experience if the structure were to remain elastic. The value of the maximum inelastic deformation divided by the elastic deformation of a structure is termed the ductility factor. If structures had unlimited ductility, they could be designed for very small elastic level forces.

It is generally believed that the P-delta stability of the structure will limit what non-liner deflections are acceptable from a structural point of view. It is interesting to note, however, that non-linear time history analyses of typical structures indicate that the maximum displacements are approximately the same for elastic and non-linear response (Clough, 1970). The limitation on structures has, therefore, more to do with the available ductility than actual non-linear displacements.

For the case where a given structure is required to resist earthquake forces much larger than those assumed, the ductility for that structure would have to be greater than that which it can reasonably be expected to provide.

The NEHRP provisions and the 1988 UBC utilize a factor termed the "R" factor to scale the required elastic level design force downward according to the presumed capacity of the system to accept non-linear deformations. Table II is from ATC-19, a report being prepared by the Applied Technology Council for the National Science Foundation. The report examines the R-factor from a historical perspective and will propose future modifications to this design parameter. The difference between the Rw factor of the UBC and the R factor of the NEHRP provisions is in the difference of the working strength versus ultimate approach of the documents. As can be seen from table II, the values of Rw range form 4 to 12. The more ductile and reliable the system, the higher the R factor.

Bertero, in the 1990 T.R. Higgins Lectureship Award, noted that "the UBC has only specified the seismic forces on the basis of the concept of ductility, through the use of a structural system factor Rw. However, the rationale for and reliability of the values recommended for the Rw factor can be questioned in view

Table 1. Comparison of Accelerations at 50, 150, and 250 years.

	50 yrs	150 yrs	250 yrs
SAN FRANCISCO	1.0	1.04	1.06
SAN DIEGO	1.0	1.15	1.28
SAN BERNADINO	1.0	1.32	1.41
ANCHORAGE	1.0	1.35	1.53
NEW MADRID	1.0	2.04	2.7
WASATCH FRONT	1.0	1.84	2.60
SEATTLE	1.0	1.32	1.43
MEMPHIS	1.0	1.97	2.33
BOSTON	1.0	1.97	2.33
CHARLESTON	1.0	1.82	2.1
ST. LOUIS	1.0	1.53	1.83

of recent research results. The UBC values appear to be too high, particularly for short-period buildings which are designed to just satisfy the minimum strength required by the UBC provisions." If there is a question surrounding a structure which has been designed in California to the California design codes, what kinds of questions, concerning the life safety of the occupants of buildings in areas of the U.S. that have the high ratios as shown in table I, should be raised. Obviously, under the current practices, there is a wide variation in the safety of the occupants in many locations of the country. A more acceptable approach to seismic safety would be based upon a uniform probability of buildings not collapsing.

Because the actual forces generated by earthquakes may be much larger than the assumed design values, a concept of dual-level design has been considered. The concept of dual level design is based on the assumption that for a specific moderate force level that might be related to a relative short time period there would be limited structural and non-structural damage due to damage control provisions such as drift limits. For a higher force level (infrequent but possible) there would be more structural damage and a much larger level of non-structural disturbance. Damage control provisions would be omitted for the higher force level. The important thing is to not have a collapse. In practice, this concept has been used on a limited basis but it is suggested that the concept has great merit for specific special facilities and for those seismic areas where the code level forces greatly understate the infrequent large earthquake force potential.

The Zonation Subcommittee of the Seismology Committee of the Structural Engineers Association of Northern California recognized in 1982 the potential problem with maps used for design based on a 50-year exposure time period (Matthiesen, et al., 1982). This committee recommended that the 2,000-year earthquake (200-250 year exposure time) be used in developing zonation maps. The choice of 2,000 years was selected because the committee believed it reflected a probability or risk comparable to other risks that the public accepts in regard to life safety. The sub-committee also observed that the mean recurrence intervals for maximum earthquakes on long faults with low slip rates may be substantially longer than 2,000 years, but that the use of longer return periods would be generally considered an unreasonable basis for code requirements.

The use of the dual-level design requirement would insure that at the lower performance level force there would be limited damage and limited function of the facilities. There would be a high level of life safety. At the high force-level the only criteria would be life-safety. Using this approach, economical designs would be produced that would better fit the seismology of many areas in the country.

WHAT IS ACCEPTABLE DAMAGE?

A criteria for damage acceptance must take into account the following questions:

> Will the occupants of the structure have an acceptable level of safety? This requires an assessment of the reliability of the ground shaking probability estimates as well as the reliability of the structural system.
>
> Will the occupants be able to safely exit the building?
>
> How many people are going to be occupying the facility? Are the occupants ambulatory or are they confined in any way? How many hours a day do the majority of the people occupy the building?
>
> For what use is the structure being constructed? Is it an essential facility? Does the use include nuclear or hazardous materials?
>
> What is the consequence of not being able to use the building for an extended period of time following an earthquake? This relates to the economic losses that result from not being able to conduct business and to the hardships that people experience when forced to leave their domiciles.

The UBC and the NEHRP provisions contain requirements that address some of these issues but not all of them. It is safe to say that many engineers and the general public do not understand the basic premise upon which the current codes are based. That is, given a large earthquake, a successful structure will probably not collapse but it might not be worth saving afterwards. The general public has a hope that they are being safeguarded from economic loss as well as injury by modern earthquake design requirements. It can be seen from figure 1 and table 1, that this is not the case for many areas of the country.

Acceptable damage statements should recognize that as an average, the structural systems of most buildings cost in the range of 20 percent of the total building cost. The remaining 80 percent of cost is expended on architectural, mechanical, and electrical systems. These percentages demonstrate that from an economic view point, the majority of the investment is vulnerable to the strengths or weaknesses of a structural system, which is a small part of the overall cost.

This paper proposes that acceptable damage can only be defined based upon the answers to the questions already posed. Different buildings should be expected to fulfill different roles during an earthquake. Some buildings are more important that others and this statement extends beyond essential facilities. The 1988 NEHRP document provides a greater range of design criteria for buildings that is based on usage than does the 1988 UBC. This concept needs to be explored further in the future and each new building owner should be educated as to what level of safety and damage control the current design provisions provide.

The 50 year, 10 percent, exceedance maps have great merit for use as a lower level design criteria in a dual level approach. These maps provide a basis from which to design facilities that are to have limited damage from an earthquake that is likely to happen. Maps, based on 250 years with a 10 percent exceedance, supply the necessary data to design structures that would fulfill a pure life-safety function. Stress and stability criteria would govern at this level. Drift control and other damage control requirements would not be imposed at this level. This approach satisfies the requirements for economical structures that will provide the necessary strength and ductility for a large earthquake that has a low probability of occurrence.

Difficulties arise, however, when one attempts to reconcile the lateral force levels that have traditionally been accepted with those associated with the 250 years/10 percent basis accelerations. Clearly the difference between these are considerable in L/MSZ. It will be difficult, without having an earthquake damage history to refer to, to increase code design force levels where the need for seismic design is still questioned.

CURRENT PRACTICE IN LOW AND MODERATE SEISMIC ZONES

Salt Lake City and New York City are examples of areas that have the probability of experiencing high intensity ground shaking over a 250 year interval as compared to a 50 year time frame.

Salt Lake City is centered along the Wasatch fault which is approximately 100 miles long. Figure 1 demonstrates that this region experiences infrequent large earthquakes. Table 1 summarizes the existing building stock along the Wasatch Front and shows that there is a large inventory of buildings that are vulnerable to ground motions that would be generated by these earthquakes. U.S.Geological Survey trenching studies have determined that 17 large (Richter magnitude 7.0-7.5) earthquakes have occurred on this fault system over the last 6,000 years. This fault has eight to ten individual segments that produced these earthquakes. Estimates are that one of these segments will produce an earthquake every 300 to 400 years, with individual segments rupturing with time intervals of anywhere from 1,400 to 2,000 years.

The UBC is enforced in Utah. The Wasatch fault zone is in seismic zone 3. This means that the base shear used in the design of buildings is 75 percent of that used in the major seismic areas of California. Figure 1 indicates that on a 50 year, 10 percent exceedance map, the base shear forces required for design would provide a comparable level of life safety to that of other seismically-prone areas.

The figure also indicates that for a long return period, the ground motion will be equal to the maximum expected in many parts of California. The lines shown in figure 1 are dashed for the Wasatch Front and other locations because the exact shape of these curves are not adequately defined by available data. Researchers have stated that they do not know when the last major earthquake took place. The area has been inhabited for 143 years and no major earthquake has occurred during this time. The decision makers have been cautioned to plan as though the next big one would occur tomorrow. This warning has been somewhat heeded by the engineering community. Earthquake design, in general, has a high degree of conformance to the requirements of the UBC. Field observations and inspections practices have also been improved. This has occurred over the last 15 years.

The acceptable damage for new buildings that the community is currently accepting is on the low side for the short time frame if one accepts the probability assessments and on the high side when considering the eventual earthquakes. The community at large has very little understanding of the risk to property and life to which the current design practices are exposing them. The engineers and building officials up to this point in time have made a decision to accept the risk associated with designing new structures for force levels far below the forces they will one day be required to resist. The debate as to whether or not to change to UBC seismic zone 4 is ongoing. [See WFF, v. 7, no. 3, p. 6-7, Ed.]

The New York City (NYC) building code is currently being revised to incorporate seismic design provisions adapted from the 1988 UBC. The principal modifications are:

- Revisions to the design response spectrum used for dynamic analysis to reduce long period ordinates.
- The addition of a soil factor $S_o = 0.67$ for hard rock sites.
- The addition of structural systems including ordinary (non-ductile reinforced concrete moment frames above (up to 160 feet on stiff soil sites) or in combination with shear walls and dual, frame-wall or braced frame, systems where the frame action is significant.
- The elimination of requirements for non-structural elements, such as access floors, partitions and equipment, that are not life threatening.
- The reduction in required building separation to 1 inch per 50 feet of total building height.
- Acceptance of reinforcement in one direction only for non-bearing masonry walls. The changes have been made to focus the provisions on life safety issues only and recognized the character of local construction practice.
- The fact that the MCE accelerations will exceed the 50 year/10 percent basis values by as much as a factor of 2.3 has been accounted for to some extent by allowing the UBC zone factor/effective peak acceleration to stand, at 0.15, while it is believed that the appropriate zero period acceleration for NYC at 50 years/10 percent is closer to 10 or 12 percent.

FUTURE DIRECTION AND ISSUES

The direction for seismic mapping for areas outside of California was discussed in a 1989 workshop at the National Center for Earthquake Engineering (NCEER) in Buffalo, New York. Some of the concepts developed in that workshop are the main points upon which this paper is based. The participants were in strong agreement that a criteria that allowed for the possibility of collapse from earthquake forces in the long term was unacceptable. The concept of a dual level criteria was given an endorsement because it answered the needs of those areas of the country that experience infrequent strong ground motion. It allows for a rational determination of acceptable damage.

One of the issues that needs to be further researched is that of the difference between costs for different levels of earthquake resistance. During the preparation of the 1985 NEHRP provisions, detailed studies were conducted in various cities to try to determine the cost of implementing the provisions. Total building cost increases ranged from 1.0 to 2.0 percent depending on what seismic map area the cities were in and to what extent current practices recognized earthquake design.

It is clear that earthquake resistance does cost money. But, it is also true that once a decision is made to provide earthquake resistance, additional resistance can be achieved for a modest additional investment. The major cost increases associated with seismic resistance are related to the detailing requirements for UBC zones 3 and 4 as compared to zones 1 and 2. Preliminary results from recent research has shown that once a structure has been designed for zone 3 forces, the costs to increase the structural elements to meet the requirements of zone 4 range from ½ of one percent to approximately 1½ of one percent of the total building cost (Taylor, et. al., 1990).

The cost implications of better designed and build structures needs to be carefully evaluated. We may be accepting greater damage, economic loss, and more injuries and deaths than is justified.

The issues that were discussed in this paper were directed towards new construction. If these concerns were directed towards buildings that are being upgraded to resist seismic forces, the concerns would be even more important. It is very difficult to change old, non-ductile structures into code-complying systems that possess a great amount of capacity for inelastic deformation. This simply implies that the seismic resistance of rehabilitated structures is highly dependent on the yield strength of the completed structure. In areas where the long term forces are much greater than the 50-year, 10 percent probability of exceedance maps would indicate, the practice of retrofitting the structure for forces less than the code requirement for new construction may well lead to totally ineffective earthquake retrofit systems.

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[The 1991 edition of the NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings is now available from the Building Seismic Safety Council, 1015 15th Street N.W., Suite 700, Washington, D.C. 20005, (202) 289-7800. As in the past, there are two volumes: Part I includes Provisions and Part II provides Commentary. They are Earthquake Hazard Reduction Series 222 and 223 and they are free.

Another related publication is "Strengthening unreinforced masonry buildings in Los Angeles--land use and occupancy impacts of the L.A. seismic ordinance: Portola Valley, California," by M.B. Tyler and Penelope Gregory. Funded by the National Science Foundation, this report explores the experience of Los Angeles, where over 5,000 unreinforced masonry buildings have been or are being strengthened or demolished in a little over eight years as part of a city-mandated program to reduce earthquake hazards. It is specifically directed to planners, offering conclusions and recommendations intended to help other cities facing the difficult task of improving seismic safety of existing buildings. See Recent Publications. Ed.]

GENERAL GUIDE TO EARTHQUAKE RESISTANCE IN WASATCH FRONT BUILDINGS

The table below is a guide to assessing the probable earthquake resistence in Wasatch Front buildings based on building type and date of construction.

PREDOMINANT BUILDING TYPES				
YEAR BUILT	HOUSING (SINGLE FAMILY)		COMMERCIAL, INSTITUTIONAL & INDUSTRIAL	
	MATERIAL TYPE	SEISMIC RATING	MATERIAL TYPE	SEISMIC RATING
1847 to 1900	———	———	URM & WOOD	POOR
1900 to 1945			URM & WOOD	POOR
	URM & WOOD	POOR	URM & CONC.	POOR
			URM & STEEL	POOR
	WOOD FRAME	FAIR	CONC. FRAME	POOR
			STEEL FRAME	FAIR
1946 to 1959			URM & WOOD	POOR
	URM	POOR	URM & CONC.	POOR
			URM & STEEL	POOR
	WOOD FRAME	FAIR	CONC. FRAME	POOR
			STEEL FRAME	FAIR
1960 to 1973			CONC. FRAME	POOR
	URM	POOR	STEEL FRAME	FAIR TO GOOD
	WOOD FRAME	FAIR	REINF. MASONRY & OTHER MAT'L	FAIR
			PRECAST CONC. FRAME	POOR
	REINF. MASONRY	GOOD	URM & OTHER MAT'L	POOR
			CONC. TILT UP	POOR
1974 to 1981			CONC. FRAME	FAIR
			STEEL FRAME	GOOD
	WOOD FRAME	GOOD	REINF. MASONRY & OTHER MAT'L	GOOD
	REINF. MASONRY	GOOD TO EXCELLENT	PRECAST CON. FRAME	POOR
			URM & OTHER MAT'L	POOR
			CONC. TILT UP	FAIR
1982 to 1987			CONC. FRAME	GOOD TO EXCELLENT
	WOOD FRAME	GOOD TO EXCELLENT	STEEL FRAME	EXCELLENT
	REINF. MASONRY	EXCELLENT	REINF. MASONRY & OTHER MAT'L	GOOD TO EXCELLENT
			RECAST CONC. FRAME	POOR TO GOOD
			CONC. TILT UP	FAIR TO GOOD

The majority of the buildings constructed in Utah are vulnerable to seismic forces. Only during the last decade has there been any significant awareness and acceptance of the earthquake problem. This increased awareness and concern has created an environment in which responsible individuals and organizations are beginning to deal with the problem of the existing hazardous buildings. It is Dr. Reaveley's opinion that most of the new buildings constructed during the last five years have good seismic resistance.
[Taken from Reaveley, L.D., 1988, The process of dealing with existing hazardous buildings in Utah, in Hays, W.W., ed., A review of earthquake research applications in the National Earthquake Hazards Reduction Program, Proceedings of Conference XLI: U.S. Geological Survey Open-File Report 88-13A, p. 474-482. Ed.]

FEDERAL EMERGENCY MANAGEMENT AGENCY

SEISMIC SAFETY OF BUILDINGS

EXISTING BUILDINGS

Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook - A method for quickly identifying buildings posing risks of death or injury in an earthquake. The methodology, "Rapid Screening Procedure," can be used by trained personnel to identify potentially hazardous buildings on the basis of a 15-30 minute exterior inspection, using a data collection form included in the handbook. Twelve structural categories are used to reach a numerical score based on the visual inspection. Intended for building officials, engineers, architects, property owners, emergency managers, and concerned citizens. (ATC-21) FEMA-154, 1988, 185 pages.

Rapid Visual Screening for Potential Seismic Hazards: Supporting Documentation - Review of the literature and existing procedures for rapid visual screening. Prepared by the Applied Technology Council, Redwood City, California (ATC-21-1) FEMA-155, 1988, 137 pages.

NEHRP Handbook for the Seismic Evaluation of Existing Buildings - A nationally applicable and consensus-backed method for engineers to identify buildings or building components that present unacceptable risks in case of an earthquake. Four structural subsystems are identified: vertical elements resisting horizontal loads; horizontal elements resisting lateral loads; foundations; and connections between structural elements or subsystems. In addition non-structural building elements are addressed. A general evaluation procedure is presented, as well as specific procedures for 15 common building types. The Handbook is compatible with the NEHRP Handbook of Techniques for Seismic Rehabilitation of Existing Buildings, FEMA-172. Originally prepared by the Applied Technology Council and modified by the Building Seismic Safety Council. FEMA-178, 1989, 224 pages.

NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings - A nationally applicable and consensus-backed compendium of techniques for use by engineers, architects, and building officials, to seismically rehabilitate buildings that pose an unacceptable risk in case of an earthquake. Both structural and non-structural components for a broad spectrum of building types are examined. Originally prepared by URS/John A. Blume and Associates and modified by the Building Seismic Safety Council. FEMA-172, 1989, 197 pages.

Typical Costs for Seismic Rehabilitation of Existing Buildings: Summary - A cost analysis of over 600 seismic rehabilitation projects throughout the U.S. The following building types are studied: unreinforced masonry, reinforced masonry, reinforced concrete, wood, and steel. Prepared by Englekirk and Hart Consulting Engineers, Inc. FEMA-156, 1988, 50 pages.

Typical Costs for Seismic Rehabilitation of Existing Buildings: Supporting Documentation - Discussion of the methodology used to obtain cost data and other related topics. FEMA-157, 1988, 100 pages.

A Benefit Cost Model for the Seismic Rehabilitation of Hazardous Buildings: A User's Manual - Explains two standard benefit/cost models that can be used throughout the U.S. by community officials, analysts, or practitioners to help evaluate the direct economic impact to owners and occupants. The single class model analyzes groups of buildings which may have several structural types and uses. Single Class and Multi-class Software included. Prepared by VSP Associates, Inc. FEMA-227, 1992, 68 pages.

A Benefit Cost Model for the Seismic Rehabilitation of Hazardous Buildings: Supporting Documentation - Includes results of a test of the model using buildings in Seattle and other background information. FEMA-228, 1992, 61 pages.

Financial Incentives for Seismic Rehabilitation of Hazardous Buildings - An Agenda for Action - Identifies current incentives for seismic rehabilitation of Federal, State, and local levels, in both public and private sectors, including an action agenda for encouraging seismic rehabilitation. Incentives could affect developers, owners, bankers, insurers, and other businesses to undertake seismic strengthening of existing buildings. Three volumes prepared by Building Technology, Inc.

> **Volume 1: Findings, Conclusions, and Recommendations** - Discusses the methodology used in this activity along with background on financial incentives that were identified and presented in An Agenda for Action. FEMA-198, 1990, 104 pages
>
> **Volume 2: State and Local Case Studies and Recommendations** - Presents over 20 case studies, 14 cities in six states. FEMA-199, 1990, 130 pages.
>
> **Volume 3: Applications Workshop Report** - Describes seven Applications Workshops held in 1990. Included are teaching materials which can be used in a workshop, and guidelines for convening a workshop. FEMA-216, 1990, 200 pages.

Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings: Handbook - Explores questions and political issues raised during the formulation of seismic rehabilitation programs, with emphasis on establishing priorities. The aim is to assist local jurisdictions in the design of a program by addressing pertinent issues that need to be considered both politically and socially. A social impact assessment process is proposed to identify, marshall, and resolve major issues. Prepared by Building systems Development, Inc. with Integrated Design Services and C. Rubin, FEMA-174, 1989, 122 pages.

Establishing Programs and Priorities for the Seismic Rehabilitation of Buildings: Supporting Report - Commentary on the Handbook, in addition to annotated bibliographies, and reproductions of selected laws and ordinances presented briefly in the Handbook, FEMA-173, 1989, 190 pages.

Proceedings: Workshop on Reducing Seismic Hazards of Existing Buildings - Includes issue papers and critical analyses of these papers on technical and societal topics and on time and cost requirements for seismic rehabilitation. Prepared by ABE Joint Venture (Applied Technology Council, Building Seismic Safety Council, and Earthquake Engineering Research Institute), Edited by Roger E. Scholl. FEMA-91, 1985, 214 pages.

Seismic Safety of Existing Buildings: Engineering Considerations - A brochure explaining the seismic rehabilitation program and identifying the relevant FEMA publications. Covers how to select a program most appropriate for the needs of a community, potential financial incentives, and how to build an agenda for action. L-172, 1990, 8 pages.

Seismic Safety of Existing Buildings: Engineering Considerations - A brochure explaining the seismic rehabilitation program and identifying the relevant FEMA publications that cover how to quickly screen buildings, evaluate those buildings at risk, and how to strengthen them. L-171, 1990, 8 pages.

Seismic Rehabilitation: A National Need - An introduction on video to FEMA's program of seismic rehabilitation of buildings and relevant FEMA publications. Produced by Building Technology Inc., Thomas & Associates, and Maguire-Reeder, Ltd. VT-EQ-1, 12 minutes, VHS format. Available only to organizations and agencies.

Seismic Rehabilitation: Societal Implications - A series of three lectures on video describing the contents of the following documents: Establishing Programs and Priorities (TRT - 9:28 min.); Typical Costs (TRT - 7:17 min.); Financial Incentives (TRT - 5:16 min.). Produced by Building Technology Inc., and Maguire-Reeder Ltd. VT-EQ-2, VHS format. Available only to organizations and agencies.

Seismic Rehabilitation: Engineering Considerations - A series of four lectures on video describing the contents of the following documents: Rapid Visual Screening (TRT - 8:00 min.); NEHRP Handbook for Seismic Evaluation (TRT) - 8:02 min.); NEHRP Handbook of Techniques (TRT - 7:21 min.); Typical Costs (TRT - 7:17 min.). Produced by Building Technology Inc. and Maguire-Reeder Ltd., VT-EQ-3, VHS format. Available only to organizations and agencies.

Free copies of these publications can be obtained by contacting:

Birch & Davis Associates, Inc.
FEMA Project, Suite 300
8905 Fairview Road
Silver Spring, MD 20910
(301) 589-6760 FAX (301) 650-0398

MEETINGS AND CONFERENCES

February 11-13, 1993, Earthquake Engineering Research Institute Annual Meeting, Infrequent large earthquakes - implications for practice and research, held at the Sheraton Seattle Hotel and Towers in Seattle, Washington. The meeting will include case studies from recent earthquakes, panel discussions, and individual presentations on designing and constructing new seismic-resistant structures, retrofitting old structures, building earthquake-resistant lifelines and infrastructure, and establishing effective codes, enforcement procedures, and public policy. For more information, contact the Earthquake Engineering Research Institute, 499 14th Street, Suite 320, Oakland, CA 94612-1902, (510) 451-0905, fax 510-451-5411.

March 22-24, 1993, 28th Symposium on Engineering Geology and Geotechnical Engineering, held at the University of Nevada, Reno. For further information, contact Dr. Gary Norris, Proceedings Editor and Co-Chairman, College of Engineering, University of Nevada at Reno, Reno, NV 89557, (702) 784-6835.

April 14-16, 1993, Seismological Society of America Annual Meeting, held in Ixtapa-Zihuatanejo, Mexico. Abstracts of papers reporting original research in seismology and earthquake engineering are invited. Abstracts must be received no later than January 10, 1993. Copies of the instructions for submitting abstracts may be obtained from and should be submitted to Program Chair, c/o SSA Headquarters, 201 Plaza Professional Building, El Cerrito, CA 94530, (510) 525-5474.

April 19-21, 1993, ASCE Structures Congress '93, Structural engineering - leadership in natural hazard mitigation, held in Irvine, California. For information, contact R. Villaverde, Secretary, Steering Committee, Structures Congress '93, Department of Civil Engineering, University of California at Irvine, Irvine, CA 92717.

May 19-21, 1993, Geological Society of America Cordilleran/Rocky Mountain Section Meeting, held in Reno, Nevada. For more information, contact Vanessa George, GSA, 3300 Penrose Place, Boulder, CO 80301, (303) 447-1133.

June 1-6, 1993, Third International Conference on Case Histories in Geotechnical Engineering, held in St. Louis, Missouri. One of the themes of this conference will be geotechnical earthquake engineering. Abstracts were due by February 28, 1992. For further information on the conference or the call for papers, contact Shamsher Prakash, Conference Chairman, III CHGE, 308 Civil Engineering, University of Missouri-Rolla, Rolla, MO 65401, (314) 341-4489, fax 314-341-4729.

August 29-September 3, 1993, Hazards-93, Fifth International Conference on Natural and Man-made Hazards, organized by the International Society for the Prevention and Mitigation of Natural Hazards and held in Quindao, China. The United Nations declared the 1990's as the International Decade for Natural Hazard Reduction. Its objective is to prevent or mitigate natural disasters and the loss of life, property damage, and social and economic disruption they produce worldwide. The 1990s are also a time when, for many countries, coping with disasters is becoming virtually synonymous with development. The cost of rehabilitation and reconstruction in the wake of disasters is consuming available capital, significantly reducing the resources for new investment. Tackling this problem requires a sound evaluation of disaster mitigation policies and tools. The theme for Hazards-93 is disaster mitigation: scientific and socio-economic aspects. The organizing committee welcomes papers on all aspects of natural and man-made disasters, but priority will be given to those emphasizing the mitigation aspects and preventative measures. For more information, contact Professor Mohammed El-Sabh, Natural Hazards Society, Centre Oceanographique de Rimouski, 310 Allee des Ursulines, Rimouski, Quebec, G5L 3A1, Canada, (418) 724-1707, fax 418-723-7234.

October 25-28, 1993, Geological Society of America Annual Meeting, held in Boston, Massachusetts. Abstracts are due by July 7, 1993 and should be sent to Abstracts Coordinator, GSA, 3300 Penrose Place, P.O. Box 9140, Boulder, Co 80301-9140. For further information about the conference, contact Vanessa George, GSA, 3300 Penrose Place, Boulder, CO 80301, (303) 447-1133.

July 10-14, 1994, Fifth U.S. National Conference on Earthquake Engineering, organized by the Earthquake Engineering Research Institute and held at the Marriott Downtown Hotel in Chicago, Illinois will have as its theme "Earthquake awareness and mitigation across the nation". The conference will provide an opportunity for both researchers and practitioners to share the latest knowledge and techniques for understanding and mitigating the effects of earthquakes. This quadrennial conference will bring together, and enhance dialogue among, professionals from the broad range of disciplines committed to reducing the impact of earthquakes on the built and natural environment: geology, seismology, geophysics, geotechnical engineering, soils and foundation engineering, structural engineering, architecture, social response, regional planning, emergency response planning, and regulation. For further information and future conference bulletins, contact the Earthquake Engineering Research Institute, 499 14th Street, Suite 320, Oakland, CA 94612-1902, (510) 451-0905, fax 510-451-5411.

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