SEISMIC RISK ASSESSMENT OF UTAH HEALTH-CARE FACILITIES AND RECOMMENDATIONS FOR RISK REDUCTION

SEISMIC SAFETY ADVISORY COUNCIL

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FOREWORD

The Utah Seismic Safety Advisory Council, established in 1977, is charged to prepare assessments of earthquake hazards and associated risks to life and property in the State of Utah, and to make recommendations for mitigating hazards which may be found.

This report presents an assessment of seismic risk for existing health-care facilities--specifically hospitals and nursing homes--in Utah and provides recommendations for abatement or mitigation of hazards identified in the study. The recommendations are set forth as judgements of the Advisory Council in terms of (1) effectiveness of the suggested action for reducing risk to life and property losses and (2) economic feasibility for the particular action. Effectiveness and economic feasibility are addressed in combination through "benefit-cost" methods.

The report is divided into a summary of findings, a set of recommendations for seismic hazards reduction, an in-depth discussion of findings, and a technical section on methods of analysis and results. The technical section utilizes current seismicity data in Utah and state-of-the-art methods for earthquake damage and risk assessments. The reader must bear in mind that earthquake risk assessment is an inexact science built upon limited understanding of earthquake phenomena and their effects upon buildings. The technical results presented here are probabilistic in nature and carry all of the imperfections implied by this term. Notwithstanding these fundamental limitations, the Advisory Council deems the conclusions to be founded on reasonable data and analytical methods.

The report presents an overview of seismic risk for classes of hospitals and nursing homes in the State. Only for a few situations are conclusions drawn and recommendations made for specific projects, and even for those cases such conclusions result from obvious problems highlighted by the methodology. In general, the report is not intended for application to specific buildings, since detailed information on individual buildings was not obtained to allow conclusions to be drawn with certainty. The purpose in the overview approach taken in this study is to develop general program directions for mitigation of seismic hazards in hospitals and nursing homes as classes of buildings rather than to identify the specific problems of any one building. The recommendations include suggested actions for dealing with individual buildings according to seismic risk indicators which are identified. From this approach, the Seismic Safety Advisory Council has been able to identify pervasive seismic risk conditions among hospitals and nursing homes and to recommend actions leading to remedies.

The report addresses both privately owned or operated and publicly owned and operated health-care facilities. No distinction is made between the two cases insofar as seismic risk may be present, but it is recognized that responsibilities for safety of occupants of such facilities are matters of concern both to the owner-operators and to the State. Suggested mitigation actions by the owners and operators of health-care facilities are recommended, and actions by the State of Utah appropriate to its regulatory role for health-care facilities are recommended.

The Seismic Safety Advisory Council urges adoption and implementation of the recommendations contained herein.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

(Continued)

Page

SECTION 1

SUMMARY OF FINDINGS

Principal findings resulting from the seismic risk assessment of existing Utah hospitals and nursing homes reported herein are presented first, without elaboration or extensive discussion. More detail is provided in Section 3. A full description of the study methodology and considerably more detail are provided in Section 4. Recommendations for dealing with principal findings of earthquake hazards are provided in Section 2 which is organized so as to allow their separation from the report without their seeming to be incomplete.

The report is organized to provide the reader with constant overview of study concerns while developing and describing a complex analysis of earthquake safety in certain classes of existing Utah health-care facilities.

This study addresses the seismic risk only for existing hospitals and nursing homes in Utah. The principal findings and recommendations which follow are limited accordingly. Seismic hazards mitigation in the construction of new health-care facilities involves conditions which are completely different from existing facilities and, consequently, remedies which also are different. New construction is treated only tangentially in this report. Here, it is enough to observe that seismic safety can be achieved quite simply in new construction in contrast to remedying safety deficiencies in existing buildings, and that providing seismic safety in new construction is inexpensive if current seismic standards are followed.

Principal findings of this study are listed below. Importance of the topic was not a basis for the list sequence. Readers will note that the findings are listed more or less in order of their appearance in the discussion sections of the report, with findings pertinent just to hospitals and just to nursing homes separately listed.

Seismicity In Utah

- Seismicity is common in most of the State of Utah with the possible exception of the easternmost portion. The most severe and frequent earthquakes historically have occurred along a central region extending from the north central border to the southwest border. This seismic region is a part of an area that has become known as the Intermountain Seismic Belt. Geologic evidence suggests that severe seismicity in the future most likely will occur within this same region, with the Wasatch fault zone being the zone of greatest risk. Although the probable frequency of strong earthquakes is expected to be very low, the Wasatch fault is said to be capable of producing earthquakes in the 7.3 Richter magnitude range. Earthquakes in the 6+ Richter magnitude range not only have occurred in historic time in the State, but Utah can expect to experience more such events in the future.

- Earthquake damage to buildings is determined primarily by three factors: (1) earthquake strength, (2) earthquake location relative to the building, and (3) building construction characteristics. Damage is found to appear in ordinary buildings at an earthquake threshold level of 4.5 to 5 Richter magnitude. As the earthquake strength increases, so does the damage. Earthquakes in the 6+ Richter magnitude range can cause severe damage and create severe hazards to life safety, although building collapse is rare. Earthquakes in the 7+ Richter magnitude range assuredly will cause collapse of many non-seismically designed buildings and could even damage some that are seismically designed.

Hospitals

- Forty five existing Utah hospitals were included in study surveys. These are all that could be identified, but some may have been missed inadvertently.

- These 45 hospitals have a combined bed capacity of just over 5,600.

- Distribution of hospitals in the State corresponds closely, although not exactly, with the distribution of population, with the greatest concentration of both in the central counties along the Wasatch Front. Nearly one-half of the hospitals are in the four most populous counties of the State--namely Davis, Salt Lake, Utah, and Weber Counties.

- Age of hospitals ranges from the new to some that are over 50 years old. It is interesting to note, however, that nearly 75% of the hospitals have been built or have had major additions since 1970, and nearly 85% since 1960. The distribution between new structures and additions to older facilities is about even during the time period.

- Hospital construction in Utah varies widely, ranging from multistory structures with steel or reinforced-concrete frames, to two-story structures of mixed steel or concrete framing and masonry bearing walls, to one-story structures of wood, steel, and masonry construction. Most of the hospitals of larger size have been built in phases across many years, and so usually have a variety of construction materials and methods.

- Construction methods for hospitals have changed during past decades, but such changes typically are in materials and assembly techniques rather than in structural framing techniques. Multistory construction does not appear to be more prevalent in recent years as a percent of the construction during any given period, but the number of multistory buildings in total has grown commensurate with the amount of new construction that has occurred. Unreinforced brick masonry, a construction type widespread in Utah among all types of buildings, is common for hospitals, and there are few that do not have some unreinforced masonry. However, in many of these buildings the unreinforced masonry is combined with other construction systems to such an extent that any generalities drawn regarding expected performance of the buildings subjected to seismic forces are bound to be oversimplifications. Only by detailed analysis will their true vulnerabilities be fully disclosed. Such detailed analysis is beyond the scope of this report.

- Some general observations regarding building vulnerability may be made, drawing upon knowledge of past construction practices in Utah. Hospitals constructed before 1950 universally were unreinforced when masonry was used, and this was the case for nearly all large buildings. Multistory buildings of such construction typically have poor seismic resistance. Pre-1940 buildings typically were not governed by construction codes. Hence, their seismic resistances are even less certain. As recently as the 1960's, little attention was given to seismic-induced lateral forces in Utah construction, and hospitals were no exception. While these newer buildings generally had better quality control in their construction, and while the applicable newer code provisions typically result in stronger buildings, lateral-force resistance remains an uncertainty for these post-1960 buildings. Seismic safety and seismic design standards received wider attention during the 1970's but, even so, there were no policies or procedures in force or use in Utah which allows one to say with confidence that these particular hospital structures meet the seismic standards of their era. With a few exceptions--notably the new St. Mark's Hospital, the University of Utah Medical Center, and the recently remodeled Veterans Administration Hospital--it is fair to conclude that few existing Utah hospitals have deliberately designed seismic lateral-force resistance, and few of the buildings have been analyzed rigorously to determine their vulnerability.

- Twenty five of the 45 hospitals surveyed lie in Utah's seismic zone of highest risk, and these 25 hospitals contain more than 85% of the State's total hospital bed capacity. Moreover, a large percentage of this bed capacity is in hospitals located near the Wastach fault line and thus are doubly jeopordized.

- Earthquake hazards to hospital populations in Utah's seismic conditions are expected to cause more injuries than deaths. These injuries will result from falling debris--toppled walls of unreinforced masonry, falling ceilings and ceiling fixtures, overturned furniture, toppled shelving used for storage, and broken window glass. However, since larger earthquakes are possible, the possibility must not be overlooked that older buildings of unreinforced masonry construction might collapse, and deaths may occur in such cases.

- The estimated numbers of deaths and injuries to populations in Utah hospitals due to earthquakes during any 100-year period are relatively small when compared with other everyday hazards that the general population faces. On the statistical basis by which computations were made for this study, the estimates are that less than 20 deaths and less than 300 injuries are expected during any 100-year period.

Still, use of statistics alone to assess seismic risk can be misleading. For example, consider the possibility that all of the deaths and most of the injuries may be associated with just one building failure caused by a single earthquake during the 100-year period. An even worse picture is created if all deaths and injuries were to occur in several building failures caused by a single severe earthquake. This might happen just once during a period of several hundred years. Such an occurrence could result in many tens of deaths and many hundreds of injuries. Annual and 100-year statistics, then, offer a means to evaluate risk, but not the only means. Worst-case situations also must be considered. Based upon worst-case and 100-year statistical considerations, a conclusion of this study, on the one hand, is that steps ought to be taken to safeguard life safety from severe single-event losses. Such risk reduction measures entail identification of high-hazard facilities and selective correction of unsafe conditions in those facilities. On the other hand, the high cost of correcting suspected unsafe conditions in all hospitals does not compare favorably with the modest life-saving and injury-prevention benefits unless the unsafe conditions are systematically corrected through long-term efforts which are tied to other safety purposes.

- Cost-effective reduction of seismic risks in Utah hospitals can be accomplished only in a limited number of cases, and even then decisions to do so will be influenced additionally by two special factors--namely the importance placed upon life safety and the critical purposes of the medical-care facility which society may deem essential immediately after an earthquake.

- By benefit-cost methods of analysis, it is demonstrated herein that major replacement or retrofitting of the entire class of Utah hospitals is not cost-effective for Utah's seismic environment. However, this finding should not be construed to mean that all Utah hospitals are seismically safe. Facilities found to be especially hazardous have been singled out in this report, and recommendations are made to reduce such hazards for these facilities. For the major portion of existing hospitals, however, it can be shown that systematic procedures to identify and correct seemingly minor problems will result in lower risk to life safety and, likely, to reduced property damage from recurring earthquakes.

- So that Utah's inventory of unsafe hospital facilities is not enlarged in time as new facilities are added, definitive steps are recommended to ensure that seismic risk is considered during the design and construction of new hospitals and when major renovations are made to existing hospitals. Such a goal may be realized by strict adherence to current earthquake-resistant design standards and by avoiding building on sites of seismically hazardous geologic conditions.

Nursing Homes

- Eighty four existing nursing homes in Utah were included in study surveys. These facilities were identified from records of the State Department of Social Services.

- These 84 nursing homes have a combined bed capacity of 6,191.

- Distribution of nursing homes in the State corresponds closely with the distribution of population, with by far the greatest number in the central counties along the Wasatch Front. Fully 75% of all existing nursing homes are in the four most populous counties of the State--namely Davis, Salt Lake, Utah, and Weber Counties.

- Nursing homes as a class of buildings are relatively new in the State. Fully 85% were constructed in the 1960's and 1970's, with nearly 50% of 1970's vintage. However, it should be noted that many of these facilities were constructed in phases, and so the percentage characterization does not provide an entirely accurate picture of their age. Still, additions to older facilities during the 1970's typically were large and account for the greater part of the overall bed capacity.

- Types of nursing home construction in Utah vary widely. Predominant among the construction types is mixed construction of masonry and wood framing; although reinforced-concrete and steel framing systems also are prevalent. Masonry construction, however, is common among all types of mixed systems.

- Some general observations regarding vulnerability of various types of nursing home construction may be made, drawing upon knowledge of past construction practices in Utah. Pre-1940 buildings typically were not governed by construction codes, and so their seismic resistance generally is considered to be poor, especially when of masonry construction which almost certainly is unreinforced. Construction codes applicable during the 1940's and 1950's typically did not include seismic resistance as a required provision, and so such buildings, while likely stronger than earlier construction types, still did not have designed resistance to lateral forces. As recently as the 1960's, little attention was given to seismic-induced lateral forces in Utah construction. Seismic safety and seismic design standards received wider attention during the 1970's, and while the seismic standards also were improved during that decade, there were no policies or procedures in force or use which allows one to say with confidence that nursing homes constructed during that time meet the standards.

- Sixty nine of the 84 surveyed nursing homes lie in Utah's seismic zone of highest risk, and these 69 nursing homes contain more than 88% of the total nursing home bed capacity in the State.

- Earthquake hazards to nursing home populations in Utah's seismic conditions are expected to cause more injuries than deaths. These injuries will result from falling debris--toppled walls of unreinforced masonry, falling ceilings and ceiling fixtures, overturned furniture, toppled shelving used for storage, and broken window glass. Any resulting deaths likely will be caused by partial collapse of portions of a few buildings rather than total collapse of structures.

- Deaths and injuries to populations in existing Utah nursing homes during any 100-year period are estimated at 11 and 160, respectively. These numbers are relatively small when compared with other everyday hazards that the general population faces. Still, use of statistics alone to assess seismic risk can be misleading. One must not overlook the historical fact that most deaths due to earthquakes are caused by those infrequent, large events; whereas property losses are likely to be caused more frequently by recurrent but smaller earthquakes. It is contended in this study that single-event earthquake losses of life and injury are taken more seriously by society, and greater effort is demanded to ensure against such possibility. Such risk reduction measures entail identification of high-hazard facilities and selective correction of unsafe conditions in those facilities.

- Cost-effective reduction of seismic hazards in Utah nursing homes can be accomplished only in a limited number of cases. In every case of high seismic risk that may be discovered, the extent of remedial action to a facility will be influenced by other social factors besides cost--namely the importance placed upon life safety and the degree of immobility of nursing home populations which causes them to be more vulnerable to earthquake hazards.

- By benefit-cost methods of analysis, it is demonstrated that major replacement or retrofitting of the entire class of Utah nursing homes is not cost-effective for Utah's seismic environment. However, this finding should not be construed to mean that all nursing homes are seismically safe. Given these incompatible observations, reduction of seismic hazards in existing nursing homes is all the more difficult to accomplish. Recommendations presented in this report weigh such considerations and suggest a modest overall seismic safety assessment program to be carried out by private nursing home operators, with oversight responsibility for the program resting with the State's regulatory agency governing nursing home licensing.

- So that Utah's inventory of unsafe nursing home facilities is not enlarged in time as new facilities are built, definitive steps are recommended to ensure that seismic risk is considered during their design and construction. Such a goal may be realized by strict adherence to current earthquake-resistant design standards both for new construction and for renovated buildings intended to be used as nursing homes.

SECTION 2

RECOMMENDATIONS FOR MITIGATION OF SEISMIC SAFETY HAZARDS IN EXISTING UTAH HEALTH-CARE FACILITIES

The following recommendations result from a benefit-cost study of the expected impact of earthquakes upon existing Utah health-care facilities, or, more specifically, nursing homes and hospitals. The study, titled "Seismic Risk Assessment of Utah Health-Care Facilities," provides detailed information upon the extent and nature of earthquake hazards in existing facilities and also guidance as to feasible remedies for identified problems. The recommendations that follow are based upon the findings of the study.

Hospitals and nursing homes have special community roles. Licensing of such facilities by the State is required to ensure the health, safety, and welfare of occupants and the suitability of facilities. During earthquakes, hospitals are essential facilities in the sense that we rely upon their continued operation to ensure the life safety of patients and to provide the increased services that often are needed. Moreover, both hospitals and nursing homes house occupants who have limited physical capacities to cope with emergency situations. The safety of hospitals and nursing homes from disruptive damage due to earthquakes, therefore, is deemed to be of paramount importance to the State.

The following recommendations regarding earthquake safety, then, are designed to balance the special characteristics of these health-care facilities with both the extent of the earthquake hazards in Utah and the costs of reducing the hazards in such facilities.

The recommendations are intended for correction of identified problems by means of a well directed, long-term program utilizing existing authorities of the State Department of Health and capabilities of the State Building Board to provide program guidance. The recommendations primarily call for hazards mitigation efforts through administrative action by regulatory agencies rather than through a major program of State intervention through legislation involving construction of health-care facilities.

1. It is recommended that seismic safety standards for hospitals and nursing homes be established by administrative procedure by the State Department of Health in cooperation with the State Building Board and that these standards be met as a condition for licensing of hospitals and nursing homes. That these standards are met should be certified by persons qualified to check for compliance. Such standards should be applicable to

new facilities, to any major modifications (over 50% of the replacement cost of the structure) made to existing facilities within any five-year period, and to conversions of existing non-health-care facilities into hospital or nursing home facilities.

The special role of hospitals during emergencies, and the limited physical capacities of some occupants in health-care facilities to cope with emergency situations, have been noted. The particularly high occupancy rates of nursing homes is another factor in assessing life-safety hazards due to earthquakes. These conditions argue for increased attention to seismic hazards reduction for such facilities.

Study data clearly show that front-end costs to achieve compliance with seismic safety standards are far less than costs of major modifications to existing structures that may be determined to be hazardous. So, new construction work (newly built, additions, and major remodeling) should be required to meet current seismic safety standards as may be established by the State Department of Health. As well, conversions of non-health-care facilities into hospitals or nursing homes should be required to meet the same standards.

The State Department of Health presently regulates the safety of hospitals and nursing homes through standards that must be satisfied for licensing of the facilities. Thus, there already exists a procedure which can include seismic safety as an additional criterion for licensing.

A seismic safety consideration in health-care facilities of nearly equal importance with the building safety is the protection of life-support and other essential equipment. Even though seismic safety guidelines for installation of essential equipment are sparse at this time, initial standards prepared by the Veterans Administration may be employed until alternative specific guidelines are developed (Cf. [21] in the bibliography of the detailed report.)

2. It is recommended that fault-related and other geoseismic hazards be used as a negative criterion in evaluating any future plans to expand hospital and nursing home bed capacities, whether by modification of existing structures or by new construction.

Past practices of locating hospitals so as to be convenient to population centers, but with little or no regard for earthquake hazards, have the result that some are sited in areas of high seismic risk. The same findings apply to nursing homes.

In view of the high costs of hospital construction in particular, relocation of several hospitals now situated hazardously close to identified fault zones is not generally feasible. However, when any expansion of bed capacities is proposed, even when such an expansion involves an addition to any one of these existing structures, it is recommended that a geological evaluation be made of each site in order to determine the seismic hazards that may be present and that any identified problems be resolved as a condition of construction approval by the State. This recommendation should apply both to hospitals and to nursing homes. Where alternative sites exist, additional bed capacity should not be licensed when it is determined that geoseismic hazards may place occupants in jeopardy.

3. It is recommended that a review be required of the older sections of existing multistory hospitals by the respective owners or operators and that, when sections are deemed to be seismically unsafe, such sections be restricted to lower occupancy capacity or else be phased out of use as expeditiously as possible.

Several hospitals in the State's zone of highest seismic activity and with large bed capacities have sections that are very old. Lateral load capacities of such sections appear to be poor. Although other sections added later may have improved the seismic resistance of the older sections, information on which seismic safety may be judged is sparse, indeed non-existent, for most facilities. Since the lateral load capacities can be more adequately assessed through direct qualified examination, a review of such sections should be made. Where extreme seismic risks appear, such hospitals should be advised and encouraged to decrease the seismic risks, such as by removing overnight patients (as has been done for sections at the Holy Cross Hospital) or by phasing out such sections. Any plans so developed also should accord with the second recommendation already made. Monitoring of this recommendation should be a responsibility of the State Department of Health in cooperation with the State Building Board.

4. It is recommended that the State Building Board undertake a detailed review of the seismic hazards at the Utah State Mental Hospital for the purpose of identifying and correcting suspected severe seismic hazards, and that this be done concurrent with studies being prepared to modify or to replace the existing structures.

The Utah State Mental Hospital has many apparent high seismic risk indicators: e.g., its proximity to a known fault, very old masonry structures that may be specially vulnerable to earthquakes, high mean occupancy, and evidence of possible hazardous parapets. In view of such factors, review both of the seismic resistance of these structures and of the specific hazards of the site should be undertaken. This recommendation could be satisfied as expansion plans are developed, but should be completed promptly in any case. Such a review may indicate that occupancy in some structures should be lowered, such as by restricting overnight use, that some structures should be replaced, or that particular sites in the zone of deformation should not be used.

5. It is recommended that the recently prepared master plan for the Utah State Training School be followed as regards work done on seismic hazards reduction.

A master plan has been developed by the State Building Board so that orderly changes can be made at the Utah State Training School. In the development of the master plan, qualified personnel evaluated the seismic capacities of various structures and made recommendations as to how to correct deficiencies. The recommendations for improved seismic safety resulting from preparation of that master plan should be carried out.

SECTION 3

DISCUSSION OF FINDINGS RESULTING FROM A STUDY OF SEISMIC SAFETY IN EXISTING UTAH HEALTH-CARE FACILITIES

SCOPE

This study is among several undertaken to determine the economic merits of replacing or altering buildings in order to make them safer in the event of earthquakes. Degree of risk and economic feasibility are the principal factors addressed.

In this study existing Utah hospitals and nursing homes are examined. Data on existing facilities are from secondary sources, that is, without direct and costly inspections of individual buildings in regard to their vulnerability to earthquakes.

In order to make a broad survey of the seismic safety of hospitals and nursing homes; information has been drawn from several disciplines and from numerous sources. The comparative seismicity of various regions of Utah have been estimated. Utah hospitals and nursing homes have been identified, and their locations and construction systems recorded. Given data on locations, construction types, and seismicity, techniques were developed to estimate property losses and also life and casualty losses that could result from the seismicity. Valuation data also were obtained so that estimated money losses could be made. For hospitals, estimates of service losses might also be made in order to put the earthquake problem into greater perspective, although such was not done for this study.

There are many ways to reduce earthquake hazards connected with existing hospitals and nursing homes. For instance, health-care personnel can be informed as to what to do when an earthquake occurs. For another instance, inspectors and others directly concerned with health-care facilities can be trained to identify existing hazards, such as unsupported parapets, cornices, unsecured overhead lights, or unfastened equipment. Such hazards may be eliminated along with other associated hazards, including fire hazards, following orderly, systematic procedures. For still another instance, major structural deficiencies can be identified through more exhaustive analysis, and required modifications to correct deficiencies can be undertaken independently or along with other modifications that frequently are made to many buildings. Still another way is to replace unsafe buildings with those more seismically resistant. The last three ways named can reduce life losses and injuries as well as property damage. The merits of any or all of these possible methods of risk reduction cannot be assessed without consideration of economics. In the end, trade-offs between mitigation costs and acceptable risk must be made. An additional weighting factor for evaluating acceptable risk for health-care facilities, however, is their relative importance to post-disaster recovery and the consequent need, in some instances, to maintain operational capability during and after severe earthquakes. Such trade-offs are the basis of recommendations made in this report for existing Utah health-care facilities.

Since this study draws from many sources of information, it contains many of the elements for, but does not directly cover, the economic feasibility of making new buildings seismically sound, at some added cost, at the time of construction. In addition, it considers only benefits and costs relating to seismic safety. The possibility is not developed that seismic benefits could be one of several classes of benefits to be realized when a building is modified. An economic study considering seismic safety benefits as one of several sorts of benefits would require addition of the costs of the non-seismic safety benefits to the costs of seismic safety benefits.

Major renovations or relocations of hospitals typically are justified in terms of numerous considerations, such as demographic changes and the need for more updated facilities. Given the many factors that typically enter into major renovations or relocations of hospitals, it can hardly be expected that seismic safety considerations alone, based only on information from secondary sources, could justify major alterations to to an existing hospital, except in cases involving extremely great risk to occupant safety.

Based upon the observation made above, this study concentrates upon general aggregate building and life and safety losses due to earthquake-induced ground motions, from which general benefit-cost conclusions regarding State policy are derived or suggested. Such a methodology has its basis in statistical extrapolations. A full examination of the methodology and assumptions used is contained in Section 4 of this report.

THE GENERAL FINDINGS

Three broad alternatives were selected for evaluation in this study: (1) The existing structure is fully replaced by one that is earthquake resistant; (2) The structure is fully retrofitted to be seismically stronger; (3) The structure is left as it is. In all cases, the facilities were treated as classes of buildings rather than on an individual basis.

From an economic analysis of these alternatives, one can derive general conclusions about what major actions or programs may be needed so that health-care facilities may be seismically safer. The various forms of evidence developed in this analysis help to specify the risks expected from earthquakes. The study does not concern itself either with construction activities that are less costly, such as instances of selective remodeling, or with various programs that might be undertaken to prepare health-care personnel for an earthquake. Analysis of selective remodeling requires separate detailed analysis of each facility, which is outside the stated purpose of this study. Also, as previously implied, preparedness information on what to do in the event of an earthquake provides no verifiable data regarding reductions in life losses or injuries and no reductions in property losses.

Forty-five hospitals and 84 nursing homes were surveyed in this study. Most of the data on construction comes from Hill-Burton reports and blueprints of some medical facilities.

Cost estimates are based upon estimated construction costs per square foot. For hospitals, $90 per square foot was used. For nursing homes, $50 per square foot was used.[1] More precise estimates would not add much to this study in which damage losses are based upon percents of replacement costs. Also, precise cost estimates for particular structures depend upon bidding processes and changes in construction prices, of which both are matters of speculation.

In spite of the limitations of this study that are mentioned earlier and which are discussed in greater detail in Section 4, the comparative economic merits of the three alternatives are clear. With possible expections that may be discovered by site inspections, the estimated costs of either replacing or fully retrofitting a health-care facility exceed the estimated costs of leaving the building as it is. That is, on the aggregate level, no economic case can be made to justify either replacing or retrofitting existing health-care facilities in order to make them seismically safe. Considerations of life safety and criticality of the facility to the community must be added to the economic arguments if any justification is to be found for seismic hazards reduction.

It may turn out, in retrospect, that an earthquake causes losses to several particular structures that exceed losses that would have occurred had the structures been fully retrofitted or replaced. This is one limitation of probabilistic type studies. Geological and geophysical studies have not developed to the point where one can be fairly well assured which structures are going to suffer earthquake damage within a short geologic time-frame. So, it cannot be predicted which, if any, structures should have been replaced. However, direct examination of hospitals and nursing homes and improvements in seismic predictions may lead to a later conclusion that a few specific buildings need large-scale seismic safety modifications. But, on the aggregate level, even the worst hospitals and nursing homes among those surveyed do not pose sufficient seismic safety hazards to justify, in economic terms, large-scale replacements or retrofitting operations. Those in the worst class may warrant inspection or replacement for other reasons, but they are too few in number to justify any more exhaustive benefit-cost analysis in order to evaluate the merits of large-scale reconstruction programs to overcome seismic safety deficiencies. It has been concluded that Statewide

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[1]According to Mr. Van Johnson at Intermountain Health Care, Utah hospital construction costs for April, 1979, are estimated to be $94 per square foot, and the inflation rate is about 1.1% per month. So, for December, 1978, the figure is about $90 per square foot. The cost includes some equipment but excludes architectural and engineering fees and costs of major nonmovable equipment, such as X-ray equipment.

or district-wide replacement or retrofit of existing hospitals and nursing homes is unnecessary. At the same time, it has been concluded that some seismic safety problems are present in health-care facilities which warrant individual attention and correction.

Even though seismically sounder structures used as health-care facilities would substantially reduce estimated property losses, and minimize expected life and casualty losses, the costs of making structures much sounder would, on the aggregate level, greatly exceed the estimated benefits of such large-scale construction activities. It must be remembered that, if one decides to leave buildings as they are, one is increasing the risks that there will be deaths and casualties that would have been preventable. Still, the costs of preventing deaths and injuries are extremely high if large-scale seismic replacement and retrofitting operations are undertaken. The costs of preventing death and injury are much less if seismic requirements are met in the initial construction phases. As a further consideration, it is here anticipated that costs for preventing death and injury due to nonseismic causes, such as with specific health or roadsign programs, are comparably much lower, both in absolute dollars spent and in life safety benefits, than for massive seismic reconstruction programs.

For the State as a whole, and with hospitals treated separately from nursing homes, deaths, injuries, property losses, and benefits from selected mitigation measures are illustrated by the following estimates. The estimates are clarified both in the discussion to follow and in Section 4 on methodology and assumptions. Estimates of structural failures, defined roughly as instances in which 50% structural loss occurs, are added parenthetically so that one may estimate how many hospitals and nursing homes can be expected to become nonfunctional (in structural terms) over a given period of time. The point again is emphasized that hospitals should remain functional during times of crisis.

<u>Life Safety and Property Loss Estimates For Hospitals</u>

Estimated cost of replacing the 45 hospitals surveyed (1978 dollars):

$526,000,000

Estimated annual average structural loss to surveyed hospitals if all are left as they are:

Dollar estimate (1978 dollars): $273,000

(Nonfunctionality estimate: 0.12% of all surveyed hospitals)

Estimated annual average structural loss to surveyed hospitals if all are replaced or fully retrofitted to meet current seismic safety standards:

Dollar estimate (1978 dollars): $ 66,000

(Nonfunctionality estimate: 0.03% of all surveyed hospitals)

Estimated annual mortality rate to all occupants of surveyed hospitals if all are left as they are:

0.19

Corresponding annual hospitalized injury rate to occupants in surveyed hospitals:

2.89

Estimated annual mortality rate to those in surveyed hospitals if all are fully replaced or retrofitted to meet current seismic safety standards:

0.06

Corresponding annual hospitalized injury rate:

0.93

In life and casualty terms, an extensive reconstruction program for seismic safety would be expected to prevent about 16 deaths and about 234 injuries in a century.

Life Safety and Property Loss Estimates For Nursing Homes

Estimated cost of replacing the 84 public nursing homes surveyed (1978 dollars):

$85,500,000

Estimated annual average structural loss to surveyed nursing homes if all are left as they are:

Dollar estimate: $47,000

(Nonfunctionality estimate: 0.10% of all surveyed nursing homes)

Estimated annual average structural loss to surveyed nursing homes if all are replaced or fully retrofitted to meet current seismic safety standards:

Dollar estimate: $11,000

(Nonfunctionality estimate: 0.03% of all surveyed nursing homes)

Estimated annual mortality rate to residents of surveyed nursing homes if all are left as they are:

0.11

Corresponding annual hospitalized injury rate to occupants in surveyed nursing homes:

1.49

Estimated annual mortality rate to residents of surveyed nursing homes if all are fully retrofitted or replaced to meet current seismic safety standards:

0.03

Corresponding annual hospitalized injury rate:

0.25

In life and casualty terms, an extensive replacement or retrofit program for seismic safety of existing nursing homes would be expected to prevent about 8 deaths and about 110 injuries in a century.

The presence of seismic risk in existing hospitals and nursing homes thus is indicated from the analyses. Further, the number of preventable deaths and injuries for both types of facilities is large enough to justify purposeful mitigation effort. Any such mitigation effort, however, must weigh cost against life and injury saving benefits.

In economic terms, where one is forced to set a dollar value on life, for every $1.00 spent on replacement for hospitals, about 1 cent of benefit would ensue. If retrofitting were to cost only one-fifth of replacement, about 4 cents of benefit would result from $1.00 spent. For perhaps the worst case among existing hospitals, the Utah State Mental Hospital, less than 3 cents of benefit would result from $1.00 spent on replacement, and less than 11 cents of benefit would result from each dollar spent on retrofitting.

For nursing homes, less than 2 cents of benefit would ensue for $1.00 spent on replacement, and barely less than 7 cents for $1.00 spent on retrofitting. For perhaps the worst case among existing nursing homes, barely over 3 cents of benefit would result from $1.00 spent on replacement, and barely over 15 cents would result from $1.00 spent on retrofitting.

In other terms, one would need to estimate the value of prolonging life at over $300 million in order to justify, in cost terms, a Statewide massive seismic safety replacement program for existing hospitals, and over $100 million in order to justify such a replacement program for existing nursing homes. That is, programs that involve less than $100 million for each life saved are economically superior to a Statewide seismic safety replacement program for existing nursing homes. Even for the worst hospital, the value of preventing one death would need to be set above $14 million if retrofitting could be achieved at one-fifth the cost of replacement. For nursing homes, the value of preventing one death would need to be set above $9 million if retrofitting were justified for the worst structure and would cost one-fifth of the replacement cost.

Since there are no doubt less costly ways to prolong the lives of those in medical facilities than by Statewide programs, the options of replacing or fully retrofitting all medical facilities do not seem to be economically feasible. Yet, based on recent geological evidence and on the fact that most medical facilities lie in the most seismically active zones, the seismic problems cannot be ignored. If less costly means of correcting the problem are available, then such means should be seriously considered.

Even though benefit-cost techniques do not here justify any large-scale seismic reconstruction projects to existing medical facilities, several other noteworthy results of this study are described in subsequent paragraphs which indicate the merits of a selective upgrading effort. Such an effort entails identification of seismic risk indicators for individual buildings and selective correction of high-risk conditions. Coupled with such a program, regulatory procedures for health-care facilities can be used to encourage and monitor progress of the mitigation effort.

SEISMICITY IN UTAH

Since expected seismic activity in Utah is considerable, especially in those densely populated areas where most medical facilities exist, the failure of a benefit-cost analysis to justify extensive replacement or retrofitting operations is not due entirely to the level of expected seismicity in the State.

A few areas of the United States have higher expected earthquake rates than does Utah. Nonetheless, Utah is one of the most seismically active states. A much more important factor in the failure to justify extensive rebuilding programs is that building vulnerability is generally only marginally hazardous, whereas the dollar investment in health-care facilities is very large in Utah. In Utah, and in the United States generally, building materials and practices are superior to those in some countries where many lives have been lost during what would in Utah be regarded as moderately damaging earthquakes. (For one comparison, see [1].) Thus, a comparison of risk with cost to reduce risk shows a somewhat unfavorable relationship for Utah's seismic environment.

In a report by S.T. Algermissen and David M. Perkins, the United States is divided into 71 seismic source areas based on expected seismicity in each area ([2], see especially pp. 17, 18). Large areas of the United States are not included in any seismic zone. That is, such areas are not believed to have hazardous earthquakes. Utah has four major seismically active zones and one non-active zone, as delineated in the Algermissen and Perkins report. Three specific zones are applicable to Utah health-care facilities, namely, Zones 32, 33, and 34 (See Figure 1). One can compare the Algermissen and Perkins zonation map published in 1976 with the map still in use in the Uniform Building Code, 1979 Edition (UBC) (See Figure 2). It can be seen that the UBC map oversimplifies Utah's seismic environment as it currently is understood by scientists. In Figure 1, Zone 33 is the most seismically active, followed by Zone 34, and Zones 32 and 43 are least active. Part of the State along the east side lies in a zone where little seismic activity has occurred or is expected (See Figure 3).

Zone 33, which extends through Utah's most densely populated areas, ranks seventh among the 71 continental United States zones in terms of expected number of Modified Mercalli Intensity V earthquakes per 100 years[2], and ties for nineteenth in terms of its expected maximum Mercalli intensity. Zones that exceed Utah seismicity levels lie predominantly in California, Nevada, and Montana, although expected maximum magnitudes are equal or greater in the St. Louis area and in South Carolina.

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[2]For a partial explanation of the Modified Mercalli Intensity Scale, see Appendix A. See also [3], pp. 202-205.

Part of the basis for predicting future earthquakes and their intensities comes from the historical record. The historical record of seismicity in Utah, even though relatively short in geologic time reference, indicates considerable seismic activity in portions of the State. In a study of records from 1850 through June, 1965, Kenneth L. Cook and Robert B. Smith identified at least seven earthquakes that would register at least 6 on the Richter Magnitude Scale ([3], pp. 703-718). From 1853 to 1975, an estimated 17 Utah earthquakes had an Intensity VII or greater ([5], p. 156). Two earthquakes, one in Richfield in 1901, and one in Kosmo in 1934, were identified as having an intensity of IX (Cf. [6], pp. 9-20).

Further evidence disclosed by Robert Bucknam at the U.S. Geological Survey (USGS) in Denver indicates that the geological record may imply even greater estimated seismic activity along the Wasatch fault than is indicated by the more limited historical record. In line with USGS findings, which have been reported in several technical papers, a revised seismic zone map of Utah has been used in this study in which Zone 33 in Figure 1 has been subdivided into two sub-zones, 33A and 33B. Zone 33A, with higher expected seismicity rates, extends approximately 20 kilometers on each side of the Wasatch fault (see Figure 4). More detailed delineation of the Wasatch Front seismic zone is shown in Figure 5. Borrowing from the Algermissen and Perkins seismic source zone data and the Bucknam geologic evidence of higher seismicity in Zone 33A, a modified seismic zone map has been used in this study to indicate variations in expected seismicity (See Figure 6). The modified map renames the Algermissen and Perkins source areas as follows:

Algermissen and Perkins Source Areas	Modified Zone Designations
Zone 43	Zone U-0
Zone 32	Zone U-1
Zone 34	Zone U-2
Zone 33B	Zone U-3
Zone 33A	Zone U-4

Increasing numbers in the modified seismic zone map correspond with areas of increasing seismicity, with Zone U-4 being the most severe in the State of Utah.

Figures 7 and 10, which indicate the distribution in Utah of existing hospitals and nursing homes, respectively, show that most such facilities lie in the most severe seismic zones. Figures 8 and 9, which indicate the approximate locations of hospitals in Salt Lake County and Weber County, respectively, show that most of them lie very close to or within known ground fault zones.

Table 1 lists the existing hospitals by name in order of bed capacity. Also included are data on construction period and other indicators of seismic risk, including seismic zone and estimated distance of some facilities from the Wasatch Fault. Table 2 lists the existing hospitals alphabetically by seismic zone and indicates the construction classification for seismic risk used in this study. (See the next sub-section for a description of this classification system.) The nineteen largest Utah hospitals in bed capacity lie in Zone U-4. Twenty six of the 45 hospitals lie in Zone U-4, 7 in Zone U-3, and 7 in Zone U-2. Thus, almost 75 percent of all existing hospitals and over 90 percent of all bed capacity in Utah hospitals (See Table 3) lie within the State's two most severe seismic zones.

Table 6 shows that 69 of the 84 surveyed nursing homes lie in the most severe seismic zone, Zone U-4, with only a small distribution among the other zones. Table 7 shows that nearly 89 percent of the nursing home bed capacity in the State is in these 69 facilities.

Study findings therefore indicate clearly that future seismic safety studies should concentrate upon Zones U-4, U-3, and U-2 (even though, say, a large earthquake once occurred in Ibapah, which is in Zone U-2 (Cf. [4], p. 706)).

Estimates of seismicity are central to the loss estimates made herein. Improved data or methods of estimating seismicity undoubtedly will be developed in future years as geological and geophysical investigations bring forward new evidence. For the present time, the evidence of seismic hazards indicated above is sufficient to support conclusions that existing Utah health-care facilities are among the highest seismic risk facilities in the State.

EARTHQUAKE LOSSES

As the aggregate loss estimates presented previously indicate, considerable property damage to all sorts of buildings can be expected as a result of future seismic activity. Losses to hospitals and nursing homes likely will be included. But, as already stated, expected structural losses do not and cannot justify expenditure for large-scale retrofitting or replacement of such health-care facilities on the basis of cost alone.

Table 1, referred to earlier, contains several columns which bear upon the assessment of structural losses to hospitals. For example, the age of the hospital is one indication of whether or not seismic features were included during the design of the structure and how strong the structure may be, based upon its date of construction. Generally speaking, hospitals built in Utah before 1970 were not built with any special seismic-resistance features. Those built during the 1950's and 1960's, while meeting construction standards of their day and which were believed to be quite adequate, typically were not designed to resist seismic forces. Very old structures, such as those built before 1933, which commonly are constructed with unreinforced masonry walls, are very vulnerable to earthquake damage. Moreover, those structures very close to or on a known fault may be expected to suffer more damage than similar structures at some distance from the fault. Here, secondary sources indicate that the Utah State Hospital is on a known fault and that Holy Cross Hospital is very close to a fault [15].

In Section 4 on methodology and assumptions, it is explained how damage estimates are derived. In that section, it is explained why such building losses cannot, <u>in principle</u>, be adequate grounds for replacing structures. If there are reasons for replacing hospitals and nursing homes, they include life and safety factors and factors related to improved health-care facilities. The basis also is explained for drawing similar conclusions for large-scale retrofitting of whole classes of hospitals and nursing homes, although it is possible, at least in principle, for retrofitting to be less costly than the expected damage to structures left as they are.

Thus, whether a health-care facility exists in California or Utah, the justification for replacing such a building cannot be based upon property values alone. As one sees from the damage and loss estimates already given, the results of this study are consistent with such a general conclusion.

Since the estimated replacement costs of Utah hospitals exceed $500 million (See Table 5), the mean cost of replacement equals about $11.2 million. On a fifty-year basis, the estimated present value of losses in hospitals due to earthquakes is $2.7 million, and the mean cost of such damage has a present value of about $61,000.

For nursing homes in Utah, the mean cost of replacement equals about $1 million (See Table 9), but the mean cost of structural damage has a present value of about $6,000.

If it were economically feasible to replace all existing structures in either class, on the basis of structural losses alone, then the present value of structural losses would exceed the replacement costs of buildings. Such is obviously not the case.

Similarly, $61,000 is at present not nearly enough money to fully retrofit a hospital which needs improved seismic resistance. Nor is $6,000 enough to retrofit a nursing home adequately.

LIFE SAFETY

Data on life and casualty estimates in Utah health-care facilities do not suggest that the number of expected deaths and casualties can ever approximate, in economic terms, the difference between building replacement or retrofitting costs and damage losses.

Although there are numerous good objections to setting dollar values on life, or the prevention of death, such must be done in order to evaluate the merits of most alternatives for loss prevention. If some economic consideration is not given to such human factors as the value of life, then no benefit-cost analysis can ever justify replacement of health-care facilities. If, that is, one ignores the issue of the value of life, then one tacitly assumes, for economic purposes, that the value of life is zero. If, in contrast, one places the value of life as being infinite, then one justifies equally every program that is expected to prolong life, no matter how slight the program's contribution to the prolongation of life and no matter how economically ruinous the program may be.

The position here taken is that, for economic purposes, some value of life must be set so that the cost-effectiveness of various programs aimed to prolong life can be compared. In addition, it is here recognized that economic considerations alone should not be determinative of the value of programs to prolong life, even though economic considerations can play a role in the assessment of such programs.

Data for life and casualty estimates due to earthquakes in Utah are lacking owing to the limited number of severe events in the historical record. Two deaths have occurred in Utah that are earthquake-related, both caused by the 1934 Kosmo (Hansel Valley) earthquake of magnitude 6.1 (Cf. [7], p. 37). The estimate in this study that in a century there would be roughly 22 deaths to occupants in hospitals and 11 deaths to occupants of nursing homes in a century, given the bed capacities, types of structures, and their distribution, is to a large extent a result of assumptions of earthquake activity extrapolated from the historical record and geological expectations.

As a beginning point of discussion, if one were to assume that the historical record were to repeat itself, with epicenters and magnitudes where they lay, then, owing to increases in population density, more than the previous two deaths would be expected. A more important factor is that geological evidence indicates that epicenters for major future earthquakes are more likely to be found in more densely populated areas than previously has been the case. The number of expected deaths and injuries therefore will increase in the future, given the same construction characteristics for Utah buildings, even if future seismicity is the very same as in the past.

Still, the estimate in this study is far less than the USGS estimate of 351 hospital deaths if a severe earthquake were to occur in Salt Lake Valley near the Wasatch fault ([6], p. 105). As explained in the section on methodology and assumptions, it is assumed in this study that there is some likelihood of a major earthquake along the Wasatch fault in the next several hundred years, but the exact location cannot be known. Also, the likelihood that such an earthquake will occur in the area where it will cause the greatest life loss, in Salt Lake City near the Wasatch fault, is not very great. The USGS estimates are derived for a worst-case situation, whereas the estimates of this study are derived from statistical probabilities of expected earthquakes of all magnitudes. Thus, the USGS estimates provide an upper bound for earthquake losses based upon building construction at the time of that study, whereas the estimates in this study give an average loss that would be expected if one were able to accumulate similar loss data caused by earthquakes occurring over many hundreds of years. The lower boundary of losses in this type of analysis is that none will occur. That is to say, it also is possible, although most unlikely, that no severe earthquakes will occur in Utah in the future.

The comments made above illustrate the difficulty of estimating earthquake losses when our knowledge today of seismic recurrence is so limited. Planning for a worst-case earthquake, from the point of view of preventing life and property losses, sounds very correct in the abstract, but when one examines the cost and social disruption to do so, less extreme alternatives become more attractive. At the other extreme, to fail to consider that damaging earthquakes can occur is to disregard all available physical and scientific evidence. Thus, we have chosen to base our analyis on expected average seismic conditions and to recommend mitigation measures commensurate with such average conditions. In doing so, reasonable loss estimates result, and it is believed that substantial loss reductions for average seismic conditions can be accomplished at societal and economic costs that can be afforded. Yet, we simultaneously acknowledge that the recommended measures will not eliminate losses either due to a worst-case earthquake, which is possible, or even due to strong earthquakes given certain unfavorable conditions.

For earthquake loss reduction purposes, one must regard the average loss estimates here given as long-term estimates. However, for disaster planning, it should be assumed that a very damaging earthquake may occur, so that the State and its communities are able to deal effectively with earthquakes that are possible.

BUILDING DAMAGE

A primary reason why benefits from replacement or retrofitting of facilities do not exceed the costs for such changes is that moderately sized earthquakes are not expected to cause severe damage to existing health-care facilities even of the worst class in Utah. Still, some hospitals in Utah are over fifty years old, many are of unreinforced masonry, and many are near the Wasatch fault. Proximity to a fault is not in itself a complete indicator of building losses. Ground shaking, which affects a much larger area than ground rupture, is the major cause of building damage and life loss or injury. Still, a fault is an indicator of seismic activity which must be acknowledged. So, many structures in the Wasatch fault zone are more vulnerable to earthquake damage than are others at some distance from the zone.

For the purposes of this study, two building classification schemes were used for estimating earthquake losses. Both classification schemes recognize that different construction types have different expected seismic resistance characteristics.

The first classification scheme comes from a report by S.T. Algermissen and K.V. Steinbrugge, and contains five main classes ([8], p. 3).

(1) Wood-frame and frame-stucco buildings.

(2) All-metal buildings.

(3) Steel-frame buildings.

(4) Reinforced-concrete buildings.

(5) Those with mixed construction, or with masonry bearing and non-bearing walls.

A complete description of these building classes is furnished in Appendix B.

Structures in Zones U-4, U-3, and U-2 are believed to be most vulnerable to earthquake damage, though on a statisitcal basis one could expect occasional damage to structures in Zones U-1 and U-0.

Of special concern are unreinforced-masonry buildings, in the fifth class, which have been observed to be highly vulnerable to earthquake forces and which have no redundant support capability if the masonry should fail.

Large hospitals often include several structural systems, due to the fact that they have grown by additions over many years. Hence, it is not uncommon to find mixtures of steel frames, concrete frames, and combinations of masonry bearing walls and framed systems. Seismic resistance of such structures is extremely difficult to evaluate when a variety of construction systems and ages occur. Thus, hospitals having exterior masonry construction are placed in Class 4 or Class 5 for purposes of analysis even though they likely have widely varying seismic resistances.

The worst subcategory in Class 5 for unreinforced masonry structures appears to fit some of the buildings at the Utah State Mental Hospital.

Of the 45 hospitals included in the survey, portions or all of 17 among them have construction systems of Class 5E, which is the least seismically resistant construction class. Twenty of the 45 are of Class D, the next most vulnerable class, and 27 of 45, or 60 percent include portions of Class 5E or Class 5D construction, or both. Moreover, of the 5,601 total bed capacity of Utah hospitals, fully 66.5 percent is in buildings of Class 5E or 5D construction.

Over 70 of the 84 surveyed nursing homes contain structures of Class 5 category. About 27 of the surveyed nursing homes contain structures built before 1960. For such structures, construction data are scanty because blueprints are not readily available. A few of the buildings, however, appear to be very old. In particular, the Bonneville Nursing Home (Salt Lake City), Granite Psychiatric Care Unit (Salt Lake County), Colonial Manor (Nephi), the Utah State Training School (American Fork), and Mayfield Manor (Sanpete County) give evidence of being especially weak or vulnerable to seismic forces.

In general, there is some evidence that older structures are more seismically vulnerable than newer ones, owing primarily to the continual upgrading of construction standards across the years and also to the fact that earlier building practices were less concerned with seismic safety.

According to the USGS report on the Wasatch Front, Salt Lake City first adopted the Uniform Building Code (UBC) in 1933. Hence, the most vulnerable structures in Salt Lake City are those built prior to 1933 and having unreinforced-masonry bearing walls laid with sand-lime mortar and wood floor and roof construction ([6], p. 296). For the Wasatch Front, the USGS report makes the following further distinctions in terms of construction dates:

1. Structures built before 1961 are designed only for gravity loads and wind forces.
2. Structures built from 1961 to 1970 are designed for earthquake forces based upon a UBC Zone 2[3] classification.
3. Structures built after 1970 are designed for earthquake forces based upon a UBC Zone 3 classification ([6], p. 91).

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[3]Zone 2 is a designation of seismic hazard contained in the pre-1971 editions of the Uniform Building Code. The UBC zone designations and associated seismic design standards have since then been changed for the Wasatch Front.

Even though an examination of the history of the adoption of the Uniform Building Code and compliance with its seismic provisions in Utah has not yet confirmed that the USGS distinctions are completely valid, age remains a factor in assessing seismic vulnerability.

In accordance with the Algermissen and Steinbrugge report, such older health-care facilities were placed in the worst class of structures. But as previous results indicate, not even the oldest structures are vulnerable enough to warrant replacement or full retrofitting for seismic reasons alone.

The second building classification scheme, adapted from the methodology used in the USGS report, gives estimates of nonfunctionality. The building classes range from 1 through 7, with those in Class 7 being the most susceptible to damage. For hospitals, one sees the use of such categories in Table 1.

Roughly speaking, the seven classes are as follows:

(1) Small wood or metal buildings, or buildings with special damage-control features; one or two stories.

(2) Spacious wood or metal buildings, or spacious buildings with special damage-control features; one or two stories.

(3) Tall steel or reinforced-concrete buildings with special damage-control features, or one- and two-story spacious buildings designed for UBC Zone 3.

(4) Tall steel or masonry buildings designed for UBC Zone 3, or one- and two-story spacious buildings designed for UBC Zone 2.

(5) Spacious buildings constructed before 1961, and tall buildings designed for UBC Zone 2.

(6) Tall buildings constructed before 1961, or small structures with unreinforced-masonry bearing walls.

(7) Tall structures with unreinforced-masonry bearing walls, or others with apparent structural defects.

On the basis of secondary sources, and as a percent of estimated square footage, about 3% of Utah nursing homes were placed in Class 7, 4% in Class 6, 10% in Class 5, 27% in Class 4, 45% in Class 3, and 2% in Class 2.

For hospitals, about 34% of all floor area is of Class 6, 5% of Class 5, 25% of Class 4, 34% of Class 3, and 2% of Class 2.

In addition to estimates of structural losses due to ground shaking, further losses may result from the proximity of medical facilities to known ground faults. As Table 1 indicates, among hospitals, only the Utah State Hospital appears to lie practically on a fault. But, several other hospitals lie fairly close to the fault. Among nursing homes, data suggest that Hillside Villa and Terrace Villa lie on the fault. The precise nature of risks of such particular sites goes beyond the limits of the data used in this report.

Direct inspections of older structures, or unreinforced masonry buildings, or buildings close to faults, by qualified personnel may indicate in some cases that expected damage estimates, and also life and casualty estimates, are too low.

UNCERTAINTIES

Major earthquake losses are expected to occur infrequently, and not by any means with an equal distribution over the years. So, estimates derived here are not suitable for some purposes, such as for earthquake preparedness programs.

In the USGS study of earthquake losses in the Salt Lake City area, it is explicitly stated that the assumptions are made for extreme circumstances.

> The numerical values associated with each problem area, such as damage to and life loss in hospitals, represent reasonable maximum expected conditions .... Errors in the estimated intensities may stem from inaccurate estimates of maximum magnitude earthquakes for the region or a poor choice of epicentral location, focal depth, and fault trace. It is believed, however, that these items have been estimated conservatively and, thus, represent worst-case assumptions. ([6], p. 58).

Assumptions made here in this benefit-cost study, however, have been made in order to estimate long-term effects of earthquakes, which should include, when averaged out, very infrequent worst-case assumptions.

Averages, then, can be very misleading for certain purposes, since there can be almost no seismic damage for many years, and then considerable damage can occur. The modal as well as the median annual damage may well be zero in Utah.

In a computer simulation of San Francisco earthquakes from 1800 to 1967, Don Friedman assumed that the 1960 distribution of dwelling properties remained constant, and then derived damage estimates from earthquakes. According to Friedman's estimates, four major earthquakes in the period accounted for 86% of all simulated damages. The 1906 earthquake alone accounted for 44% of the damage. So, the 1906 earthquake alone contained damage 73 times the average annual loss, and the four earthquakes combined accounted for 142 years of the average annual loss ([9], p. 163).

Recent earthquake experience also can be misleading. When Friedman determined the average annual loss from 1948 through 1967, he found that the San Francisco earthquake caused losses that were 339 times the average annual loss in the most recent twenty-year period ([9], p. 163). Were this study to base its estimates, say, on very recent activity along the Wasatch fault, or even upon the historic record, estimated losses would be different from those indicated above.

In a report made public by Senator Alan Cranston (California), the total property damage due to earthquakes in the United States is estimated to be $1,862 million (1971 dollars). Three earthquakes, the 1906 San Francisco earthquake, the 1964 Alaska earthquake, and the 1971 San Fernando Valley earthquake, produced over 84% of the estimated property losses ([10], p. 187).

In Utah, several earthquakes have been intense enough to cause considerable losses. It is estimated that there have been, at least potentially, 40 damaging earthquakes in Utah in the past 128 years, and that the most damaging earthquake occurred in 1962 in Cache Valley, where property losses have been estimated at $1.7 million. Whereas the Cache Valley earthquake registered at 5.7 on the Richter scale, the Hansel Valley earthquake, in Kosmo, Utah, in 1934, caused two deaths as it registered 6.1 on the Richter scale ([7], pp. 37, 38). The extent of loss depends upon the amount of development and population density of the area affected by the earthquake.

So, even though losses due to earthquakes may be estimated reliably for the purpose of a benefit-cost analysis, actual losses at any given time depend upon many factors, and so may far exceed even the present value of expected losses.

Since there is such a discrepancy between the losses that occur on some infrequent occasions and the present value of estimated losses given annual loss estimates, and since large portions of Utah are seismically active, the cost estimates used in this study are not appropriate for all public earthquake safety programs. As stated previously, earthquake preparedness programs probably are more suitably based on what actions would need to be taken if earthquakes of high intensity, or higher than might soon be expected, were to occur.

Illustration of the problem of evaluating average losses comes when one considers various service losses in hospitals. Based on seismicity and on bed capacity, the following 100-year estimates may be made of service losses in Utah hospitals.

Service Function	100-Year Loss
bed loss	-- 4.8% or 308 beds
communications loss	-- 1.2%
elevator outage	-- 7.5%
electrical power outage	-- 1.8%
medical supplies	-- 7.8%

Taken on an annual basis, such losses can easily be compensated for, or circumvented. An average loss of 3 beds per year, for instance, is not especially serious. If, though, as might be the case, one earthquake were to cause 100 times the annual average, then such service losses might also imply further economic and human losses. Indeed, such a service loss alone in any one event likely would lead to new mitigation mandates after the occurrence.

Some evidence exists to the effect that such service losses can imply further losses. The 1971 San Fernando Valley earthquake affected hospitals perhaps more than any other type of facility. The majority of deaths occurred in hospitals. There was a 23.3% overall loss to buildings and equipment, and nearly 20% or 1,147 of the 6,751 beds were lost. There also was heavy elevator damage ([11], Vol. I, pp. 713, 736). Emergency rooms and ambulances were rendered inoperative when needed most. At Olive View Hospital and a V.A. Hospital, communication equipment was destroyed. Owing to elevator damage and loss of a major stair tower at Olive View Hospital, patients had to be evacuated by means of interior stairwells.

Not all service losses were irremedial. A pre-existing surplus of beds made other beds available, and other remedies, such as suspending elective surgery schedules, made other beds available. Still, as a result of power failure, loss of life-support systems led to two deaths at Olive View ([11], Vol. II, pp. 282, 283).

Experience from the San Fernando earthquake highlighted the generally accepted position that hospitals are essential community facilities. As such, they are expected to remain operational during and after all sorts of severe situations. And, the public is less tolerant of failure among such facilities than among ordinary-use offices and shops.

SECTION 4

METHODS OF ANALYSIS AND TECHNICAL RESULTS

PART A: SUMMARY OF METHODS AND RESULTS

The chief function of a benefit-cost analysis is to provide information relevant to the determination of which of several courses of action is most economic. In this study, three alternatives for existing hospitals and nursing homes are examined in terms of seismic safety: leaving the structures as they are, replacing the structures with earthquake-resistant buildings, and retrofitting the structures to improve their earthquake resistance.

Numerous other alternatives have been omitted from detailed evaluation, such as implementing disaster-preparedness programs, selective mitigation as by removing hazardous cornices and parapets, devising ways to mitigate associated fire hazards, and securing equipment that might fall as a result of ground shaking.

Since at present there is no way to predict with reasonable certainty the date or exact location of an earthquake, assessment of the losses due to earthquakes requires one to make estimates of the likelihood of occurrences. Herein, earthquake source zones are used so that the likelihood of an earthquake within a given zone is estimated. Such probabilities and frequencies are developed here in terms of earthquake intensities, since earthquake intensities are so closely associated with building damage.

Because the seismic zones here used are extensive in area, results for particular hospitals would no doubt be different if seismic microzones were constructed based upon such factors as local soil conditions and position relative to faults.

Building damage also depends upon the type of construction. Masonry structures with unreinforced-brick exterior bearing walls, for instance, are more vulnerable to earthquake damage than are wood-frame structures. Expected damage resulting from an earthquake of a given intensity is thus a function of building construction.

In this study, data on building classes are limited to secondary sources. Site inspections of particular structures would lead to improved estimates regarding the vulnerability of specific health-care facilities to earthquake damage.

Given the location and construction type of a building, its expected damage can be determined for various seismic conditions. The expected damage for such a building either retrofitted or replaced likewise can be determined from a characterization of the seismic resistance that the building would have were it either retrofitted or replaced. Hence, one can compare damages for the three alternatives.

Such damages are those due to ground shaking, and do not include estimated fire loss that might follow a large earthquake, or damage due to other factors, such as liquefaction or rockslides.

Property damages, though, form only a part of a benefit-cost analysis of replacing or retrofitting health-care facilities. Costs of retrofitting a structure commonly are out-of-the-pocket costs, and costs of replacing a structure now rather than later involve borrowing rates. As shall be shown, property costs of replacing a structure now rather than later are of necessity greater than property costs of leaving the building as it is, even if an earthquake should cause the original building to collapse. Moreover, it is highly unlikely that it will be less costly, in terms of property losses alone, to retrofit a structure rather than to leave it as it is.

Due to the economic conditions indicated above, losses due to deaths and casualties also must be considered in order to overcome the prejudice in favor of waiting to spend later, when the building needs to be replaced, rather than spending now. Even though there are important reasons for not considering the value of life in economic terms, there are also important reasons for assuming that life has economic value. First, to disregard the value of life is to assume tacitly that life has an economic value of zero. Second, if one derives an economic value for the prolongation of life, it is possible to consider the value as being limited to economic terms. So, one can discuss matters pertaining to the prolongation of life in non-economic terms as well as in economic terms, and estimates involving life-saving and injury-reduction can be useful for either sort of discussion. Given, then, data on construction types and occupancy rates, life and casualty estimates can be constructed for each of the three alternatives. Life and casualty estimates can be used also to determine the risks taken on each of the alternatives.

Hence, for a particular building, either retrofitting or replacing a structure is economic if the lesser damage and life and casualty estimates overcome, in dollar value, the prejudices in favor of waiting to spend money later.

In Part B of this section, the benefit-cost method, assumptions, and theoretical results are expressed mathematically. Such a presentation allows for a condensation of the mathematical implications of the use of discount rates, so that the key factors in the analysis may be seen in their most mathematically direct relationships. In Part C of this section, the method for estimating earthquake intensities are explained. In Part D, the method for deriving damage estimates from earthquake intensities is explained. Different results are obtained from different classification schemes for buildings, where different estimates are relied upon for the vulnerability of structures to loss at given earthquake intensities. In Part E, the method for arriving at speculative life and casualty estimates is explained. In Part F, improvements in the methodology, as suggested by reviewers, are introduced. In Part G, particular results from the analytical studies are interpreted for the benefit of readers. Finally, in Part H, some of the significant sources of data, not mentioned in the bibliography, are identified.

PART B: THE GENERAL METHOD EXPRESSED MATHEMATICALLY

Let us consider three alternatives.

(a) The original building is left as it is (until its life-span ends).

(b) The original building presently is replaced with an earthquake-resistant building.

(c) The original building is fully retrofitted to improve its earthquake-resistance.

We shall employ symbols as follows.

Let C = the present replacement costs for a given building.

Let y = its age.

Let z = the number of years that the building is expected to remain in use.

Let i = the appropriate discount rate.

Let d = the expected annual damage loss due to earthquakes. "d" is determined as a percent of C, and d includes only losses to the structure (and excludes losses to the contents) due to ground shaking. Let d_a refer to the annual damage for the first alternative, d_b for the second alternative, and d_c for the third alternative

Let L = the expected annual loss due to deaths and injuries, so that L_a refers to the percent loss for the first alternative, and L_c for the third alternative.

Let R = the retrofitting cost.

There are numerous assumptions made in assigning or computing values for the listed variables, any of which may warrant fresh examination.

Since we do not know how building prices are going to change, we shall assume that they are going to change at the same rate as all prices. In assuming that building prices rise at the same rate as overall prices, we recognize that there are occasions when some people will be privy to information that building prices are going to rise, say, faster than the rate of overall prices. We have, though, no grounds for predicting long-term discrepancies between changes in building prices and changes in overall prices. Hence, we shall be assuming that, if building prices are determined in 1978 dollars, then such money values do not need to be adjusted upwards or downwards for projects undertaken in the future.

So, we shall assume that the replacement costs of a building today are, in constant dollar values, equal to the discounted replacement costs of the building at a later date.

We shall presuppose also that the recorded present value of a building, where the term "present value" refers to something other than the replacement cost, is not relevant to our considerations. For hospitals, at least, and possibly for larger nursing homes, such an assumption seems to be warranted. Hospitals and larger nursing homes, as such, appear to have no meaningful market value. According to Stewart Grow, Jr., present owner of the old St. Mark's Hospital site, costs of hospital construction exceed by so far the market value of hospital facilities as structures for alternative uses that the market value of the original site is a very minor consideration in relocation decisions. The chief determinants of the present value of hospitals and larger nursing homes, then, are the life spans of the structures, their present age, their replacement costs, and their present capacity to serve a given population until the life-span of the building is over.

The expression "present capacity to serve a population" conceals a variety of factors that may bear upon decisions to alter facilities or to relocate them, factors that are by and large tangential or only distantly related to the aims of this study.

When asked what reasons were given to justify the relocation of St. Mark's Hospital, Tom Hartford, chief administrator of the new St. Marks Hospital, mentioned four main ones: plant obsolence, increasing industrialization near the old facilities, changing demographic characteristics in Salt Lake County, and change in the character around the hospital. In a more thorough study in which Mr. Hartford assisted, the following cost and relocation factors were included.

(1) Reluctance of patients to go to the old facility.

(2) Difficulty in recruiting and retaining staff, especially interns and residents not associated with other doctors already on the staff.

(3) A population shift about 5 miles south, a decline in obstetrical patients, and a site with numerous hospitals nearby.

(4) Poor traffic patterns both within and outside the hospital.

(5) Insufficient land to make future expansions.

(6) Outmoded or inadequate facilities with regard to multibed rooms, linen chutes, humidity control, electricity, plumbing, fire safety, nursing units, floor kitchens, surgical and nurses stations, morgue, and main kitchen (Cf. [12], p. 162).

Given the large number of considerations that do and can lead to relocation, replacement, or alteration of a large health-care facility, seismic safety costs become one among many possible considerations, and, in the case of the relocation of St. Mark's Hospital, a consideration not entertained. Other possible considerations are utility savings and suitability as a place of refuge during emergency periods. In this study, seismic safety benefits are considered in isolation from such other possible benefits, but it can be assumed that other possible benefits would also require added costs.

Age of structures itself implies certain economic costs where the design is outmoded or inflexible. In the literature on hospital facilities, it is stressed that new procedures require sophisticated equipment, that nursing units become obsolete in a decade or so, and that some adjunct facilities, such as paramedic facilities, may become obsolete monthly ([13], p. 24). Improved design concepts can save time and money in regard to hospital traffic, communications, transfer of materials, eating, and laundering ([13], p. 138). It is here assumed, though, that the considerable savings that may be achieved through improved design concepts also require additional costs.

In this study, we have not examined in detail alternative uses of smaller nursing homes for those cases where seismic risk may be great enough so that discontinued use as a nursing home may be advisable. The possible alternative of relocating smaller nursing homes to other facilities might have some plausibility if the existing facilities were converted to uses in which life and casualty risks are reduced. For instance, if either the occupancy rates or the susceptibility of occupants to death or injury during earthquakes is reduced, then there may be another use for the facility that is worth considering. Structural losses, though, would remain the same for the building converted to some new use, and only the vulnerability of occupants would be altered by such a conversion of use. A reduction in life and casualty loss in nursing homes, though, is here not assumed to be of social value, if the reduction occurs at the expense of others, such as may happen if the structure becomes converted into an apartment for older people.

We further shall assume that the expected damage to the contents of the buildings, such as X-ray machines in a hopsital that normally are not considered in building capital costs, is the same, no matter which alternative is decided upon.

We shall assume also that the cost of money, as a function of the discount rate, is a social cost, and so is not influenced by different ways of financing. To at least a large extent, the consumer ultimately pays for capital costs in constructing medical facilities, such as by direct payment for medical services, through the government, or through private insurance. There are grounds, too, for regarding philanthropy as also being a social cost, to be discounted at a social rate. The value now of philanthropy is greater than the value tomorrow, insofar as the funds can be used today. Moreover, the value of philanthropy can be compared with its other possible uses. At any rate, we shall assume that the appropriate discount rate is social, so that the special budgetary problems of the particular health-care facility are neglected. We shall thus disregard, say, cases where the particular hospital or nursing home has such budgetary problems that it cannot concern itself with long-term benefits. Money raised for construction presumably still has a long-term social borrowing cost, in constant dollar values. One function of a benefit-cost analysis is to determine whether or not the benefits of borrowing now, rather than later, exceed the costs, from which reasonable alternative courses of action may be identified.

Costs of medical service losses due to earthquakes have not been explicitly entered into the calculations, although a special list was developed of possible service losses. In some cases, the cost of service losses may be minimal. For instance, there are various ways to circumvent the loss of a bed, or damage to an elevator. In other cases, such service losses may result in added costs, such as when patients die as a result of being moved. No firm estimates were developed in this study for such costs due to lost services that result from earthquake damage.

Given these numerous simplifying assumptions, it is possible to derive various conclusions and to express the analysis mathematically. Sources of data and further clarification of terms are given later.

If a earthquake occurs t years from now, and the earthquake destroys the original building, but would not have affected at all a replaced building, then there still would be the following property loss for having replaced the building now rather than at time t:

(1) $C\ [(1+i)^t - 1]$ = money costs of replacing now rather than when the building collapses.

Therefore, if such human factors as potential life and safety hazards are not considered, it is more economic to replace a hospital or nursing home later. Equation (1) represents the worst case for alternative (a) as opposed to alternative (b). So, if one fails to consider deaths and casualties, then, no matter how low one estimates the discount rate as being, alternative (b) would be more costly than alternative (a).

In general, the borrowing cost of selecting (b) rather than (a) is

(2) $C\ [(1+i)^z - 1]$ = the borrowing loss of alternative (b) as opposed to alternative (a).

Given that $d_a - d_b$ equals the annual difference between damages estimated for the two alternatives, and that $L_a - L_b$ equals the difference between casualty and life estimates, then the damage and casualty loss of selecting (a) rather than (b) is

(3) $[(d_a-d_b) + (L_a-L_b)] \sum_{j=0}^{z-1} (1+i)^j$ = damage and casualty loss of selecting (a) rather than (b).

Equation (3) represents the total of such annual differences discounted for remaining expected years of the original building. Since

(4) $\sum_{j=0}^{z-1} (1+i)^j = [\frac{(1+i)^z-1}{i}]$,

it follows that

(5) $[(d_a-d_b) - (L_a-L_b)]\ [\frac{(1+i)^z-1}{i}]$ = damage and casualty loss of selecting (a) rather than (b).

Thus, it is economic to replace the building, rather than to leave it as it is, only when the damage and casualty loss of selecting (a) rather than (b) exceeds the borrowing loss of alternative (b) as opposed to alternative (a), that is, when

$$(6) \quad [(d_a - d_b) - (L_a - L_b)] \left[\frac{(1+i)^z - 1}{i}\right] > C\,[(1+i)^z - 1].$$

Equation (6) can be simplified algebraicly to read that replacement is justified as opposed to leaving the building as it is when

$$(7) \quad (d_a - d_b) + (L_a - L_b) > C \times i.$$

Otherwise, the two alternatives are identical, or alternative (a) is more economic.

The ratio of benefits of replacement to costs of replacement may thus be expressed as follows:

$$(8) \quad \frac{(d_a - d_b) + (L_a - L_b)}{Ci} = \text{ratio of benefits of replacement}$$

to costs of replacement.

When such a ratio exceeds unity, then it is economic to replace a given structure.

When one considers retrofitting costs, one conceives that the building retrofitted will have roughly the same life span as the building left as it is. So, apart from damages and casualties, alternative (c), as opposed to alternative (a), is a loss in the amount of

$$(9) \quad R\,(1+i)^z = \text{money costs of retrofitting now, as}$$

opposed to leaving the building as it is.

Damage and casualty losses are greater for alternative (a) than for alternative (c) by the amount of

$$(10) \quad [(d_a - d_c) + (L_a - L_c)] \frac{(1-i)^z - 1}{i} = \text{damage and casualty}$$

losses for leaving the building as it is rather than retrofitting it.

So, alternative (c) is more economic than alternative (a) when damage and casualty losses for leaving the building as it is rather than retrofittin it exceed money costs of retrofitting the building. That is, alternative (c) is more economic when

$$(11) \quad (d_a - d_c) + (L_a - L_b) > R \times i.$$

Equations (7) and (11) represent, then, the mathematical outlines of the benefit-cost analyses here undertaken.

If a discount rate of 10% is used, then one can multiply either the replacement or retrofitting costs by 10% in order to determine how much the annual differences in damage and casualty estimates must be in order to justify either replacement or retrofitting.

The present value of annual losses of value v and at discount rate i equals

$$(12)\quad \frac{[(1+i)^j-1]v}{(i)(1+i)^j} = \text{present value of annual losses of}$$

value v at discount rate i.

As j becomes very great, given i = 10%, the present value approaches 10 x v. So, for purposes of presentation, we shall assume that the present value of annualized losses is ten times the annual value. However, if buildings are replaced in a very short time, such losses, of course, decrease in present value.

Throughout this report a discount or borrowing rate of 10% is assumed. According to one economist, Frank Hachman, Associate Director of the Bureau of Economic and Business Research at the University of Utah, 10% is presently the absolute minimum discount rate for this study, and higher rates might be more reasonable. In other words, a 10% discount rate minimizes the prejudice in favor of waiting to spend money later. Even though no formula has been developed here for calculating a discount rate, and choice of discount rate can be a very controversial matter, the general benefit-cost results of this study would not be changed substantially if higher or somewhat lower discount rates were chosen (Cf. [14], pp. 243-332).

PART C: METHOD FOR CONSTRUCTING SEISMIC MACROZONES

The equations employed in the previous subsection presuppose that there is some way to determine both damage estimates and life and casualty estimates for a given hospital or nursing home.

Both sorts of estimates depend in turn upon estimating the seismicity at various sites.

In the Algermissen and Perkins study referred to earlier (Cf. [2]), the United States is divided into 71 zones. Three zones, Zones 32, 33, and 34, are specially applicable to Utah. For each zone, the values of the coefficients a and b_I are developed and implicitly available so that one can employ the following equation:

$$(13)\quad \log N = a + b_I I_O,$$

wherein N is the number of yearly earthquake occurrences with maximum intensity I_O, such that I_O is either the observed historical maximum intensity, or is determined from the equation

$$(14)\quad M_C = 1.3 + 0.6 \cdot I_O,$$

wherein M_C is the Richter magnitude corresponding to I_O in equation (13). That is, I_O can be derived from data about Richter magnitudes.

For each zone, we are given the estimated number of earthquakes of Intensity V per 100 years. We also are given b_I for each zone ([2], pp. 17, 18). So, at the 90% probability level, we have the following information.

Zone	Number of Modified Mercalli Maximum Intensity V's Per 100 Years	b_I
Zone 32	17.0	-0.56
Zone 33	126.8	-0.56
Zone 34	71.0	-0.56

If we assume that there is an equal distribution of earthquakes over the years, or that the above estimates of earthquakes of Intensity V can be reduced suitably to annual estimates (where, say, there are 1.268 such earthquakes expected annually in Zone 33, at 90% probability level), then we can use the above information, in conjunction with equation (11), in order to derive values of the coefficient a. Given such assumptions, we have the following values for the coefficient a.

Zone	a
Zone 32	2.03
Zone 33	2.90
Zone 34	2.65

Hence, for each zone, we can derive the expected annual frequencies for earthquakes of a given intensity if we employ the following equations.

Zone	Frequency (N)
Zone 32	$10^{2.03-0.56\ I}$
Zone 33	$10^{2.90-0.56\ I}$
Zone 34	$10^{2.65-0.56\ I}$

Given the assumption that the occurrence of an earthquake having a given intensity is equiprobable for each year during a 100-year period, then, with a 90% probability, we can derive the following 100-year expected earthquake occurrences by zone and by maximum intensity.

Zone	Maximum Intensity					
	X	IX	VIII	VII	VI	V
Zone 32	0.03	0.10	0.35	1.29	4.68	16.98
Zone 33	0.20	0.72	2.63	9.55	34.67	125.89
Zone 34	0.11	0.41	1.48	5.37	19.50	70.79

So, for example, in Zone 33, about 35 earthquakes of every 100 occurrences can be expected to have intensities with a maximum of VI, about 10 with a maximum of VII, and so on.

The information derived from the Algermissen and Perkins study, however, is based primarily upon historical records adjusted for gaps in data. Geological evidence, in contrast, as revealed by Robert Bucknam of the U.S. Geological Survey (USGS), indicates that the expected activity along the Wasatch fault, in Zone 33, may be greater than that expected in terms of historical records.

In particular, in order to appraise the effects of such increased activity as indicated by new geological evidence, we may assume that, along the fault line, which is about 350 kilometers in length, about one earthquake between 7.0 and 7.6 on the Richter scale may be expected to occur every 500 years. Such an earthquake would not have an epicenter, but would create an assumed 50-kilometer break along the fault line.

In order to estimate seismicity of sites based upon such information, we shall construct a zone, called Zone 33A, that extends approximately 20 kilometers on each side of the fault. Zone 33A thus covers 350 km. x 40 km. Very crudely, we approximate the areas of the other zones as being 261,000 sq. km. for Zone 32, 43,200 sq. km. for Zone 33, and 76,400 sq. km. for Zone 34. If the remainder of Zone 33 is labeled Zone 33B, then Zone 33B covers about 29,200 sq. km.

An examination of the limited historical data indicates that about one-half of all earthquakes of Intensity V or greater that have occurred in Zone 33 have been located in Zone 33A. So, too, about one-half of all Intensity V's in Zone 33 have occurred in Zone 33A (Cf. [6], pp. 9-20).

In Zone A, we shall assume, then, that about 63.4 earthquakes with a maximum Intensity V are expected to occur in 100 years. Also, the slope chosen for the logarithmic curve (13), -0.52, is such that values of X and over will barely exceed a frequency of 0.20. That is, if one expects one maximum Modified Mercalli Intensity X (about 7.3 on the Richter scale) every 500 years, then one expects 0.20 every 100 years. Hence, we have constructed 100-year frequencies for Zone 33A.

Zone	Intensity					
	X+	IX	VIII	VII	VI	V
Zone 33A	0.22	0.52	1.8	5.8	19.2	63.4

In order to estimate the frequencies for Zone 33B, one first subtracts the frequencies of Zone 33A from the frequencies in Zone 33. Then, because frequencies at higher intensities will be too low, since geological evidence has increased those values for Zone 33A and hence for the zone in general, one fits the lower values to a logarithmic curve. So, for Zone 33B, one derives the following expected maximum frequencies.

Zone	Intensity				
	IX	VIII	VII	VI	V
Zone 33B	0.30	1.15	7.8	16.5	63.4

So far, then, estimated frequencies have been derived for each main macrozone. However, the estimate of frequencies at maximum intensities does not by itself give specific information about the expected frequencies of a given intensity at some site within a given zone. The seismicity at specific sites is needed in order to estimate property and human losses for a particular structure.

In order to use the information about the seismicity in a zone to derive conclusions about the possible seismicity at a specific location within the zone, one needs to estimate how earthquakes with certain epicentral or maximum intensities will attenuate.

Attenuation curves have been developed in order to determine the intensity of an earthquake at a certain distance from the epicenter. From the USGS study of the Salt Lake City area (Cf. [7], p. 39), one finds the following curve:

(15) $I_o - I = n \, Log_{10} \, [(\Delta^2 + h\,)^{0.5} / h]$, wherein

Δ = the epicentral distance (km.) from I_o to I,

h = depth of focus (km.),

I_o = maximum intensity at the epicenter,

I = intensity at Δ from the epicenter, and

n = an exponent determined empirically.

According to Dr. Walter Arabasz, geophysicist at the University of Utah, a good approximation for Utah can be constructed if we let n = 4.0.

The assumption for h can make a substantial difference. In terms of area covered, the assumption of 10 km. in depth as opposed to 5 km. in depth makes a difference of four times the area covered.

From a list of recent earthquakes in Utah that was supplied by Walter Arabasz and Bill Richins at the University of Utah Department of Geology and Geophysics, the mean and median of focal depths are less than 6 kilometers. A more relevant notion to the consideration of areas, the root mean square, the square root of the mean of squares, is also less than 7 kilometers. Focal depths did not seem to vary with intensity, although the sample was skewed with a preponderance of lower intensities. So, for this study, 7 kilometers was chosen as the focal depth.

Hence, for Utah, one can determine Δ for $I_o - I = 1$, for $I_o - I = 2$, and so on.

We shall assume that a given intensity ceases to exist at the midpoint between two numerically successive Δ's. That is, if $I_0 - I_1 = 1$, and $\Delta = 10$ kilometers, then the maximum intensity, I_o, extends for a distance of 5 kilometers. So, too, if for $I_o - I$, $\Delta \approx 21$ kms., then the second highest intensity, $I_0 - I$, extends from 5 kms. from the epicenter to 15.5 km. from the epicenter.

Given the abovementioned assumptions for Utah, and equation (15), then we have the following values for Δ, given various differences in intensity.

$I_o - I$	(km.)
1	10.3
2	21.0
3	38.7
4	69.7
5	124.3
6	221.3
7	393.6
8	700.0
9	1,244.8

Given the assumption about the use of a midpoint in order to determine the distance covered by the maximum intensity, we can, with other suitable assumptions, determine the area covered by each intensity.

In the general case, for all earthquakes except for those major earthquakes that cause a 50-kilometer break along the Wasatch fault, we shall assume that intensities can be mapped as a group of concentric circles, with the epicenter at the center, with the maximum intensity covering the inner circle, and with each lesser intensity found in each next outer circle. Given such a mapping of intensities, along with assumptions made about the use of the midpoint, one can estimate the area for each intensity, given a value for the maximum intensity. For a given I_o, the areas covered by I_o-I, for $0 \leq I_o < 10$, are as follows.

I_o-I	Area (sq. km.)
0	83
1	686
2	2,034
3	6,424
4	20,310
5	64,230
6	203,100
7	652,700
8	2,021,000
9	6,423,000

For a given value of I_o, one can use the above areas. If, say, I_o, the maximum intensity of an earthquake, is V, then 83 sq. km. are covered with an Intensity V, 686 sq. km. by Intensity IV, and so on.[4] Likewise, whatever the maximum intensity is assumed to be, it covers 83 sq. km., the next lower intensity covers 686 sq. km., and so on.

For Zones 32 and 34, which are more extensive in area, we shall assume that all of the relevant attenuated area (down to a Mercalli Intensity VI) lies within the zone. In other words, we shall assume that the impact of earthquakes originating outside the zone is counterbalanced for our purposes by the attenuated areas of earthquakes that go outside the zone even though the epicenter lies within the zone.

For all cases where we can suitably regard the attenuation pattern as a sequence of concentric circles, we can derive the approximate areas covered at a given intensity as a result of attenuation. Given expected epicentral frequencies, such areas can be derived. If, for instance, 0.11 is the expected frequency of earthquakes having Intensity X, then one can expect such earthquakes to cover 0.11 x 83 sq. km. at Intensity X, 0.11 x 686 sq. km. at Intensity IX, 0.11 x 2,034 sq. km. at Intensity VIII, and so on. In general, for Zone 32, one can use the same method to derive a table analogous

[4]Attenuation curves are generally imprecise very close to the epicenter. The result here that the epicentral intensity extends about 5 km. is at least consistent with the general conclusion of William Gordon (member of the Utah Seismic Safety Advisory Council and a geotechnical engineer) that attenuation curves have not been defined precisely for the first 5 kilometers.

to the one shown below for Zone 34 which gives the values used to estimate areas covered per 100 years at given intensities.

Epicentral Intensity	Expected Frequency of Epicentral Intensity	Area for Attenuated Intensity -- Zone 34					
		X	IX	VIII	VII	VI	V
X	0.11	9	75	224	707	2,234	7,065
IX	0.41		34	281	834	2,634	8,327
VIII	1.48			123	1,015	3,010	9,508
VII	5.37				446	3,684	10,923
VI	19.50					1,619	13,377
V	70.79						5,876
Cumulative Areas in Zone 34 Covered at the Given Intensity		9	109	628	3,002	13,181	55,076

This table illustrates how the contribution of each epicentral intensity to intensities at lower levels can be established.

So for any given intensity, the expected area covered is the expected area covered at such an intensity as a result of the attenuation of higher epicentral intensity earthquakes plus the expected area covered at the given intensity given its expected epicentral frequency. Since expected epicentral frequencies vary from zone to zone, so too will vary expected frequencies of areas covered by given intensities. For Zone 32, there are the following expected areas (in square kilometers) covered at various intensities.

Zone	Intensity					
	X	IX	VIII	VII	VI	V
Zone 32	3	29	159	744	3,238	13,454

The total areas in all zones and subzones can be crudely approximated as follows.

Zone	Area
Zone 32	261,000 sq. km.
Zone 33A	14,000 sq. km.
Zone 33B	29,200 sq. km.
Zone 34	76,400 sq. km.

For all zones, we shall assume that buildings are randomly distributed throughout the zone. Only for Zones 32 and 34 shall we assume that areas covered by earthquakes within the zone do not extend beyond the zone.

For Zones 32 and 34, we can determine the expected frequencies of the occurrence of an earthquake whose area covers a given building. Such an expected frequency equals the expected area covered by a specific intensity and in the zone divided by the total area within the zone. Such frequencies might be regarded as point-frequencies. So, we have for any building the following expected 100-year frequencies at the following given intensities.

Zone	Intensity					
	X	IX	VIII	VII	VI	V
Zone 32	0	0	0.0006	0.0028	0.0124	0.0515
Zone 34	0.0001	0.0014	0.0083	0.0393	0.1726	0.7212

In order to estimate property and human losses for the other zones, it is necessary to derive analogous point-frequencies.

However, two problems arise in regard to the two subzones, Zone 33A and Zone 33B, in pursuing this methodology. First, the subzones are small enough so that one cannot fairly assume that the amount of attenuation into the area roughly equals the amount of attenuation outside the area. Some method must be devised in order to estimate how much ground shaking attenuates outside the subzone, and how much ground shaking enters into the subzone from other zones. Secondly, the attenuation pattern for an assumed 50-kilometer break along the Wasatch fault is not a pattern of concentric circles. Higher intensity earthquakes in Zone 33A, then, are regarded as attenuating more so in the pattern of rectangles having semi-circles at the two ends.

For such a 50-kilometer break, it is assumed that the rectangles are formed by lines parallel to the break, and the semicircles have their centers at the ends of the break. As with the previous method, it is assumed that the distance covered from one intensity to the next is determined by equation (14) and by the assumption that the midpoint between two distances so determined is where the one intensity ends and the next lower intensity begins. So, the distances covered in one direction are 5.15 kilometers for the maximum intensity, 15.65 kilometers for the next highest intensity, 29.9 kilometers for the third highest intensity, and so on.

Since, though, the total width of Zone 33A is only 20 kilometers on each side of the fault, only the first two distances yield areas entirely within the zone, and only part of the third distance is within the zone, so that the following attenuated areas are calculated for an epicentral Intensity X.

X	IX	VIII
515 sq. km.	1,050 sq. km.	435 sq. km.

For the semicircles, only the area within the width of Zone 33A is to be included. Given such areas, aspect ratios were determined in order to estimate the number of semicircles expected to lie within the length of Zone 33A. Since once the earthquake occurs along any 50-km. segment, the endpoints could occur at any point along 300 kms. Given a 350-km. fault line and r as the radius of the intensity, it was assumed that there are (300/r) + 1 possible points uniformly distributed, of which all but one point are in the interior of the break.

For the following radii, the following aspect ratios obtain.

If r = 5.15, then the ratio of area in is 0.983.
If r = 15.65, then the ratio of area in is 0.950.
If r = 29.90, then the ratio of area in is 0.909.
If r = 54.20, then the ratio of area in is 0.847.
If r = 98.00, then the ratio of area in is 0.756.
If r = 172.80, then the ratio of area in is 0.635.

The following attenuated areas (sq. km.) lie within the width of the zone.

Intensity					
X	IX	VIII	VII	VI	V
83	686	1,493	2,621	3,535	6,470

Multiplied by aspect ratios, one obtains the following areas (sq. km.) both in the width and in the length.

Intensity					
X	IX	VIII	VII	VI	V
82	652	1,357	2,220	2,672	4,108

To find the total areas included, one sums the semicircular areas included and the rectangular areas included.

Intensity					
X	IX	VIII	VII	VI	V
597	1,702	1,792	2,220	2,672	4,108

Since the above areas are assumed to be affected for 500 years, one divides by five to obtain the following 100-year areas covered.

Intensity					
X	IX	VIII	VII	VI	V
119	340	358	444	534	822

For maximum intensities of IX and below, typical concentric patterns were used, except that aspect ratios were again used in order to estimate, given a uniform distribution of intensities, the percent of the attenuated areas that could be expected to lie within the zone. In particular, if $r < w \leq \ell$, given length ℓ (350 km.), and width w (40 km.), then the zone may be divided into ℓ/r units by w/r units. There are hence $(\ell/r + 1) \times (w/r + 1)$ uniformly distributed points.

The total attenuation area for all points is thus $(\ell/r + 1)\ (w/r + 1)\pi r^2$.

Of the four points on the corners, three-fourths of their area lies outside the zone, and of the $2(\ell/r - 1 + w/r - 1)$ other boundary points, one-half of their area lies outside the zone. So, the following aspect ratio obtains.

$$1 - \frac{(\ell/r + w/r + 1)}{(\ell/r + 1)\ (w/r + 1)} = 1 - \frac{(370 + r)}{(350 + r)\ (40 + r)}$$

Where r > w, it is assumed that the aspect ratio is

$$\frac{2\ (\ell/r)}{2\ (\ell/r + 1)} = \frac{\ell}{(\ell + r)}$$

Therefore, on the assumption that the points occur along the fault, it is determined trigonometrically what percent of the area lies within the zone. So, using both methods, one obtains the following aspect ratios for various radii.

For r = 5.15, the ratio is 0.98.
For r = 15.65, the ratio is 0.98.
For r = 29.90, the ratio is 0.72.
For r = 54.20, the ratio is 0.40.
For r = 96.77, the ratio is 0.21.

Hence, the area covered

for I_o - I = 0 is 82 sq, km.,
for I_o - I - 1 is 754 sq. km.,
for I_o - I = 2 is 2,018 sq. km.,
for I_o - I = 3 is 3,692 sq. km., and
for I_o - I = 4 is 6,204 sq. km.

So, the area covered at the lower intensity, the total area covered to the lower intensity minus the area covered by the higher intensities, is as follows.

For I_o-I = 0, 82 sq. km.
For I_o-I = 1, 672 sq. km.
For I_o-I = 2, 1,264 sq. km.
For I_o-I = 3, 1,674 sq. km.
For I_o-I = 4, 2,512 sq. km.

Given the previously derived intensity figures based on a Modified Mercalli Intensity X, we are able to derive the cumulated areas covered in Zone 33A due to all maximum intensities by means of the following table.

Epicentral Intensity	Intensity					
	X	IX	VIII	VII	VI	V
X (previous calculation)	119	340	358	444	544	822
IX = 0.52		42	350	657	870	1,306
VIII = 1.8			147	1,210	2,275	3,012
VII = 5.8				474	3,900	7,332
VI = 19.2					1,569	12,910
V = 63.4						5,180
Cumulative Area Covered In Zone 33A	119	382	855	2,785	9,148	30,562
Point-Frequencies (given 14,000 sq. km.)	0.0085	0.0273	0.0611	0.1990	0.6535	2.1830

The value for Intensity V is lower than that derived for Zone 33 because the value in Zone 33A does not include the attenuation of earthquakes from outside the subzone. In order to adjust the values, we must attenuate expected earthquakes from outside the area. In effect, the expected frequencies in Zone 33B might be approximated by subtracting the expected frequencies in Zone 33A from those in Zone 33, and result in the following initial estimates.

Intensity				
IX	VIII	VII	VI	V
0.20	0.8	7.8	16.5	63.4

Let us suppose that the attenuated areas that move into Zone 33A, for each radius of attenuation, are 6.9%, 21.2%, 27%, and 32.6%, respectively. For very small r's, the ratio [(390 + 2r)r]/[29,200 + 118r] holds.

Then, we add the following point-frequencies to those already in Zone 33A.

Intensity				
IX	VIII	VII	VI	V
0.0001	0.0025	0.0205	0.1563	0.7546

We then obtain the following estimated point-frequencies in Zone 33A.

Intensity					
X	IX	VIII	VII	VI	V
0.0085	0.0274	0.0636	0.2195	0.8098	2.9376

In estimating earthquake frequencies for the remainder of Zone 33, namely Zone 33B, though, it is assumed that adjustments had to be made for the higher intensities, since our assumptions for Zone 33A imply higher expected values for Zone 33 as a whole. In addition, aspect ratios were developed, and estimates were made of the areas attenuated into Zone 33B from Zone 33B. Given such assumptions, the following point-frequencies eventually were obtained for Zone 33B.

Intensity					
X	IX	VIII	VII	VI	V
0.0002	0.0009	0.0111	0.0647	0.3764	1.5735

In summary, we have obtained the following point-frequencies for the various zones and subzones.

Zone	Intensity					
	X	IX	VIII	VII	VI	V
Zone 32	0	0	0.0006	0.0028	0.0124	0.0515
Zone 33A	0.0085	0.0274	0.0636	0.2195	0.8098	2.9376
Zone 33B	0.0002	0.0009	0.0111	0.0647	0.3764	1.5735
Zone 34	0.0001	0.0014	0.0083	0.0393	0.1726	0.7212

PART D: METHOD FOR DERIVING ESTIMATES OF STRUCTURAL LOSSES

In this subsection, we use the seismic frequencies developed in the previous subsection in conjunction with each of two classification schemes for buildings in order to make long-term estimates of losses to various sorts of structures in given zones or subzones. Two estimates are furnished, based upon slightly different assumptions regarding vulnerability of construction classes.

In a paper referred to earlier, Algermissen and Steinbrugge have developed a figure in which earthquake losses at various intensities are estimated for different types of construction based upon observed damage from past earthquakes (Cf. [8], p. 11).

Algermissen and Steinbrugge employ a system of classification as shown in Appendix B. Using their figure, and their taxonomy, one can derive one set of estimates of average percent loss due to ground shaking to buildings in a given class and given a specific intensity.

So, for example, buildings in Class 5E (the most vulnerable class) suffer a 35% average loss at Intensity IX, a 25% loss at Intensity VIII, and so on.

Such estimates of percent losses at given intensities, when used in conjunction with expected frequencies of given intensities for a particular building, can be used to derive expected damage losses.

For a building in Zone 33A, for instance, if the average expected loss from an earthquake of Intensity X is 50%, and if 0.0085 such earthquakes are expected in a 100-year period, then one expects 0.43% losses per 100 years due to intensities of X. If one further adds the percent loss due to each intensity, one finds the cumulative expected loss. The expected loss to a given structure due to ground shaking is the sum of all losses due to expected earthquakes of different intensities. Table 10 illustrates how the Algermissen and Steinbrugge estimates are combined with our table of expected frequencies in order to derive expected 100-year percent losses for various classes of structures in Zone 33A.

In general, for the relevant zones and subzones, one can use the same method in order to derive the 100-year loss factors based on Algermissen and Steinbrugge estimates, as shown in Table 11.

From such loss factors, one can estimate, given the replacement costs of a building and its location, the 100-year expected dollar losses, and so the annual average expected dollar losses. Such estimates are the dollar estimates for this study.

For expected structural failures, we use a different classification scheme and a different set of estimates by building class that can be used in conjunction with seismic frequencies by zone or subzone. This classification scheme is borrowed and adapted from a study of estimated earthquake damage in the Wasatch Front region prepared for the U.S. Geological Survey.

In particular, for the USGS study of earthquake losses in the Salt Lake City area, a system of classification was developed, and a corresponding set of structural loss estimates at given intensities was established. The classification scheme, as adapted, is given in Section 3. Using the same method as was followed to develop Table 11, 100-year factors for structural failures, estimated based on this second classification scheme, are given in Table 12.

From such percentages of nonfunctional structures, one can establish how many structures can be expected to suffer at least a 50% structural loss over 100 years.

In the Algermissen and Steinbrugge report, the percent loss is defined as "the average percentage of the total actual cash value required to fully repair, in kind, any building of a particular class by a particular degree of Modified Mercalli Intensity Scale. Only losses associated with ground shaking are estimated." ([8], p. 1.). The USGS estimates, in contrast, are percentages of buildings rendered non-functional due to earthquake damage. Fifty percent structural damage is assumed to render a building non-functional. The estimates in Table 12, then, more accurately are thought of as the expected long-term decimal fractions of buildings by class and zone that are rendered non-functional.

Given estimates of annual damage losses derivable from Table 12, one can further estimate the losses to a given structure until its life cycle runs out, which losses are equal to:

$$(16) \quad d_a \sum_{j=0}^{z} (1+i)^j = d_a \left[\frac{(1+i)^z - 1)}{i}\right]$$

Tables 11 and 12 therefore enable one to compare the percent losses and the long-term losses of different classes of structures in Utah. For instance, in Zone 33A, a building that is in Class 5E has an expected 100-year loss of 9.40% (here, the loss is a percent of the replacement cost). Thus, the expected annual loss is 0.094% of the replacement cost of the structure. In contrast, a structure of Class 5B in Zone 33A has an expected loss of only 1.44% over 100 years. So, if in Zone 33A, a building in Class 5E were either retrofitted or replaced by a building so as to qualify as Class 5B, then the expected damage loss would be 7.96% less for the retrofitted or replaced structure.

PART E: METHOD FOR DERIVING ESTIMATES OF LIFE AND CASUALTY LOSSES

The equations employed in Part B presuppose not only that damage losses can be estimated but also that estimates can be made for life and casualty losses.

In this section, we shall first clarify how estimates can be made concerning expected life and casualty losses. Afterwards, we shall clarify some of the historical and economic limitations of the estimates.

In the USGS report on earthquake losses in the Salt Lake City area, it is assumed that one can estimate percents of occupants expected to die or to suffer hospitalized injury from earthquakes of a given intensity. Such basic estimates are modified according to the type of the building that is considered. Table 13 summarizes the basic estimates that include several types of occupants of hospitals and nursing homes.

These estimates must be modified by coefficients according to the following types of structures.

Type	Description	Coefficient
A	Fully retrofitted nursing home	0.25
B	Fully retrofitted hospital	0.40
C	1-story built after 1962 (for UBC Zone 2)	0.75
D	1-story built before 1962	1.00
E	2-story or more built after 1962 (for UBC Zone 2)	1.25
F	2-story or more built before 1962	1.50
G	Within zone of deformation	2.00

The estimate of 0.25 for fully retrofitted nursing homes was added to original USGS estimates on the basis of the contrast between expected structural losses for Class 5B structures as opposed to those of other classes. The estimate of 0.40 for fully retrofitted hospitals was based on the assumption that full retrofitting of hospitals would produce only slightly better than a Class 5C structure.

Given such percent estimates in Table 13, and the estimated seismic frequencies developed in Part D, one can, for each zone, derive the percent of deaths and casualties by type of occupant as shown in Table 14. The estimates must be modified by the coefficients given above for any particular structure.

In order to estimate the mean number of occupants in a hospital, the following ratios were adopted from the USGS methodology.

- -- Members of the general public (including doctors, nurses, staff) = 0.92 times the number of beds.
- -- In-patients = 0.89 times the number of beds.
- -- Visitors = 0.41 times the number of beds.

So, if a hospital has 100 beds, then the hospital occupancy includes an estimated 92 members of the general public, 89 in-patients, and 41 visitors. As an example, if the same structure were 2 stories and built before 1962, then the expected number of deaths due to earthquakes over 100 years would be, on the average,

1.5 (92 x 0.1229% + 89 x 0.1883% + 41 x 0.0899%)
= 1.5 (0.11 members of the general public + 0.17 in-patients + 0.04 visitors)
= 0.48 people.

For nursing homes, it is assumed that there is one in-patient per bed, and no further assumptions are made on visitors or staff members.

The estimates made in Table 14 are based on a sketchy historical record of deaths and injuries caused by earthquakes. We know, for instance, that on some occasions a total building loss is compatible with few casualties to occupants in the building (Cf. [6], p. 90). So, the data take into account only average expected deaths and casualties.

The number of lives lost in the United States as a result of earthquakes has been low in comparison to the number of lives lost in other countries. As of 1975, the estimated number of lives lost in the United States due to earthquakes had been 1,624 ([10], p. 188). The United States experience, in contrast to the experience in other countries, is here assumed to be chiefly a function of comparatively better building practices and materials (Cf. [6], p. 73).

Estimates of deaths and injuries for all hospitals and nursing homes in the State can be approximated from data in Table 14, given bed capacities of the facilities as indicated in Tables 3 and 7. Tables 15 and 16 furnish such bed capacities, respectively, for surveyed hospitals and nursing homes in the aggregate according to seismic zone in which the buildings are located and according to type of construction as given in the table above. Applying appropriate coefficients as given above to data in Table 14 and using the bed capacities from Table 15, we obtain in Table 17 100-year estimates of deaths and injuries for existing Utah hospitals. In a like manner, using Tables 14 and 16, we obtain in Table 18 100-year estimates of deaths and injuries for existing Utah nursing homes.

Two observations are made with respect to Tables 17 and 18. First, the estimated 100-year totals of deaths and injuries to hospital and nursing home occupants due to seismicity are likely to occur in only a few earthquakes, or even just one earthquake. Hence, although one death every five or so years in hospitals, or one death every 9 years in nursing homes, may appear small, a large number of deaths in any one earthquake most likely would cause questions to be raised by the public concerning the safety of health-care facilities. Such public response should be anticipated, and certainly adds justification to application of preventative measures before the earthquakes strike.

The second observation is that nearly all of the risk is found in Zone U-4, the most populous as well as the most seismically active region in the State. From the data, one readily can conclude that earthquake mitigation measures applied to buildings in Zone U-4, and to a lesser degree in Zone U-3, will be most effective from a benefit standpoint.

Estimates of benefits in reduced life loss and injury rates, that might result from retrofitting of existing buildings to achieve improved earthquake resistance, can be made in a manner similar to that described in the preceeding paragraphs. Such estimates may be made for retrofit of the entire classes of facilities, or for retrofit of selected classes and in selected seismic zones. In any case, new assumptions must be made as to the degree of improvement that might be achieved in building performance--that is, full retrofit will result in greater reductions in mortality and casualty rates than will selective retrofit. Since, numerous combinations are possible for such analyses, it is enough to observe in this report that the best benefit-cost relationships obtain when buildings in Zone U-4 are upgraded.

Various other ways could be used to estimate deaths and serious casualties. In the USGS study on Salt Lake City, the assumption is made that there are four hospitalized injuries per life lost (Cf. [6], p. 305). According to one survey made of ten earthquakes, one death is expected per $2 million property damage (1970 dollars) ([10], p. 197). Since 1970 dollars must be multiplied by about 1.61 in order to derive 1978 dollars (for January), then one lost life is expected for about $3.2 million damage.

Since the annual estimate of property losses is $273,000 if all hospitals are left as they are, then the estimate of hospital deaths in this method of analysis would be 0.09 per year. For retrofitted structures, the corresponding figure would be 0.02. Hence, there would be 0.07 preventable hospital deaths per year if such retrofitting were done. Such results may be compared to that result of the actual method used in this report which was 0.16 preventable deaths per year. Since the annual estimate of property losses is $47,000 if all nursing homes are left as they are, and $11,000 if replaced, the expected number of preventable deaths would be 0.01, as opposed to the 0.08 derived in this study.

The way to determine the economic impact of such estimates is less certain. For hospitalized casualties, one can determine the cost of various hospitalized injuries. Here, one can use the average cost of hospitalization, or one can use other data, such as those for the San Fernando earthquake, in order to estimate percents of types of injuries and then use data on costs per type of injury (Cf. [11], p. 262).

The issue of the economic value of life is more controversial, as has been stated previously. One available method for determining the economic value of life, introduced into Utah civil courts by Boyd Fjeldsted, senior research economist at the University of Utah, and presented and developed by Dorothy P. Rice, Director of the National Center for Health Statistics, is to take the economic value of life as the estimated present value of future earnings (Cf. [16], p. 3; [17], [18]).

For reasons already stated, no detailed economic formulas were developed in this report to determine exactly the economic value of either injuries or lives lost. Estimates of lives lost and casualties as determined from Tables 17 and 18 are here taken as being adequate for conclusions to be drawn in this study.

PART F: REVIEWERS COMMENTS AND METHODOLOGY REFINEMENTS

Two objections regarding the methodology presented in this section have been raised by reviewers. First, according to S.T. Algermissen, the modeling of a major earthquake along the Wasatch fault should be modified. In particular, as a result of the principle of the conservation of energy, one should expect that the same areas attenuate to a given intensity, whether one assumes the attenuation pattern is a series of concentric circles or a fifty-kilometer break with more or less oval-shaped attenuation patterns. That is, if one expects an area of 686 sq. km. to be affected at Intensity IX for an attenuation pattern consisting of a series of concentric circles with

Intensity X as the epicentral pattern, then one should expect an equal area of 686 sq. km. at Intensity IX for any other attenuation pattern developed for an epicentral intensity of X.

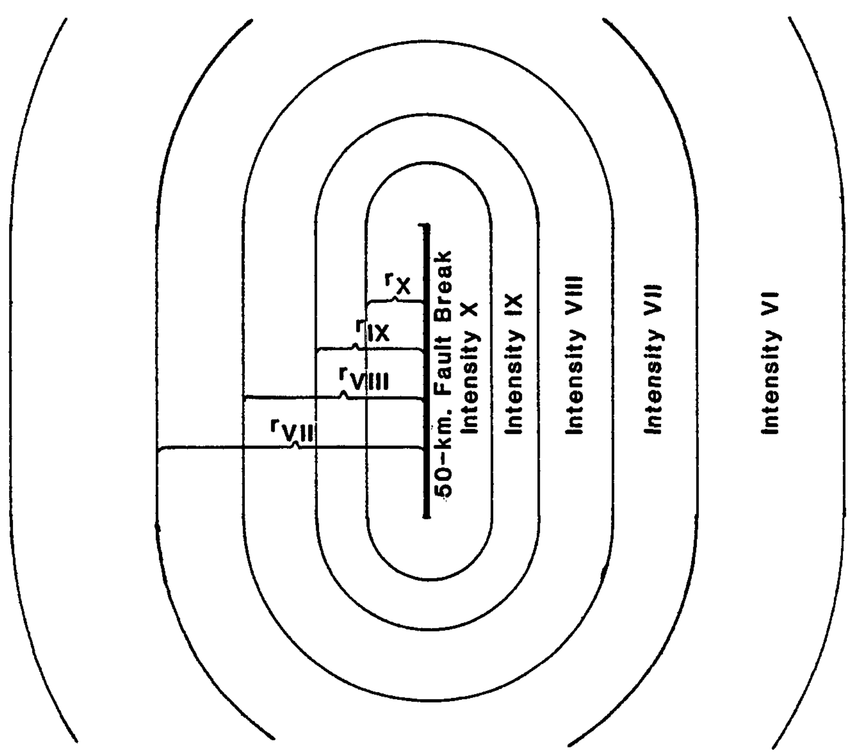
Second, as observed by W.W. Hays, USGS, soil conditions and associated amplication effects were not used as parameter in the methodology. Seismic waves are amplified in unconsolidated soils, and higher intensities therefore are expected. Hence, earthquake loss estimates for macrozones having a high percentage of such soils should reflect such possible increases.

In this sub-section, earlier results for Zone 33A are modified in order to meet the two objections. Since the bulk of losses is expected to occur in Zone 33A, the additional task of correcting for soil conditions in other zones was not undertaken.

Considering first the modeling for attenuation, and in accordance with earlier assumptions made about attenuation, and to correct earlier estimates made for a major earthquake postulated along the Wasatch fault, the areas covered by an earthquake with an epicentral intensity of X are revised as follows.

At Intensity X:	83 sq. km.
At Intensity IX:	686 sq. km.
At Intensity VIII:	2,034 sq. km.
At Intensity VII:	6,424 sq. km.
At Intensity VI:	20,310 sq. km.
At Intensity V:	64,230 sq. km.

Earlier, it was assumed that a 50-kilometer break would occur somewhere along the Wasatch fault every 450 or so years. The attenuation pattern for such a break appears as follows.



The area covered at Intensity X should equal 83 sq. km., and so on. r_X is defined as the length of the perpendicular to the break measured from the break to one of the boundaries of Intensity X. In general, r_j stands for the length of the perpendicular measured from the break to the boundary of some intensity j. Given the expected areas at each intensity, one can compute values of r_j for $X \leq j \leq V$ if one knows that the sum of all areas for Intensity X to Intensity j equals $\pi r_j^2 + 100 r_j$.

So, for instance, for Intensity X, one uses the following equation.

$$83 \text{ sq. km.} = \pi r_X^2 + 100 r_X$$

For Intensity IX, one uses the following equation.

$$83 \text{ sq. km.} + 686 \text{ sq. km.} = \pi r_{IX}^2 + 100 r_{IX}$$

One thus derives the following radii.

r_X = .79 km.
r_{IX} = 5.67 km.
r_{VIII} = 17.93 km.
r_{VII} = 40.58 km.
r_{VI} = 82.36 km.
r_V = 157.62 km.

Since Zone 33A is only 40 km. wide, the following areas in Zone 33A are ascribable at given intensities to the rectangular portion of the break.

At Intensity X:	79 sq. km.
At Intensity IX:	488 sq. km.
At Intensity VIII:	1,147 sq. km.
At Intensity VI:	207 sq. km.

At each end of the break, a semicircle is formed, with r_j as the radius out to a given intensity. The aspect ratio for determining how much of r_j lies inside the length of the zone is 300 / (300 + r_j).

The determination of how much lies within the width of the zone, for $r_j \geq$ 20 km., can be made trigonometrically. Accordingly, the following areas were estimated to lie within the semicircles and in Zone 33A at the specified intensities.

At Intensity X:	2 sq. km.
At Intensity IX	97 sq. km.
At Intensity VIII:	854 sq. km.
At Intensity VII:	2,224 sq. km.
At Intensity VI:	4,441 sq. km.
At Intensity V:	4,805 sq. km.

Thus, the following total areas in Zone 33A are ascribable to a major earthquake along the fault.

At Intensity X:	81 sq. km.
At Intensity IX:	585 sq. km.
At Intensity VIII:	2,001 sq. km.
At Intensity VII:	2,431 sq. km.
At Intensity VI:	4,441 sq. km.
At Intensity V:	4,805 sq. km.

Since 0.22 such earthquakes are expected every 100 years, the areas expected to be affected by the various intensities on a 100-year basis are as follows.

At Intensity X:	18 sq. km.
At Intensity IX:	128 sq. km.
At Intensity VIII:	440 sq. km.
At Intensity VII:	535 sq. km.
At Intensity VI:	977 sq. km.
At Intensity V:	1,057 sq. km.

Adding such estimates to the previous estimates made for all other earthquakes in Zone 33A, one derives the following 100-year estimates.

At Intensity X:	18 sq. km.
At Intensity IX:	171 sq. km.
At Intensity VIII:	937 sq. km.
At Intensity VII:	2,874 sq. km.
At Intensity VI:	9,591 sq. km.
At Intensity V:	30,797 sq. km.

So, the above estimates are adjustments that result from correcting earlier estimates of attenuated areas due to a major earthquake.

Consideration of soil conditions is a more complicated problem. On page 77 in a report titled <u>Estimation of Earthquake Losses to Buildings</u> (Except Single Family Dwellings), S. T. Algermissen, K.V. Steinbrugge, and H.L. Lagorio use the following intensity increments for different surficial materials.

Alluvium:	+1
Tertiary marine sediments:	0
Pre-tertiary marine and nonmarine sediments:	0
Franciscan formation:	-1
Igneous rocks:	+1

That is, if all of Zone 33A were alluvium, then all previous estimates for intensities would have been increased one intensity higher. I.e., if all of Zone 33A were alluvium, then 937 sq. km. would be affected at Intensity IX.

No map of geologic surficial materials directly bearing upon attenuation presently exists for Zone 33A. With the aid of Fitzhugh Davis at the Utah Geological and Mineral Survey, the following rough translations were made for the Utah State Geological Map.

Q (Quaternary)	=	+1
T, J, D, E, pEmf	=	0
P, K, M, PE, Tv, Tr, Tilp, Tqm	=	1

A mapping of Zone 33A produced the following area estimates.

47%	=	+1
27%	=	0
24%	=	-1

In order to adjust the earlier results and take into account geological surficial materials, and using a suggestion made by S.T. Algermissen, one increases 47% of all expected intensities by +1 and one decreases 24% of all expected intensities by -1. Thus, the following areas at expected intensities result.

At Intensity X:	94 sq. km.
At Intensity IX:	494 sq. km.
At Intensity VIII:	1,663 sq. km.
At Intensity VII:	5,566 sq. km.
At Intensity VI:	17,946 sq. km.

Given that the area of Zone 33A is 14,000 sq. km., the following point-frequencies for 100 years result.

At Intensity X:	0.0067
At Intensity IX:	0.0353
At Intensity VIII:	0.1188
At Intensity VII:	0.3976
At Intensity VI:	1.2819

Used in conjunction with data on structural types, the following 100-year estimates of structural loss result for different classes of buildings.

Construction Class									
5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A
0.1545	0.1257	0.1105	0.1042	0.0967	0.0761	0.0227	0.0180	0.0129	0.0177

For expected deaths for the general public, the following 100-year estimated rate is obtained from the modified results.

0.1703%

The above value may be used in place of the value 0.1229% for Zone 33A in Table 14.

For expected injuries for the general public, the following 100-year estimate is obtained.

3.204%

This value may be used in place of the value 1.968% for Zone 33A in Table 14.

Earlier estimates of structural losses, then, are increased between 55% and 69% for various classes of structures when the suggestions of reviewers are incorporated into the methodology. Mortality estimates are increased 39%, and injury estimates are increased 63%.

It is noteworthy that even with these increases in loss estimates, the benefit-cost results and consequent conclusions reached earlier are not changed. While higher mortality and injury rates tend to make more favorable the cases for replacement and full retrofit programs, they still cannot be justified in economic terms alone. However, the corresponding case for selective correction of seismic hazards in existing health-care facilities, already concluded to be feasible in economic terms, is further enhanced.

PART G: INTERPRETATION OF RESULTS

While the preceding subsections provide a complete development and discussion of the methodology for seismic risk analysis as applied to Utah's existing health-care facilities, the details and bulk may cause the reader some difficulty in interpreting results and drawing his or her own conclusions regarding the degree of risk that may be present. In this subsection, those results immediately pertinent to the goal of obtaining conclusions about seismic risk are identified, and comments on interpretation of analytical data are furnished.

As a point of beginning this discussion, it may be helpful to state succinctly the objectives of the risk analysis.

These are:

(a) To identify regions or zones of varying degrees of seismic hazard in Utah.

(b) To identify the degree of seismic risk exposure of classes of buildings (classified in terms of their vulnerability) to the varying degrees of seismic risk.

(c) To estimate expected property losses to existing health-care facilities throughout the State according to their vulnerabilities to seismic exposure.

(d) To estimate expected life loss and casualty rates for occupants of hospitals and nursing homes throughout the State as a result of building vulnerability to seismic exposure.

(e) To estimate possible reductions in property, life, and casualty losses which could result from alternative mitigation programs.

(f) To identify the most cost-effective program for seismic hazards reduction from among alternatives, commensurate with extent of exposure, if any such program seems justified.

Regions of various levels of seismic risk are indicated in Figure 6. Clearly, the zone of highest risk coincides with the Intermountain Seismic Belt which also is indicated in the figure. Within Zones U-3 and U-4 one finds the likelihood of most frequent and most severe seismicity.

The analysis pointedly recognizes that earthquakes of magnitude above approximately 4.5 Richter magnitude can cause damage to buildings, and that the expected damage, on the average, will increase with increasing earthquake magnitudes. Also, the degree of expected damage is greatly influenced by the type of construction of the buildings. Accordingly, the analysis considers, first, the area distribution of expected earthquakes, including frequency and strength, and, second, the vulnerabilities of various classes of hospital and nursing home construction given the distribution of exposure. Distribution of earthquake frequency and strength is made in accordance with the zones shown in Figure 6. Skipping over several tables in Part C which explain the development of data, the last table in that subsection summarizes the point-frequencies of various earthquake intensities for those zones of importance in the State, namely Zones 32, 33A, 33B, and 34 which correspond, respectively, to Zones U-1, U-2, U-3, and U-4 shown in Figure 6.

From this table, it is evident that earthquake frequences, in order of severity, are greatest in Zone U-4, and become successively smaller for Zones U-3, U-2, and U-1, in that order. Moreover, it can be seen that point-frequency values in Zone 33A (U-4) are on the order of two or more times the corresponding values in Zone 33B (U-3) for each earthquake intensity above the threshold damage intensity of V for buildings.

Part D discusses expected building losses based upon the frequencies just discussed. Tables 11 and 12 summarize such expected losses for the various classes of building construction and for the various seismic zones. Data is given as a percentage of damage to each building class. Table 11 data are for property losses, from which dollar losses, in turn, may be estimated. Table 12 data are for estimates of structural failures.

Since the majority of Utah health-care facilities are of Class 5 construction (mixed construction with masonry bearing and non-bearing walls), and since Class 5 construction is seen to exhibit the highest seismic vulnerability, the values from Class 5 columns alone provide a pretty good picture of earthquake risk in present health-care facilities.

Note, however, that for Zone 33A (U-4), the jump from Class 5E to Class 5D (Table 11) is an improvement of approximately a factor of 2 in reduced seismic vulnerability, i.e., from 0.0940 to 0.0589, and from Class 5E to 5B is an improvement of a factor of over 6, i.e., from 0.0940 to 0.0144. In other words, one could reduce the seismic vulnerability of unreinforced masonry buildings over 6 times if appropriate modifications were made. Such assessments of the data form the basis of conclusions reached in this report.

Life loss and casualty estimates are derived somewhat differently in order to utilize available data gathered by others regarding correlations between construction types and mortality and morbidity rates. The methodology is described in Part E. In Tables 17 and 18 it is evident that, in relative terms, Zone U-4 is the most severe, and that selective retrofit of some hospitals and nursing homes can be justified. However, because of the large number of facilities which, by their construction characteristics, are classed as among the most hazardous, more rigorous analysis of individual buildings of such classes is needed than was provided in this study, in order that costs for such retrofit be kept minimal. Such detailed review of health-care facilities having high seismic hazards indicators is a principal recommendation of this report.

Possible reductions in property, life, and casualty losses are most readily evaluated from assumptions and effects resulting from upgrading of buildings into construction classes that offer improved performance in resisting seismic forces, or resulting from replacement by buildings of improved construction class. Whichever alternative may be chosen, it should be noted that life and casualty losses cannot be entirely eliminated--at least in a statistical sense. Such losses only can be reduced, since there are no earthquake-proof buildings, only earthquake-resistant ones.

If, for example, one were to retrofit all Class 5E hospitals (Table 2) in Zone 33A (U-4) so as to upgrade them to classify as Class 5D, and given that 49% of all bed capacity of the surveyed existing hospitals in the zone classify as Class 5E, with a corresponding upgraded classification to the next higher level, then one finds a corresponding 325% reduction in expected mortality and 308% reduction in expected injuries.

Such upgrading of existing hospital construction is not so easy, however, because most of the problems are associated with seismic resistance of unreinforced-masonry walls, a condition which is costly to upgrade. Still, there are improvements that can be made to such masonry construction. Bracing walls can be added, shear walls can be added along with strengthened floor and roof diaphragms, and unnecessary unsupported masonry can be removed. Since the proper retrofit action for each building will be unique, such detail is beyond the scope of this study.

PART H: SOURCES OF DATA

In addition to the references listed in the bibliography, of special mention is that information obtained chiefly from the files of Richard Jenkins and Louis Reese, both with the State Bureau of Health Facilities Construction. The author was allowed access to blueprints and other construction data on hospitals and nursing homes, and also was provided reports on particular projects.

Richard Hughes, of the H.C. Hughes Company, structural engineers in Salt Lake City, furnished structural data on hospitals and also provided elaboration upon his own methodology for estimating property losses and life and injury losses as was followed in the USGS report on earthquake losses in the Salt Lake City area [6].

Tom Hartford, chief administrator of St. Mark's Hospital, kindly

furnished a copy of the Kreeger report [12]. Kathy Vernon, of the Office of Health Planning and Resource Development, passed along data on the Utah State Training School, and Richard Tholen, of the State Building Board, provided information on a new master plan for this facility. J. Linton, of Environmental Associates, who prepared the master plan for the State Training School, reviewed his study of seismic safety of the facility for the benefit of the author. Additional assistance was received from Dr. Bruce Walter, director of the Branch of Medical Care and Facilities, State Department of Social Services, regarding the status of health-care facilities in Utah.

Special acknowledgement is made regarding assistance from Einar Johnson, Jr., of the State Building Board, who opened his files to the author. From these files, survey data and photographs of many facilities were obtained which were of great help in evaluating the construction characteristics of hospitals and nursing homes.

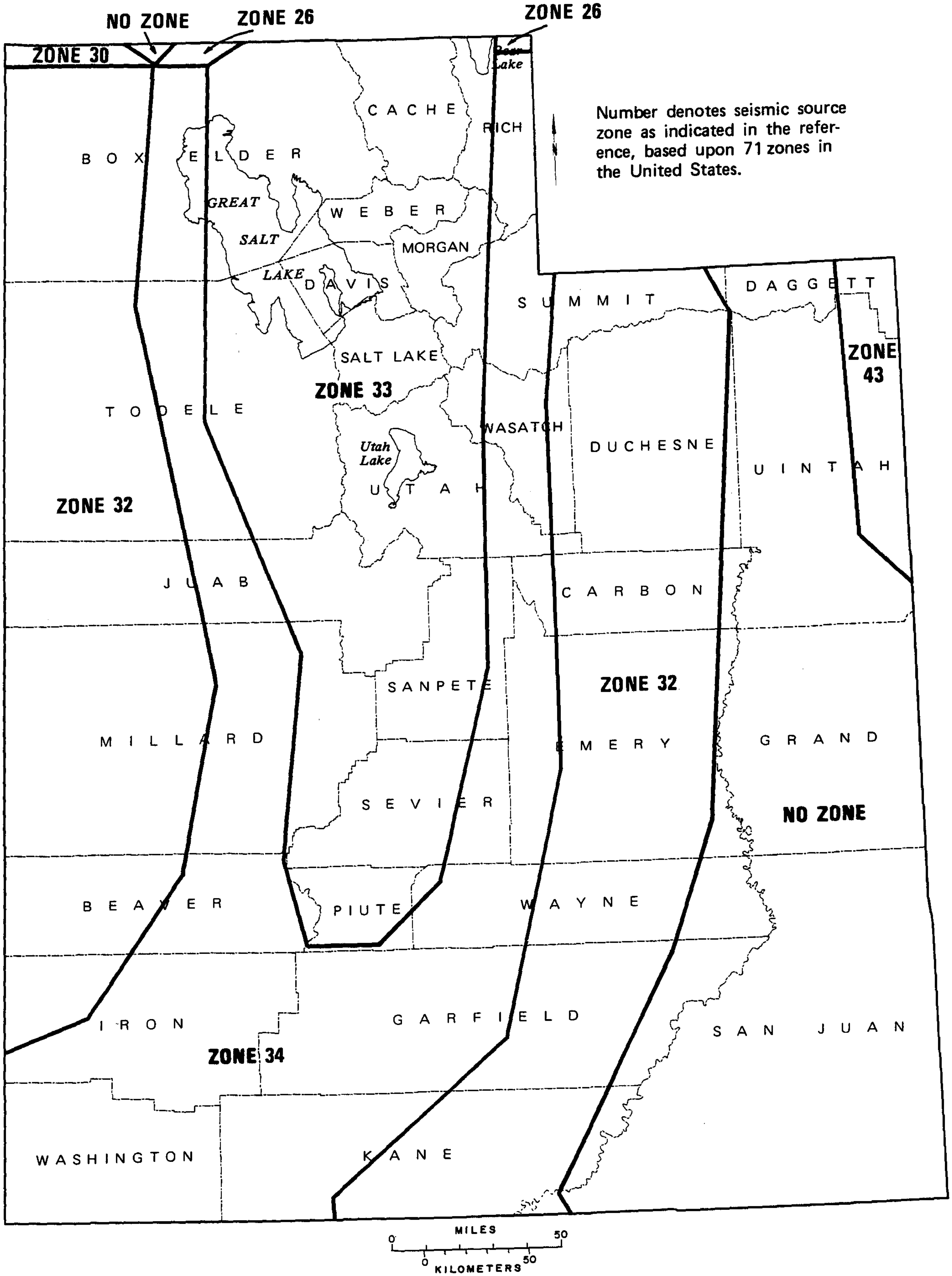


Figure 1
SEISMIC SOURCE AREAS IN UTAH
(Reference: S.T. Algermissen, and D.M. Perkins, USGS Open File Report 76-416)

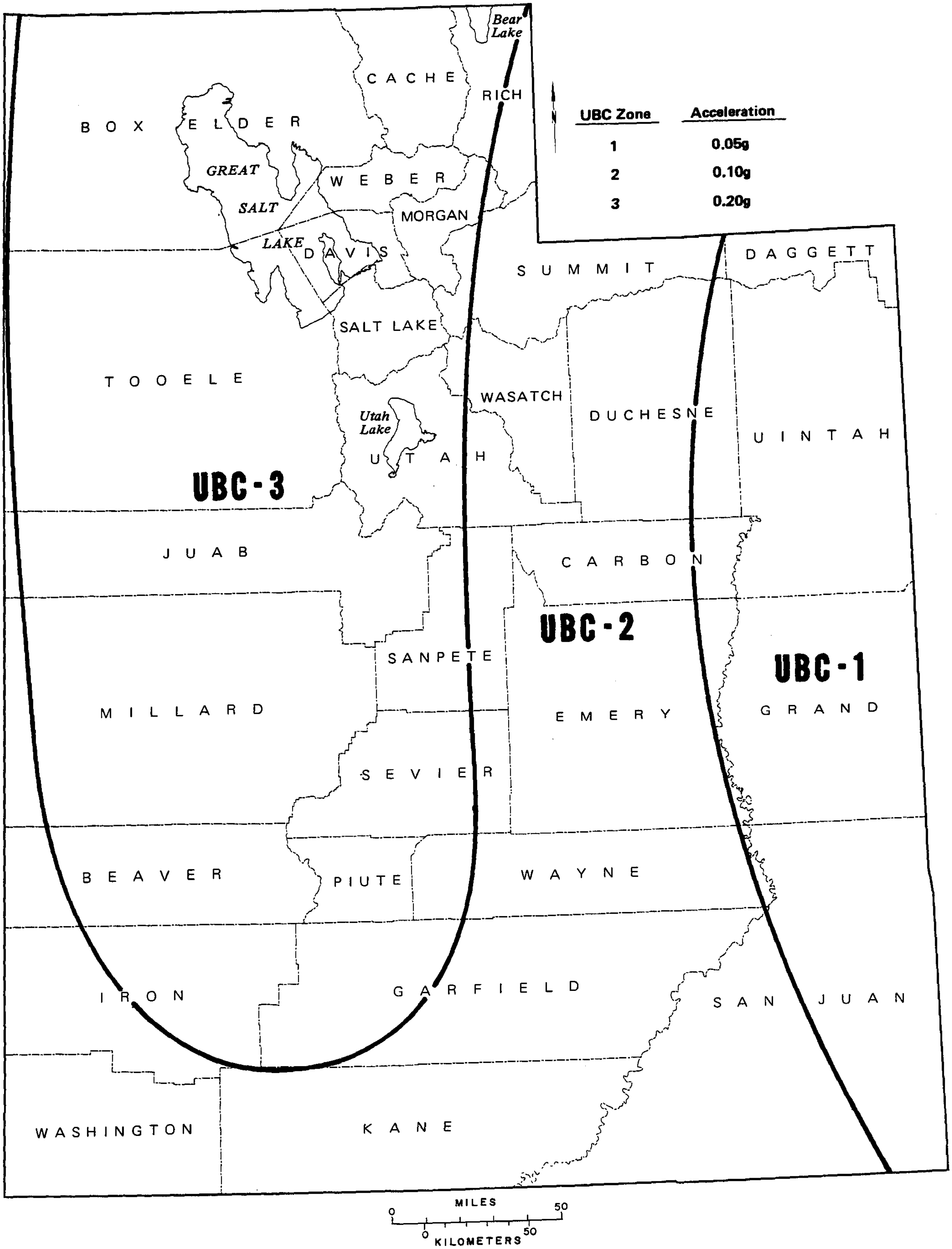


Figure 2
SEISMIC ZONES—1976 UNIFORM BUILDING CODE
STATE OF UTAH

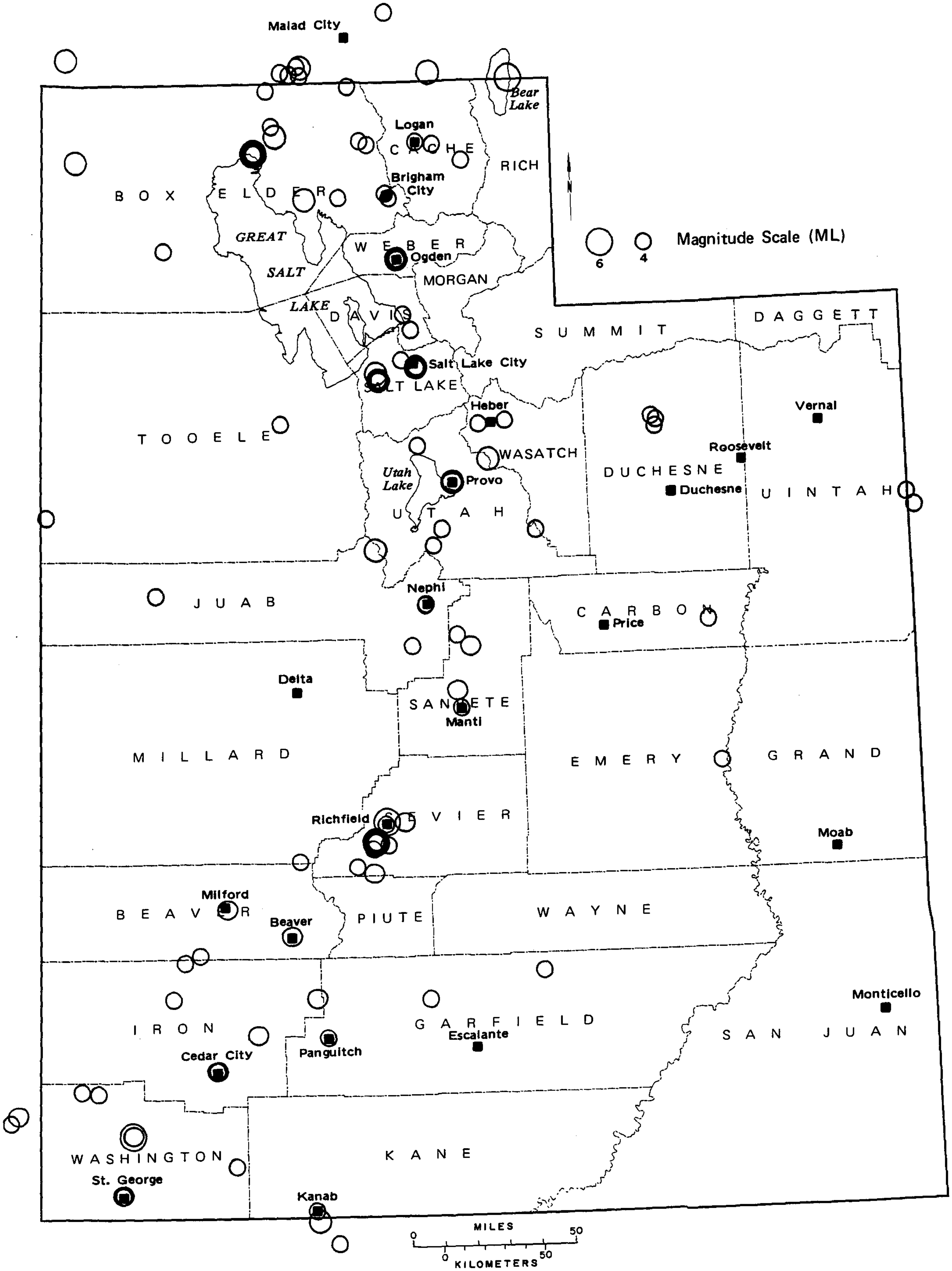


Figure 3
HISTORICAL SEISMICITY IN UTAH -- 1850 - JUNE 1978
MAGNITUDE 4.0 (INTENSITY V) OR GREATER
(Reference: *Earthquake Studies In Utah*, W.J. Arabasz, R.B. Smith, and W.D. Richins)

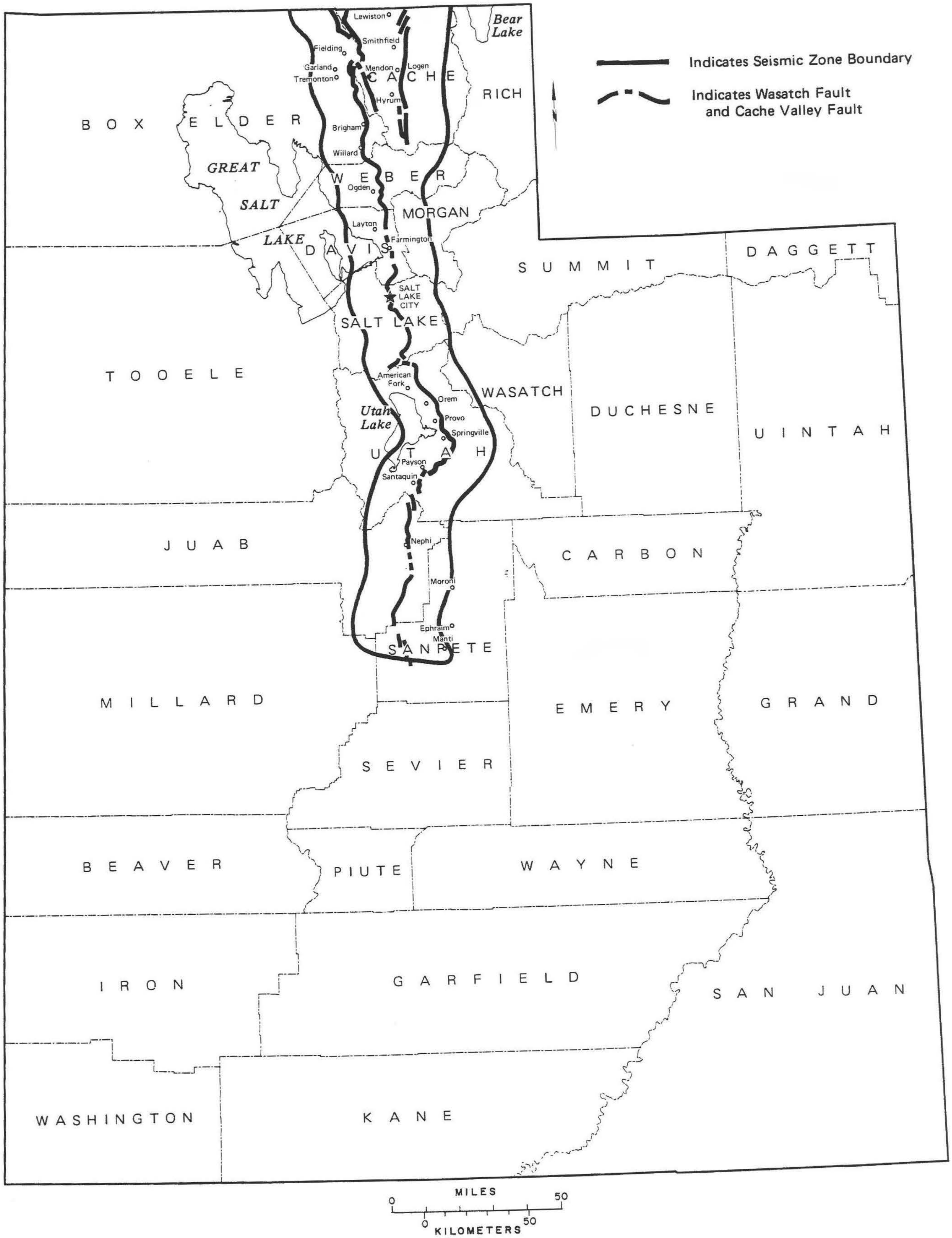


Figure 4

WASATCH FRONT SEISMIC ZONE, WASATCH AND CACHE VALLEY FAULTS
STATE OF UTAH

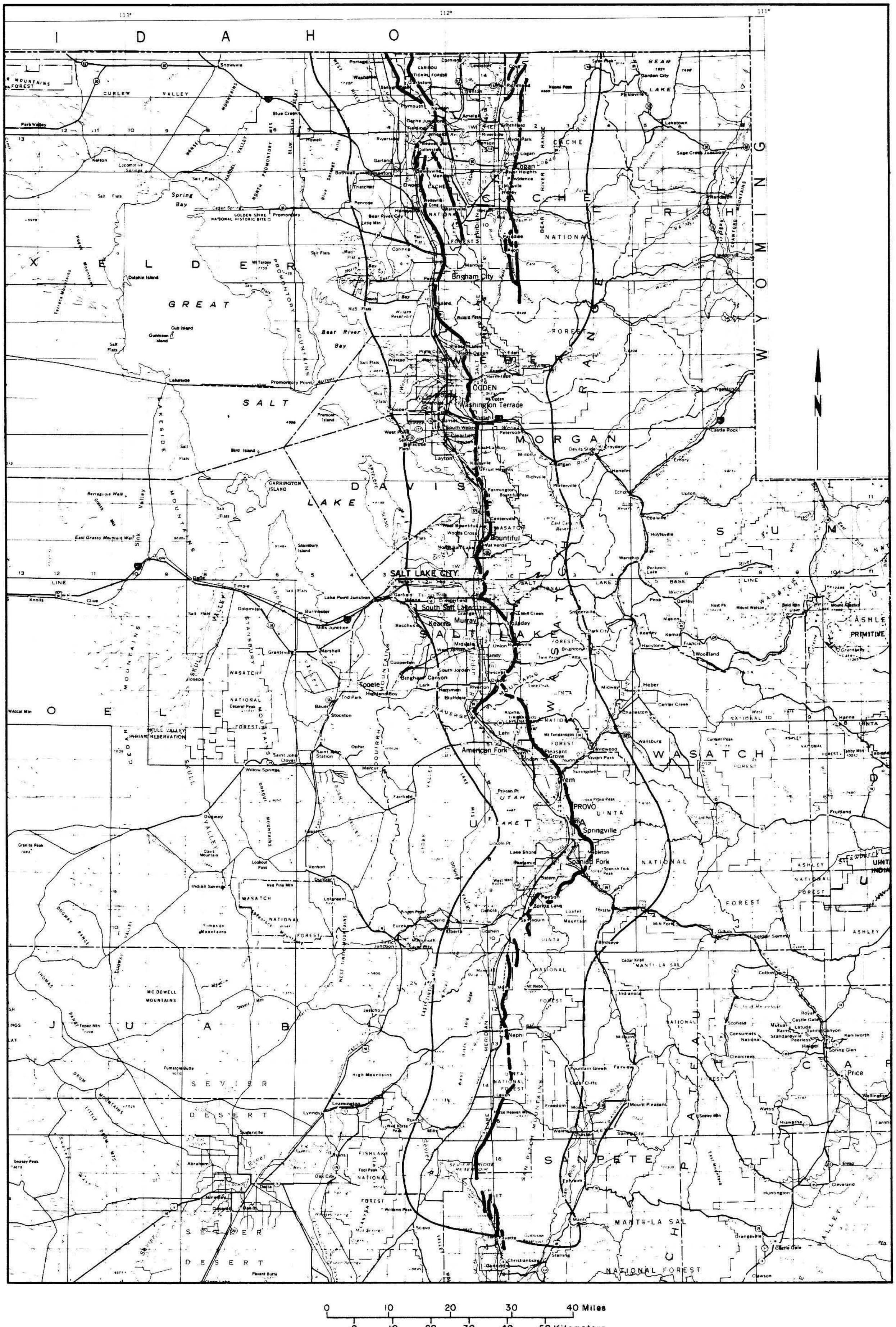


Figure 5

WASATCH FRONT SEISMIC ZONE

STATE OF UTAH

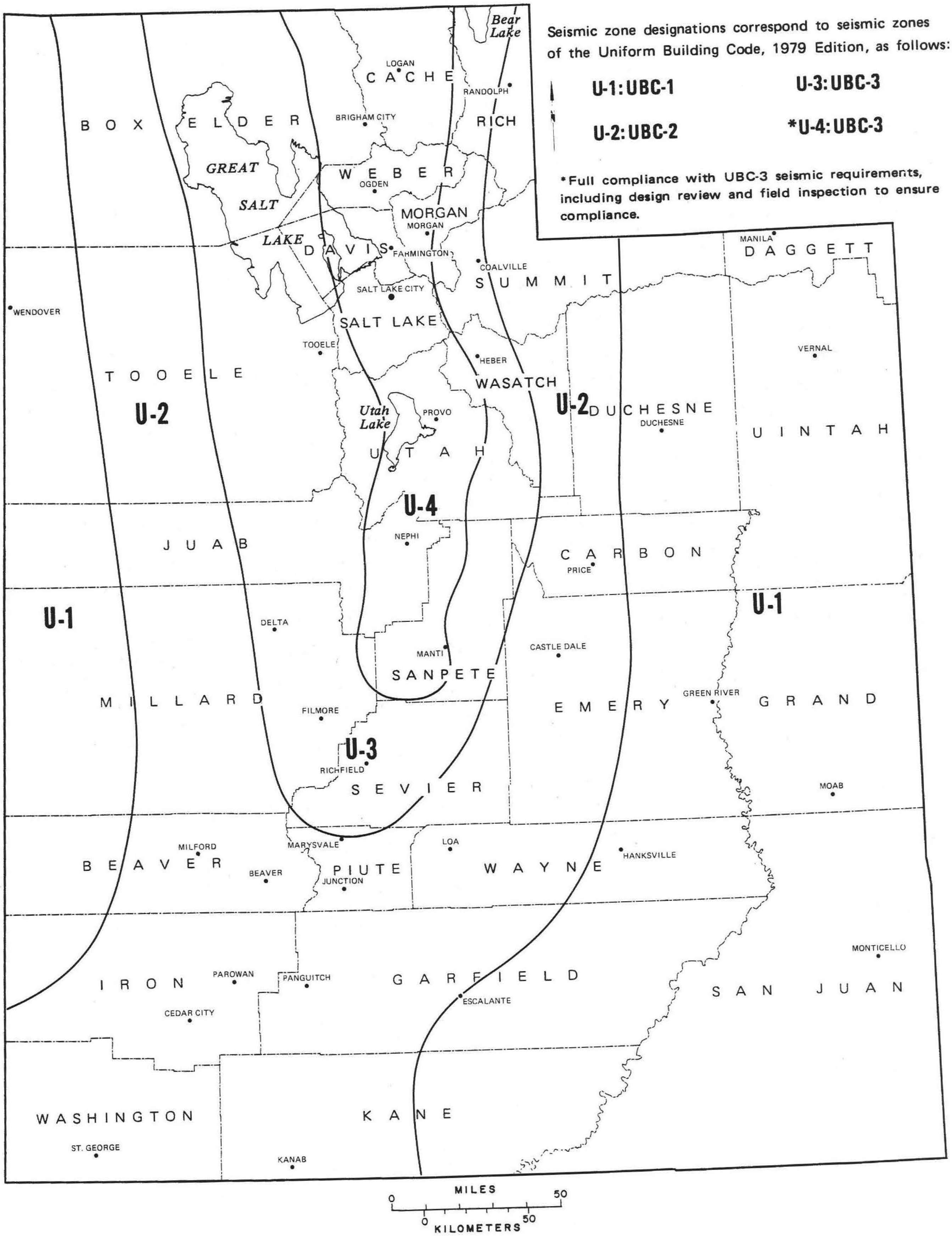


Figure 6
SEISMIC ZONES
January 1980
(Recommended by the Utah Seismic Safety Advisory Council)

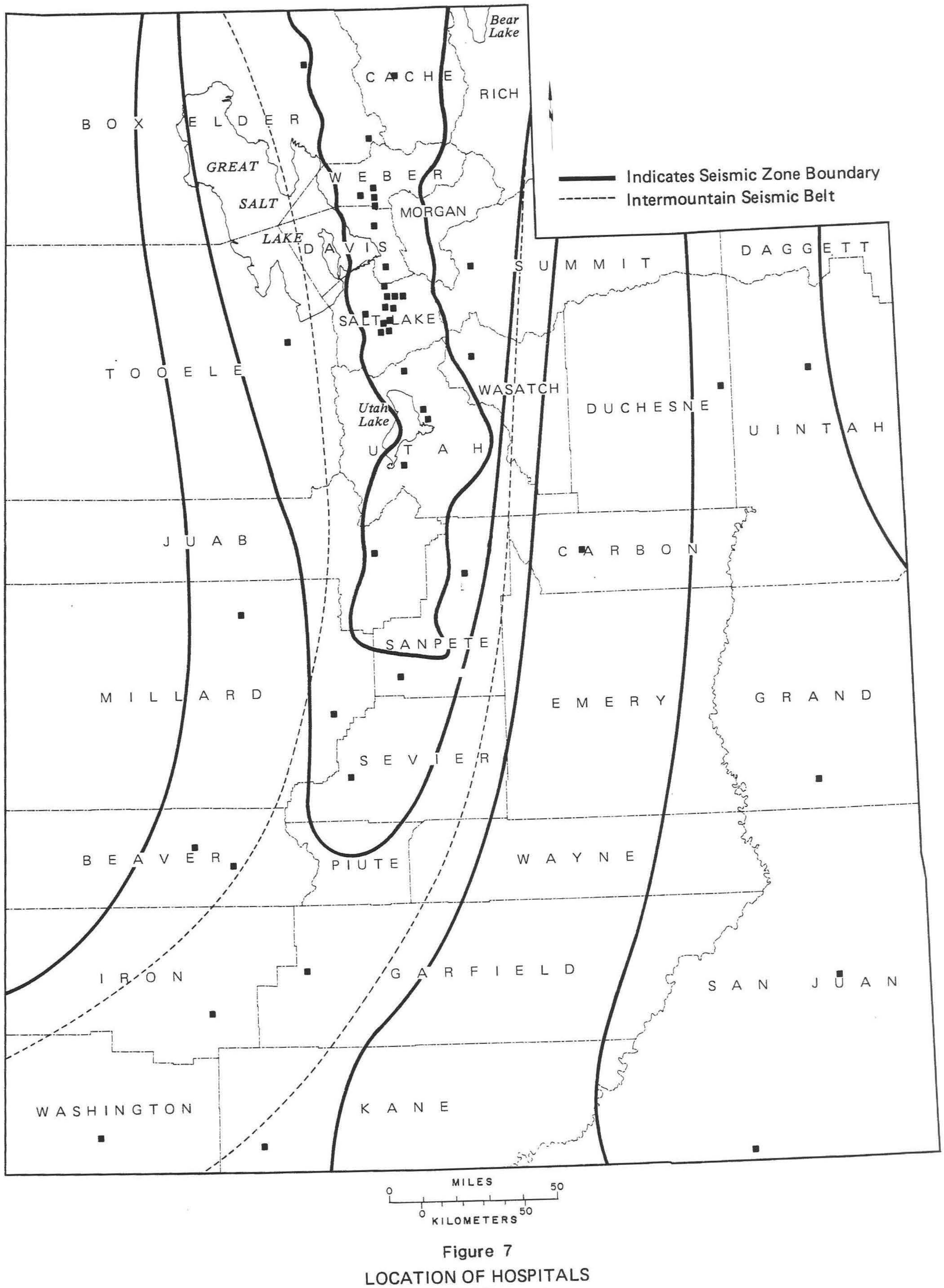


Figure 7

LOCATION OF HOSPITALS
STATE OF UTAH

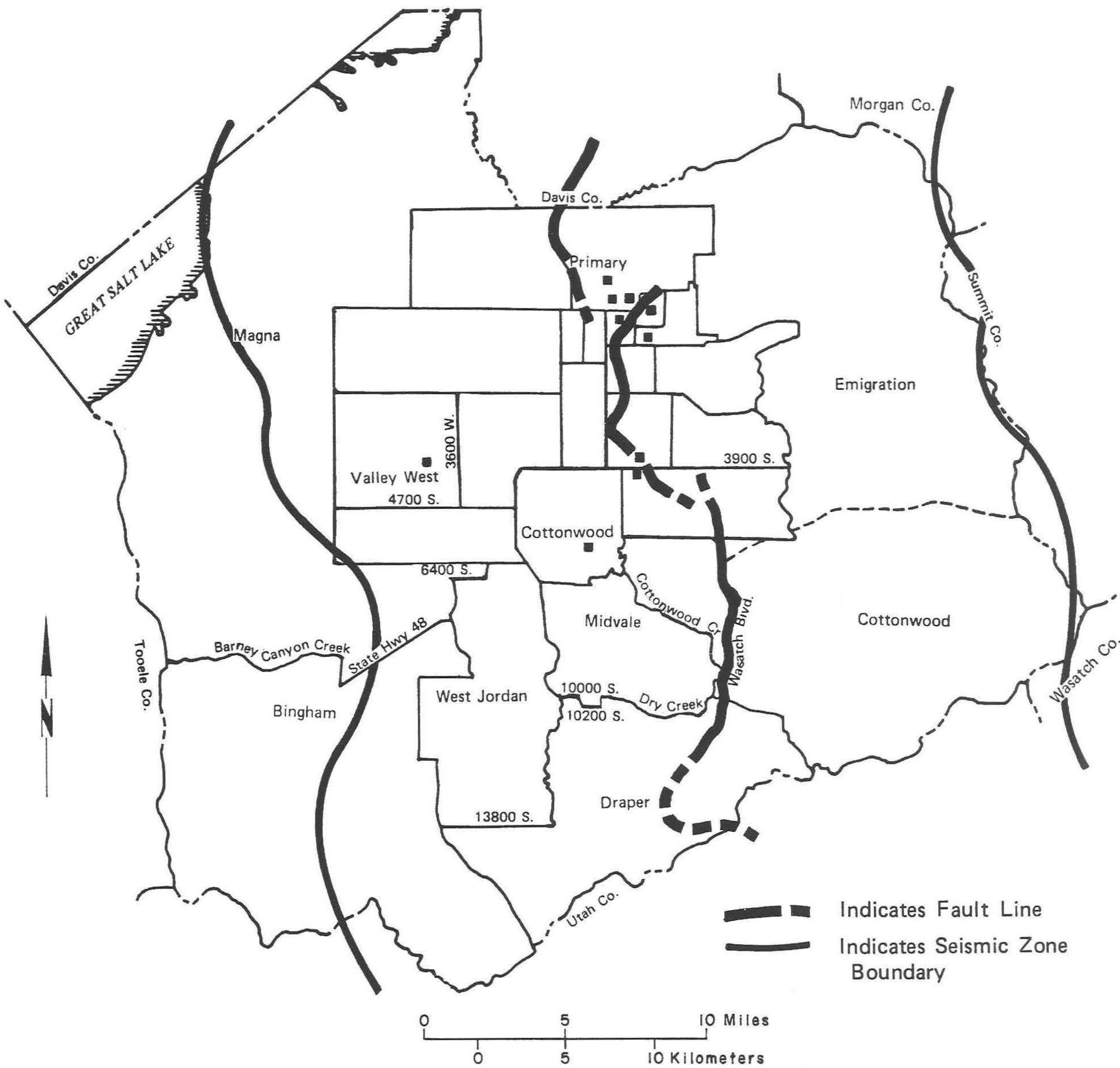


Figure 8

LOCATION OF HOSPITALS IN SALT LAKE COUNTY
STATE OF UTAH

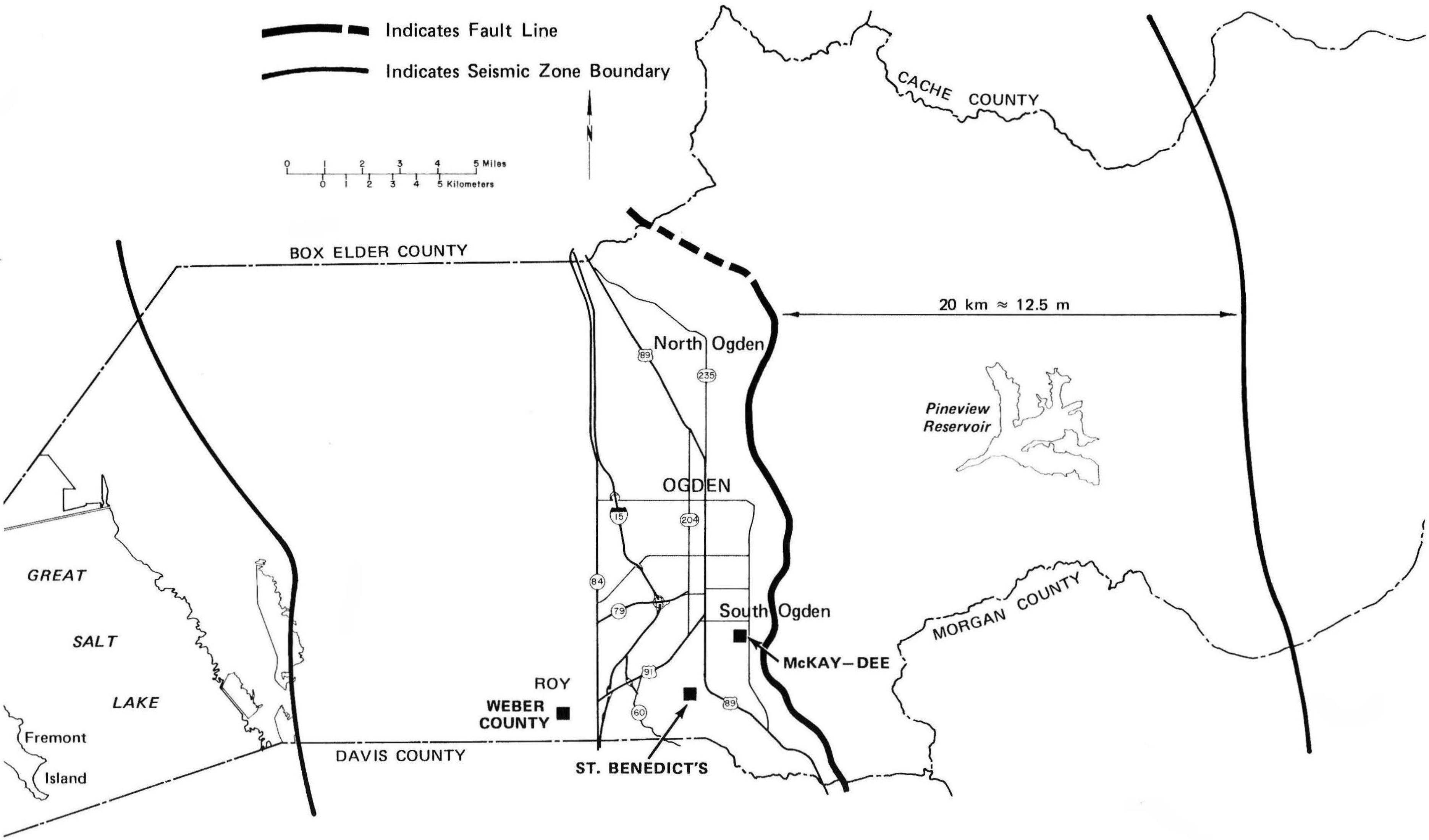


Figure 9

LOCATION OF HOSPITALS IN WEBER COUNTY
STATE OF UTAH

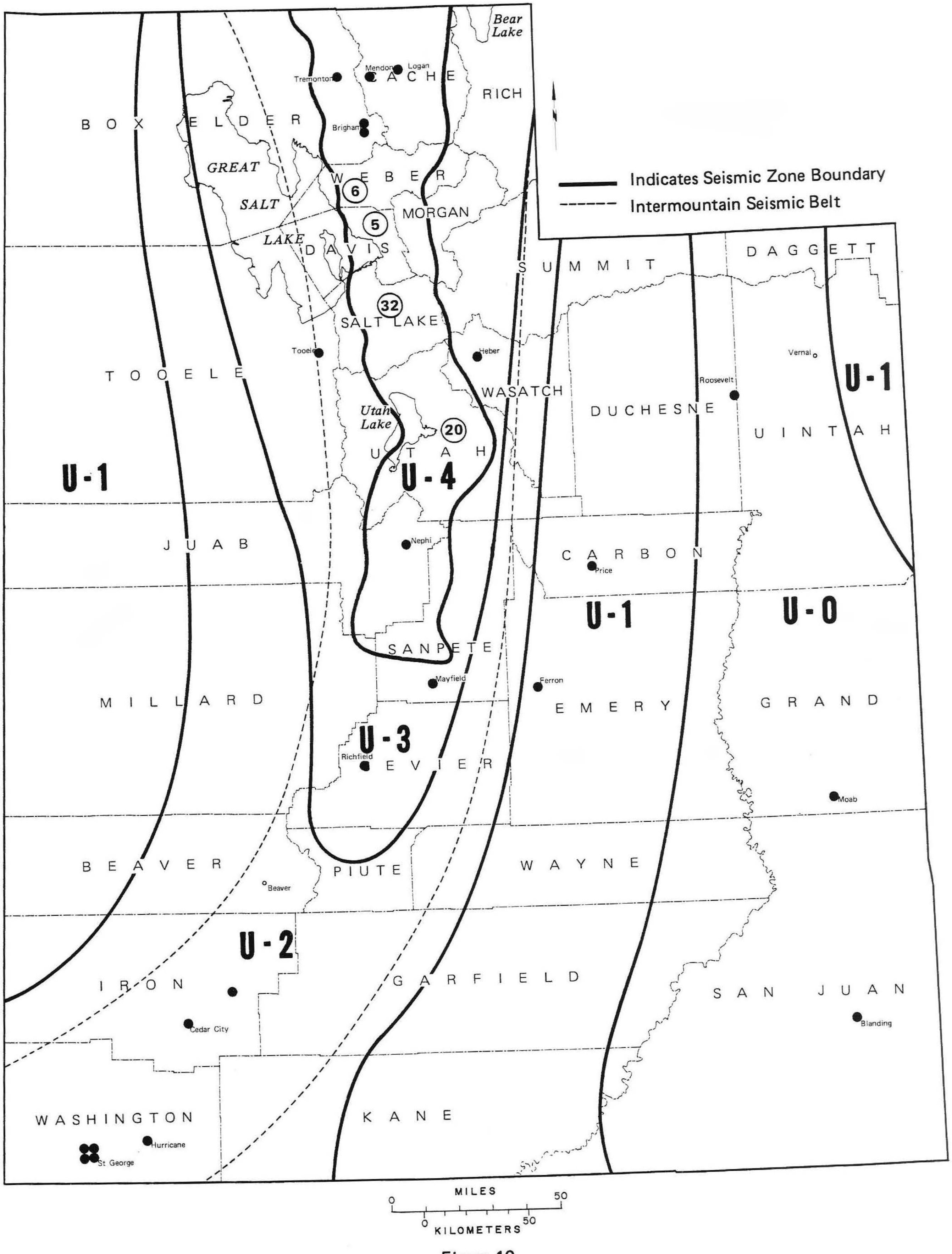


Figure 10

DISTRIBUTION OF NURSING HOMES BY SEISMIC ZONE AND COUNTY
STATE OF UTAH

Table 1

EXISTING UTAH HOSPITALS BY BED CAPACITY AND BY OTHER SEISMIC FACTORS

Name Of Facility	Bed Capacity	Age (Oldest Unit)	Number Of Stories (Highest Units)		Proximity To Wasatch Fault (Range Of Estimates Given) (Source: R. Hughes, [15], [20])
LDS Hospital	570	1905-68	8	U-4	1.4 miles
Veterans Administration Hospital	476	1950-78	8	U-4	1.2 miles
University of Utah Medical Center	450	1956-79	6	U-4	2,400-2,600 feet
Utah State Hospital	368	1928-72	3	U-4	
McKay-Dee Hospital	366	1910-72	5	U-4	2,700-5,200 feet
Holy Cross Hospital	343	1909-71	6	U-4	1,300-2,600 feet
St. Mark's Hospital	306	1969	5	U-4	2,600-3,200 feet
Utah Valley Hospital	270	1939-72	3	U-4	1.5-1.7 miles
Cottonwood Hospital	243	1963-75	1	U-4	2.3 miles
Weber County Memorial Hospital	198	1960	1	U-4	5 miles
Doxey Hatch Hospital	180	1975	4	U-4	2,200-3,200 feet
Primary Children's Hospital	154	1952-71	3	U-4	1.5 miles
St. Benedict's Hospital	133	1976	1	U-4	2 miles
Lakeview Hospital	128	1976	1	U-4	1 mile
Logan Hospital	123	1978	3	U-4	1.2 miles
Davis North Hospital	100	1976	1	U-4	1 mile
Valley West Hospital	97	1963-73	1	U-4	7 miles
Payson City Hospital	94	1978	1	U-4	1-2 miles
American Fork Hospital	78	1950-73	1	U-4	2.5 miles
Carbon County Hospital	75	1958-73	4	U-1	
Valley View Medical Center	72	1962-68	1	U-2	
Dixie Medical Center	65	1973	4	U-2	
Brigham City Hospital	50	1976	1	U-4	1-1.7 miles
Shriner's Hospital	45	1951	3	U-4	500-2,600 feet
Wasatch County Hospital	40	1967	1	U-3	
Allen Memorial Hospital	38	1955-75	1	U-0	
Tooele Valley Hospital	38	1952-66	1	U-3	
San Juan County Hospital	36	1960-78	1	U-0	
Raleigh Hills Hospital	35	1975	4	U-4	2,200-3,200 feet
Hill Air Force Base Hospital	35	1973	1	U-4	2.5-5.5 miles
Fillmore Hospital	34	1947	1	U-3	
Milford Valley Hospital	34	1965-71	1	U-2	
West Millard Hospital	34	1963-71	1	U-2	
Kane County Hospital	33	1962-70	1	U-2	
Duchesne County Hospital	32	1970	1	U-0	
Uintah County Hospital	32	1978	1	U-0	
Juab County Hospital	31	1951-72	1	U-4	2,400-3,200 feet
Sevier Valley Hospital	28	1974	1	U-3	
Monument Valley Hospital	27	1956	1	U-0	
Sanpete County Hospital	25	1948-59	1	U-3	
Gunnison Valley Hospital	21	1968	1	U-3	
Bear River Hospital	20	1977	1	U-4	
Garfield Memorial Hospital	20	1974	1	U-2	
Summit County Hospital	14	1939	1	U-3	
Beaver Valley Hospital	10	1965-70	1	U-2	

Table 2

CLASSIFICATION OF EXISTING UTAH HOSPITALS
IN TERMS OF CONSTRUCTION VULNERABILITY TO EARTHQUAKES[1]

Name of Facility	Bed Capacity	Seismic Zone	Construction Classification Steinbrugge System	Construction Classification USGS Study
Allen Memorial Hospital	38	U-0	---	---
American Fork Hospital	78	U-4	5E,5D,5C	5
Bear River Hospital	20	U-4	5C	2
Beaver Valley Hospital	10	U-2	5D	4
Brigham City Hospital	50	U-4	5C	3
Carbon County Hospital	75	U-1	5E,5D,5C	5
Cottonwood Hospital	243	U-4	5D,5C	4
Davis North Hospital	100	U-4	4C	2
Dixie Medical Center	65	U-2	5D	4
Doxey Hatch Hospital	180	U-4	5C	3
Duchesne County Hospital	32	U-0	---	---
Fillmore Hospital	34	U-3	5E	5
Garfield Memorial Hospital	20	U-2	5D	4
Gunnison Valley Hospital	21	U-3	5D	4
Hill Air Force Base Hospital	35	U-4	4C	3
Holy Cross Hospital	343	U-4	5E,4E,4C,4B	6
Juab County Hospital	31	U-4	5E,5D,5C	5
Kane County Hospital	33	U-2	5E,5D	5
Lakeview Hospital	128	U-4	5C	3
LDS Hospital	570	U-4	5E,5D	6
Logan Hospital	123	U-4	5C	3
McKay-Dee Hospital	366	U-4	5E,4C	6
Milford Valley Hospital	34	U-2	5D	4
Monument Valley Hospital	27	U-0	---	---
Payson City Hospital	94	U-4	5C	3
Primary Children's Hospital	154	U-4	5E,5D,4C	6
Raleigh Hills Hospital	35	U-4	5C	3
St. Benedict's Hospital	133	U-4	5C	3
St. Mark's Hospital	306	U-4	4B	3
San Juan Hospital	36	U-0	---	---
Sanpete County Hospital	25	U-3	5E	6
Sevier Valley Hospital	28	U-3	5C	3
Shriner's Hospital	45	U-4	5E	6
Summit County Hospital	14	U-3	5E	6
Tooele Valley Hospital	38	U-3	5E,5D	5
Uintah County Hospital	32	U-0	---	---
University of Utah Medical Center	450	U-4	5D,5C	4
Utah State Hospital	368	U-4	5F,5E,5D	6
Utah Valley Hospital	270	U-4	5E,5D,5C	6
Valley View Medical Center	72	U-2	5E,5D	4
Valley West Hospital	97	U-4	5D,5C	4
Veterans Administration Hospital	476	U-4	5B	3
Wasatch County Hospital	40	U-3	5D	4
Weber County Memorial Hospital	198	U-4	5E	5
West Millard Hospital	34	U-2	5D,5C	3

[1]Construction classification may be of several types for some facilities which were constructed in phases, at different dates and of different structural systems Also, Construction classification is based upon best data available. More detailed investigation of individual facilities could result in reclassification.

Table 3

BED CAPACITIES OF EXISTING UTAH HOSPITALS BY CONSTRUCTION CLASS AND SEISMIC ZONE[1]

Zone	Construction Class										
	5E	4D	4E	4B	5D	3B,3D, 4C,5C	3C,4A, 5B	3A	2B	2A	TOTALS
Zone U-0	-	-	-	-	-	-	-	-	-	-	165
Zone U-1	75	-	-	-	-	-	-	-	-	-	75
Zone U-2	105	-	-	-	163	-	-	-	-	-	268
Zone U-3	111	-	-	-	61	28	-	-	-	-	200
Zone U-4	2,410	-	-	306	800	901	476	-	-	-	4,893
TOTALS	2,701	-	-	306	1,024	929	476	-	-	-	5,601

[1]Owing to lack of data on bed locations within individual hospitals, all beds are classified in the most vulnerable construction class for each building in accordance with the listing in Table 2. Thus, the above classification represents the probable worst conditions. This assumption will result in some overstatement of seismic risk for those computations that are made using data from this Table.

Table 4

FLOOR AREAS OF EXISTING UTAH HOSPITALS
BY CONSTRUCTION CLASS AND SEISMIC ZONE

(Square Feet)

Zone	Construction Class										
	5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A, 5B	3A	2B	2A	TOTALS
Zone U-0	-	-	-	-	-	-	-	-	-	-	123,037
Zone U-1	22,500	-	-	-	42,400	-	-	-	-	-	64,900
Zone U-2	6,478	-	-	-	231,411	9,922	-	-	-	-	247,811
Zone U-3	95,400	-	-	-	48,844	24,900	-	-	-	-	169,144
Zone U-4	176,446	-	-	262,733	824,878	1,709,867	677,000	-	-	-	3,650,924
TOTALS	300,824	-	-	262,733	1,147,533	1,744,689	677,000	-	-	-	4,255,816

Table 5

ESTIMATED REPLACEMENT COSTS[1] OF EXISTING UTAH HOSPITALS (1978)
BY CONSTRUCTION CLASS AND SEISMIC ZONE

($ in Thousands)

Zone	Construction Class										
	5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A	Totals
Zone U-0	-	-	-	-	-	-	-	-	-	-	$ 11,073
Zone U-1	$ 2,025	-	-	-	$ 3,816	-	-	-	-	-	$ 5,841
Zone U-2	$ 583	-	-	-	$ 20,827	$ 893	-	-	-	-	$ 22,303
Zone U-3	$ 8,586	-	-	-	$ 4,396	$ 2,241	-	-	-	-	$ 15,223
Zone U-4	$158,801	-	-	$23,646	$ 74,239	$153,888	$60,930	-	-	-	$471,504
Totals	$169,995	-	-	$23,646	$103,278	$157,022	$60,930	-	-	-	$595,944

[1]Replacement cost is estimated at $90 per square foot times the enclosed space.

Table 6

CLASSIFICATION OF EXISTING UTAH NURSING HOMES IN TERMS OF CONSTRUCTION VULNERABILITY TO EARTHQUAKES[1]

Zone	Building Classification											
	5F[2]	5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A	1	Totals
Zone U-0	0	0	0	0	0	2	0	0	0	0	0	0	2
Zone U-1	1	0	0	0	0	1	0	0	0	0	0	0	2
Zone U-2	0	3	0	0	0	1	3	0	0	0	0	0	7
Zone U-3	0	2	0	0	0	1	1	0	0	0	0	0	4
Zone U-4	2	19	1	0	0	14	32	0	0	1	0	0	69
Totals	3	24	1	0	0	19	36	0	0	1	0	0	84

[1]Classification is made for analytical purposes in term of seismic vulnerability and may not accurately depict the actual construction of each building. To the extent possible from available data, nursing homes are classified in the most vulnerable category when more than one construction class is evident, such as due to additions to an older building. That is, a nursing home categorized as Class 5E, for example, may have a Class 5C section.

[2]Owing to lack of data for estimating damage losses for Class 5F buildings, these have been considered as Class 5E in analyses prepared for this report.

Table 7

BED CAPACITIES OF EXISTING UTAH NURSING HOMES
BY CONSTRUCTION CLASS AND SEISMIC ZONE[1]

Zone	Construction Class												
	5F[2]	5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A	1	Totals
Zone U-0	-	-	-	-	-	82	-	-	-	-	-	-	82
Zone U-1	57	-	-	-	-	48	-	-	-	-	-	-	105
Zone U-2	-	105	-	-	-	27	134	-	-	-	-	-	266
Zone U-3	-	85	-	-	-	48	98	-	-	-	-	-	231
Zone U-4	168	1,819	24	-	-	1,180	2,216	-	-	100	-	-	5,507
Totals	225	2,009	24	-	-	1,385	2,448	-	-	100	-	-	6,191

[1]Nursing Home construction classes are as given in Table 6.

[2]Owing to lack of data for estimating damage losses for Class 5F buildings, these have been considered as Class 5E in analyses prepared for this report.

Table 8

FLOOR AREAS OF EXISTING NURSING HOMES BY CONSTRUCTION CLASS AND SEISMIC ZONE[1]

(Square Feet)

Zone	Construction Class											
	5F[2]	5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A	1	Totals
Zone U-0	-	-	-	-	-	27,853	-	-	-	-	-	-	27,853
Zone U-1	19,521	-	-	-	-	18,315	-	-	-	-	-	-	37,836
Zone U-2	-	15,200	-	-	-	12,738	44,979	-	-	-	-	-	72,917
Zone U-3	-	23,836	-	-	-	11,150	23,781	-	-	-	-	-	58,767
Zone U-4	19,100	455,909	4,800	-	-	362,472	780,036	-	-	32,316	-	-	1,654,633
Totals	38,621	494,945	4,800	-	-	432,528	848,796	-	-	32,316	-	-	1,852,006

[1]Floor areas are allocated to construction classes for portions of buildings, in accordance with available data which implies seismic vulnerability. Thus, for example, a nursing home may include some area of Class 5D and some area of Class 5E. This table therefore does not correspond exactly with Table 6.

[2]Owing to lack of data for estimating damage losses for Class 5F buildings, these have been considered as Class 5E in analysis prepared for this report.

Table 9

ESTIMATED VALUATION OF EXISTING UTAH NURSING HOMES (1978)
BY CONSTRUCTION CLASS AND SEISMIC ZONE[1]

($ in Thousands)

Zone	Construction Class											
	5E	4D	4E	4B	5D	3B,3D 4C,5C	3A,4A 5B	3A	2B	2A	1	Totals
Zone U-0	-	-	-	-	-	-	-	-	-	-	-	-
Zone U-1	$ 976	-	-	-	$ 916	-	-	-	-	-	-	$ 1,892
Zone U-2	$ 760	-	-	-	$ 640	$ 2,249	-	-	-	-	-	$ 3,649
Zone U-3	$ 1,192	-	-	-	$ 558	$ 1,189	-	-	-	-	-	$ 2,939
Zone U-4	$18,132	$240	-	-	$18,124	$38,902	-	-	$1,616	-	-	$77,014
Totals	$21,060	$240	-	-	$20,238	$42,340	-	-	$1,616	-	-	$65,494

[1]Nursing home construction classes are as given in Table 6, except that Class 5F buildings are considered as Class 5E.

Table 10

EXPECTED 100-YEAR LOSSES TO BUILDINGS IN ZONE 33A
BY CLASS OF CONSTRUCTION EXPRESSED AS A PERCENT OF THE CLASS

(Based on Algermissen and Steinbrugge Loss Estimates)

PERCENT LOSS AT A GIVEN INTENSITY

Intensity	Construction Class									
	5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A
X	50%	42%	37%	33%	30%	23%	18%	15%	12%	8%
IX	35%	30%	27.5%	25%	22.5%	17.5%	13%	11%	8%	7%
VIII	25%	22%	19%	18%	16%	12.5%	7.5%	6%	4.5%	4%
VII	14.5%	12.5%	11%	10%	9%	7%	2%	1.5%	1%	2.5%
VI	4%	3%	2.5%	2.5%	2.5%	2%	0	0	0	0

FREQUENCY CONTRIBUTION OF EACH INTENSITY IN SUBZONE 33A

Intensity	Frequency	Construction Class									
		5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A
X	0.0085	0.0043	0.0036	0.0031	0.0028	0.0026	0.0019	0.0016	0.0013	0.0010	0.0006
IX	0.0274	0.0096	0.0082	0.0075	0.0069	0.0062	0.0048	0.0036	0.0030	0.0022	0.0019
VIII	0.0636	0.0159	0.0140	0.0121	0.0115	0.0102	0.0080	0.0048	0.0038	0.0029	0.0025
VII	0.2195	0.0318	0.0274	0.0242	0.0219	0.0197	0.0154	0.0044	0.0033	0.0022	0.0055
VI	0.9098	0.0324	0.0243	0.0202	0.0202	0.0202	0.0162	0	0	0	0

CONTRIBUTIONS OF ALL FREQUENCIES COMBINED -- ZONE 33A

Construction Class									
5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A
9.40%	7.75%	6.71%	6.33%	5.89%	4.63%	1.44%	1.14%	0.83%	1.05%

Table 11

EXPECTED 100-YEAR LOSS TO UTAH BUILDINGS
BY ZONE AND BY BUILDING CLASS

(Based on Algermissen and Steinbrugge Estimates)

Zone	Building Class									
	5E	4D	4E	4B	5D	3B,3D 4C,5C	3C,4A 5B	3A	2B	2A
Zone 32	0.0011	0.0009	0.0007	0.0007	0.0007	0.0005	0.0001	0	0	0
Zone 33A	0.0940	0.0775	0.0671	0.0633	0.0589	0.0463	0.0144	0.0114	0.0083	0.0105
Zone 33B	0.0278	0.0222	0.0189	0.0182	0.0173	0.0136	0.0022	0.0018	0.0012	0.0021
Zone 34	0.0153	0.0123	0.0106	0.0101	0.0094	0.0075	0.0022	0.0013	0.0009	0.0014

Table 12

EXPECTED 100-YEAR LOSS FACTORS FOR UTAH BUILDINGS BY ZONE AND BY BUILDING CLASS

(Based on Adapted USGS Classification)

Zone	Building Class							
	7	6	5	4	3	2	1b	1a
Zone 32	0.0034	0.0026	0.0020	0.0010	0.0006	0.0003	0.0001	0.0001
Zone 33A	0.2894	0.2244	0.1728	0.1113	0.0624	0.0347	0.0193	0.0110
Zone 33B	0.0917	0.0711	0.0555	0.0324	0.0166	0.0072	0.0041	0.0023
Zone 34	0.0492	0.0379	0.0294	0.0178	0.0095	0.0046	0.0027	0.0015

Table 13

DEATHS AND INJURIES AS A PERCENT OF HOSPITAL AND NURSING HOME OCCUPANTS BY TYPE OF OCCUPANT AND BY DEGREES OF MODIFIED MERCALLI INTENSITY

Intensity	Deaths			Injuries		
	General Public	In-patients in Hospitals	Visitors	General Public	In-patients in Hospitals	Visitors
VII	0	0	0	4%	5%	4%
VIII	0.67%	1%	0.5%	8%	10%	6%
IX	2%	3%	1.5%	15%	20%	10%
X	3%	5%	2%	20%	30%	15%

Table 14

MORTALITY AND SEVERE CASUALTY RATES
BY SEISMIC ZONE AND BY TYPE OF OCCUPANT
AS A PERCENT OF OCCUPANTS

Zone	Deaths			Injuries		
	General Public	In-patients	Visitors	General Public	In-patients	Visitors
Zone 32	0.0004%	0.0006%	0.0003%	0.0160%	0.0200%	0.0148%
Zone 33A	0.1229%	0.1883%	0.0899%	1.968 %	2.537 %	1.661 %
Zone 33B	0.0098%	0.0148%	0.0074%	0.3626%	0.4585%	0.3374%
Zone 34	0.0077%	0.0130%	0.0065%	0.2466%	0.3105%	0.2225%

Table 15

BED CAPACITIES IN SURVEYED UTAH HOSPITALS BY SEISMIC ZONE AND TYPE OF BUILDING[1]

(Based Upon Table of Coefficients)

Zone	Building Type						Totals
	B	C	D	E	F	G	
Zone U-0	-	100	65	-	-	-	165
Zone U-1	-	-	-	-	75	-	75
Zone U-2	-	20	183	65	-	-	268
Zone U-3	-	28	172	-	-	-	200
Zone U-4	476	900	307	644	2,198	368	4,893
TOTALS	476	1,048	727	709	2,273	368	5,601

[1]Total bed capacity of each hospital has been lumped in a single building class according to its oldest date of construction or worst seismic condition. Hence, some facilities having newer additions may have some bed patients that are less vulnerable to earthquakes than are indicated in this table. More data than were assembled for this study would be needed to improve upon the building type allocations as used here.

Table 16

BED CAPACITIES IN SURVEYED UTAH NURSING HOMES BY SEISMIC ZONE AND TYPE OF BUILDING[1]

(Based Upon Table of Coefficients)

Zone	Building Type						Totals
	A	C	D	E	F	G	
Zone U-0	-	51	31	-	-	-	82
Zone U-1	-	48	-	-	57	-	105
Zone U-2	-	204	26	-	36	-	266
Zone U-3	-	146	-	48	37	-	231
Zone U-4	-	2,618	809	642	1,223	215	5,507
TOTALS	-	3,067	866	690	1,353	215	6,191

[1]Total bed capacity of each nursing home has been lumped in a single building class according to its oldest date of construction or worst seismic condition. Hence, some facilities having newer additions may have some patients that are less vulnerable to earthquakes than are indicated in this table. More data than were assembled for this study would be needed to improve upon the building type allocations as used here.

Table 17

ESTIMATED 100-YEAR DEATHS AND INJURIES TO HOSPITAL POPULATIONS IN UTAH AS A RESULT OF EARTHQUAKES

DEATHS

Zone	Building Type B	C	D	E	F	G	Totals
Zone U-0	-	0	0	-	-	-	0
Zone U-1	-	-	-	-	0.0011	-	0.0011
Zone U-2	-	0.0032	0.0391	0.0174	-	-	0.0597
Zone U-3	-	0.0053	0.0473	-	-	-	0.0526
Zone U-4	0.6046	2.1432	0.9748	2.5560	10.4684	2.3369	19.0839
Totals	0.6046	2.1517	1.0612	2.5734	10.4695	2.3369	19.1973

INJURIES

Zone	Building Type B	C	D	E	F	G	Totals
Zone U-0	-	0	0	-	-	-	0
Zone U-1	-	-	-	-	0.0434	-	0.0434
Zone U-2	-	0.0892	1.0878	0.4829	-	-	1.6599
Zone U-3	-	0.1849	1.5136	-	-	-	1.6985
Zone U-4	9.0430	32.0591	14.5809	38.2334	157.1612	34.9563	286.0339
Totals	9.0430	32.3332	17.1823	38.7163	157.2046	34.9563	289.4357

Table 18

ESTIMATED 100-YEAR DEATHS AND INJURIES TO NURSING HOME POPULATIONS IN UTAH AS A RESULT OF EARTHQUAKES

DEATHS

Zone	Building Type						Totals
	B	C	D	E	F	G	
Zone U-0	-	0	0	-	-	-	0
Zone U-1	-	0.0002	-	-	0.0005	-	0.0007
Zone U-2	-	0.0199	0.0034	-	0.0070	-	0.0303
Zone U-3	-	0.0162	-	0.0089	0.0082	-	0.0333
Zone U-4	-	3.6973	1.5233	1.5111	3.4544	0.8097	10.9958
Totals	-	3.7336	1.5267	1.5200	3.4701	0.8097	11.0601

INJURIES

Zone	Building Type						Totals
	B	C	D	E	F	G	
Zone U-0	-	0	0	-	-	-	0
Zone U-1	-	0.0072	-	-	0.0171	-	0.0243
Zone U-2	-	0.4751	0.0807	-	0.1677	-	0.7235
Zone U-3	-	0.5021	-	0.2751	0.2545	-	1.0317
Zone U-4	-	49.8140	20.5243	20.3594	46.5413	10.9091	148.1481
Totals	-	50.7984	20.6050	20.6345	46.9806	10.9091	149.9276

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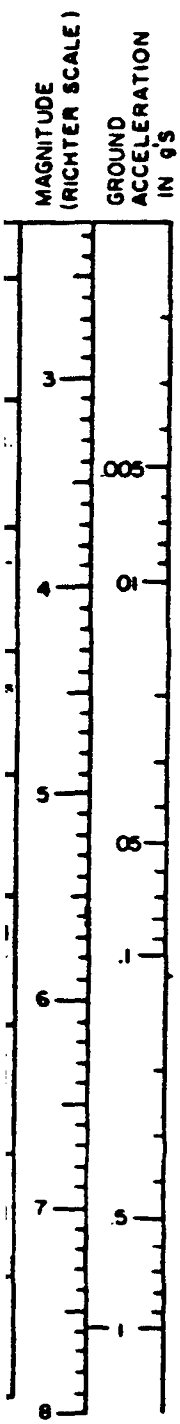
APPENDIX A

MODIFIED MERCALLI INTENSITY SCALE APPROXIMATE RELATIONSHIP WITH MAGNITUDE AND GROUND ACCELERATION

ABRIDGED
MODIFIED MERCALLI INTENSITY SCALE

I	Not felt except by a very few under especially favourable circumstances.	
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.	
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars	may rock slightly. Vibration like passing of tru Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sen-	sation like heavy truck striking building. Stan ing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned.	Disturbance of trees, poles and other tall obje s sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.	
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures;	considerable in poorly built or badly design structures; some chimneys broken. Noticed b persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures.	Fall of chimneys, factory stacks, columns, mon ments, walls. Heavy furniture overturned. San and mud ejected in small amounts. Changes i well water. Persons driving motor cars disturbe
IX	Damage considerable in specially designed structures, well designed frame structures thrown out of plumb; great in substantial buildings, with	partial collapse. Buildings shifted off foundation Ground cracked conspicuously. Undergroun pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations, ground badly cracked. Rails	bent. Landslides considerable from river bank and steep slopes. Shifted sand and mud. Wate splashed (slopped) over banks.



Modified Mercalli Intensity Scale after Wood and Neumann, 1931. (Intensities XI and XII not included).

Magnitude and acceleration values taken from Nuclear Reactors and Earthquakes, TID-7024, United States Atomic Energy Commission.

APPENDIX B

BUILDING CLASSIFICATIONS FOR ESTIMATING EARTHQUAKE LOSSES

(As Suggested by K.V. Steinbrugge, et al.)

CLASS I: WOOD FRAME:

Class I-A:

1. Wood frame and frame stucco dwellings regardless of area and height.
2. Wood frame and frame stucco buildings, other than dwellings, which do not exceed 3 stories in height and do not exceed 3,000 sq. ft. in ground floor area.
3. Wood frame and frame stucco habitational structures which do not exceed 3 stories in height regardless of area.

Class I-B: Wood frame and frame stucco buildings not qualifying under Class I-A.

CLASS II: ALL-METAL BUILDINGS:

Class II-A: One story all-metal buildings which have a floor area not exceeding 20,000 sq. ft.

Class II-B: All-metal buildings not qualifying under Class II-A.

CLASS III: STEEL FRAME BUILDINGS:

Class III-A: Buildings having a complete steel frame with all loads carried by the steel frame. Floors and roofs shall be of poured-in-place reinforced concrete, or of concrete fill on metal decking welded to the steel frame (open web steel joists excluded). Exterior walls shall be of poured-in-place reinforced concrete or of reinforced unit masonry placed within the frame. Buildings shall have a least width to height about ground (or above any setback) ratio of not exceeding one to four. Not qualifying are buildings having column-free areas greater than 2,500 sq. ft. (such as auditoriums, theaters, public halls, etc.)

Class III-B: Buildings having a complete steel frame with all loads carried by the steel frame. Floors and roofs shall be of poured-in-place reinforced concrete or metal, or any combination thereof, except that roofs on buildings over three stories may be of any material. Exterior and interior walls may be of any non-load carrying material.

Class III-C: Buildings having some of the favorable characteristics of Class III-A but otherwise falling into Class III-B.

Class III-D: Buildings having a complete steel frame with floors and roofs of any material and with walls of any non-load bearing materials.

CLASS IV: REINFORCED CONCRETE, COMBINED REINFORCED CONCRETE AND STRUCTURAL STEEL FRAME:

Note: Class IV-A, B, and C buildings shall have all vertical loads carried by a structural system consisting of one or a combination of the following: (a) poured-in-place reinforced concrete frame, (b) poured-in-place reinforced concrete bearing walls, (c) partial structural steel frame with (a) and/or (b). Floors and roof shall be of poured-in-place reinforced concrete, except that materials other than reinforced concrete may be used for the roofs on buildings over 3 stories.

Class IV-A: Building having a structural system as defined by the note (above) with poured-in-place reinforced concrete exterior walls or reinforced unit masonry exterior walls placed within the frame. Buildings shall have a least width to height above ground (or above any setback) ratio of not exceeding one to three. Not qualifying are buildings having column-free areas greater than 2,500 sq. ft. (such as auditoriums, theaters, public halls, etc.)

Class IV-B: Buildings having a structural system as defined by the note (above) with exterior and interior non-bearing walls of any material.

Class IV-C: Buildings having some of the favorable characteristics of Class IV-A but otherwise falling into Class IV-B.

Class IV-D: Buildings having (a) a partial or complete load carrying system of precast concrete, and/or (b) reinforced concrete lift slab floors and/or roofs, and (c) otherwise qualifying for Classes IV-A, B, or C.

Class IV-E: Buildings having a complete reinforced concrete frame, or a complete frame of combined reinforced concrete and structural steel. Floors and roofs may be any material while walls may be of any non-load bearing material.

CLASS V: MIXED CONSTRUCTION:

Class V-A:

1. Dwellings, not over two stories in height, constructed of poured-in-place reinforced concrete, with roofs and second floors of wood frame.
2. Dwellings, not over two stories in height, constructed of adequately reinforced brick or hollow concrete block masonry, with roofs and floors of wood.

Class V-B: One story buildings having superior earthquake damage control features including exterior walls of (a) poured-in-place reinforced concrete, and/or (b) precast reinforced concrete, and/or (c) reinforced brick masonry or reinforced concrete brick masonry, and/or (d) reinforced hollow concrete block masonry. Roofs and supported floors shall be of wood or metal diaphragm assemblies. Interior bearing walls shall be of wood frame or any one or a combination of the aforementioned wall materials.

Class V-C: One story buildings having construction materials listed for Class V-B, but with ordinary earthquake damage control features.

Class V-D:

1. Buildings having reinforced concrete load bearing walls with floors and roofs of wood and not qualifying for Class IV-E.

2. Buildings of any height having Class V-B materials of construction, including wall reinforcement; also included are buildings with roofs and supported floors of reinforced concrete (precast or otherwise) not qualifying for Class IV.

Class V-E: Buildings having unreinforced solid unit masonry of unreinforced brick, unreinforced concrete brick, unreinforced stone, or unreinforced concrete, where the loads are carried in whole or in part by the walls and partitions. Interior partitions may be wood frame or of the aforementioned materials. Roofs and floors may be of any material. Not qualifying are buildings with non-reinforced load carrying walls of hollow tile or other hollow unit masonry, adobe, or cavity construction.

Class V-F:

1. Buildings having load carrying walls of hollow tile or other hollow unit masonry construction, adobe, and cavity wall construction.
2. Any building not covered by any other class.

CLASSES VI-A, B, C, D, AND E: EARTHQUAKE RESISTIVE CONSTRUCTION:

Any building or structure with any combination of materials and with earthquake damage control features equivalent to those found in Classes I through V buildings. Alternatively, a qualifying building or structure may be classed as any class from I through V (instead of VI-A, B, C, D, or E) if the construction resembles that described for one of these classes and if the qualifying building or structure has an equivalent damageability.