SEISMIC SAFETY ADVISORY COUNCIL

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SEISMIC RISK ASSESSMENT OF

STATE-OWNED BUILDINGS IN UTAH

AND RECOMMENDATIONS FOR RISK REDUCTION

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SEISMIC SAFETY ADVISORY COUNCIL
STATE OF UTAH

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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 the hazards which may be found.

This report presents an assessment of seismic risk for State-owned buildings. It includes recommendations for reducing the vulnerability of various buildings of the study class taken as an aggregate group and for selected specific facilities owned by the State. Although existing buildings are the focus of the study and of the recommendations for earthquake hazards reduction, comments also are made regarding prudent practices for making new construction less vulnerable to earthquake effects.

The recommendations are set forth as judgements of the Seismic Safety Advisory Council in terms of (1) effectiveness of the suggested action for reducing earthquake 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 topical sections. Section 1 presets a summary of earthquake safety findings for State-owned buildings. Section 2 contains a set of general and specific recommendations for risk reduction. Section 3 discusses the general findings in greater detail. Sections 4 through 7 describe the scope of the studies that were made and the analytical basis for assessing earthquake risk. Section 8 provides a detailed description of the technical method of analysis and results. Technical sections utilize current seismicity data in Utah and state-of-the-art methods for predicting earthquake damage and for assessing earthquake risk.

The reader must bear in mind that earthquake risk assessment is an inexact science built upon incomplete understanding of earthquake phenomena and their effects upon buildings. The technical results presented in this report are probabilistic in nature and carry all of the imperfections implied by this term. Notwithstanding these fundamental limitations, the Advisory Council believes the conclusions and recommendations are founded upon reasonable data and analytical methods.

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

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SECTION 1

SUMMARY OF FINDINGS

Prinicpal findings resulting from this earthquake risk assessment of existing buildings owned by the State of Utah are presented first, without extensive elaboration upon or discussion of the methods of analysis that were used. Such details appear in Sections 3 through 8 which follow. Recommendations for dealing with earthquake safety problems that have been identified for State-owned buildings are provided in Section 2. In Section 2, information has been included so that reasonable completeness is retained in the event that the section is separated from the more lengthy report.

This study addresses earthquake risk only for existing buildings owned and used by the State of Utah. The principal findings which follow are limited accordingly. No attempt has been made to prepare risk assessments for other buildings and spaces that are leased by the State, even though there are a large number of such buildings and even though some of them pose similar earthquake hazards to State employees and public users of State services. In the recommendations, we have addressed this issue by suggesting that earthquake resistance of a building be considered when space is leased, but we have neither attempted to evaluate any buildings presently under lease nor recommended any action pertaining to facilities that the State does not own.

Earthquake hazards mitigation in the construction of new State buildings involves considerations that are completely different from existing facilities and, consequently, remedies which also are different. However, new construction is treated only tangentially in this report. Here, it is enough to observe (1) that earthquakes safety can be achieved relatively easily in new construction in contrast with the great cost and difficulties for remedying safety deficiencies in existing buildings, (2) that providing earthquake safety in new construction is inexpensive if introduced during conceptual design for most buildings, and (3) that consideration of earthquake safety is strongly recommended for all new State construction.

Principal findings from this study of State-owned buildings are listed below. Importance of the topic was not a basis for the list sequence, and the findings are listed more or less in order of their appearance in the discussion sections of the report.

- o Buildings owned and used by the State of Utah number just under 300. University buildings are not included in this total. Of the 293 buildings that could be identified, 267 were included in the statistical analyses of this report.

- o Of the 267 State-owned buildings included in the report surveys, 151, or 56.5 percent, are located within the zone of greatest seismicity. Twenty nine, or 10.9 percent, are located within the zone of second highest seismicity.

- Total gross floor area of the 267 surveyed buildings amounts to 3,009,169 square feet. Of this floor area, 2,731,841 square feet, or 90.8 percent, lies within the zone of greatest seismicity. Because of the wide variation in size of buildings, gross floor area is a better indicator of the scope and distribution of State-owned buildings.

- Building use and extent of occupancy are additional factors in evaluating earthquake risk. This is an especially significant consideration for State-owned buildings, because their uses range from relatively unoccupied warehouses to highly populated offices and public-use buildings. Of the 267 surveyed State-owned buildings, just 152 of them may be considered to be of moderate or high occupancy. However, 112 of these, or 41.9 percent of the 267 total, are within the zone of highest seismicity in the State. Moreover, these 112 buildings combined have a gross floor area of 2,666,279 square feet, or 88.6 percent of the total gross floor area of surveyed State-owned buildings. The vast majority of State-owned buildings, by number of buildings, by gross floor area, and by exposed populations, therefore, is within the zone of greatest earthquake risk in the State of Utah.

- As determined from vulnerability characteristics of these State-owned buildings to earthquake effects, which are described in greater detail in subsequent portions of the report, approximately one-third of them (54 of 151) lie in the zone of highest seismicity and are of construction types that historical evidence has shown to be the most likely to experience damage from earthquakes.

- From such data as alluded to in the above paragraphs, one may estimate life loss and casualty rates due to earthquakes. There is some data available, although it is not extensive, which provide a statistical basis for such estimates. It is estimated that, in the long term, there would be, on the average, 8.64 deaths and 139 hospitalized injuries per 100 years due to earthquakes in State-owned facilities as they presently exist. Special note is made, however, that strong earthquakes are infrequent events that may occur less often than every 100 or so years, and so we would expect to find that there will be long periods of time between such losses and possibly greater losses for a single strong earthquake.

- Similary, it is estimated that, in the long term, there would be, on the average, approximately $8.92 million (1979 dollars) property losses per 100 years to State-owned buildings. Again, these losses are not expected to be uniformly distributed over the years but, instead, will be concentrated coincident with just a few earthquake events.

- Earthquake risks to life and property can be reduced by one principal means within current technological capability -- by improved construction resistance to earthquake forces. The state-of-the-technology does not allow one either to predict earthquake events or to move their effects to some other location. Within such a constaint, the modification of existing buildings to better resist earthquake forces, or their replacement with earthquake-resistant structures, or abandonment of high-hazard buildings are the three available options. All are very costly. Hence, before any such action might be selected, one must evaluate the degree of risk and losses and compare these with the costs either of modification, repair, or abandonment. The final decision on what to do about the problem must be made by comparing benefits with costs for the chosen option.

- By benefit-cost methods, we have determined that neither modification nor replacement are economically reasonable for complete classes of buildings. In general, and disregarding any economic value that might be assigned to life, for every $1 spent on retrofit or replacement, less than 1¢ of benefit will ensue. Any arguments for retrofit or replacement of buildings therefore must be made on the merits of the value of life and prevention of injury. These are social and political problems.

- Analysis indicates that selective retrofit and a long-term program of selective replacement of buildings, even though not with especially favorable benefit-cost ratios, can be used to reduce earthquake risk for Utah seismic conditions. Such a program could reduce the number of estimated deaths and injuries per 100 years by as much as a factor of 4 and property losses by as much as 4 times. In this report, we have pointed out the direction for such retrofit and replacement programs, but we have not presented the details for these. Such will require additional study that is beyond the scope of the study reported herein.

SECTION 2

RECOMMENDATIONS FOR REDUCING SEISMIC HAZARDS IN STATE-OWNED BUILDINGS IN UTAH

The following recommendations result from a benefit-cost study of the possible impact of earthquakes upon existing State-owned buildings. The study, titled "Seismic Risk Assessment of State-Owned Buildings In Utah," provides information on the extent and nature of earthquake hazards in existing State-owned buildings and also guidance as to feasible remedies for identified problems. The following recommendations are based upon the findings of the study.

State-owned buildings vary considerably in use, from rest rooms and pavilions to employment offices; in construction systems, from multistory concrete structures to small wood-frame residences; and in type of occupancy, from road sheds for equipment and maintenance stations to dormitories, prison facilities, and coliseums with human occupancies. Over half of all State-owned structures lie in Utah's greatest seismic risk zone, and over 70% (112 of 152) of the moderate to high occupancy State-owned structures lie in the greatest risk zone.

The recommendations that follow reflect an attempt to balance both the seismic risk of existing State-owned structures resulting from their location, occupancy, and construction systems and the cost of remedying identified hazards. In spite of the fact that the majority of moderate to high occupancy State-owned buildings lie in the greatest seismic risk zone, an overall examination of State-owned buildings indicates that guidelines and standards are needed which take into consideration the wide variations in use (occupancy), construction types, and risk levels. It is evident from the study of State-owned facilities that no single standard is applicable for all conditions, and this argues against adopting just a single generalized State-wide hazards reduction program for State-owned buildings. Rather, several programs and actions are needed, each dealing with a particular class of high-risk situations, and each uniquely tailored to mitigate specific risks. Consideration of this has been given in the recommendations which are made, and consequently they are directed predominantly to those facilities serving more than just a few people.

The detailed study indicates that there are a number of seismically vulnerable State-owned buildings. Occupants in some of these buildings appear to be exposed to undesirably large seismic risk. It is the Seismic Safety Advisory Council's position that high-risk conditions in State buildings should be corrected where feasible. Not only does the State have a responsibility to ensure public safety in its own facilities, it also should provide leadership in implementing policies for seismic safety that it would encourage others to follow.

It should be noted that State-occupied buildings comprise two classes--those it directly owns and others that are rented or leased. While the recommendations which follow are concerned primarily with State-owned buildings, many apply equally to leased facilities and should be liberally so construed.

1. <u>It is recommended that there be complete compliance with current seismic standards as adopted by the State Building Board when new State facilities are constructed, when existing State facilities are remodeled, and when the State assumes title of existing property for public use</u>.

    This recommendation for compliance with seismic standards expresses general life safety and economic concerns for prudent investment of public funds, for reduction of potential property damage, and for safety of State employees and the general public users of State facilities. Such compliance for new, remodeled, and assumed-title facilities will operate to ensure that the inventory of seismically hazardous State-owned buildings will not grow larger.

2. <u>It is recommended that site inspection procedures be established and implemented by the State Building Board in order that the State may avoid building or buying buildings, other than those expected to be comparatively unoccupied, on geoseismically hazardous sites, such as in zones of deformation. Whenever a major new State facility is to be constructed, or whenever there is question about the hazards of a site, qualified site inspection should be made to determine if special fault-related or other geoseismic hazards exist and if discovered hazardous conditions can be mitigated</u>.

    This recommendation provides a general earthquake safety policy for future State buildings, especially office buildings and other high-occupancy facilities. While there is no evidence that past practices of the State have resulted in widespread use of hazardous sites; it has been determined that a few such situations exist. Thus, this recommendation is intended to ensure against inadvertent development on hazardous sites.

    Among State-owned buildings surveyed as a part of this study, only a fish hatchery is known to lie within a zone of faulting deformation. University facilities were not included within the scope of the study, and seismic hazards identified for the State Mental Hospital are discussed in another report on health-care facilities.

    Special note is made that several State buildings on Capitol Hill in Salt Lake City are sited near the Warm Springs fault.

However, the zone of deformation for this fault is not well defined in the vicinity of these buildings, and so although there are seismic hazards present in the vicinity, it is not known whether they are high-risk situations.

3. It is recommended that the State Building Board should supplement an existing comprehensive inventory of existing State-owned and State-occupied buildings to include construction information pertaining to their seismic safety, that preliminary evaluations of seismic vulnerability be made for those buildings having public or employee occupancies, and that specific recommendations be made for reducing hazards that may be present under moderate seismic loadings.

State Government has an apparent responsibility to provide at very least the same degree of earthquake safety in its own facilities as it may expect from local governments and the private sector. In some respects, this responsibility may, in fact, be more pronounced both in a legalistic and moralistic sense. This recommendation, that a preliminary seismic hazards assessment be made for State-owned and State-occupied buildings normally occupied by more than a few people and that severely hazardous conditions be corrected, is a necessary first step toward meeting such responsibility.

Available inventory information on State-owned facilities compiled by the State Building Board has been found to be insufficient for preparing definitive evaluations of seismic hazards that may be present. It is believed that the additional data needed to allow preliminary evaluations to be made can be obtained relatively easily. Overall enhancement of State awareness of its own seismic risk posture argues for adoption of this recommendation.

Because State-owned and State-occupied facilities encompass such a variety of uses, potential risk to life safety is the focus of this recommendation. Numerous other structures, including equipment sheds, warehouses, open pavilions, and other low-occupancy or no-occupancy facilities, are of lower priority even though the possibility of property losses due to earthquakes may be present.

4. It is recommended that plans be prepared and expeditiously implemented to remove evident seismic hazards from several selected State-owned buildings having high or special occupancy use.

Among the State-owned facilities having high or special occupancy use and showing evidence of high seismic risk are the

Utah State Training School, the State Mental Hospital, School for the Deaf, and the State Prison. Various features contribute to the high seismic risk for these buildings, including nearness to fault deformation zones, older construction with little lateral resistance, and relatively vulnerable occupancies due either to large capacities, handicaps, or movement constraints. Recommendations for the Utah State Training School and State Mental Hospital are contained in a separate report on health-care facilities.

Unusual liabilities exist at the State prison where occupants are confined and existing facilities show some evidence of structural distress, such as cracked walls and possible settlement. Also, it appears that some facilities are precast concrete construction systems which, in spite of likely reinforcement, tend to be more vulnerable to lateral forces than most other types of construction. As major construction developments occur at the prison facility in the future, these possible hazardous conditions should be examined and corrected as may be feasible.

High-occupancy structures at the School for the Deaf are very old and appear to be of unreinforced-masonry construction. Hazardous conditions, which likely are present, should be confirmed by the State Building Board, and plans should be made for their removal or for replacement facilities.

5. <u>It is recommended that any future plans to renovate facilities at the Utah State Fair should place special emphasis upon correcting existing known seismic-related structural deficiencies of high-occupancy public assembly buildings</u>.

Particular note is made of deficiencies which have been discussed and reported for the coliseum building at the State Fair Grounds. Seismic evaluations of selected buildings having relatively frequent public assembly use at the Fair Grounds have progressed far enough to expose some high-hazard conditions. Known structural defects in these public buildings pose special liabilities for the State in the event of seismically-induced failures, and so should be corrected as expeditiously as possible.

6. <u>It is recommended that seismic safety should be considered for all State-owned buildings designated as or intended to be designated as "historic buildings" which are open for public use, and that high seismically hazardous conditions be corrected for such buildings or restrictions placed upon their public use</u>.

Although buildings of historic significance often fail to meet current construction standards and special allowance is made for such deficiencies in the preservation of these buildings, public safety must not be completely disregarded in doing so. There is a definite possibility that seismic risk may be undesirably high for those historic buildings of masonry construction. Such situations require analysis and, possibly, limits upon their occupancy unless the unsafe conditions are corrected in any remodeling that may be done for extending the life and use of the buildings.

SECTION 3

DISCUSSION OF FINDINGS RESULTING FROM A STUDY OF SEISMIC HAZARDS IN EXISTING STATE-OWNED BUILDINGS IN UTAH

SCOPE

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

In this study, earthquake safety aspects of existing buildings owned by the State of Utah are examined. Data on existing buildings 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 earthquake safety of State-owned buildings, information has been drawn from several disciplines and from numerous sources. The comparative seismicities of various regions of Utah have been estimated. State-owned buildings of various types and uses have been identified, and their locations and construction systems recorded. Given data on locations, construction systems, and seismicity, techniques were developed to estimate property losses. Given additional data and assumptions on occupancy rates, life and casualty losses owing to seismicity have been estimated. Valuation data on buildings also were obtained so that estimated money losses caused by earthquake events could be made.

There are many ways to reduce earthquake hazards associated with existing buildings. For instance, employees in the buildings can be informed as to what to do when an earthquake occurs. Appropriate actions at the time of an earthquake may reduce life and casualty losses but will not alter property losses. For a second instance, and to reduce life and casualty losses, especially vulnerable buildings may be converted to low-occupancy uses. For another instance, inspectors and others directly concerned with State-owned buildings can be trained to identify existing seismic hazards, such as unsupported parapets, cornices, unsecured overhead lights, or unfastened bookshelves, and these hazards can be eliminated following orderly systematic procedures. For yet another instance, major structural deficiencies for seismic resistance can be identified through more exhaustive analysis of individual structures, and required modifications to correct deficiencies can be undertaken independently or along with other modifications that are frequently made. Still another way is to replace the most hazardous buildings with new ones that have greater seismic resistance.

All but the first way suggested can reduce life and casualty losses as well as property damage. The merits of any or all of these possible methods of risk reduction cannot be assessed apart from economic considerations. Ultimately, trade-offs between mitigation costs and acceptable risk must be made. Such trade-offs are the basis of recommendations for risk reduction made in this report for existing State-owned buildings in Utah.

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.

The study concentrates upon general aggregate building and life and injury losses due to earthquake-induced ground motions, from which general benefit-cost conclusions regarding State policy are derived or suggested. A full examination of the methodology and assumptions is contained in Section 8 of this report.

In any evaluation of earthquake hazards, there are three primary seismicity considerations -- (1) the maximum credible earthquake that is expected in any region; (2) the general and likely frequency of earthquakes of all strengths in the region; and (3) the probable distribution of these earthquakes. From an engineering perspective involving building vulnerability to earthquakes, other parameters of seismicity also are used, e.g., duration of the shaking, frequency of the vibrations, depth of the earthquake mechanism, and characteristics of the overlaying rock and soil that affect wave propogation. Although we have considered these other parameters in the detailed analyses presented in this report, we shall here comment only upon the primary seismicity considerations.

A simplified view of earthquake activity is that for every event of 7 Richter magnitude strength, there will be about 10 earthquakes of Richter magnitude 6, 100 of magnitude 5, and so on. Although this is merely a very rough approximation, the numbers help to point out that moderate to strong earthquakes, because of their greater frequency of occurrence, may imply just as much risk as the single strong events.

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 the most 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 Effects Upon Buildings

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.

The relationship that a building location may have relative to an earthquake fault also must be considered. Faults, by definition, are fractures of the earth. We tend to think of them as surface ruptures, but, in fact, they also may not be visible, either because of their depth or because surface elements have eroded the signs of the fracture. Fault-related hazards to buildings are localized problems, in contrast to area-wide ground shaking. From a structural safety standpoint, a building is either on a fault zone of deformation, or it is not. If it is within a zone of deformation, then little can be done if the supporting ground under the building should move. Such buildings very likely will be damaged, perhaps seriously. If the building is not within a zone of deformation, then faults do not represent an earthquake hazard to the building. However, since a fault is a manifestation that earthquakes have occurred in the geologically recent past, the presence of a fault near a building site is an indicator that earthquake motions are likely to occur in the future along the same fracture.

Zones of deformation along the Wasatch fault in Utah are known approximately but have not been completely mapped. We therefore can only approximate such zones at this time. Still, zones of deformation typically are relatively narrow (on the order of a few hundred feet or less); whereas ground vibrations may spread over hundreds of square miles. For this reason, evaluations of earthquake risk to buildings focus most heavily upon the ground vibration aspect.

Ground vibration is attenuated as the distance from the earthquake epicenter is increased. Offsetting this, however, is a tendency for some soils (mostly unconsolidated alluvial deposits) to amplify some of the motions. Accurate modeling of these effects becomes extremely complicated. In this study, we have taken these effects into account, although in a less rigorous mathematical manner.

State-Owned Buildings In General

In this report, earthquake risk assessments of State-owned buildings have considered the use (occupancy) as well as construction characteristics of the buildings. This is because the exposure of occupants varies so widely. Warehouses and storage sheds essentially are unoccupied, whereas other buildings used as offices and for conducting public affairs are occupied in various densities. Thus, while property losses must be considered for all sorts of buildings, only those that are occupied present any significant threat to life safety. Accordingly, the reader will find in the report statistical data on both aspects for State-owned buildings. The property loss, life loss and injury estimates furnished are drawn from appropriate sets of data.

On the assumption that property losses caused by earthquakes may be an important consideration in the development of hazards reduction policies, along with life loss and casualty estimates, both sorts of estimates are furnished and used in the report. Tabulated data are separately summarized and discussed in accordance with their significance for property loss or life safety estimates.

Two hundred sixty seven buildings were included in the surveys for this study. About 293 State-owned buildings were included in a survey of public buildings in Utah by Einar Johnson of the State Building Board which was used as the data base for this study. Fourteen buildings in the survey by E. Johnson were omitted in this study either because no information was available on their construction systems or because the buildings were low-occupancy structures. Another 12 structures omitted in this study were special historical structures or visitors centers that would require more detailed examination and for which special comments are in order. No high-occupancy structures that might affect significantly the results presented here were among the 26 structures omitted.

The 267 buildings include almost every imaginable type of construction, age of construction, size, and height. No pronounced patterns are observable among any of these descriptors that have significance for earthquake safety planning.

Given the wide range of State-owned building uses, types, and sizes, little attention is given in the report to aggregate evaluations or conclusions. Instead, data on classes of buildings, organized in terms of uses, types, and sizes, are assembled, and conclusions are derived from these classes and subclasses. However, taken comparatively, the data provide information that suggests which classes of buildings contribute greater life safety and property loss risks than others. From such information, priorities of earthquake safety efforts may be set.

Additional insight regarding the vulnerability of State-owned buildings may be gained from a general overview of construction practices in Utah in the past. Although many State-owned buildings are exceptions to these traditional construction practices, such information nonetheless is helpful.

Buildings 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 State-owned buildings 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 buildings meet the seismic standards of their era. With a few exceptions, it is fair to conclude that few existing State-owned buildings have deliberately designed seismic lateral-force resistance, and few of the buildings have been analyzed rigorously to determine their vulnerability. Notable exceptions are the earthquake vulnerability studies that have been made for the State Fair buildings and those buildings housing the State schools for the deaf and blind. Those studies reveal specific and serious hazardous conditions for a handful of buildings.

Of the surveyed State-owned buildings, 56.5 percent are located within the zone of greatest seismicity. Of the total gross floor area for State-owned buildings, 90.8 percent are within the zone of greatest seismicity. Most of this space has moderate to high occupancy use. Moreover, much of it is located near the Wasatch fault zone and so can be expected to experience whatever strength of earthquake the Wasatch fault might someday produce.

Alternatives for Hazards Reduction

Three broad alternatives were selected for evaluation in this study.

(1) The existing structures are fully replaced by those that are earthquake resistant.

(2) The structures are fully retrofitted to be less vulnerable to earthquake effects.

(3) The structures are left as they are.

In general, the facilities were treated as classes of buildings rather than on an individual basis.

From an economic analysis of these three alternatives, one can derive general conclusions about what major actions or programs may be needed so that State-owned buildings will 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 State employees and the general public for an earthquake. Analysis of selective remodeling options requires separate detailed analysis of each facility, a task that is outside the scope of this study. As previously noted, preparedness information on what to do in the event of an earthquake provides no verifiable data regarding reductions in life losses or injuries and yields no reductions in property losses.

In spite of the limitations of this study that are mentioned earlier and that are discussed in greater detail in later sections, the comparative economic merits of the three alternatives for the 267 State-owned buildings are clear. The gains achievable through reduction of seismic losses by replacement or retrofit methods are far less than the costs in terms of capital outlays for achieving such gains. That is, on the aggregate level, no economic case can be made to justify either replacing or retrofitting existing State-owned buildings in order to make them seismically safer. Considerations of life safety and importance of the facility to State government operations must be added to the economic arguments if any justification is to be found for seismic hazards reduction.

Life Safety and Property Loss Estimates for State-Owned Buildings

For the State as a whole, results are illustrated by the following estimates. The first is expected dollar losses due to earthquake-induced ground motions; the second is expected nonfunctionality in percent that might be caused by building damage. Clarification of these estimates is found both in the discussion to follow and in Section 8 on methodology and assumptions applied in this study. The primary use of estimates of structural failures (a building is held to be nonfunctional if there is a 50 percent structural loss) is to determine overall vulnerability of various classes of State buildings and to assess distribution of the expected property losses both geographically and by class for earthquakes of different strengths.

Estimated replacement cost of the 267 State-owned buildings surveyed:

$150,000,000 (1979 dollars).

Estimated cost of fully retrofitting surveyed structures to meet current seismic safety standards:

$18,000,000 (1979 dollars).

Estimated annual average earthquake losses to surveyed buildings if they are left as they are:

$90,000 (1979 dollars).

Estimated annual average earthquake losses to surveyed buildings if they are replaced by structures that meet current seismic safety standards.

$20,000 (1979 dollars).

Estimated annual average earthquake losses to surveyed buildings if they are fully retrofitted to meet current seismic safety standards.

$47,000 (1979 dollars).

Estimated annual average of deaths if surveyed buildings are left unmodified:

0.09

Estimated annual average of deaths if surveyed buildings are extensively modified to correct seismic safety deficiencies:

0.02

Estimated annual average of injuries if surveyed buildings are left unmodified:

1.39

Estimated annual average of injuries if surveyed buildings are extensively modified to correct seismic safety deficiencies:

0.33

Earthquake hazards to building 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 State-owned buildings 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 10 deaths and less than 150 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 State-owned buildings 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 State-owned buildings 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 facility.

Benefit/Cost Conclusions

Even though replacement or retrofitting can reduce seismic hazards both to life and to property, the costs of such reductions far exceed the benefits from such reductions.

In economic terms, where one is forced to set a dollar value on life, for every $1.00 spent on replacement, about 1¢ of benefit would ensue. For every $1.00 spent on retrofitting, about 6¢ of benefit would ensue. If one imagines the worst sort of structure with the highest occupancy rate (about one employee per 60 square feet during main business hours) and in the worst earthquake zone, one still finds only 13¢ of benefit for each $1.00 spent on retrofitting.

In other terms, one would need to estimate the value of prolonging life at over $200 million dollars in order to justify, in cost terms, a Statewide program to replace seismically unsafe buildings owned by the State. We conclude, then, that programs involving expenditures of less than $200 million for each life saved are economically superior to a Statewide building replacement program for earthquake safety. Using a similar analysis in order to justify retrofitting of hazardous buildings, one would need to set the value of life at about $25 million dollars. For the worst sort of structure, the value of life would still need to be set about $9 million dollars in order to justify retrofitting.

It may turn out, in retrospect, that an earthquake causes losses to several particular structures which exceed losses that would have occurred had all the structures been fully retrofitted or replaced. This is one limitation of probabilistic type studies. Unfortunately, geological and geophysical studies have not advanced to the point where one can be fairly well assured which site locations are going to suffer damage within a short geologic time-frame, although individual building safety can be predicted if an earthquake of known strength is assumed to act on that structure. So, it cannot be predicted which, if any, structures should have been replaced in any particular seismic zone. However, it is expected that direct examination of selected State-owned buildings and improvements in seismic predictions may lead to a later conclusion that a few specific buildings need large-scale construction modifications for seismic resistance. On the aggregate level, even the worst State-owned buildings do not pose sufficient seismic safety hazards to justify, in economic terms, large-scale replacements or retrofitting operations. Those buildings in the worst class may warrant inspection or replacement for other reasons, but they are too few in number to justify any further broad benefit-cost analysis of State-owned buildings in order to evaluate the merits of large-scale seismic reconstruction programs to overcome seismic safety deficiencies. It has been concluded that a Statewide replacement or retrofit program is unnecessary for this general class of buildings. At the same time, it has been concluded that some seismic safety problems are present that should be given individual attention. The individual situations are identified in the section on recommendations.

Even though seismically sounder State-owned structures 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 structures unmodified, 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 for entire classes of buildings. The costs of preventing death and injury are much less if seismic requirements are met in the initial construction phases.

There are less costly ways to reduce losses to life, injuries, and property losses that earthquakes might cause than by extensive Statewide programs aimed at all buildings in the general class. Yet, any such alternatives necessarily add another element of uncertainty that is additional to the uncertainty of earthquake events. One alternative is selective replacement or retrofit of those buildings most vulnerable to earthquake effects. The uncertainty results from technical limitations and our inability to always correctly evaluate the seismic resistances of structures. Notwithstanding this particular problem, technical capability to identify the most hazardous building conditions generally is good, and so selective replacement or retrofit programs can be demonstrated to be superior in benefit-cost terms and certainly are more feasible economically.

Analysis of Utah's earthquake history and earthquake environment clearly indicates that hazards to life safety and property are present. Further analysis of the expected response of certain State-owned buildings to earthquakes indicates the presence of risks that may be unacceptable either to the people of Utah or to State government which, as owner of these buildings, carries a degree of liability.

In Sections 4 and 5, the chief factors for assessing earthquake risk are examined in connection with State-owned structures. Location, construction systems, construction costs, and occupancy rates are examined to show how each contributes to the overall conclusions in this report.

SECTION 4

LOCATION OF STATE-OWNED BUILDINGS IN RELATION TO EARTHQUAKE ACTIVITY IN UTAH

Two typical ways to assess earthquake risk for a given situation are, first, to examine the consequences of a postulated worst-case earthquake and, second, to examine the historical record of past earthquakes and their long-term damage effects.

In a report on earthquake losses in the Salt Lake City area prepared by the U.S. Geological Survey, the first approach is taken (Cf. [1], p. 58). Such an approach allows one to estimate the difficulties that could occur as a result of a large earthquake. The hazards posed by a damaging earthquake depend upon many factors, such as how many people are occupying the various buildings at the time and where the epicenter of the earthquake happens to be. If preparations are made for a comparatively worst case, such as when the epicentral location of a large earthquake is in Salt Lake City, then, presumably, preparations also have been made for all earthquakes that would cause less damage.

However, since such a postulated large earthquake may occur very infrequently, an overall assessment of the earthquake risk in a given area also requires that one estimate the frequency and severity of the entire range of earthquakes, both large and small, in the area.

The primary source for the overall earthquake activity in Utah is the historical record.

In a report by S.T. Algermissen and D.M. Perkins, the United States is divided into 71 seismic source areas based on expected seismicity in each area ([2], pp. 17, 18). Expected earthquake rates in the report are based chiefly on historical records of occurrences.

Utah is one of the most seismically active states. According to the report, only a few areas of the United States have higher expected earthquake rates than does Utah.

Utah has four major seismic source areas and one non-active area, according to the Algermissen and Perkins report. Three specific source areas are of special interest, 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. 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 zones in the continental United States (Algermissen and Perkins data) in terms of expected number of Modified Mercalli Intensity V earthquakes per 100 years[1], and ties for nineteenth in terms of its expected maximum Mercalli intensity. Zones that exceed Utah's seismicity levels lie predominantly in California, Nevada, and Montana, although expected maximum magnitudes are equal in the St. Louis area and in South Carolina.

In another study of the historical record 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 ([4], 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. [1], pp. 9-20). So, the historical record indicates considerable seismic activity in Utah.

Even though the historical record provides important data for assessing the earthquake environment in Utah, the use of the historical record alone has several shortcomings. One shortcoming is that future epicenters are not likely to occur exactly where past epicenters have occurred, so that a simulation of the past record alone does not predict future hazards. Another is that the historical record, which in geologic time reference is very short, may be misrepresentative of the much longer geological record.

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 map 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 zones 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

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[1]For a partial explanation of the Modified Mercalli Intensity Scale, see Appendix A.

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

As is explained in Section 8 on methodology, seismicity rates for the zones in Utah have been developed on the assumption that, except for major earthquakes on the Wasatch fault, earthquakes of lesser intensity may have their epicenter anywhere within the given zone.

Location of State-owned structures relative to these zones of varying seismicity provides one measure of their vulnerability. In general, only those facilities in Zones U-4, U-3, and U-2 deserve special attention for seismic hazards, since seismicity rates are very low in Zone U-1 and are assumed to be negligible in portions of the State Zoned U-0.

Figure 7, which shows the distribution of moderate to high occupancy State-owned structures, indicates that the vast majority of such structures lie in the State's worst seismic zone. For the various classes of State-owned structures surveyed, Table 1 indicates their distribution in the seismic zones.

As Table 1 indicates, approximately 56 percent of the State-owned structures lie predominantly or exclusively in the worst seismic zone, the other 44 percent are spread through the less severe seismic zones. Nearly all of the most hazardous State-owned structures in terms of type and size of occupancy are located in the worst seismic zone.

Number of buildings often is a poor indicator of the amount of construction when the size of the buildings may vary widely, such as a multistory office building that has many thousands of square feet of floor area in contrast with a storage shed that may have just a few hundred square feet. Although each of these would be counted as one building, they are not comparable for analyses that derive conclusions from such factors as construction costs and occupancies. Consideration of number of buildings alone is especially misleading for the entire class of State-owned buildings; since there are wide ranges of floor areas, occupancies, and even types of uses. Table 2 thus attempts to provide a broader perspective of the true nature of State-owned buildings. In the table, gross floor areas of buildings are shown by type of building (use) and by seismic zone location in the State. From this table, it is seen that an even larger percentage of real State-owned construction (90%) lies within Zone U-4 than is suggested by the percentage of buildings (56%) in the zone. Further, almost 60 percent of the space in Zone U-4 is office space. So, the amount of State-owned building space occupied by people is, in the vast majority, in Utah's worst seismic zone.

Estimates of earthquake recurrence rates, explained in greater detail in the section on methodology, provide another important factor in assessing long-term earthquake risks. Such estimates depend heavily both upon geological and historical studies, some of which are yielding new results. According to current seismological research, Utah's earthquake environment is less severe than in many parts of California but is more severe than in most of the rest of the United States.

Information about recurrence rates is useful for estimating degrees of damage to structures, which is the major cause of deaths and injuries, and for evaluating the relative risks of multiple earthquakes of moderate size that occur more frequently in comparison with more devastating large earthquakes that are infrequent. For example, one may wish to know if the property losses that might be caused by earthquakes of Richter magnitude 6 every ten or so years are greater or less in the long run than the more severe losses that might be caused by a large earthquake of Richter magnitude 7 every 475 or so years. Since it is far more costly to provide building resistance to earthquakes of Richter magnitude 7 than for Richter magnitude 6, such information is valuable in evaluating the relative merits of one course of action over the other, at least in cost terms.

As the detailed discussion of this issue shows in Section 8, replacement and major retrofit programs for existing buildings to improve their seismic safety cannot be justified in general for Utah's earthquake environment. The low probability of large earthquakes and the high costs for replacement or retrofit cannot be balanced in benefit-cost terms. However, selective retrofit and replacement programs can reduce life safety risks in certain cases and at reasonable cost. Although the use of seismicity recurrence rates limits the conclusions of this study to aggregate groups of buildings in the various classes, some especially hazardous structures were identified during the analysis which appear to merit more detailed investigation and, possibly, replacement. These are high-occupancy facilities for special populations (handicapped and confined) that are operated by the State. All are in the worst seismic zone.

Further geological investigations are needed in order to provide a more comprehensive site-specific account of the seismic vulnerability of State-owned facilities upon which to base any specific replacement and retrofit programs. As noted previously, site-specific evaluations were not prepared for this study, so the results presented in this report should be used only as indications of risk, not as conclusive evidence.

SECTION 5

CLASSIFICATION OF STATE-OWNED BUILDINGS IN ACCORDANCE WITH THEIR COMPARATIVE SEISMIC RESISTANCES

Another major factor in assessing the vulnerability of a facility to earthquakes is the type of construction of the structure. Given such information and the distribution of earthquake activity, it is possible to estimate the comparative earthquake resistance of structures.

There are two methods used in this report to assess the earthquake resistance of particular types of structures. Both methods are discussed in detail in the section on methology.

The first method derives from a classification scheme used by S.T. Algermissen and K.V. Steinbrugge in their studies of earthquake losses in California (Cf. [6], p. 3). Algermissen and Steinbrugge developed their classifications from observed damaged and undamaged structures resulting from several earthquakes. They observed that the type of construction, particularly the structural system of a building, greatly influences the amount of damage that will be sustained, and they have correlated these observations with various earthquake strengths.

The classification includes five basic structural types that are commonly found, with subclasses to differentiate the quality of the construction and other unique characteristics. The five main classes are:

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

(2) All-metal buildings.

(3) Steel-frame buildings.

(4) Concrete buildings.

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

The five main classes are further subdivided into subclasses in accordance with particular characteristics or features that give different vulnerabilities to earthquake forces. The entire classification is given in Appendix B.

Of the five main classes, the first two classes contain the safest buildings in terms of their earthquake resistance, even when such buildings are comparatively old. In the third class, two subclasses are of special interest.

(3B) Steel-frame buildings with ordinary damage-control features.

(3D) Steel-frame buildings with floors and roofs not concrete.

Due to unique structural characteristics, such buildings are more earthquake resistant than most other framed structures and especially are superior to bearing-wall systems.

In the fourth class, a subclass of special interest is:

(4D) Precast reinforced-concrete buildings and lift-slab structures.

Structures of these types are especially vulnerable to seismically-induced lateral forces unless special precautions are taken in connection details.

In the fifth class, a subclass of special interest is:

(5E) Buildings having unreinforced solid-unit masonry of unreinforced brick, unreinforced concrete brick, or unreinforced stone, or buildings of unreinforced concrete, where the loads are carried in whole or in part by the walls and partitions.

Structures of these construction types seem to be the least resistve to earthquake forces, and considerable damage often is observed due even to small and moderate earthquakes. Damage can range from minor to serious cracking of walls, which may cause large economic losses, and from partial to total building collapse, which endangers life safety as well as causes property losses.

Generally speaking, steel-frame and wood-frame buildings are safer than are older concrete or masonry structures subjected to earthquake forces.

The other building classification scheme is derived from work of the H.C. Hughes Company, structural engineering consultants that prepared the USGS report on earthquake losses in the Salt Lake City area [6]. The Hughes classification consists of seven main classes of buildings in order of their comparative seismic resistances. Roughly speaking, the seven classes are as follows:

(1) Small frame and metal buildings; and small specially designed structures with reinforced-concrete bearing walls.

(2) Large frame and metal buildings; large low-rise reinforced-concrete or steel-frame structures with reinforced-masonry or concrete shear walls, and built after 1970; and small specially designed structures with reinforced-masonry bearing walls.

(3) Large low-rise reinforced-concrete or reinforced-masonry structures built in the 1970's; and multistory reinforced-concrete or steel-frame structures, with reinforced-concrete or reinforced-masonry shear walls, built in the 1970's.

(4) Multistory high-rise steel-frame structures built in the 1970's; multistory masonry bearing-wall structures built in the 1970's; large reinforced-concrete or reinforced-masonry structures built in the 1960's; and multistory reinforced-concrete or steel-frame structures, with reinforced-concrete or reinforced-masonry shear walls or bracing, built before 1970.

(5) Large reinforced-concrete or steel or reinforced-masonry buildings using precast elements on walls or floors and roof, and built after 1970; large reinforced-concrete or steel or reinforced-masonry structures built prior to 1961; and multistory steel-frame or masonry bearing-wall structures built between 1961-1970.

(6) Multistory reinforced-concrete structures built after 1970 and with lift-slab construction; multistory masonry bearing-wall structures built before 1961; and small structures with unreinforced-masonry bearing walls, and wood floors and roof.

(7) Large multistory structures with unreinforced-masonry bearing walls, and wood floors and roof; precast-concrete frame or wall structures built prior to 1970; and any category with apparent structural design weakness.

The significance of the dates in the foregoing classification scheme depends upon the presumption that the structure was built in accordance with the Uniform Building Code in effect at the time, unless site inspection or other data indicate otherwise. On such an assumption, structures built before 1961 are designed only for gravity loads and wind forces, those built from 1961 to 1970 are designed for earthquake forces in accordance with UBC seismic zone 2[2] provisions or less, and those built in the 1970's are designed in accordance with the more recent UBC seismic provisions and zone map (see Figure 2) (Cf. [1], p. 91).

Site inspection may, in particular cases, override these general assumptions, as is evidenced by the inspections made on facilities at the Utah State Training School, where some of the more recent structures were rated as being below code standards (Cf. [7], especially for Wing A and Seizure Control).

An examination of both building classification schemes also leads to the conclusion that their use requires judgement and some guesswork. Users of the first classification scheme must employ the notions of ordinary, intermediate, and superior damage control features for earthquake resistance, and these are not readily apparent in most structures. The second classification scheme contains some 13 structural characteristics which, if the scheme were complete, would lead to a matrix containing at least 2^{13} separate categories. Practically speaking, such a large number of classes would be both unmanageable, and it would be nearly impossible to classify buildings correctly. For this report, then, the classifiction schemes are used basically to grade given structures on their comparative seismic vulnerability, and it is accepted that some error of classification may occur in a few cases. Also, the incompleteness of the categories leads to possibly alternative classifications of given structures, even though the user has a general notion of what features make a structure more or less vulnerable to earthquake effects.

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[2]Zone 2 is 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 been changed since then for the Wasatch Front.

Both building classification schemes have been utilized in this study, but for different reasons. The Algermissen and Steinbrugge classification scheme was used for the purpose of estimating property losses caused by a range of earthquake intensities and for a variety of construction types. There is no comparable information from which to make similar estimates using other available building classifications. The Hughes classification scheme, as used in the USGS study of earthquake losses in the Salt Lake City area, was the basis for estimating life losses and injuries due to building failures. Again, no comparable information from which to make similar estimates is available that would permit use of some other building classification scheme. Thus, in order to utilize available research data and to avoid additional research, we have utilized portions of both classification methods to separately derive property loss and life safety estimates. Tables 3 and 4 indicate the distribution of State-owned buildings in accordance with the classification systems described above, each by seismic zone.

SECTION 6

ESTIMATED EARTHQUAKE LOSSES TO STATE-OWNED BUILDINGS

Using data on the location of various structures and on their structural types, one can estimate long-term losses for classes of buildings according to construction type and use due to ground-shaking. Since there are two classification schemes for structural types, two separate estimates can be made for any given facility. The first estimate, based upon Algermissen and Steinbrugge taxonomy, is used to determine expected dollar loss. The second estimate, based on the USGS taxonomy, provides information on expected number of structural failures that is used to estimate life loss and injuries. Failure is defined here as occurring when loss due to damage exceeds 50 percent of replacement cost and is an indication of extent of damage from which casualty estimates may be made.

Details of specific calculations for estimates are made available in Section 8 on methodology. Those structures in Zone U-4 have the greatest estimated structural losses, and structures of unreinforced-masonry construction have higher expected losses than those of any other class. For one set of estimates, the average 100-year expected dollar loss to buildings in class 5E, (unreinforced-masonry construction) exceeds 9% of the replacement cost. For the other set of estimates, one can expect almost 29% of the structures in class 7 (multistory buildings with unreinforcd-masonry bearing-wall construction) in Zone U-4 to suffer from structural nonfunctionality over a century.

If one takes all five classes and their subclasses as defined by Algermissen and Steinbrugge and compares the expected loss in each category and zone against that subclass having the maximum expected loss, which occurs in category 5E and in Zone U-4, one derives the comparative expected dollar losses to State-owned buildings as shown in Table 5. The numbers given are comparative against a base of 100 and so also may be viewed as comparative percentages -- that is, for each $100 loss to Class 5E structures in Zone U-4, there would be, comparatively speaking, just $20 loss to Class 4E structures in Zone U-3, or 20 percent of the base line loss.

Several conclusions can be drawn from Table 5 that are confirmed by other means as well. In the first place, the expected loss to structures in Zone U-1 is very small in comparison to the expected loss in the other three zones. Losses to structures in Zone U-1 add little to expected total ground-shaking losses in the State. In the second place, the average expected loss to a structure in Zone U-3 is less than one-third of what it would be if it were in Zone U-4, and the expected average loss to a structure in Zone U-2 is about one-sixth of what it would be if it were in Zone U-4. For purposes of comparison, then, the approximate ratios of one-third and one-sixth give one a rough idea of how the zones differ in seismicity. As a result, some steel-frame structures in Zone U-4 have higher expected losses than any type of structure in any other seismic zone. In the third place, wood-frame and metal-frame structures can be expected to fare considerably better than other structures, and steel-frame structures, except for those in the worst subcategories, are also comparatively safe.

A similar table can be constructed on the basis of the Hughes taxonomy. Table 6 shows the results abbreviated to Zone U-4.

The Hughes taxonomy, to repeat, is gradated in terms of comparative seismic resistance.

Tables 5 and 6, based on comparative estimates, indicate which types of structures are most preferable in a given seismic zone and also, by implication, how the zones compare in seismicity. Tables 5 and 6 do not, though, directly indicate which specific structures are either most economically replaced or retrofitted. Only classes of structures are treated.

In order to consider comparative suitability for replacement, one must take into account the seismic zone and type of structure that serves as the replacement. If all structures could be moved from a zone of high seismic risk to one of lower or no risk, then, of course, tables 5 and 6 would indicate that nearly all expected losses or structural failures due to earthquakes could be eliminated. Since such relocation is not practical, it is here assumed that the hypothetical replacement structure remains within the same earthquake zone as the original structure. Consequently, earthquake losses or structural losses can only be minimized within the zone rather than eliminated altogether. As regards the Algermissen and Steinbrugge taxonomy, it is here assumed that a building of Class 5 will be replaced by the most earthquake-resistant building of Class 5, that a building in Class 4 will be replaced by the most earthquake-resistant building in Class 4, and so on. Hence, the most earthquake-resistant structures in a given class are not considered as being suitable for replacement.

Given such assumptions, one can define the preventable loss to a given structure by replacement as the difference between its expected loss and the expected loss to the most earthquake-resistant structure in its class. It turns out that the maximum preventable loss through replacement is for buildings in Class 5E in Zone U-4, and amounts to 8 percent of the replacement cost of the structure over 100 years. Using the maximum preventable loss as the standard, one can compare the loss reduction benefits of replacing various structures in various seismic zones. If, further, one uses the ratio of one-third for Zone U-3 and one-sixth for Zone U-2, one can abbreviate the comparisons to a table for Zone U-4. Table 7 gives such an abbreviation.

From Table 7, one can identify those structures that would be most worth replacing in terms of structural losses. For example, it would be more beneficial to replace some steel-frame structures (Classes 3B and 3D) in Zone U-4 than any structures in the other seismic zones (the maximum for any other zone is 1/3 times 100, or 33). Using the ratios of one-third and one-sixth, one can conclude that it would be more beneficial to replace even Class 5D structures in Zone U-4 than any structures in Zone U-2 (the maximum for Zone U-2 is 1/6 times 100, or approximately 17).

A similar abbreviated table can be constructed based on the Hughes taxonomy, on the assumption that any replaced structure remains within its seismic zone and turns out to be at least a Class 2 structure. On such assumptions, the standard for replacement consists of Class 7 structures in Zone U-4, which would have expected reduced cases of nonfunctionality of about 25 percent of the replacement cost over 100 years. Table 8 gives such data, again only for seismic Zone U-4. Ratios of one-sixth for Zone U-2 and one-third for Zone U-3 can be applied here also for comparsions.

Table 8 implies that replacement of even the worst sort of structures in Zone U-3 would barely have more expected seismic safety benefits than replacement of Class 4 structures in Zone U-4. Once again, seismicity of the location is a dominant factor in evaluating the benefits of replacement.

Suitability for being retrofitted, though, produces a different set of rankings than does suitability for being replaced, because certain types of buildings can be retrofitted much more cheaply than others. So, the preventable loss per dollar spent on retrofitting also will depend upon how many dollars need to be spent to retrofit a given type of structure.

Based upon assumptions clarified in the section on methodology, masonry structures were considered to be retrofitted at a cost of 22 percent of the replacement value of the building, concrete structures at 13 percent of the replacement value of the building, and steel-frame structures at 9 percent of the replacement value of the building. The comparative ease of retrofitting steel-frame structures, as implied by the lower cost, means that, if the benefits of such retrofitting were equal with the benefits of retrofitting other sorts of structures, then the value of such retrofitting per dollar spent would be greater for steel-frame structures.

In order to estimate the benefits of retrofitting various buildings, the following assumptions are made in terms of what can be achieved through retrofitting.

-- Class 5E multistory (3 or more story) structures can be converted into Class 5C (equivalent) structures.

-- Other Class 5E, and all Class 5D and 5C structures can be converted into Class 5B structures.

-- Class 4 structures can be converted into Class 4C structures.

-- Class 3B and 3D structures can be converted into Class 3C structures.

Such assumptions, based partly upon the fact that the taxonomy used can be regarded as being gradated and upon the view that less can be done to multistory masonry structures, imply that only selected structures are considered as being suitable for retrofitting. Just as retrofitting structures in Zone U-1 would yield few returns, retrofitting wood-frame or metal-frame structures also would produce few benefits.

A similar set of assumptions is made in terms of the Hughes taxonomy.

-- Masonry structures can be converted into Class 3 structures.

-- Steel-frame and concrete structures can be converted into Class 2 structures.

Such assumptions result in another set of priorities as to which sorts of facilities should be examined first for the purposes of being retrofitted. If one lets retrofitting of Class 5E buildings in Zone U-4 be the standard for retrofitting, so that one can compare structures by class and zone for preventable loss per dollar spent, than one develops the abbreviated data for Zone U-4 shown in Table 9.

Here also, Zones U-3 and U-2 can be estimated by means of the ratios of one-third and one-sixth, respectively. Table 9 suggests that, in some cases, retrofitting steel-frame structures may have almost as much benefit per cost as retrofitting masonry structures.

The information contained in Table 8 is further developed in Table 10 to give information about comparative structural failures, based upon the Hughes classifications.

Table 10 indicates that, given different price estimates to retrofit different types of structures, the most seismically vulnerable steel and concrete structures can be retrofitted with more expected benefits per dollar spent than can masonry structures. Steel-frame structures, it is true, are comparatively safe from collapse when subjected to earthquake forces. In the 1906 San Francisco earthquake, none of the 17 high-rise steel-frame structures collapsed ([1] p. 86). Yet, hazards may exist even where structures are fairly safe from collapse, such as may be caused by falling ceilings, fixtures, etc., and Tables 9 and 10 take into account the comparative safety of steel-frame structures as well as the comparative ease with which they can be upgraded.

Since the type of construction is such a dominant factor in both a building's earthquake resistance and also in the retrofitting cost, and since some buildings do not pose *significant* life-safety hazards (e.g. rest rooms, garages, and storage sheds), a means is needed for separating buildings of concern from buildings that can be omitted from the risk analysis. Table 11 indicates such separation by building type and by construction class for State-owned buildings. Although even this refinement does not always provide sufficient separation in making the risk analysis (e.g. not all buildings at the State Prison have large occupancies), Table 11 does allow one to consider different occupancy conditions as a factor in deciding where the most hazardous conditions are and which buildings have the most favorable property loss prevention benefit-cost ratios for replacement or retrofit.

In like manner, Table 12 provides additional information that is used to determine the best life-safety benefit-cost ratios.

Hence, ranking of buildings for retrofitting is not identical with ranking of buildings for replacement, since cost estimates for retrofitting vary with the severity of the problems faced in retrofitting. However one may choose to evaluate the information presented in Tables 5 through 10, the highest priorities for either retrofitting or for replacement are for the vulnerable buildings in Zone U-4.

SECTION 7

ESTIMATED LIFE AND CASUALTY LOSSES TO OCCUPANTS OF STATE-OWNED BUILDINGS AS A RESULT OF EARTHQUAKES

Even though deaths and injuries in earthquakes are due generally to structural failures, an account of structural failures alone does not yield a benefit-cost analysis. As explained in Section 8 on methodology, if no human losses were considered in this study, then it would be less expensive overall to allow an earthquake to topple a building rather than to replace the building now with one that is earthquake resistant. In general, it is only worthwhile to replace buildings to protect the human functions that go on in them. For purposes here, and as explained in Section 8, where life and casualty losses are not expected in a building, no benefit-cost analysis is worthwhile in regard to the structure.

Hence, many State-owned buildings are not of significance to this study inasmuch as their occupancy rates are very low. In particular, rest rooms, rest areas, open pavilions, ports of entry, road sheds, garages, maintenance stations, and storage sheds can be eliminated from consideration, since, in the main, risks to people are low in such structures.

As explained in Section 8, once occupancy rates have been estimated, then estimates can be made as to expected deaths and casualties in a given building. Such estimates, once again, depend upon seismic zone and structural features. One-story structures are regarded as being safer than two-story and taller structures. Structures built after 1962, when the Uniform Building Code was applied more widely in Utah, are assumed to be less hazardous than those built before 1962. Since deaths are estimated to occur chiefly at the highest earthquake intensities, and since the highest intensities are much more likely to occur in Zone U-4, the liklihood of deaths in Zone U-4, although not high in comparison with possible causes of death other than earthquakes, is much greater than in the other seismic zones. In particular, if the structures and occupancy rates considered are identical, then the number of deaths expected in Zone U-4 would be about twelve times the number expected in Zone U-3 and about sixteen times the number expected in Zone U-2. Almost no earthquake-caused deaths are anticipated in the rest of the State.

So, once again, location is the dominant factor in assessing the life and safety hazards posed by earthquakes. More structural losses and many more deaths are expected in Zone U-4 than in any other zone, even if the same number of people and buildings were found in each zone. But, this is not the case, and we find that the numbers of occupants and buildings are much larger in Utah's worst seismic zone.

Data on occupancy rates are, of cource, difficult to establish with any degree of precision. For State-owned offices, according to Steve Milligan, research analyst at the Utah State Building Board, the mean occupancy rate is one employee per 167 square feet of floor area. So, unless other information was available, we have assumed that an office had one mean occupant per 500 square feet. For such offices as Job Service, where there is also a flow of non-employees, higher occupancy rates were posited. the worst case assumed was one occupant per 170 square feet on the basis that, according to Steve Milligan, the highest occupancy rate in the State is about one employee per 60 square feet. It is obvious, then, that earthquake hazards vary directly with occupancy rates as well as with type of structure.

For the Utah State Fair complex in Salt Lake City, based on data provided by E. Johnson at the Utah State Building Board, it was assumed that there are 350,000 annual visitors who spend two hours each at the fair, that there are 320 employees for the month of the fair, that there are 14 regular employees, that there are 25 people normally flowing through at other times, and that there are 61 annual special events with 50 people at each such event. The mean occupancy rate, given such assumptions, is 120. For the Coliseum, one of the buildings in the Fairgrounds Complex, it was assumed that there are 31 annual events with 100 persons attending for 3 hours each, there are 10 mean occupants from the fair, and 2 mean occupants from among employees. Even given such generous assumptions, the mean number of occupants derived at the Coliseum, as well as the fair facilities in general, is less than that for the ordinary State office. The method for setting priorities on risk exposure, thus, is evident.

Just as the location of a large earthquake's epicenter can make a great difference in hazards to populations, so, too, other contingencies, such as whether large, vulnerable auditoriums or coliseums are filled or empty, can have considerable implications affecting the expected losses for a given event. The use of mean occupancy rates here is an attempt to take a very long-term view of the earthquake risk situation.

In order to develop some notion of the impact upon various occupancy rates of the hazards in a building, and also to develop a benefit-cost analysis for earthquake safety to buildings, it is necessary to place some economic value on the prolongation of life. As explained in Section 8, if the value of life is infinite, then any program that would prevent loss of life would be justified, no matter what its costs were and no matter what means were used to implement the program. For this report, primarily for purposes of simplification, the value of any life has been posited as $1 million dollars, a dollar value that would exceed most estimates based on the discounted present value of future earnings.

Given such a postulate on the value of life, another factor that affects the benefit-cost analysis is the cost per square foot of a building. Cost estimates used in this report are based primarily on two sources, <u>1979 Dodge Construction Systems Costs</u> [8] and <u>Building Construction Cost Data 1979</u> [9]. From such information, lists of cost estimates were developed for various sorts of buildings, such as "auditoriums," and attempts were made to classify State-owned buildings accordingly. The resulting cost estimates, then, have some justification but are not intended to reflect more than approximately the overall costs of building construction in the State. For instance, the following estimates were used in regard to various classes of State-owned buildings.

Rest Rooms, Rest Areas, etc.	$25/square foot
Road Sheds, Garages, Maintenance Stations	$30/square foot
Residences	$35/square foot
Prison Security Facilities	$68/square foot
Small Office Buildings	$52/square foot
Dormitories	$46/square foot

What is important to understand is how the replacement costs per square foot of area are affected by structural losses and life losses in terms of the benefit-cost analysis. In applying the benefit-cost equations that are given in Section 8 on methodology, the following relationships must be borne in mind.

-- The benefit-cost ratios for replacement or retrofitting increase if cost per square foot decreases (all other things being equal).

-- The benefit-cost ratios for replacement or for retrofitting increase as mean occupancy per square foot increases.

-- The benefit-cost ratios for 2-story structures built without seismic resistance are higher (all other things being equal) than for other structures.

-- The benefit-cost ratios are higher (all other things being equal) for facilities housing people who might have difficulty responding to earthquakes, such as hospital patients.

Thus, in addition to the structural type of the facility and its location, several other factors enter into the risk assessment of a building. In particular, for State-owned facilities, those in Zone U-4 having high occupancy rates and comparatively low costs would be the most hazardous structures.

As a result of factors mentioned, benefit-cost results shown in Table 13 have been derived for various classes of State-owned structures. Such results are a breakdown of the general findings given in Section 1 of this report.

Such results indicate that, on the aggregate level, no economic jusification can be given for major seismic modifications to complete classes of State-owned facilities.

As regards particular buildings, several conclusions can be drawn.

First, historic buildings, such as those on Capitol Hill and the Territory State House in Fillmore, raise special considerations that lie outside the scope of this report. The earthquake faulting near Capitol Hill is not well-defined. In view of the public importance of such buildings, and in view of the possibility that their age, construction systems, and expected future use, may pose several seismic hazards, such buildings should be given a complete seismic review with a concern for possible future seismic modifications.

Second, facilities studies underway for the Utah State Prison[3] should involve detailed seismic analysis of new, renovated, and of unmodified structures, inasmuch as data indicate both high occupancy rates and the presence of precast concrete systems of unknown seismic resistance capabilities. The State Prison, like most high-occupancy State-owned structures, lies in the worst seismic zone.

Third, structural engineering reports prepared by the H.C. Hughes Company of the buildings at the Utah State Fair indicate that some lateral load problems exist in at least the Coliseum, the Horticultural Building, and the Industrial Arts Building. Since such structures as the Coliseum have high occupancy at various times during the year, remedying such hazards, such as through modifications or through reduction in occupancy rates, would seem to be in order.

Finally, except for unknown fault features near Capitol Hill, the only State-owned buildings known to lie on the fault (or within the zone of deformation) are the Fish Hatchery Buildings in Springville that appear to cause relatively low life-safety risks.

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[3]Plans are extensive in the Utah State Prison Master Plan [10].

SECTION 8

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 State-owned buildings are examined in terms of earthquake 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 evaluations, such as implementing educational programs to reduce earthquake risk, 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 occurences. 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 State-owned buildings would no doubt be different if seismic microzones were constructed based upon such factors as local soil conditions and if building positions relative to faults were examined in greater detail.

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 State-owned buildings 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 earthquake resistance that the building would have were it either retrofitted or replaced. Hence, one can compare damages for the three alternatives.

Such damages considered herein 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 buildings. 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 is 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 discrepanices 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 irrelevant to our considerations. Whatever conversion of use might be made for a structure, though, its sale still results in structural and human losses. So, from a public standpoint, social costs are not reduced unless occupancy is reduced or the structure is replaced or retrofitted. Even though some data exist to the contrary, we shall assume, in the main, that buildings are presently suited for their purposes. Where it is known that a given building is dysfunctional, the life span of the building can be adjusted accordingly. In addition, repairs for fire safety or other matters not directly related to seismic repairs are not considered part of the costs either of retrofitting or of losses due to earthquakes.

One possible assumption for the benefit-cost analysis is that each State-owned building has a 50-year life span, or that $z = 50-y$. This assumption would give a bias in favor of waiting until later to spend money for replacement or retrofit. Since, though, many State-owned buildings in Utah are older than 50 years, such an assumption was not found to be reasonable. Accordingly, a 100-year life span is assumed for buildings, although this time frame, too, may be short.

We shall further assume that the expected damage to the contents of the building is the same, no matter which alternative is decided upon.

We shall also assume 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. So, even if the State can borrow at a 6 percent rate, the discount rate, the rate of borrowing is nonetheless higher, since the source of funds to the State has a higher discount rate. Likewise, the discount rate shall be applied to funds spent even if such funds happen to be financed in any of the following ways:

(i) A percentage of funds is provided by the federal government.

(ii) The construction cost is paid off immediately.

or (iii) The funds are borrowed for twenty years at a rate of 12 percent on the remaining balance.

The reason for adopting a constant discount rate is that the additional money raised 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 overall costs, from which one may identify which alternative courses of action are reasonable.

It is here assumed that the bulk of relocation costs will be such social costs as reduced services, including delays, rather than property costs. If a State-owned building were to suffer considerable damage, other buildings might be used (if any suitable ones were available) but the costs of renovating other sorts of buildings, leasing them, and stocking them, is an alternative so costly in many cases that other remedies would likely be sought first. In addition, there are also relocation costs resulting from replacing or retrofitting State-owned buildings now.

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 latter.

If an 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 any building 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) $[(d_a-d_b) + (L_a-L_b)] \sum_{j=o}^{z-1} (1+i)^{j}$ = 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) $\sum_{j=o}^{z-1} (1+i)^{j} = \dfrac{[(1+i)^{z}-1]}{i}$,

it follows that

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

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

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

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 retrofitting it exceed money costs of retrofitting the building. That is, alternative (c) is more economic when

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

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

If a discount rate of 10 percent is used, then one can multiply either the replacement or retrofitting costs by 10 percent 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 percent is assumed. According to one economist, Frank Hachman, Associate Director of the Bureau of Economic and Business Research at the University of Utah, 10 percent is presently the absolute minimum discount rate for this study, and higher rates might be more reasonable. In other words, a 10 percent 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. 11, 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 building.

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

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

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. 1, 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. [1], p. 39), one finds the following curve:

$$(15) \quad I_o - I = n \operatorname{Log}_{10} [(\Delta^2 + h)^{1/2} / h],$$

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 $I_o-I_1 = 1$, and $\Delta = 10$ kilometers, then the maximum intensity, I_o, extends for a distance of 5 kilometers. So, too, if for I_o-I, $\Delta = 21$ kms., then the second highest intensity, I_o-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 to the one shown below for Zone 34 which gives the

[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.

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.

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

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 <u>initial</u> 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. [6], 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 14 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 15.

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 2. Using the same method as was followed to develop Table 15, 100-year factors for structural failures, estimated based on this second classification scheme, are given in Table 16.

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." ([6], 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 16, 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 15, one can further estimate the losses to a given structure until its life cycle runs out, which losses are equal to:

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

Tables 15 and 16 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 subsection, 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 17 summarizes the basic estimates that were used in this study.

These estimates of Table 17 must be modified by coefficients according to the following types of structures.

Type	Description	Coefficient
A	Fully retrofitted building	0.25
B	Fully retrofitted health-care facility	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 all buildings other than health-care facilities 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 health-care facilities was based on the assumption that full retrofitting of such buildings would produce only slightly better than a Class 5C structure.

Given such percent estimates in Table 17, and the estimated seismic frequencies developed in Part D, one can, for each zone, derive the percent deaths and casualties by type of occupants shown in Table 18. The estimates must be modified by the coefficients given above for any particualr structure.

Using estiamtes in Table 18, one can derive mortality and morbidity estimates. For instance, if a facility has 10,000 square feet, and a mean occupancy rate of 1 person per 500 square feet, and if the facility is a two-story structure built after 1962, then one has the following 100-year estimates.

10,000 sq. ft. x 1 person per 500 sq. ft.
x 1.25 x 0.1229% deaths = 0.03 deaths,

and 10,000 sq. ft. x 1 person per 500 sq. ft.
x 1.25 x 1.968% serious injuries
= 0.49 serious injuries.

The estimates made in Table 18 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. [1], 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 earthquake had been 1.624 ([12], 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. [1], p. 73).

Two observations are made with respect to the injury and mortality rates obtained from the methodology just described. First, the estimated 100-year totals of deaths and injuries to building 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 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 State-owned buildings. 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. [1], p. 305). According to one survey made of ten earthquakes, one death is expected per $2 million property damage (1970 dollars) ([12], 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.

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. [13], 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. [14], p. 3; [15], [16]).

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. The basis of these conclusions is furnished in Table 13.

PART F: METHOD FOR ESTIMATING SEISMICALLY RESISTANT CONSTRUCTION COSTS

The methodology developed in Part D presupposes that estimates are available for both replacement and for retrofitting a building.

Estimates of replacement costs were developed from estimated costs per square foot found in the 1979 Dodge Construction Systems Costs and Building Construction Cost Data 1979. Since Utah construction costs were estimated as being somewhere between the median and the 75th percentile costs, an average was taken of median costs and 75th percentile costs for various classes of buildings (Cf. [8], [9]).

In order to determine retrofitting costs, a breakdown of component costs was used, and an estimate was made as to the percent of the total cost for each building element that likely would require modification to upgrade the earthquake resistance. Estimates were made for various classes of structures. For example, the following estimates were used of how much construction would be necessary to fully retrofit a masonry structure for earthquake safety.

Masonry work	100%
Structural steel	0%
Finishes	50%
Concrete work	10%
Rough carpentry	25%
General conditions	(general percent overall)

In Estimation of Earthquake Losses to Buildings (Except Single Family Dwellings), S.T. Algermissen and others provide various estimates of component or element costs of construction (Cf. [21], pp. 57-59). For nonreinforced brick structures, for instance, the following percentages of total costs for each phase of the construction were estimated for various components.

(For buildings with no air conditioning and no partitions)

Masonry work	14.6%
Finishes	5.5%

Concrete work	13.1%
Rough carpentry	15.8%
General conditions	4.0%

So, for retrofitting one expects the following component costs.

Masonry work	14.6%
Finishes	2.8%
Concrete work	1.3%
Rough carpentry	4.0%
General conditions	0.9%
TOTAL	23.6%

Using this same method for all classes of nonreinforced brick structures, 22% of the replacement cost was estimated for retrofitting. For concrete structures, 13% was estimated, and for steel structures 9% was estimated.

PART G: 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.

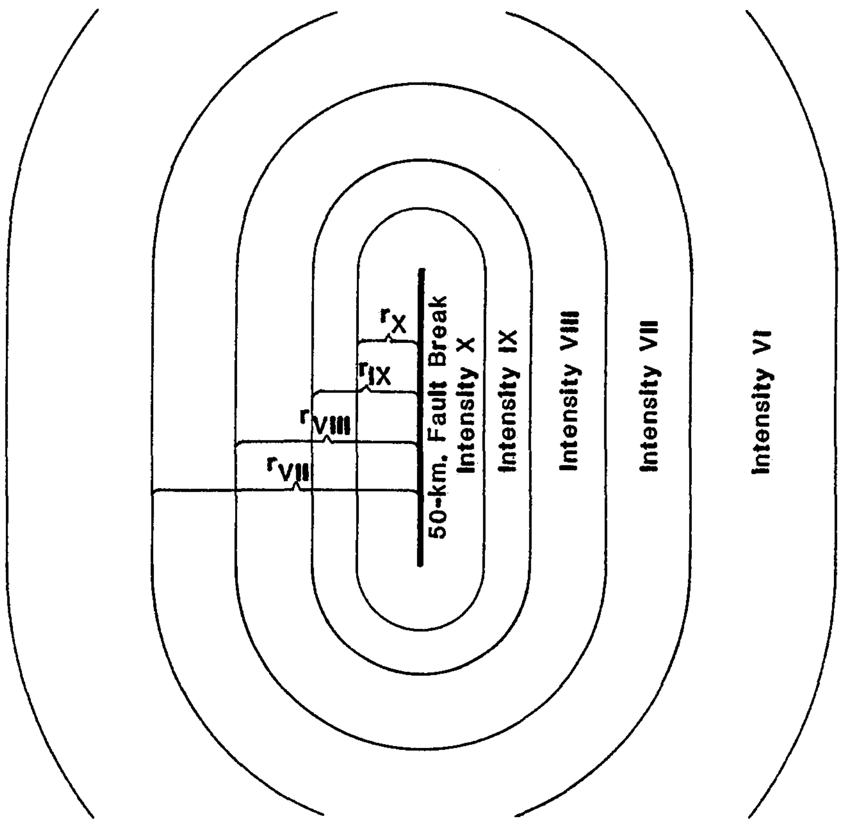
In this sub-section, earlier results for Zone 33A are modified in order to meet the two objections. Since the bulk of losses is expected to occur in Zone 33A, the additional task of correcting for soil conditions in other zones was not undertaken.

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 $r_j + 100r_j$.

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

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

For Intensity IX, one uses the following equation.

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

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 Estimation of Earthquake Losses to Buildings (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 sq. km.
At Intensity IX:	0.0353 sq. km.
At Intensity VIII:	0.1188 sq. km.
At Intensity VII:	0.3976 sq. km.
At Intensity VI:	1.2819 sq. km.

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 18.

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 18.

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 facilities, already concluded to be feasible in economic terms, is further enhanced.

PART H: INTERPRETATION OF RESULTS

While the preceding subsections provide a complete development and discussion of the methodology for seismic risk analysis as applied to State-owned buildings in Utah, 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 facilities throughout the State according to their vulnerabilities to seismic exposure.

(d) To estimate expected life loss and casualty rates for occupants of State-owned buildings 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 building 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, 34, 33B, and 33A 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 15 and 16 summarize such expected loss factors for the various classes of building construction and for the various seismic zones. Data are given as a percentage of damage to each building class. Table 15 data are for property losses, from which dollar losses, in turn, may be estimated. Table 16 data are for estimates of structural failures. These data are translated in Table 13 into structural losses in dollars for the various classes of State-owned buildings.

Since the majority of Utah buildings 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 State-owned buildings.

Note, however, that for Zone 33A (U-4), the jump from Class 5E to Class 5D (Table 14) 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 Table 18 it is evident that, in relative terms, Zone U-4 (Zone 33A) is the most severe. From Table 16, it also is evident that buildings of Classes 7, 6, and 5 are the more vulnerable. Indeed Class 7 buildings are, on the average, nearly three times more vulnerable than are Class 4 buildings. Since, vulnerability to damage here is used as a measure of expected injuries and deaths, one may conclude from Table 2 (Gross Floor Areas) and from Table 12 that more than one-half of the buildings at the Utah State Prison and nearly one-half at the Utah State Fair pose higher risks to life safety than most other State-owned buildings. Also in this group of highest risk buildings are several buildings at the State School for the Deaf. Although the number of Class 7 buildings used as offices or for similar purposes is large, other more detailed data reveal that occupancy of these buildings is not large. Accordingly, the priority for strengthening or replacement of these buildings is lower than for other buildings that house persons having physical, mental, or social handicaps.

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. Such information may be found in a general way in Table 13. 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.

In Table 13 it is seen that the most favorable benefit-cost ratios may be obtained, both for property loss reduction and life and injury reductions, by upgrading those buildings at the State Prison. Other favorable ratios obtain for upgrading office buildings facilities at the Schools for the Deaf and Blind, and at the State Fair. In no case is the economic benefit for upgrading especially good. The merits of such an effort would necessarily need to be justified by consideration of the importance of life safety.

Such upgrading of existing buildings 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 I: SOURCES OF DATA

In addition to the references listed in the bibliography, of special mention is that information obtained chiefly from the files of Einar Johnson, Jr., of the State Building Board. From these files, survey data and photographs of many facilities were obtained which were of great help in evaluating their construction characteristics.

Richard Hughes, of the H.C. Hughes Company, structural engineers in Salt Lake City, furnished structural data on State buildings 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 [1].

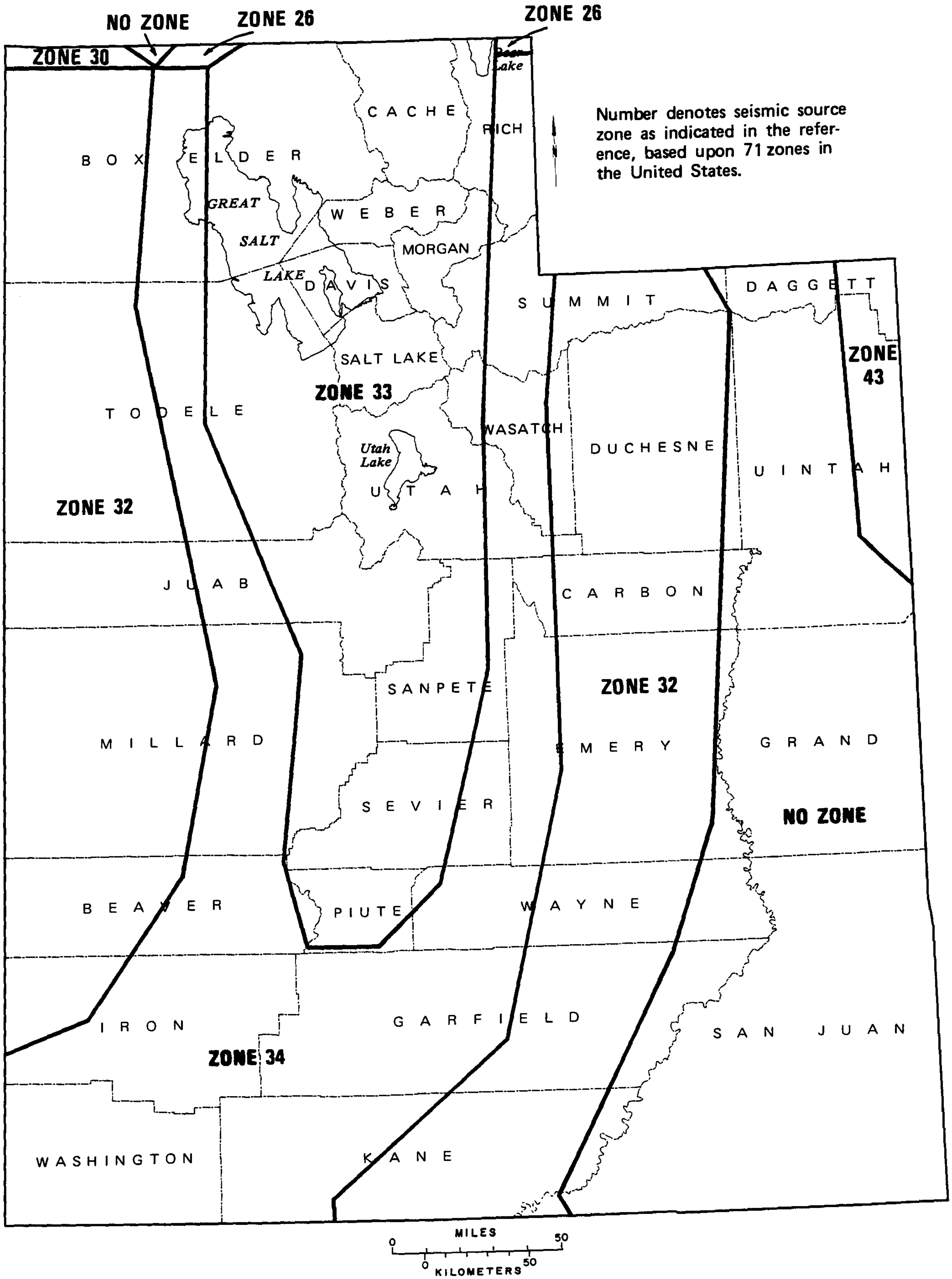


Figure 1
SEISMIC SOURCE AREAS IN UTAH
(Reference: S.T. Algermissen, and D.M. Perkins, USGS Open File Report 76-416)

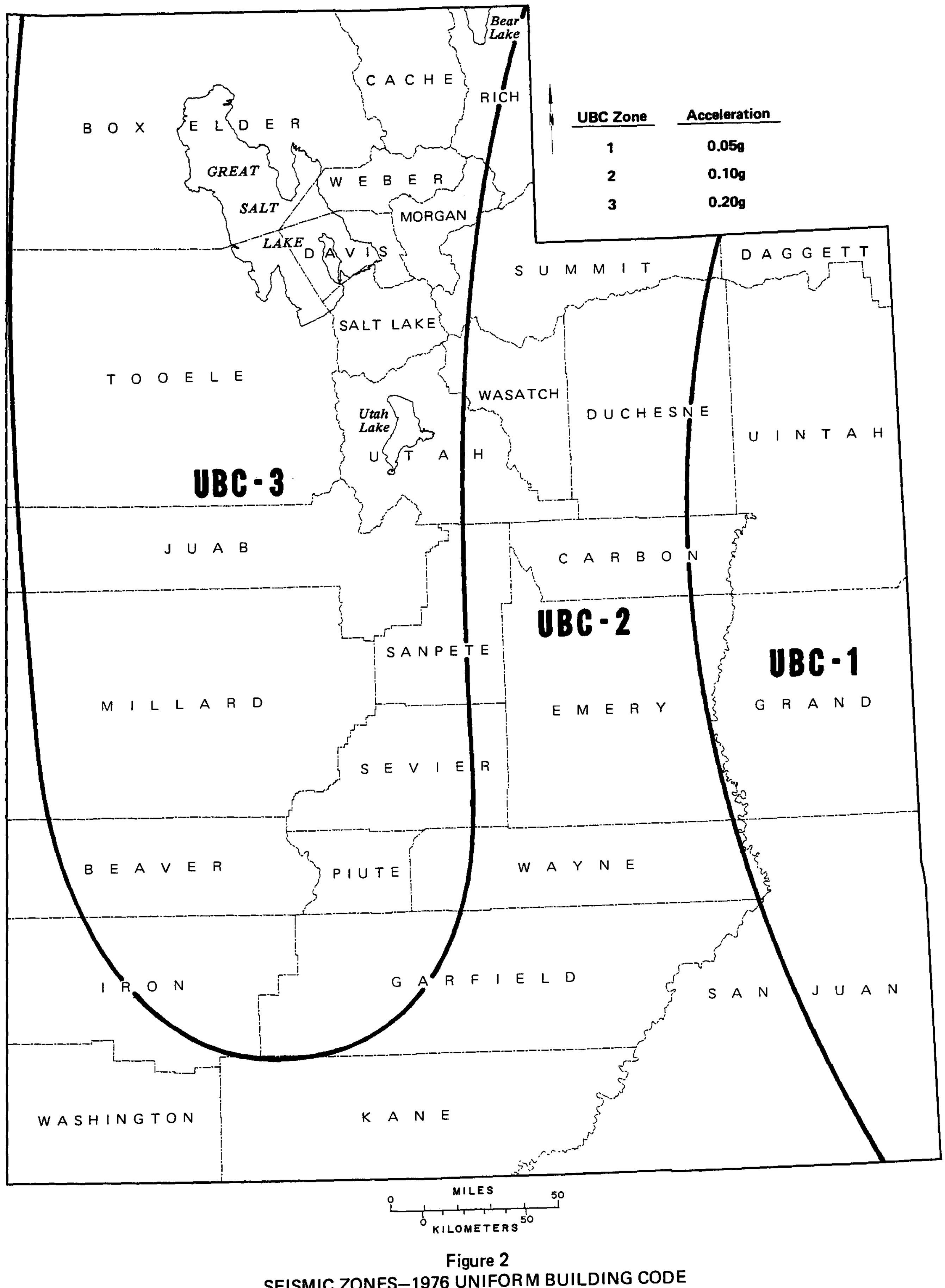


Figure 2
SEISMIC ZONES—1976 UNIFORM BUILDING CODE
STATE OF UTAH

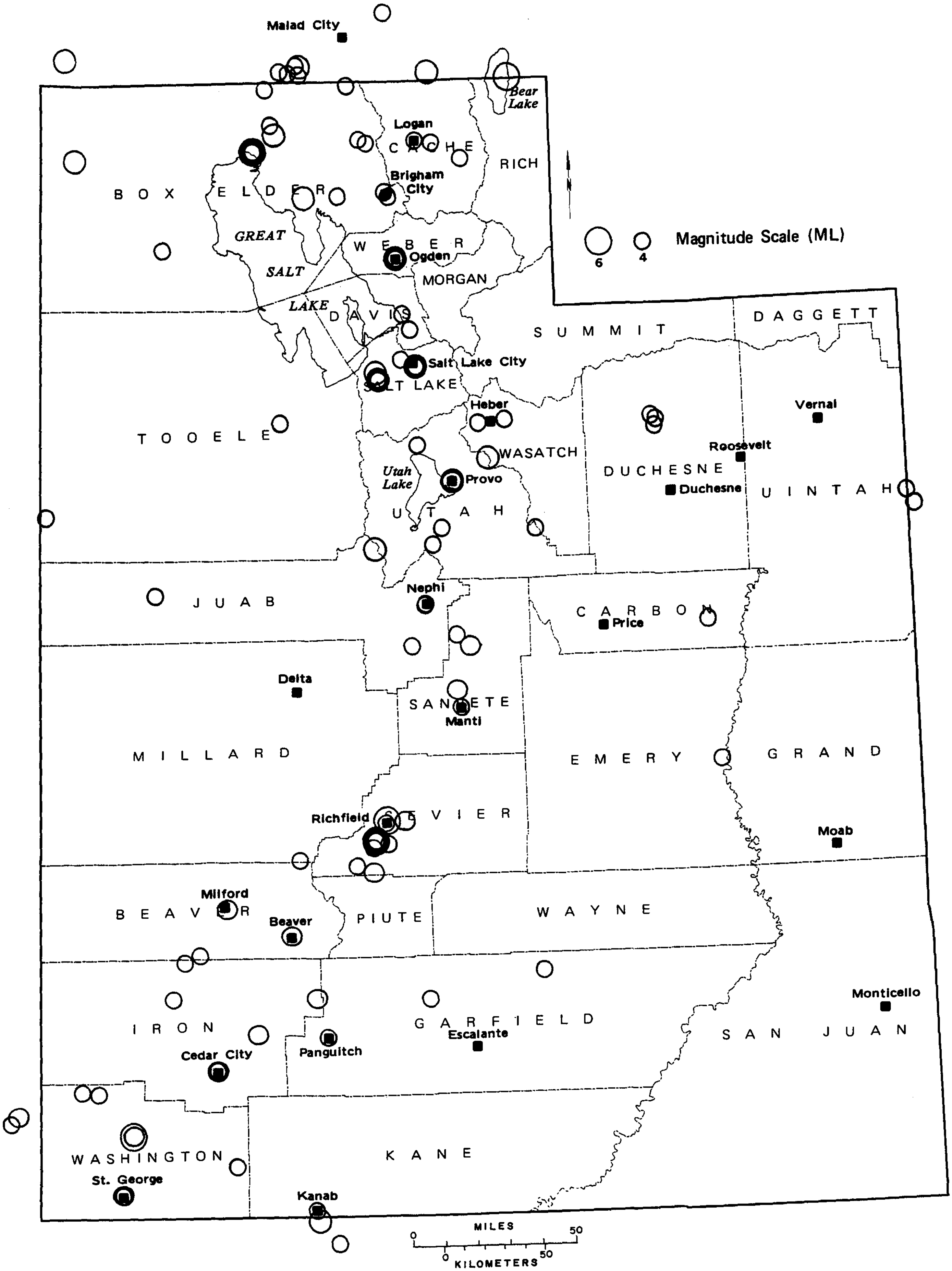


Figure 3
HISTORICAL SEISMICITY IN UTAH -- 1850 - JUNE 1978
MAGNITUDE 4.0 (INTENSITY V) OR GREATER
(Reference: *Earthquake Studies In Utah*, W.J. Arabasz, R.B. Smith, and W.D. Richins)

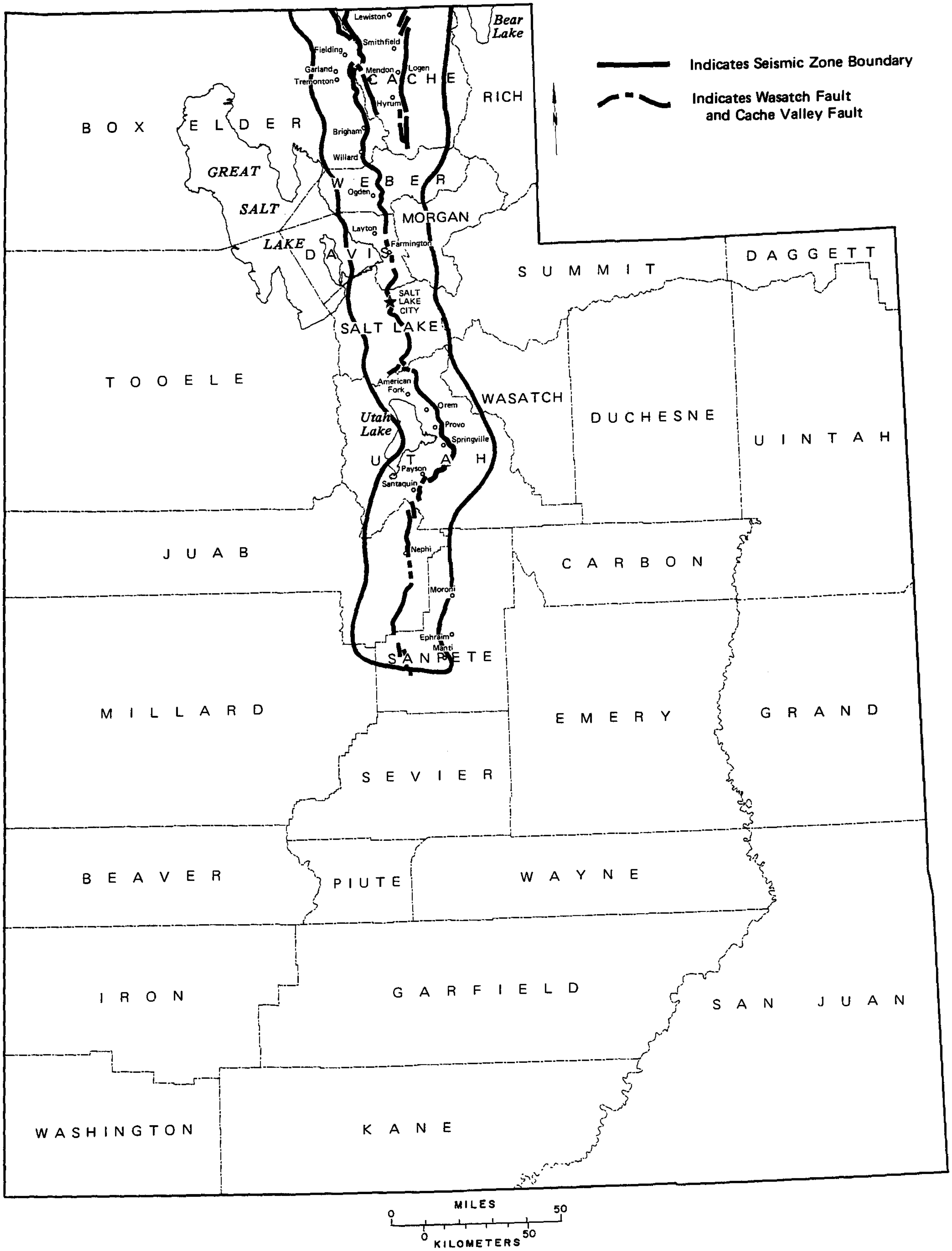


Figure 4
WASATCH FRONT SEISMIC ZONE, WASATCH AND CACHE VALLEY FAULTS
STATE OF UTAH

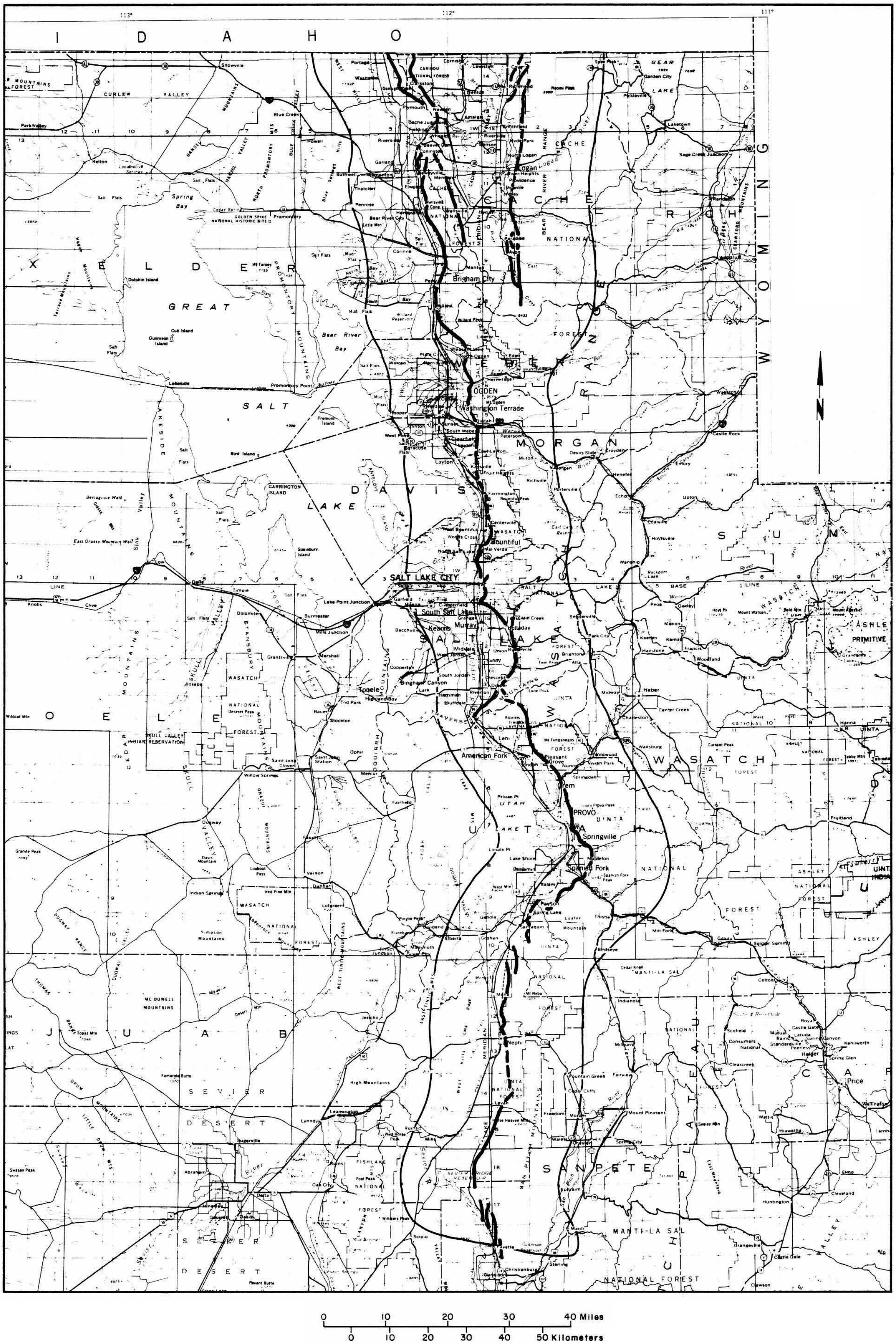


Figure 5

WASATCH FRONT SEISMIC ZONE

STATE OF UTAH

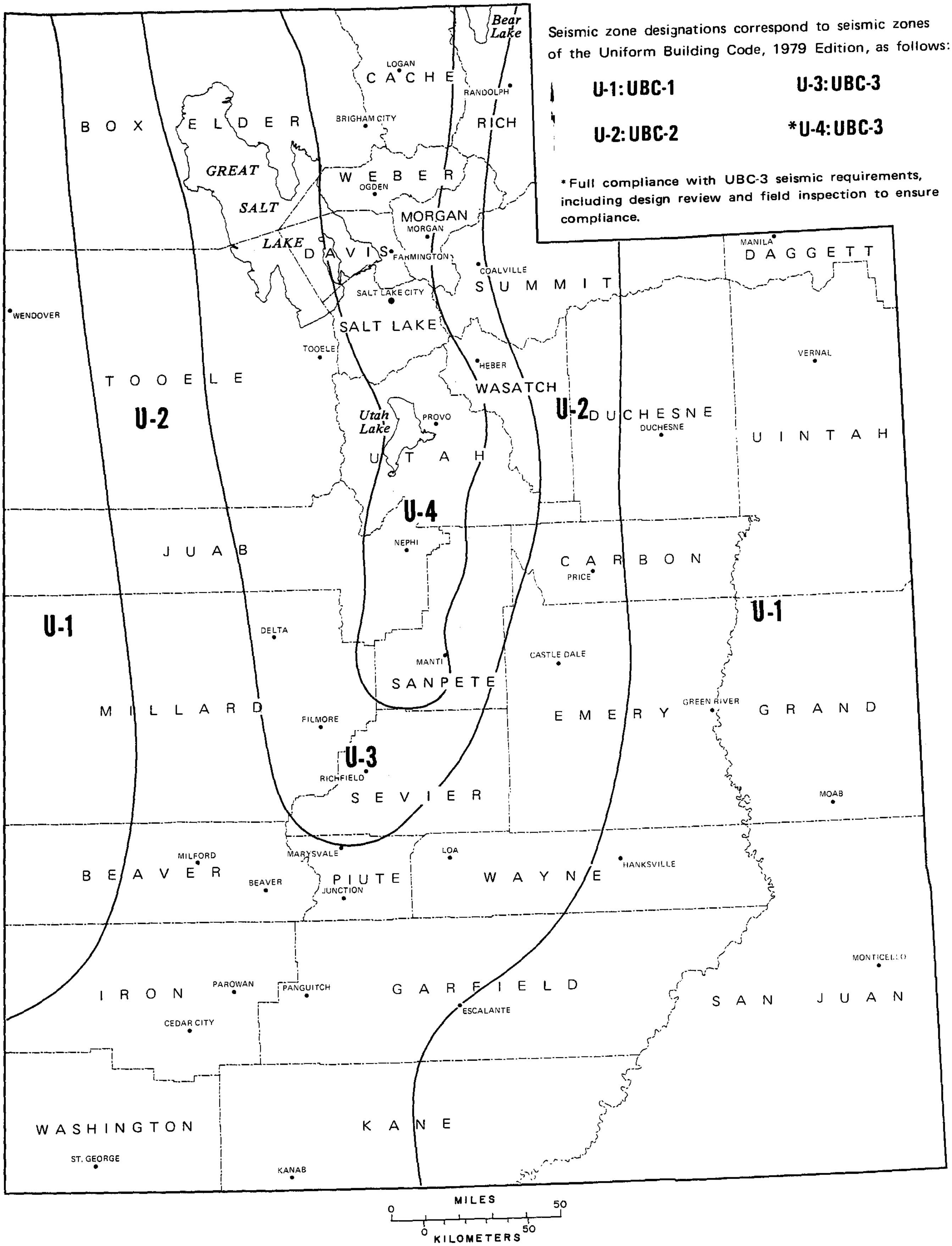


Figure 6
SEISMIC ZONES
January 1980
(Recommended by the Utah Seismic Safety Advisory Council)

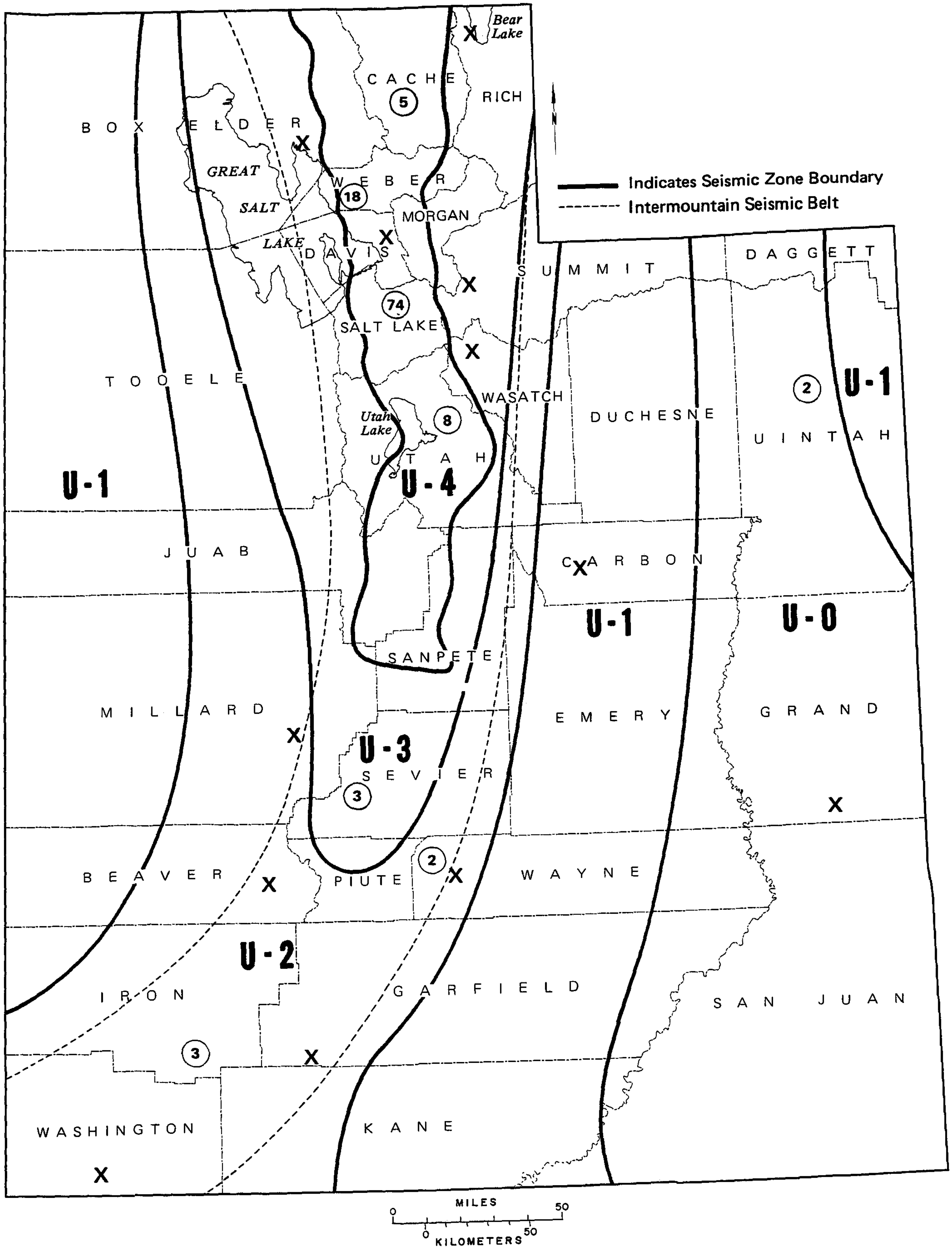


Figure 7

DISTRIBUTION OF STATE–OWNED VISITOR CENTERS, PRISONS AND OFFICES SURVEYED BY SEISMIC ZONE AND COUNTY *
STATE OF UTAH

* (includes State Juvenile Court, Job Service, Museums, Utah State Fair, Schools for the Deaf and Blind and Laboratories)

Table 1

DISTRIBUTION OF VARIOUS CLASSES OF SURVEYED STATE-OWNED BUILDINGS BY SEISMIC ZONE

Type Of Building	Seismic Zone					
	Zone U-0	Zone U-1	Zone U-2	Zone U-3	Zone U-4	All Zones
Rest Rooms, Rest Areas, Pavilions	6	2	5	7	23	43
Road Sheds, Garages, Maintenance Stations, Storage Sheds	11	12	16	13	15	67
Ports Of Entry	1	1	2	0	1	5
Residences	10	2	8	2	8	30
Utah State Prison	0	0	0	0	14	14
Schools For Deaf, Blind, Girls' Group Homes	0	0	0	0	21	21
Offices	0	1	7	5	29	42
Visitors Centers, Museums	1	0	2	2	3	8
Utah State Fair	0	0	0	0	37	37
TOTALS	29	18	40	29	151	267

Table 2

GROSS FLOOR AREA OF SURVEYED STATE-OWNED BUILDINGS IN UTAH
BY TYPE OF USE AND BY SEISMIC ZONE
(Square Feet)

Type of Building	Seismic Zone					
	Zone U-0	Zone U-1	Zone U-2	Zone U-3	Zone U-4	All Zones
Rest Rooms, Rest Areas, Pavilions	3,456	1,000	2,260	3,070	12,143	21,929
Road Sheds, Garages Maintenance Stations, Storage Sheds	33,245	41,589	42,694	41,651	51,691	210,870
Ports Of Entry	6,000	712	1,800	0	1,728	10,240
Residences	18,400	2,200	10,000	4,300	13,400	48,300
Utah State Prison	0	0	0	0	377,087	377,087
Schools For Deaf, Blind, Girls Group Homes	0	0	0	0	320,593	320,593
Offices	0	6,273	22,193	15,692	1,638,024	1,682,182
Visitors Centers, Museums	5,000	0	3,310	12,483	41,496	62,289
Utah State Fair	0	0	0	0	275,679	275,679
TOTALS	66,101	51,774	82,257	77,196	2,731,841	3,009,169

Table 3

CLASSIFICATION OF SURVEYED STATE-OWNED BUILDINGS
IN ACCORDANCE WITH THE
ALGERMISSEN AND STEINBRUGGE CLASSIFICATION SYSTEM
AND BY SEISMIC ZONE

Seismic Zone	Building Class										Totals
	5E	5D	3B,3D 4C,5C	5B 3C,4A	4D	4E	4B	3A	2B	2A	
Zone U-0	4	7	3	0	0	0	0	1	0	14	29
Zone U-1	2	4	4	0	0	0	0	1	0	7	18
Zone U-2	8	10	10	0	0	0	0	0	0	12	40
Zone U-3	12	8	3	0	0	0	0	0	0	6	29
Zone U-4	37	17	16	5	16	0	2	5	0	53	151
TOTALS	63	46	36	5	16	0	2	7	0	92	267

Table 4

CLASSIFICATION OF SURVEYED STATE-OWNED BUILDINGS
IN ACCORDANCE WITH THE
H.C. HUGHES COMPANY CLASSIFICATION SYSTEM
AND BY SEISMIC ZONE

Seismic Zone	Building Class								Total
	7	6	5	4	3	2	1B	1A	
Zone U-0	0	0	4	0	7	3	11	4	29
Zone U-1	0	0	2	0	4	4	6	2	18
Zone U-2	0	1	7	0	8	12	10	2	40
Zone U-3	1	1	10	1	7	3	4	2	29
Zone U-4	10	22	24	6	16	15	48	10	151
TOTALS	11	24	47	7	42	37	79	20	267

Table 5

COMPARATIVE PERCENTAGES OF EXPECTED DOLLAR LOSSES TO BUILDINGS BY STRUCTURAL TYPE AND SEISMIC ZONE

(Algermissen and Steinbrugge Categories)
(Loss to a building of Class 5E in Zone U-4 = 100%)

Seismic Zone	Building Class									
	2A	2B	3A	3B,3D 4C,5C	3C,4A 5B	4B	4D	4E	5D	5E
Zone U-1	0	0	0	1	0	1	1	1	1	1
Zone U-2	2	1	1	8	2	11	13	11	10	16
Zone U-3	2	1	2	14	2	19	24	20	18	30
Zone U-4	11	9	12	49	15	67	82	71	63	100

Table 6

COMPARATIVE PERCENTAGES OF EXPECTED STRUCTURAL FAILURES TO BUILDINGS BY STRUCTURAL TYPE IN SEISMIC ZONE U-4

(Hughes Taxonomy)
(Losses to Class 7 structures in Zone U-4 = 100)

Seismic Zone	Building Class 7	6	5	4	3	2	1B	1A
Zone U-4	100	78	60	38	22	12	7	4

Table 7

COMPARATIVE PERCENTAGES OF PREVENTABLE LOSSES THROUGH REPLACEMENT BY CONSTRUCTION CLASS IN SEISMIC ZONE U-4

(Algermissen and Steinbrugge Taxonomy)
(Preventable losses to Class 5E structures in Zone U-4 = 100)

Seismic Zone	Building Class 5E	4D	5D	5C	3B,3D	5B	3C	3A	2B	2A
Zone U-4	100	83	56	40	44	--	4	--	--	3

Table 8

COMPARATIVE PREVENTABLE STRUCTURAL FAILURES
TO BUILDINGS IN SEISMIC ZONE U-4
THROUGH REPLACEMENT OF THE ORIGINAL STRUCTURAL TYPES
WITH AN EARTHQUAKE-RESISTANT STRUCTURE OF THE SAME TYPE

(Hughes Taxonomy)
(Preventable losses for Class 7 structures in Zone U-4 = 100)

Seismic Zone	Building Class						
	7	6	5	4	3	2	1
Zone U-4	100	74	54	30	11	--	--

Table 9

COMPARATIVE PERCENTAGES OF PREVENTABLE LOSSES TO BUILDINGS IN SEISMIC ZONE U-4 PER DOLLAR SPENT ON RETROFITTING BY BUILDING CLASS

(Algermissen and Steinbrugge Categories)
(Preventable losses for Class 5E structures in Zone U-4 = 100)

Seismic Zone	Building Class						
	3B,3D	4D	4E	5C	5D	5E Lowrise	5E Highrise
Zone U-4	98	66	44	40	56	100	72

Table 10

COMPARATIVE PERCENTAGES OF PREVENTABLE STRUCTURAL FAILURES IN SEISMIC ZONE U-4 PER DOLLAR SPENT ON RETROFITTING BY BUILDING CLASS

(Hughes Categories)
(Preventable structural failures for Class 7 structures in Zone U-4 = 100)

Seismic Zone	Building Class											
	7	7	6	6	5	5	5	4	4	4	3	3
	Masonry	Concrete	Masonry	Concrete	Masonry	Concrete	Steel	Masonry	Concrete	Steel	Concrete	Steel
Zone U-4	100	169	71	141	57	103	149	22	57	82	18	27

Table 11

CLASSIFICATION OF SURVEYED STATE-OWNED BUILDINGS IN UTAH
IN SEISMIC ZONE U-4 AND BY TYPE OF USE

(Algermissen and Steinbrugge Classification System)

Building Type	Building Class										Totals
	5E	5D	3B,3D 4C,5C	3C,4A 5B	4D	4E	4B	3A	2B	2A	
Rest Rooms, Rest Areas Pavilions	11	0	3	0	0	0	0	0	0	9	23
Road Sheds, Garages, Maintenance Stations, Storage Sheds	2	9	0	1	0	0	0	0	0	3	15
Ports Of Entry	0	0	0	0	0	0	1	0	0	0	1
Residences	0	0	0	0	0	0	0	0	0	8	8
Utah State Prison	1	1	0	0	7	0	0	1	0	4	14
Schools For Deaf, Blind, Girls' Group Homes	7	2	3	0	1	0	0	1	0	7	21
Offices	6	5	8	3	2	0	1	0	0	4	29
Visitors Centers, Museums	1	0	1	0	1	0	0	0	0	0	3
Utah State Fair	9	0	1	0	5	0	0	4	0	18	37
TOTALS	37	17	16	4	16	0	2	6	0	53	151

Table 12

CLASSIFICATION OF SURVEYED STATE-OWNED BUILDINGS IN UTAH
IN SEISMIC ZONE U-4 AND BY TYPE OF USE

(H.C. Hughes Company Classification System)

Building Type	Building Class								Totals
	7	6	5	4	3	2	1B	1A	
Rest Rooms, Rest Areas, Pavilions	0	4	7	0	0	3	4	5	23
Road Sheds, Garages, Maintenance Stations, Storage Sheds	0	0	2	0	9	1	3	0	15
Ports Of Entry	0	0	0	1	0	0	0	0	1
Residences	0	0	0	0	0	0	8	0	8
Utah State Prison	1	2	5	0	1	0	4	1	14
Schools For Deaf, Blind, Girls' Group Homes	2	4	4	0	0	4	7	0	21
Offices	6	0	3	5	6	5	3	1	29
Visitors Centers, Museums	1	1	0	0	0	1	0	0	3
Utah State Fair	0	11	3	0	0	1	19	3	37
TOTALS	10	22	24	6	16	15	48	10	151

Table 13

BENEFIT-COST ESTIMATES FOR VARIOUS CLASSES
OF STATE-OWNED BUILDINGS IN UTAH
(1979 Dollars)

Type Of Building	Estimated Replacement Cost	Estimated Cost To Retrofit	Estimated Annual Structural Dollar loss			Estimated Number Of Deaths/100 years		Benefit For $100 Cost	
			If Unmodified	If Replaced	If Retrofitted	If Unmodified	If Modified	If Replaced	If Retrofitted
Rest Rooms, Rest Areas, Pavilions	$ 548,000	$ 68,000	$ 170	$ 40	$ 40	--	--	$ .23	$1.90
Ports Of Entry	$ 471,000	$ 25,000	$ 40	$ 10	$ 10	--	--	$ .06	$1.10
Road Sheds, Garages, Maintenance Stations	$ 6,667,000	$ 1,036,000	$ 1,340	$ 270	$ 310	0.01	0	$ .18	$1.01
Residences	$ 1,666,000	$ 19.000	$ 80	$ 50	$ 60	0.03	0.03	$ .02	$ .94
Utah State Prison	$ 20,321,000	$ 2,564,000	$12,000	$ 2,890	$ 8,310	2.03	0.43	$1.40	$7.80
Schools For Deaf, Blind, Girls' Group Homes	$ 16,248,000	$ 2,558,000	$10,200	$ 2,140	$ 3,830	0.86	0.20	$ .90	$5.10
Offices	$ 94,072,000	$10,651,000	$59,190	$12,470	$32,220	5.56	1.25	$ .97	$6.70
Utah State Fair	$ 10,562,000	$ 1,188,000	$ 6,180	$ 1,330	$ 2,480	0.15	0.03	$ .57	$4.10
TOTALS	$150,555,000	$18,109,000	$89,200	$19,200	$47,260	8.64	1.94	$ .92	$6.13

Table 14

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 15

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

(Based on Algermissen and Steinbrugge Estimates)

Seismic 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 16

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

(Based on Adapted USGS Classification)

Seismic 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 17

DEATHS AND INJURIES AS A PERCENT OF BUILDING OCCUPANTS BY DEGREES OF MODIFIED MERCALLI INTENSITY

Intensity	Deaths	Injuries
VII	0	4%
VIII	0.67%	8%
IX	2%	15%
X	3%	20%

Table 18

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

Zone	Deaths	Injuries
Zone 32	0.0004%	0.0160%
Zone 33A	0.1229%	1.968 %
Zone 33B	0.0098%	0.2466%
Zone 34	0.0077%	0.2466%

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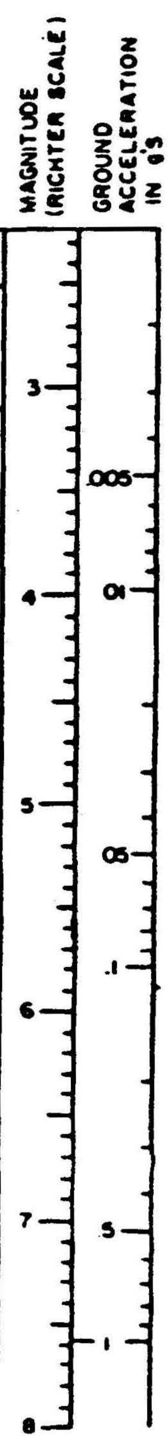
MODIFIED MERCALLI INTENSITY SCALE APPROXIMATE RELATIONSHIP WITH MAGNITUDE AND GROUND ACCELERATION

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 truck. 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. Sensation like heavy truck striking building. Standing 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 objects 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 designed structures; some chimneys broken. Noticed by 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, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
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 foundations. Ground cracked conspicuously. Underground 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 banks and steep slopes. Shifted sand and mud. Water 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.