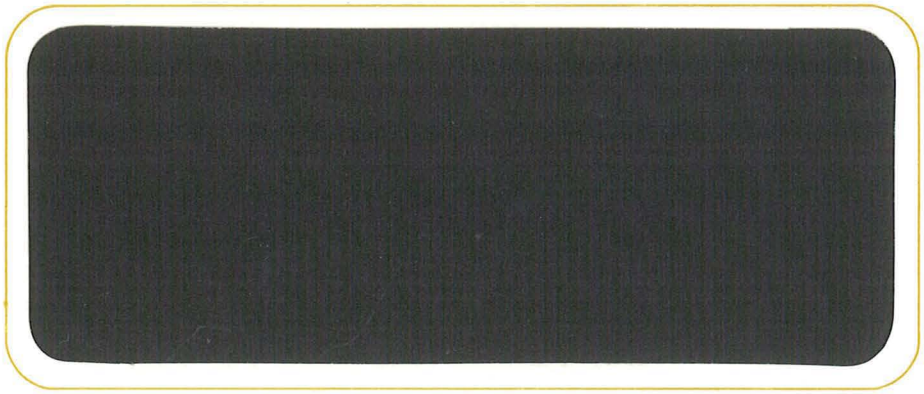

SEISMIC SAFETY ADVISORY COUNCIL

STATE OF UTAH

807 EAST SOUTH TEMPLE STREET
SUITE 103
SALT LAKE CITY, UTAH 84102

SEISMIC SAFETY CONSIDERATIONS FOR DAMS AND RESERVOIRS IN UTAH

April, 1980

Issued By

SEISMIC SAFETY ADVISORY COUNCIL
STATE OF UTAH

Prepared By

Delbert B. Ward
Executive Director

USSAC-08

FOREWORD

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

This report examines water impoundment facilities in Utah from the perspective of earthquake hazards. The report identifies situations relating to procedures and policies which affect seismic safety in the construction of dams and reservoirs, and recommends several actions, primarily of a procedural nature, which would improve and strengthen current practices in the design, construction, and evaluation of such facilities from the standpoint of seismic safety.

The Council has been given specific statutory responsibilities regarding development of State policy for earthquake safety. Those pertaining directly or indirectly to water impoundment facilities include the following activities.

1. To recommend a consistent policy framework for seismic safety.

2. To recommend statewide and local programs to reduce earthquake hazards.

3. To assist with coordination of seismic safety activities of governments at all levels and the private sector which may be involved in practices important to seismic safety.

4. To recommend that State agencies devise criteria to provide or improve seismic safety.

5. To recommend methods for improving siting and design of critical facilities, such as those dams which could cause property damage or casualties through failure induced by effects of earthquakes.

The report presents a broad overview of seismic safety conditions relating to dams and reservoirs in the State. Included in separate sections of the report are: Discussion of Utah's seismic environment; general comments regarding the significance of this seismic environment for dams and reservoirs; operation of Utah's dam safety program, with discussion of associated statutory authorities and administrative responsibilities; identification of seismic safety concerns for dams and reservoirs; and recommendations to improve their seismic safety and to safeguard people and property from seismic hazards. The report also includes, in Appendix A, an outline of recommended procedures for evaluating the seismic safety of dams and reservoirs.

The report gives special attention to practices and procedures in the siting, design, construction, and evaluation of water impoundment facilities in which seismic safety is a concern. Technical details relating to such practices and procedures are not treated herein, nor is any attempt made to address site-specific facilities, their possible seismic safety deficiencies, or specific remedies for such conditions.

The purpose of this report is to suggest general program directions for mitigation or reduction of seismic hazards in dams and reservoirs as a class of facilities. The Council has identified practices in the construction of such facilities potentially involving matters of seismic safety. From these findings the Council has recommended actions that would lead to improvement of such conditions on a statewide basis. In that sense, the recommendations are policy oriented.

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

CONTENTS

LIST OF FIGURES

Section 1

SCOPE OF SEISMIC SAFETY EVALUATIONS FOR DAMS

The scope of this report is limited to an evaluation of seismic hazards for water impoundment facilities in Utah and an evaluation of current practices and procedures to safeguard such facilities from seismic effects. Consideration has been given to earthquake hazards in the construction of new facilities and to the safety of existing facilities.

Evaluation of seismic hazards for construction of new water impoundment facilities has been directed primarily to current practices and procedures for siting, planning, designing, and constructing these facilities as these activities involve earthquake factors. Because the State Engineer has final authority in these activities, the practices and procedures of that office have received special attention.

In the evaluation of seismic hazards for existing water impoundment facilities, emphasis has been placed upon the effectiveness of the State's dam safety program to safeguard against seismic risks, and special attention has been given to criteria for dam safety evaluations as established by the U.S. Corps of Engineers. These criteria are being applied in the dam safety review program in Utah. Special attention has been given to the adequacy of these criteria and to the information gathering procedures for allowing adequate earthquake safety estimates of existing dams to be made.

Evaluations for both new dam construction procedures and existing dam review procedures have been made utilizing information about the Utah seismic environment which has been compiled by the Utah Seismic Safety Advisory Council from other expert sources. The degrees of seismic hazards have been compared judgementally with indicators of possible risk which are implicit in the dam safety criteria, practices, and procedures.

Seismic analysis of individual dam structures in the State was not undertaken during the preparation of this report. Although engineering analyses of some existing dam structures may be necessary to fully determine their seismic vulnerability, such analyses were not within the scope of this policy development effort. Hence, we make no specific comments herein regarding the seismic safety of specific dam facilities, and we restrict our comments to the general procedures and practices that are followed in determining their seismic safety.

Several recent reports dealing with particular proposed dam facilities were reviewed as a part of the Council's dam safety evaluations. These reports provided helpful insights as to how earthquake hazards evaluations are included as a part of feasibility and planning studies for new dams. As well, one can infer from such reports the extent of study given to earthquake safety for particular facilities--at least insofar as earthquake considerations are indicated in the written reports.

From the evaluations described above, the Seismic Safety Advisory Council has identified portions of the current practices and procedures that, if modified, would improve those measures intended to reduce the risks that earthquakes pose for dam and reservoir facilities.

Section 2

UTAH'S SEISMIC ENVIRONMENT

Earthquakes are common in most of the State of Utah, with the possible exception of the easternmost portion. Although these tectonic characteristics have been recognized almost since settlement of the State began in the middle of the nineteenth century, only since the 1960's have earthquakes been recorded systematically by means of an instrument network. Hence, the earthquake record prior to the 1960's combines some data from instruments and a considerable amount of other data drawn from reports of occurrences felt by people in the region of the earthquakes. The historical record, consisting of both instrument records and reports of events, is limited to the period from approximately 1850 to the present.

The historical record of earthquakes in Utah, even though relatively short in geologic time reference, indicates that the amount of seismicity varies considerably across the State. The seismic activity in some portions of the State is relatively large, yet in other areas there is almost no activity. The most frequent and severe earthquakes historically have occurred along a central region, known as the Intermountain Seismic Belt, extending from the north central border to the southwest border.

A distribution of historical seismicity in Utah from 1850 to June, 1978, for earthquakes of Richter magnitude 4.0 or greater, is shown in Figure 1 [1]. This figure indicates there were approximately 90 such events during that 128-year period. In a study of records from 1850 through June, 1965, K.L. Cook and R.B. Smith identified at least seven earthquakes that would register at least 6 on the Richter magnitude scale ([2], pp. 703-718).

Richter magnitude is one of two commonly used scales which indicates earthquake strength. The Richter magnitude is determined from instrument recordings of ground motion induced by the seismic waves which propogate outward from the earthquake. The scale is logarithmic, and a doubling of the Richter magnitude does not imply a doubling of earthquake strength. In fact, the increase in earthquake strength is several times larger than two. Although the Richter magnitude scale has no theoretical upper value limit, no earthquake has been recorded above a value of about 9.0.

Intensity, the other common measure of earthquake strength, has been used to describe seismic occurrences based upon observed damage. Intensity is therefore a different type of measurement than Richter magnitude. Intensity is a qualitative scale which describes damage levels but is not derived from instrumented data. The Modified Mercalli Intensity (MMI) Scale, that scale currently used to define intensity, is given in Appendix B of this report. The MMI scale has 12 steps, increasing in severity from I to XII. By the MMI scale, from 1853 to 1975, an estimated 17 Utah earthquakes had an Intensity VII or greater ([3], p. 156). Two earthquakes, one in Richfield in 1901, and one in Kosmo in 1934, were identified as having an intensity of IX ([4], pp. 9-20).

Earthquakes having Richter magnitudes and Modified Mercalli Intensities of the degree cited above have significance from the standpoint of risks to life and property. Earthquakes are deemed hazardous in the sense that life safety and property may be affected. Earthquakes of small strength normally do not pose such risks, and only those of strength sufficient to cause damage directly, or indirectly through secondary effects such as landslides, soil liquefaction, or subsidence, are of concern. Statistical evidence drawn from damage assessment studies indicates that earthquake strengths of Richter magnitude 4.5 or larger are necessary before damage is noticeable. There is a rough correlation between magnitude and intensity, and one finds that a 4.0 Richter magnitude corresponds approximately with Intensity V. As the earthquake strength increases, one expects to find increasing evidence of damage, with Richter magnitude 7.0 or larger earthquakes (approximately equivalent to Intensity IX) being considered severe.

Further evidence of Utah seismicity, disclosed by R. Buckman of the U.S. Geological Survey (USGS), indicates that the geological record may imply even greater estimated seismicity along the Wasatch fault than is indicated by the more limited historical record of felt earthquakes. Recent studies of faulting along the Wasatch fault tend to confirm estimates by seismologists that earthquake strengths of 7.0 or greater Richter magnitude have occurred in the past. Such earthquake strengths are believed to be possible and recurrent in portions of Utah in future years.

Although the data base is incomplete and although seismic phenomena are far from fully understood by the scientific community, techniques have been developed to estimate the seismic hazards in an area or region. From such information, and given other data about construction characteristics, it is possible to estimate the effects of earthquakes upon various types of buildings and other construction and to estimate the associated risks to life and property.

Currently, earthquake hazards estimates are made following a methodology developed by S.T. Algermissen and D.M. Perkins. The methodology utilizes historical seismicity in designated earthquake source zones to compute expected possible ground accelerations, velocities, and displacements. Such parameters are the basis for evaluating the seismic resistance of existing structures and for designing new ones.

In a report by Algermissen and Perkins published in 1976, the United States is divided into 71 seismic source zones based on expected seismicity in each area [5]. Areas of the nation that are not subject to hazardous earthquakes are not included in any seismic zone. Only a few areas of the U.S. fit this category. Most regions are subjected to some seismicity, though the degree of hazard varies greatly. Utah has four seismically active zones--namely source areas 32, 33, 34, and 43--and one non-active area, as delineated in the Algermissen and Perkins report (Figure 2). Source area 43 impinges upon only a small portion of the State. Source area 33 is seismically the most active, with source areas 34 and 32 successively less severe.

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

Algermissen and Perkins developed from these seismic source area data a contour map of the United States indicating lines of equal bedrock acceleration based upon a 90-percent probability of nonexceedance in 50 years. The horizontal acceleration contours for Utah are shown in Figure 3.

One can compare the Algermissen and Perkins source areas (Figure 2) and ground accelerations (Figure 3) in Utah (published in 1976) with an earlier seismic zone map still in use in the Uniform Building Code, 1979 Edition (UBC) which is shown in Figure 4. It can be seen that the UBC map seems to oversimplify Utah's seismic environment as it presently is understood by scientists.

Findings disclosed by the U.S. Geological Survey regarding geologic evidence of strong earthquakes in the Wasatch fault zone and historical seismicity data as compiled by Algermissen and Perkins have been combined in a report by the Utah Seismic Safety Advisory Council which shows a revised seismic zone map for Utah. This revised seismic zone map has been used as the basis for seismic risk analysis studies carried out by the Council. In this revised seismic zone map, source area 33, as shown in Figure 2, has been divided into two sub-areas, 33A and 33B. Source area 33A, with higher expected seismicity rates, extends approximately 20 kilometers on each side of the Wasatch fault, as shown in Figure 5. The revised seismic zone map for Utah, as recommended by the Utah Seismic Safety Advisory Council, is shown in Figure 6. In Figure 6, the seismic zones correspond with the seismic source areas shown in Figure 2 (from Algermissen and Perkins) as follows.

Algermissen and Perkins Source Areas	Modified Zone Designations
Source Area 43	Zone U-0 (deleted in map)
Source Area 32	Zone U-1
Source Area 34	Zone U-2
Source Area 33B	Zone U-3
Source Area 33A	Zone U-4

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

Borrowing further from the work by Algermissen and Perkins, contours of expected bedrock accelerations have been approximated in Figure 7 for the State as a whole. In this figure, interpolation has been used to plot acceleration contours corresponding to values at 0.025g, 0.075g, and 0.15g. The seismic zones shown in Figure 6 are defined by these contours. These values are mid-point between the UBC-designated acceleration values

of 0.05g, 0.10g, and 0.20g, and they coincide, respectively, with the accelerations said to apply to UBC Zones 1, 2, and 3. The contours of 0.04g, 0.10g, and 0.20g shown in Figure 7 for comparison are as developed by Algermissen and Perkins and are the same as appear in Figure 3.

The importance of the information shown in Figure 7 to the seismic risk analysis at hand is that seismic zone boundaries represent discrete steps of increasing seismic hazards. However, the change across a boundary from one zone to another zone does not represent an abrupt change in the applicable bedrock acceleration. This characteristic of a seismic zone boundary should be kept in mind when such information is used.

Special note is made that bedrock accelerations are not necessarily the same as accelerations at the surface of the ground (ground accelerations). Owing to the influence of soil deposits on vibration transmission and to the broad range of soil deposits in any region, the ground accelerations at any location may be amplified or supressed. Thus, bedrock accelerations provide only a beginning point for evaluating the ground shaking caused by earthquakes and only a general picture of earthquake severity. Ground attenuation modeling may be necessary additionally for site-specific earthquake hazards evaluations of projects that are unusually large or that are deemed sensitive to vibration effects.

From all of the above, we now are able to examine dam and reservoir facilities in Utah in terms of their likely seismic environments. The seismic hazards may be seen in broad perspective from seismic zone information, but it must be noted that site-specific seismic conditions, such as may be represented by nearby faulting or unstable soils, can be determined only from more detailed investigation. Whether or not the design basis bedrock acceleration, as may be obtained from seismic zone map, is applicable to a specific dam or reservoir site should be established after considering the specific site situation and geologic conditions. In other words, the seismic zone map furnishes only an estimate of the seismic environment at a particular location, and more information is needed for evaluating the strength or vulnerability of the dam structure. We examine these additional considerations next.

Section 3

UTAH'S DAM SAFETY PROGRAM

Authority and responsibility for design and construction of water impoundment facilities in Utah are vested by statute with the State Engineer who also serves as director of the Division of Water Rights, an agency of the State Department of Natural Resources. Although other governmental agencies (federal, State, and local) and the private sector may initiate and undertake construction of water impoundment facilities, the State Engineer has final authority in matters of engineering practices and in approval of plans and specifications for all such facilities.

The State Engineer also has responsibility for monitoring and evaluating the operation of existing water impoundment facilities in the State. In carrying out this responsibility, the State Engineer and his staff make periodic inspections of dam facilities for the purpose of assessing their safety of structure and operation. Responsibilities for the dam safety program in Utah are assigned administratively to the Dam Safety Office. This program is in the State's Division of Water Rights. A statement prepared by the State Division of Water Rights indicates the extent of oversight responsibilities relating to dam safety.

> The dam safety staff reviews plans and specifications of new dams and diversion structures to be built. Approval is necessary before construction can begin. Inspection is required during construction. Existing dams are reviewed annually. Those dams that have problems and need repair may be restricted as to their storage capacity, if determined unsafe. Repair work on existing dams must also be approved and inspected during construction. An inventory and file is maintained on all dams to assist in the inspection, management and regulation by the division. [6]

In addition to the above activities relating to dam safety, the Division of Water Rights also is engaged in carrying out reviews of water impoundment facilities in Utah in conjunction with the National Dam Inspection Act, Public Law 92-367. That Act, dated August 8, 1972, authorized the Secretary of the Army, acting through the Chief of Engineers, to carry out a national program of inspection of non-federal dams for the purpose of protecting human life and property [7]. The Utah Dam Safety Office has contracted with the U.S. Corps of Engineers to carry out the first phase of this inspection program in Utah.

The following activities are encompassed in Phase 1 of the federal dam safety program.

- The inventory of dams in the State of Utah has been updated.
- Preliminary information has been assembled from which initial dam safety estimates may be made.

- Dams contained in the inventory have been classified as to their potential hazard (low, significant, or high) in accordance with criteria established by the U.S. Corps of Engineers.
- Those dams classified as "high hazard potential" presently are being reviewed in greater detail in order to identify deficiencies and possible remedies for unsafe conditions.

Earthquake hazards are among the factors being investigated in this program. Subsequent phases of the federal program, although not yet funded by Congress, presumably will aim at preparing plans for correcting unsafe conditions for specific dams, and undertaking construction modifications of selected facilities as may be deemed necessary.

The U.S. Corps of Engineers has established the criteria for inspections of existing dams, inspection procedures to be followed, and the scope of the initial dam inspection effort. Funding for the inspections and evaluations has been limited to preparing an inventory and preliminary safety evaluations for "high hazard potential" dams in the Phase 1 effort. The Utah Dam Safety Office is bound by contract to meet the criteria established by the U.S. Corps of Engineers and to complete its initial work within the available funding.

Given the constraints of the federally funded dam safety program, the Seismic Safety Advisory Council has evaluated the review procedures for existing dams in Utah in terms of their adequacy for discovering earthquake safety deficiencies. The findings are included in Section 5 of this report.

Section 4

SEISMIC HAZARDS FOR DAMS AND RESERVOIRS

In this section we identify and discuss briefly those characteristic features of dams and reservoirs which may be vulnerable to earthquake effects, the nature of the risk exposure which may involve life safety or property losses if a water impoundment facility should fail, and the implications of these factors for establishing criteria by which to evaluate the seismic safety of such facilities. Some of the information presented herein is general in the sense that it is pertinent to water impoundment facilities in any location. Other information relates primarily to the seismic environment and other conditions unique to Utah.

Seismic Effects on Dams and Reservoirs

The principal effects of earthquakes pertinent to Utah are ground vibration, ground rupture, and soil liquefaction or subsidence. All of these effects can be hazardous for a water impoundment facility. As well, there is the possibility of other effects from an earthquake which also may be hazardous for dams and reservoirs. Earthquake-induced landslides and seiches (large waves) are among these.

Ground vibration is the most widespread earthquake effect both in terms of geographic distribution and in terms of potential damage to construction of all kinds. These ground motions induce lateral forces in structures which must be resisted to avoid failure of the structures. The forces will occur in dam structures--both earth-filled and arched structures--as well as in buildings. Dam structures may be affected in several ways by these ground motions. The effects depend upon the type of structure. For earth-filled dams, the slope of the fill may be affected when soil shear resistance decreases as a result of cyclic loading. For arched structures, cracking and displacement of the concrete may result. Spillways and other control devices to regulate water flow also may be displaced or jammed so they cannot operate.

Ground rupture, soil liquefaction, and subsidence, although less extensive in geographic extent, can be especially troublesome if any occur at the dam. Geologic investigations at the dam site are essential to discover conditions susceptible to these effects.

A seismic phenomenon less understood in the scientific community is that large water impoundments themselves may be a cause of earthquakes. The cause probably is a combination of factors--among them being the weight of the stored water, the soil permeability under the reservoir, and subsurface soil consolidation. Although engineering geologists have developed some capability to address this phenomenon, the scientific understanding nonetheless is limited. Hence, we merely note this as an additional seismic safety consideration in this report.

Seismic Risks for Dams and Reservoirs

Although the risks to life and property that dam failures could cause may be obvious, we nonetheless summarize them here for reasons of report completeness.

The primary and immediate risk due to a dam failure is the resulting flooding that can endanger life and damage property. The type and amount of development downstream from any dam therefore is a major consideration which must be addressed in siting and building the dam. To the extent that hazardous seismic conditions may exist for a dam whose flood path may pass through geographic locations moderately or densely developed, an alternate site may be preferred.

Other possible problems resulting from dam failures are loss of water supply for culinary and irrigation use, loss of power generators, and damages to transportation systems and utility lines. Such losses may include indirect economic losses as well as direct property losses.

Implications for Seismic Safety

The vulnerability of dam structures to earthquake effects appears to depend upon the type of structure (earth-filled vs. arched), size of the structure, underlying soils (geologic conditions), and the design of the structure. Although one cannot generalize all of these factors into a simple set of rules for the design of dams, one can find in the literature discussions of sensitive elements or of comparative seismic vulnerabilities for some dam features. For example, H. Bolton Seed, Professor of Civil Engineering at the University of California (Berkeley) has reported that earth-filled dams constructed of clayey soils are far more resistant to earthquakes than are dams contructed of saturated sands or other noncohesive soils [8]. For another example, the slope of the downstream face for an earth-filled dam should be determined from estimates of earthquake ground motion at the site which may be obtained from review of seismicity in the region of the dam and from evidence of ground faulting at or near the site, if any exists. Ground vibration tends to reduce the shear resistance of soils and so causes them to be less able to maintain steep slopes that normally would be stable under static loading. For yet another example, earth and rock-fill dams typically are less vulnerable to earthquakes than are arched dams, since the latter are far more brittle and prone to cracking.

Section 5

CURRENT PRACTICES AND PROCEDURES FOR ACHIEVING SEISMIC SAFETY FOR DAMS

In this section we describe and discuss current practices and procedures in Utah for achieving seismic safety for dams. New dam construction and existing dams are treated separately due to fundamental differences in the two problems.

New Dam Construction

Development of new water impoundment facilities can occur in a variety of ways and by a variety of groups or organizations. These include water user groups, local governments or improvement districts, State government, federal government, and private organizations, such as a utility company. It often is the case that the dam or reservoir is developed through a consortium of groups, each having its own interests to be served.

In all dam construction projects, the State becomes involved in the project--either because of jurisdiction over water rights or because the size of the impoundment facility places the structure under authority of the State Engineer. The State Engineer's office is the single point through which all water impoundment facilities may be monitored. State interests in earthquake safety of dams therefore may be addressed through the State Engineer and within the present statutory authorities of that office. Moreover, there is high probability that every proposed or new dam for which earthquake safety may be considered will be subject to review by the State Engineer before construction commences. It is appropriate that earthquake safety considerations for dams continue to be addressed through this procedure.

To a limited extent, the Seismic Safety Advisory Council examined practices and procedures for dam construction review as are followed in the State Engineer's Office. This examination was for the purpose of assessing the adequacy of the practices and procedures for identifying potential seismic hazards and for reviewing seismic hazards reduction measures that may be proposed by those who design the dams. Some findings pertinent to earthquake safety are summarized below.

- The State Engineer's office presently has no written guidelines or criteria for earthquake safety of new water impoundment facilities. It is reported that a written guideline is to be prepared which will include earthquake safety criteria among numerous other criteria governing the design and engineering of dams.

- Design engineers receive no written instructions for procedures that are to be followed in evaluating the earthquake hazards of a proposed dam site or for preparing seismic studies of the dam structure. It has been suggested to the Seismic Safety Advisory Council that such procedures are well understood by design engineers for dams, and that such formalized procedures may be

unnecessary. Our review of several engineering reports for proposed dams indicates there is great inconsistency and varying degrees of thoroughness in earthquake safety evaluations. This, in turn, suggests either that proper procedures and the necessary thoroughness may not be well understood, or that the complete seismic evaluations are not always documented in written reports, or that, in fact, the necessary procedures are not well understood.

- The State Engineer's office receives final reports and construction drawings and specifications for new dams which are reviewed and must be approved before construction of the facility commences. It appears that the State Engineer's office may not receive all preliminary reports which, for large projects, often are numerous at interim stages of project development. The State Engineer's staff therefore may be unaware of some factors that influence design decisions. Such lack of information may be a handicap in evaluating earthquake factors which should influence siting decisions.

- The State Engineer's staff includes competent geologists, but none are considered earthquake experts. The State Engineer therefore must seek assistance from qualified experts in other government agencies or from private contractors in order to obtain adequate seismic reviews for some projects that are submitted for approval. There are no specific procedures now in force which prescribe when or how a dam project should be reviewed by external consultants.

The Seismic Safety Advisory Council has concluded from these findings that certain modifications of current procedures and practices in the development, design, and construction of new dams would greatly improve the thoroughness by which earthquake considerations are taken into account. It must be noted here that the Council takes no position that seismically unsafe dams are being constructed in Utah. Comment was made at the beginning of this report that such determinations were not included in the scope of the Council's analysis. Rather, the Council asserts that certain modifications of present procedures and practices would reduce the possibility of unexpected seismic risk for dams.

Seismic Safety of Existing Dams

Recognizing that the State of Utah, acting through the State Engineer, presently is engaged in inventorying and reviewing most existing water impoundment facilities within the State from a safety perspective, we direct our discussion here to that aspect of the effort which involves earthquake safety.

The Utah dam safety program for inventorying and reviewing existing dams is essentially as defined by the U.S. Corps of Engineers (see Section 3 of this report). Although the State Dam Safety Office has other responsibilities besides the dam inventory and review program, those other responsibilities at the present time involve earthquake safety matters only indirectly and so are not included in this discussion. Our evaluation of the dam safety

inventory and review program included both the criteria and constraints established by the U.S. Corps of Engineers and the procedures followed by the Utah Dam Safety Office in carrying out the contract program.

Some elements of the federal dam safety program directly address earthquake safety. As noted earlier, Phase 1 of the federal program is for the purpose of inventorying dams, classifying them in terms of their risk to life safety and property hazards, and preparing preliminary reviews to discover obvious safety deficiencies. Classification of the dams is as "low hazard," "significant hazard," or "high hazard," and the classification is to be judged on the basis of the people and development downstream from the dam that are exposed to possible flooding.

Preliminary reviews of the dams are to be made in priority of their hazard classification, with those of "high hazard" classification to be reviewed in Phase 1 of the program. The preliminary review process comprises several steps--among them an inspection of the dam site to examine the condition of the dam structure and spillways and to note any obvious problems with the structure or the nearby geologic conditions. Engineering data typically is obtained from files and drawings, so that almost no field data collection is involved.

Approximately 160 "high hazard" and 90 "significant hazard" dams and reservoirs have been identified in the inventory for Utah. These classifications are based on definitional criteria established by the U.S. Corps of Engineers. Reviews of approximately 40 of the "high hazard" dams were scheduled to be made in the first-year Phase 1 program, with the remainder to be reviewed at a rate of about 40 per year thereafter as funding is available.

Criteria for seismic analyses, as established by the U.S. Corps of Engineers, include identification of the seismic hazard zone of each dam structure plus an examination of the seismicity records and faulting information for the dam site and for the surrounding region. Seismic hazard zones are as indicated in the Uniform Building Code. Funding limitations for the program are insufficient to allow on-site geologic investigations as a means to discover seismic hazards that may not have been addressed when the dam was constructed and also may not show up on seismic hazards mapping which, in Utah, is not comprehensive.

Based upon the information briefly described above, several conclusions have been reached regarding the adequacy of the dam safety program in Utah from the perspective of earthquake hazards.

- Classification of dams in terms of risk exposure to downstream populations and development is reasonable and provides an adequate basis for setting priorities for follow-up dam safety reviews.

- Preliminary review procedures for "high hazard" dams do not appear to be thorough enough so that unknown seismic hazards may be discovered. Reliance upon existing seismic records and maps for determining earthquake potential has limited validity when such data are known to be incomplete. Visual site inspections will not reveal much valuable information about the seismic vulnerabilities of the dam structures. Fill

characteristics for earth-filled dams, for example, cannot be determined from visual inspection, nor can one be confident that the fill is as shown on the drawings, if drawings even exist, for dams constructed many years ago before seismic safety was considered. Yet, fill conditions have direct significance to the stability of a dam subjected to earthquake motions. The Seismic Safety Advisory Council is not convinced that the present review procedures will add new knowledge regarding the earthquake safety of existing dams. The Council recognizes that these procedures are established by the U.S. Corps of Engineers and not by the Utah Dam Safety Office, but the deficiencies in these procedures from the point of view of seismic safety cannot be left without comment.

- Classification of dams in accordance with their location in seismic risk zones prescribed in the Uniform Building Code causes certain theoretical and practical problems which could result in underestimates of the seismic hazard for particular dams.

  One theoretical problem is that the Uniform Building Code seismic zones are intended to be used in concert with other sections of the code for the design of buildings. The seismic zones do not include values for accelerations; although these data may be obtained from other sources. The more important point, however, is that the accelerations one can infer from the seismic zones are derived from consideration of bedrock motion and structure response to the motion. The acceleration values are not ground motions. The actual earthquake ground motions are likely to have larger accelerations. Hence, use of accelerations inferred from the Uniform Building Code is not theoretically correct.

  A practical problem in using the seismic zones contained in the current Uniform Building Code (UBC) is that these zones are out of date. Present knowledge of seismicity in the State of Utah has advanced a great deal since the UBC seismic zones were established in 1970, and these advances in knowledge have yet to be introduced into the code. We observe these advances here; since the central portion of the State (defined roughly by the Wasatch fault) is believed to have a more severe seismic environment than heretofore has been considered; whereas seismicity in other portions of the State may be less severe than is implied by the UBC seismic zones.

As is the situation with new dam construction procedures and practices, the Seismic Safety Advisory Council has concluded that modifications could be made in the dam safety program for existing facilities that would improve the effectiveness of the program for evaluating the seismic safety of these facilities.

Public Responsibilities

We have so far discussed the responsibilities of those who build water impoundment facilities in safeguarding the public from hazards that

might be caused by earthquakes. There is yet another type of responsibility that is borne by the public to safeguard themselves. It is not uncommon that population settlement and development tend to occur in areas where water impoundments already exist. Dams and reservoirs originally constructed in areas of no or low population and development may in later years be designated as "high risk" facilities simply because of this ever expanding settlement.

Utah's citizens and local governments have a responsibility to avoid settlements and developments in downstream flood-plain areas that may create high risk exposure where none existed before settlement or development. Since such settlement is the root cause of the "high risk," and since design standards for the water impoundment facility likely were based upon different risk conditions at the time of its construction, these conditions should be taken into consideration when subdivisions are approved and when roads and utilities are constructed at a later date.

Given the life safety risks and potential for large property losses that are created by imprudent development downstream from dams, the State may find that strict zoning controls for land use need to be applied in conjunction with the construction of dams if the public and local governments fail to meet their responsibilities in this matter.

Section 6

RECOMMENDATIONS TO IMPROVE SEISMIC SAFETY FOR DAMS

In this section are listed those recommendations set forth by the Utah Seismic Safety Advisory Council that are believed, if adopted and implemented, would beneficially improve the State's capabilities to protect life and property from hazards posed to water impoundment facilities by earthquakes. These recommendations deal primarily with administrative procedures by which the State oversees and regulates the construction and operation of water impoundment facilities. Technical criteria for the design of new facilities and the criteria used in evaluating the safety of existing facilities are not directly treated, though some recommendations that deal with procedures are derived from technical considerations regarding earthquake effects.

Recommendations

1. An analysis of the seismic hazards of the site should be required for each new water impoundment facility 25 or more feet in height or that will have an impoundment capacity of 50 acre-feet or more of water, unless in the judgement of the State Engineer other criteria may be suitable for a specific facility. The State Engineer may require such analyses for other water impoundments when risk exposure of downstream populations and developments may, in his judgement, be hazardous. The extent of analysis may vary in accordance with the degree of risk that considers population and development density in downstream flood areas, the size of the impoundment, and the seismicity of the region. A risk classification system should be established to be used as a guide for siting and constructing the dams so that the hazards posed by earthquakes are appropriately mitigated, either by locating the dam in a less hazardous location or by constructing the dam to resist the possible earthquake effects. The seismic hazards evaluation should be prepared as a part of feasibility studies before final decisions are made regarding the location and siting of any dam. The findings of such an analysis should be documented in a report for each facility which will become a part of the permanent records of the facility.

2. Seismic design criteria for each dam should be derived from the seismic hazards analysis, should be followed in the design of the facility, and should be the basis for subsequent design reviews regarding adequacy of the facility. The seismic design criteria should be documented in a written report.

3. The State Engineer should require that a preliminary seismic report be furnished for review before approval is given for locating any water impoundment facility. Subsequent seismic reports should be required for all facilities which are found

to be potentially hazardous, and these reports should describe the seismic conditions, the hazards, and the methods that will be employed to mitigate or reduce the hazards. Subsequent reports normally will not be necessary for non-hazardous dams.

4. Independent review of the seismic conditions should be provided for all large or high-hazard dams. Such independent review should be coordinated by the State Engineer, and should be by qualified persons who have no other relationship with the project, either those developing and constructing the dam or those employed by the State to approve the construction. Independent review should be for the purpose of confirming the validity of decisions involving the seismic safety of the facility or for discovering errors and ommissions in final construction documents.

5. The dam safety program for evaluating the safety of existing dams and reservoirs presently being conducted by the State, under contract with the U.S. Corps of Engineers, should be modified to provide more extensive evaluation of earthquake hazards for those facilities classified as either "high risk" or "significant risk." Program modifications should include (1) more thorough evaluation of the site (field and office investigations) for the purpose of discovering conditions of seismic risk, and (2) the taking of core samples from embankments of earth-filled dams when fill materials are not known. Since the dam safety program referred to has been established by the U.S. Corps of Engineers, the State Engineer should proceed to seek appropriate changes in the contracted work which will satisfy this recommendation.

REFERENCES

[1] Arabasz, W.J., R.B. Smith, and W.D. Richins, Earthquake Studies In Utah: 1850 to 1978,

[2] Cook, K.L., and R.B. Smith, "Seismicity in Utah, 1850 through June, 1965," Bulletin of the Seismological Society of America, Volume 57, No. 4, pp. 689-718; August, 1967.

[3] U.S. Geological Survey, A Study of Earthquake Losses in the Salt Lake City, Utah Area (Washington, D.C.: United States Department of the Interior, Geological Survey, 1976, Open-File Report 76-89).

[4] Cook, K.L., "Earthquakes Along the Wasatch Front, Utah -- The Record and the Outlook," Earthquake Research and Knowledge, Hearing before the Committee on Aeronautical and Space Sciences, United States Senate (Washington, D.C.: United States Government Printing Office, 1975).

[5] Algermissen, S.T. and D.M. Perkins, A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States (Washington, D.C.: United States Department of the Interior, Geological Survey, Open-File Report 74-416, 1976).

[6] Description of the Division of Water Rights, appearing in Notebook of the Department of Natural Resources, State of Utah; 1979.

[7] Federal Register, Volume 44, No. 188, September 26, 1979; pp. 55336-55375.

[8] "Research Identifies Causes of Earth Dam Failures," EERC News, Volume 3, November 2 (Earthquake Engineering Research Center, University of California; June, 1979).

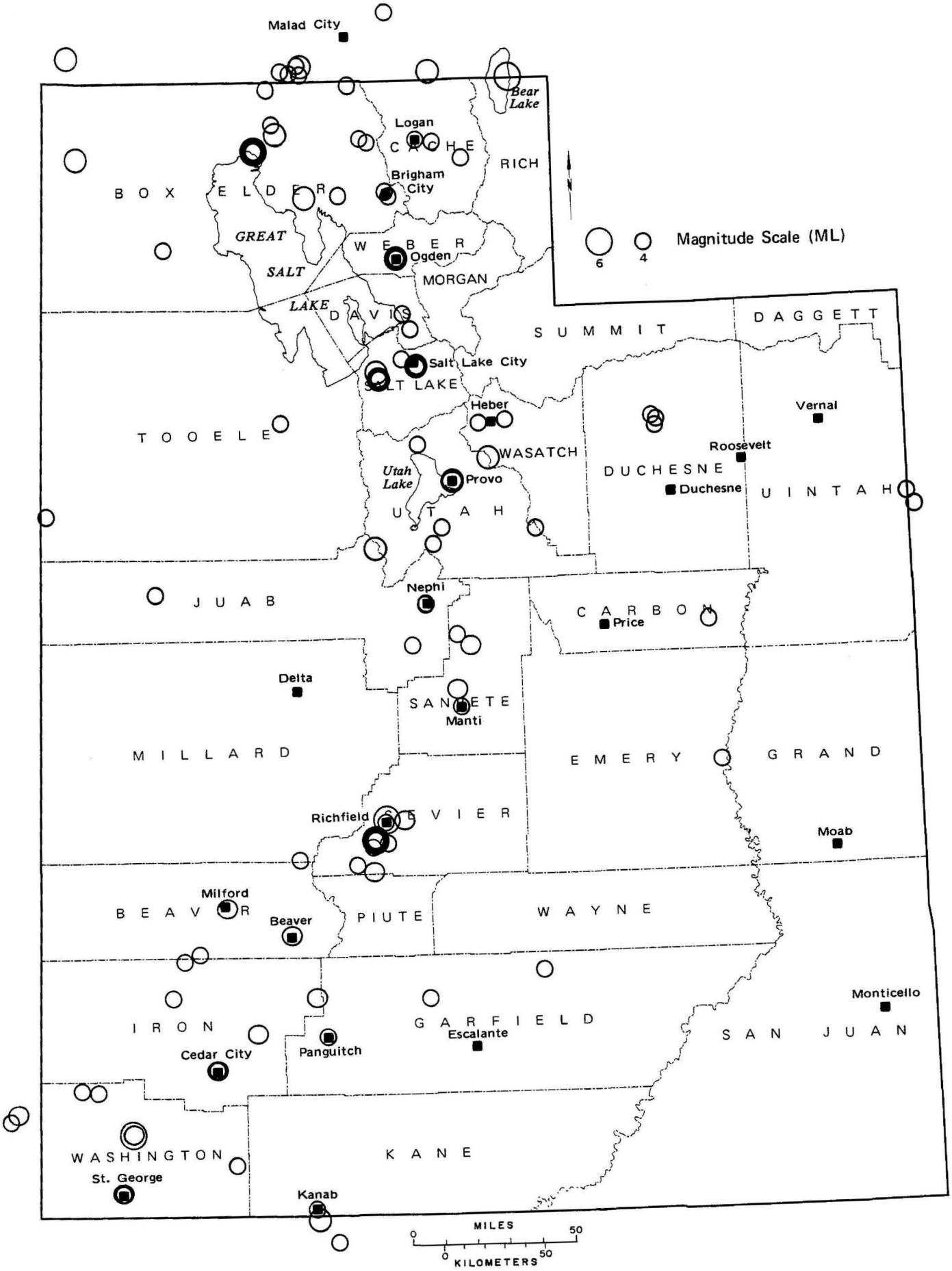

Figure 1

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)

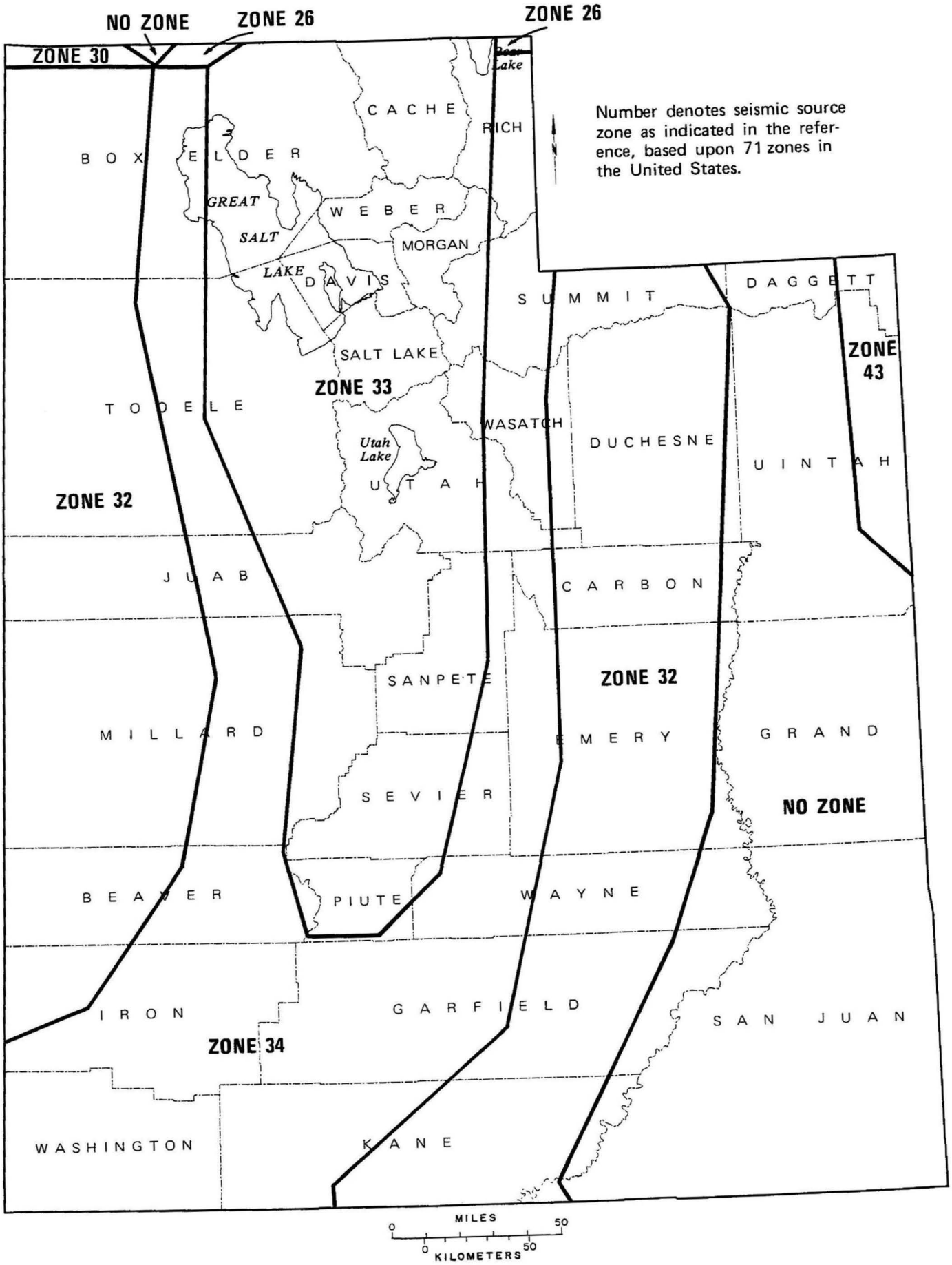

Figure 2

SEISMIC SOURCE AREAS IN UTAH

(Reference: S.T. Algermissen, and D.M. Perkins, USGS Open File Report 76-416)

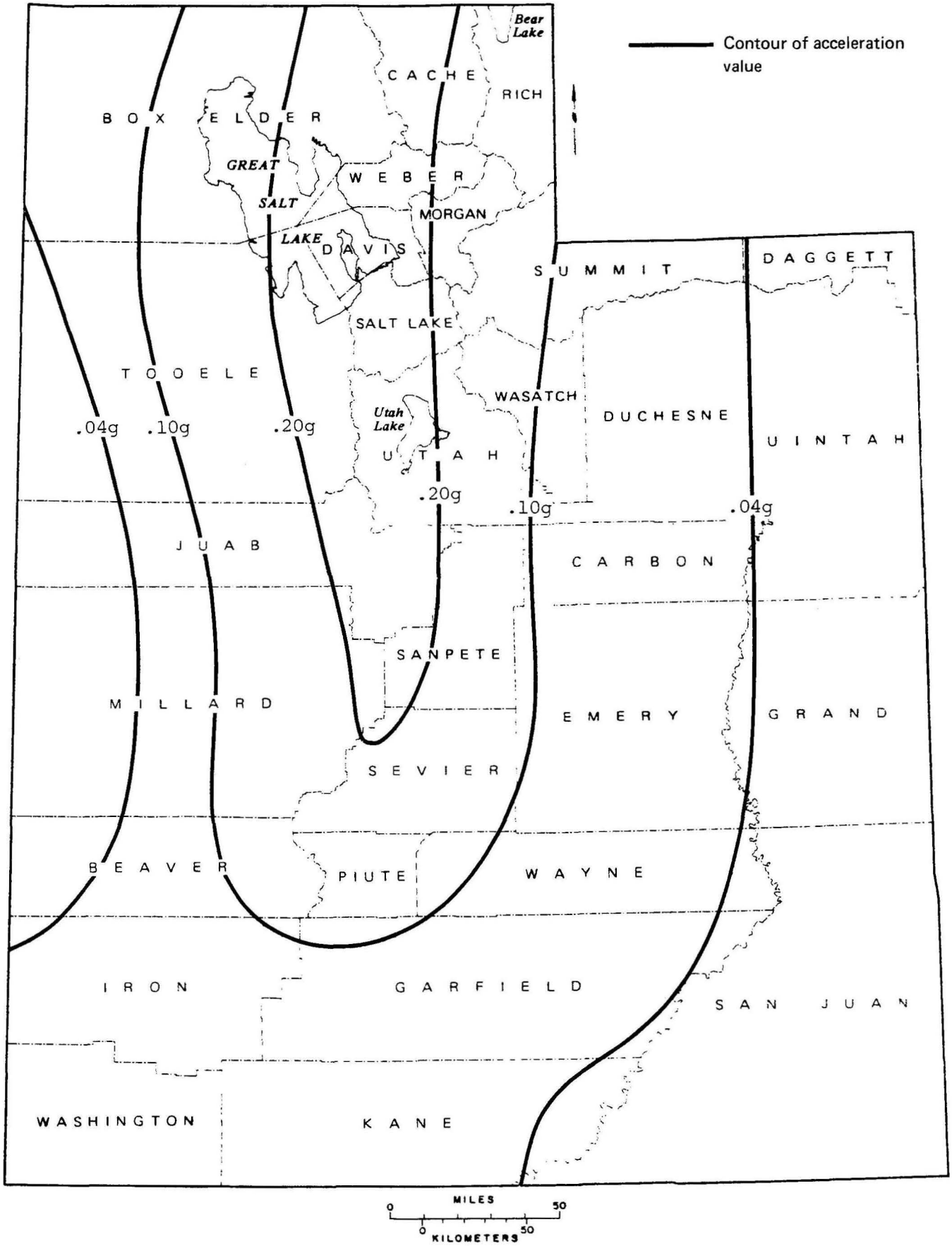

Figure 3

HORIZONTAL ACCELERATION IN ROCK WITH 90 PERCENT PROBABILITY OF NOT BEING EXCEEDED IN 50 YEARS (EXPRESSED AS PERCENT OF GRAVITY)
STATE OF UTAH
(From S.T. Algermissen & D.M. Perkins, USGS Open File Report 76-416, 1976)

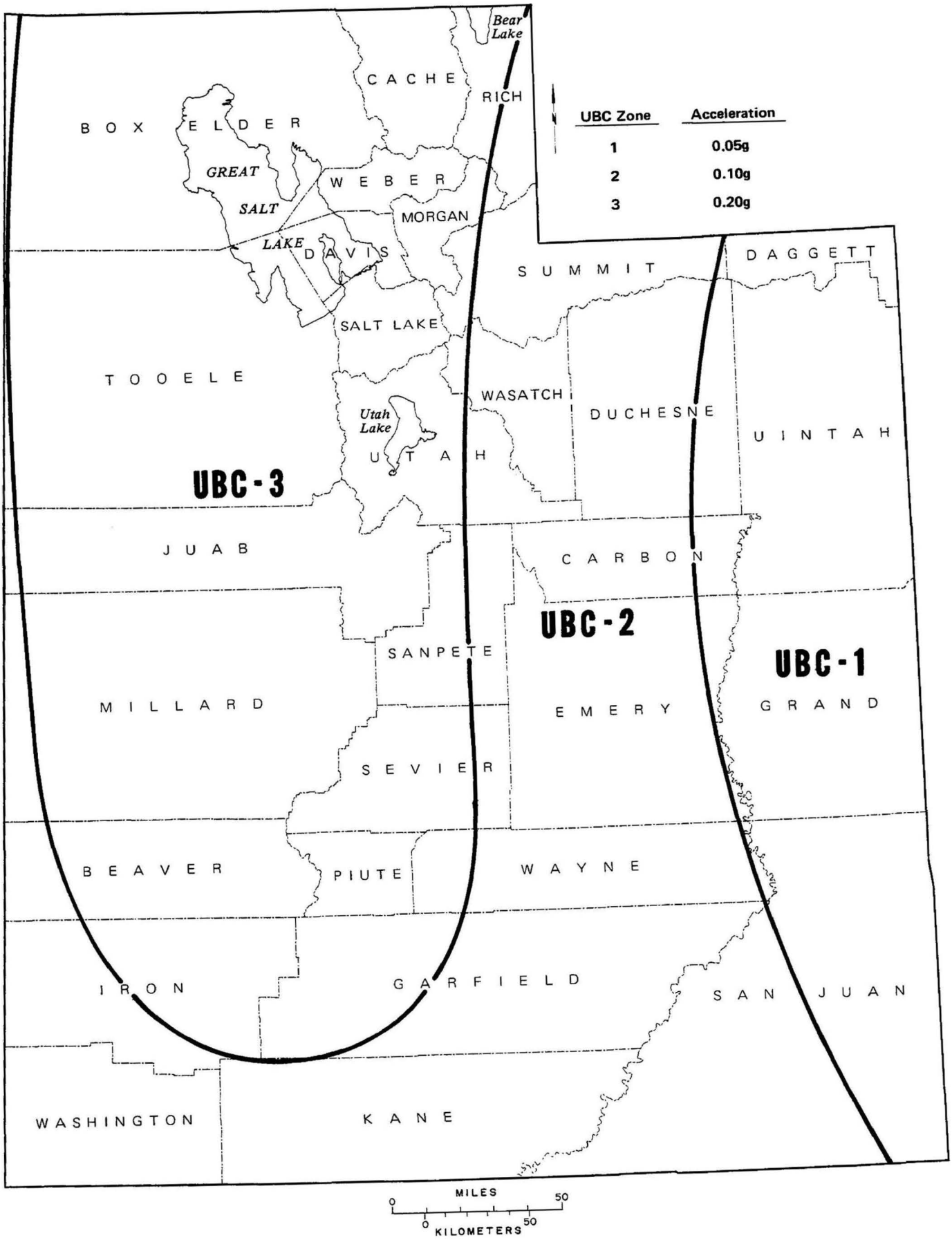

Figure 4

SEISMIC ZONES—1976 UNIFORM BUILDING CODE
STATE OF UTAH

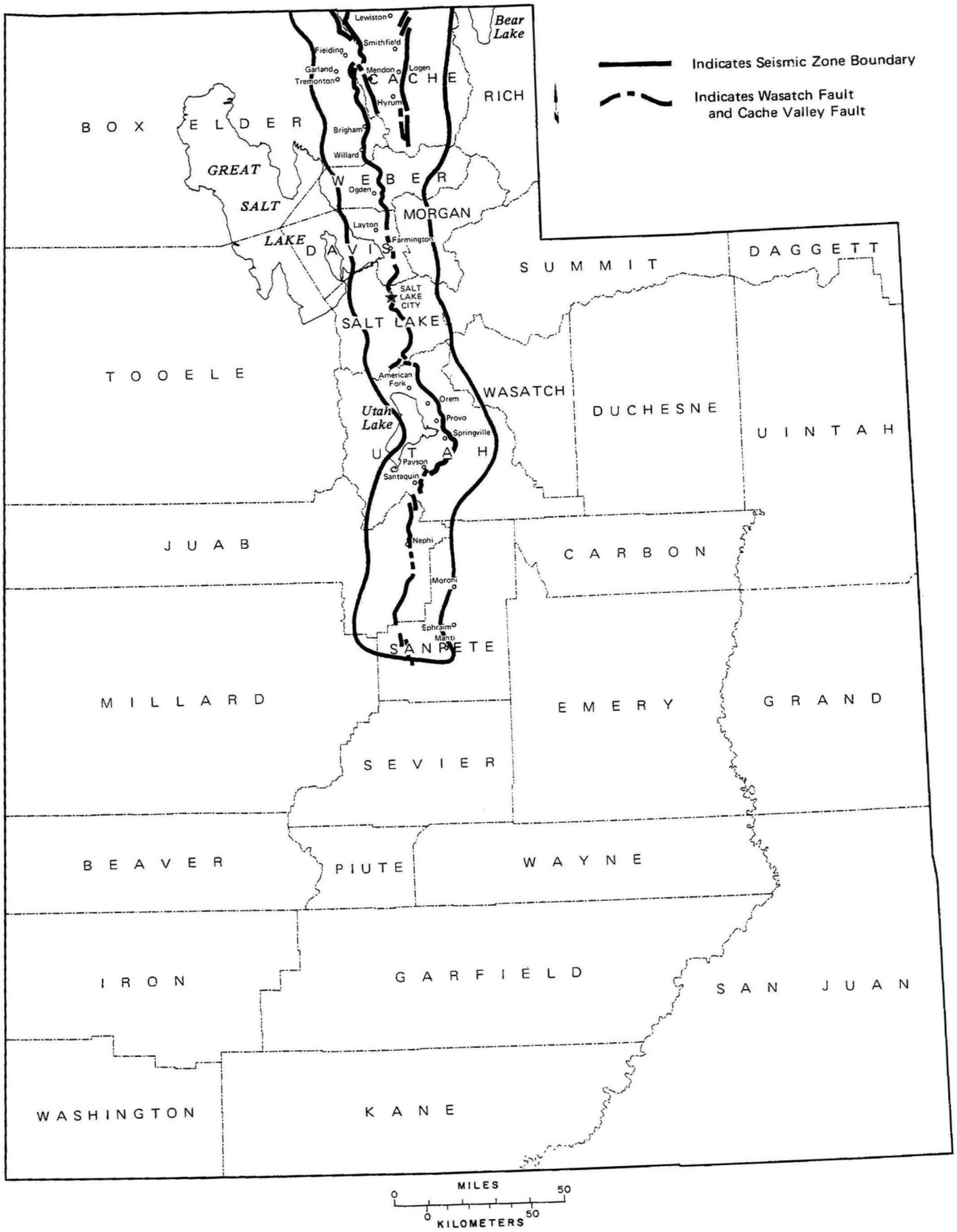

Figure 5

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

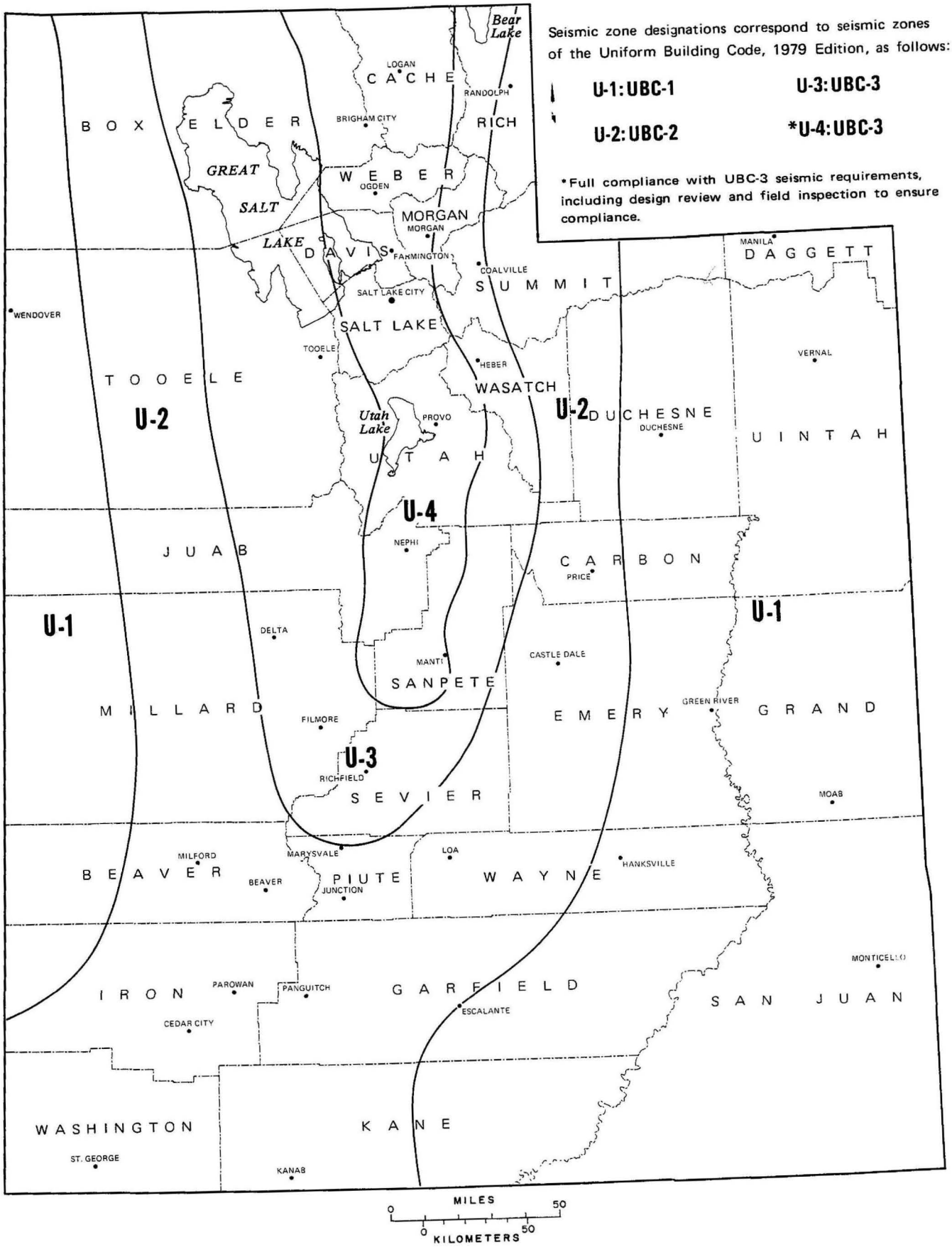

Figure 6

SEISMIC ZONES

January 1980

(Recommended by the Utah Seismic Safety Advisory Council)

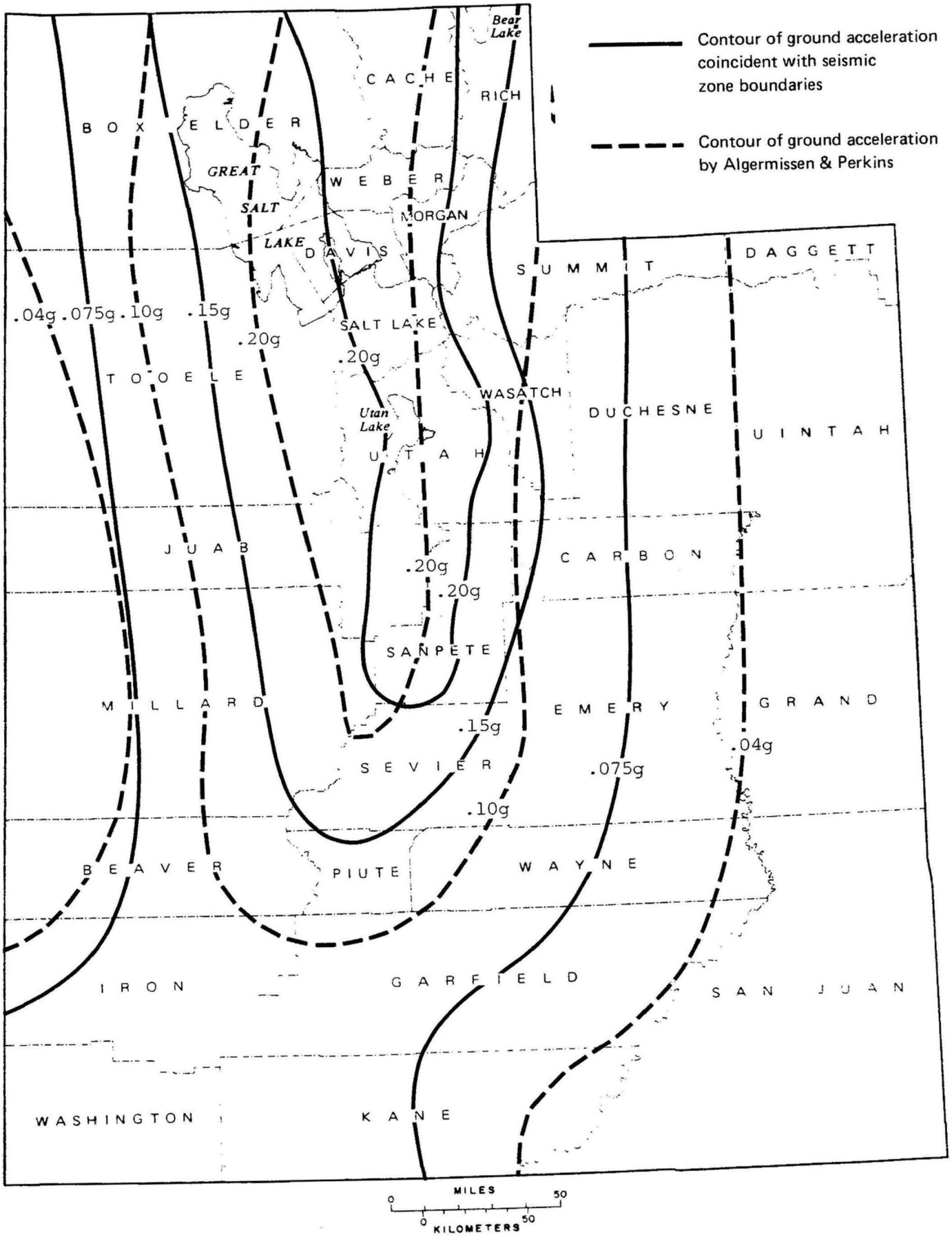

Figure 7

GROUND ACCELERATION CONTOURS DETERMINED BY ALGERMISSEN & PERKINS
COMPARED WITH CONTOURS COINCIDENT WITH SEISMIC ZONE BOUNDARIES FOR CONSTRUCTION
STATE OF UTAH