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A Study of Geologic Hazards and Geotechnical Input for Selected Critical Facilities - Cache Valley, Utah

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A STUDY OF GEOLOGIC HAZARDS AND GEOTECHNICAL INPUT FOR SELECTED CRITICAL FACILITIES - CACHE VALLEY, UTAH

by

Kenneth Robert Green

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Engineering

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1977

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Kenneth Robert Green

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ABSTRACT

A Study of Geologic Hazards and Geotechnical Input for Selected Critical Facilities - Cache Valley, Utah

by

Kenneth Robert Green, Master of Science

Utah State University, 1977

Major Professor: Dr. Loren Runar Anderson
Department: Civil and Environmental Engineering

Important public facilities located in Cache Valley, Utah, were studied to assess their exposure to geologic hazards. Also, the level of geotechnical and geologic expertise involved in the siting, design, and construction of critical public facilities was studied. A discussion of several individual facilities, that were exposed to some degree of hazard, was presented to illustrate the nature of the problem.

Earthquake hazards probably constitute the greatest threat to facilities and to the general welfare of the public. Many earthquake hazard mitigation measures were discussed and recommendations were made, based on aseismic design criteria which has been developed for seismically active areas such as California.

A goal of this study was to present information concerning the seriousness of the current geologic hazard situation in Cache Valley, Utah, in an attempt to help generate public interest in understanding and correcting the problem.

(140 pages)

CHAPTER 1

INTRODUCTION

Nature of Problem

Cache Valley and other parts of Utah are susceptible to certain types of geologic hazards. For the purpose of this study a geologic hazard has been defined as a geologic condition that poses a threat to a structure or community in a manner that threatens life, property, and essential activities. This study was conducted to evaluate geotechnical input and to identify geologic hazards that could influence vital facilities used by the public.

Certain geologic processes or events pose hazards which if not properly guarded against could cause damage or destruction. This damage could in turn lead to social and political disorder, loss of life, and loss of financial or physical investment. Proper planning, analysis, and design of structures and appropriate consideration of the natural forces acting on them will minimize the negative effects of disruptive forces.

During the course of this study, lifeline facilities, emergency service structures, and other important public facilities were studied from a geotechnical and geologic viewpoint. Lifeline facilities are utilities such as pipelines, transmission lines, transportation and communication lines which are owned and operated by public entities and utility companies. These facilities are classified into four general categories by the American Society of Civil Engineers and are listed below:

- Energy
- Water
- Transportation
- Communication

A further breakdown of lifelines is shown in Table 1-1 after Duke (1975).

Table 1-1. Lifeline facilities (after Duke, 1975).

Energy	Water
Electricity	Potable
Gas	Flood
Liquid fuel	Sewage and solid waste
Transportation	**Communication**
Highway	Telphone and telegraph
Railway	Radio and television
Airport	Main and press
Harbor	

Emergency service structures can be identified as:

- Government buildings housing principal emergency operating centers
- Police stations and security cells
- Fire stations and ambulance housing stations
- Hospitals and medical clinics
- Convalescent homes

Lifeline and emergency service structures are facilities which must remain operable in the event of a major geologic disruption as well as during everyday activities. Special design and construction considerations are, threfore, warranted to assure that these facilities remain operational during and after all types of natural and man created disasters. Because of the nature of certain lifeline and critical facilities, additional precaution should be taken to protect life, property, and certain essential activities from the disruption of the facility itself. Disruption of gas or liquid fuel lines, contamination of potable water supplies because of broken sewage lines, or release of large bodies of water contained by a dam are just a few examples of such problems. Duke (1975) summarizes several serious implications associated with failure of lifeline and emergency service structures, considered from the viewpoint of their impact on society.

- Direct financial losses
- The inability to protect against secondary disasters such as fires, famines, epidemics, and crime.
- The inability to protect against the lifeline itself if its nature is such that it may become a hazard to life and property.
- Suspension of employment and other activities which are dependent upon the lifeline.

It is important that high occupancy and certain other important public facilities be designed to provide public safety. These structures must be analyzed, designed, and constructed to minimize the level of risk associated with geologic hazards. Although these structures may not be required to remain operable after a disruption, a serious failure of the structure clearly poses a threat to loss of life, property, and human activity. Also, during this study, the following types of existing and proposed high occupancy and important public facilities were reviewed from a geotechnical viewpoint:

- Schools
- Large apartment complexes
- Office buildings higher than 3 stories
- Dams higher than 20 feet (6 meters) or retaining more than 50 acre-feet (61,700 cubic meters) of water.

Many types of geologic processes act slowly to degrade engineering works. Proper planning, analysis, design, construction, and appropriate consideration of the natural forces at work will greatly minimize the problem.

Characteristics of Cache County

Cache Valley, Utah, is a geographical subdivision lying within the bounds of Cache County and is located in the northeast corner of Utah. Figure 1-1 shows the county boundary and indicates the approximate limits of Cache Valley, Utah. Figure 3-14 shows the location of Cache County within the bounds of Utah. Box Elder County, a much larger county lies to the west, and Rich County, a smaller county, lies to the east.

Cache County is one of 29 Utah counties. It ranks 5th in population and 23rd in size among the other counties. The 1970 census indicates that about 42,300 people reside in Cache County and Logan is the largest city with a population of approximately 24,000. Most of the people live in towns and rural communities but many live on farms.

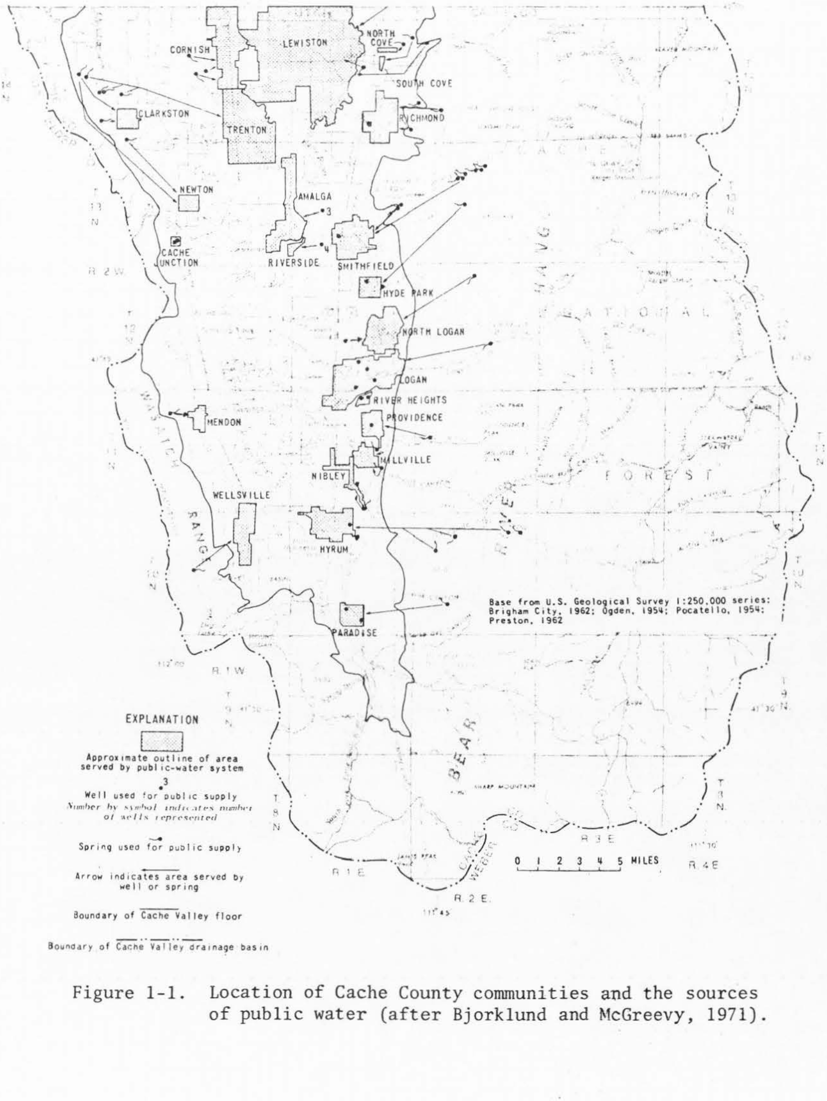

Figure 1-1. Location of Cache County communities and the sources of public water (after Bjorklund and McGreevy, 1971).

Agriculture and light industry provides the primary economic activity of the county. Most of the valley land, up to the foothills, is irrigated and farmed and in many areas where topography and slope permits, the foothill benches are dry-farmed.

Utah State University is located at Logan and was founded in 1888. The university is widely recognized as one of the leading institutions in Agriculture and Water Resource Technology. Its presence plays an important part in the economic and cultural life style of the county.

Cache County's climate is moderate and dry. Average summer maximum temperatures range from 80°F to 90°F and average winter conditions are cold. The valley normally receives approximately 20 inches (50.8 cm) of precipitation annually with the accumulations of up to 50 inches (127 cm) normally occurring in the mountains (Jeppson et al. 1968). Snow usually covers the valley floor during December, January and February. The frost-free season is usually about 150 days, lasting from May through September (Bjorklund and McGreevy, 1971).

Purpose of Study

For this study, geologic hazards were divided into two groups; seismic hazards and other geologic hazards. These hazards, some of which may influence many local vital facilities, are listed below and are described in detail in Chapter 3.

Seismic hazards

- Strong ground shaking
- Surface fault rupture
- Liquefaction

- Miscellaneous ground failure
- Seiches

Other geologic hazards

- Landslides
- Flooding
- Erosion
- Expansive soil
- Subsidence

The purpose of this investigation was to study the level of geotechnical and geologic expertise that was involved in the siting, design, and construction of existing critical public facilities, and to study geologic hazards threatening existing structures in Cache Valley, Utah, in an effort to provide insight to improve future construction. This study was intended to be indicative of the adequacy of current design practices in Cache County.

Geologists and geotechnical engineers should both play an important role in the siting, design, and construction of vital public facilities. The geologist is involved in the study of geology which Legget (1962) defines as:

> "That branch of natural science devoted to the study of the physical features of the earth, the composition and structure of the rocks composing it, the forces at work in altering it, and the record of the animals and plants that have lived on its lands and inhabited its seas." (Legget, 1962)

The geologist's input into the planning of engineering works is based largely on observation. Geologic events that have transpired in the past are studied in an effort to define the physical nature, composition, and forces which may act on earth materials in the future.

The role of the Geotechnical Engineer is to study the earth materials and their ability to support engineering works. The Geotechnical Engineer often uses tests on the soil and various analytical procedures to help predict future behavior. The chief difference between the fields of geology and geotechnical engineering is that in geology, observation predominates and in geotechnical engineering, testing and analysis predominates. Competency in these disciplines requires experience. Proper evaluation of a site should incorporate a planning, testing, and analysis program which is based on a team effort involving both a geologist and a geotechnical engineer.

Methodology

Most of the facilities reviewed during this study are owned and operated by communities within Cache County, Utah. Table 1-2 is a list of communities involved and the approximate population of each (1970 census). Figure 1-1 by Bjorklund and McGreevy (1971) shows the location of the communities and indicates the sources of public water.

Basic data was collected on existing and proposed vital facilities. This data was studied to assess the level of geotechnical input and to identify problem areas associated with geologic hazards. Collection of the basic data for each facility consisted of a detailed site examination of the facility and its environment, conversations with persons known to be knowledgeable about the design or construction of the facilitiy, reviews of published environmental and geotechnical reports pertaining to the facility and reviews of all available plans, specifications, design or construction notes, and reports on the facility. In some cases, especially those involving older structures, little or no information or documentation was available to indicate design considerations or thoroughness of the geotechnical investigation. Accurate and meaningful collection of facility data was largely dependent upon the cooperation received from the design professionals, owners, and persons knowledgeable about the facility. If their cooperation was lacking or if the information was not available, the evaluations of the facility may have reflected less geotechnical design and construction considerations than actually may have been addressed.

Table 1-2. List of communities included in this study.

Community	Population
Amalga	220
Benson	90
Clarkston	550
Cornish	200
Cove	50
Hyde Park	1200
Hyrum	2400
Lewiston	1300
Logan	24000
Mendon	365
Millville	450
Newton	470
Nibley	380
North Cove	50
North Logan	1500
Paradise	420
Providence	1700
Richmond	1050
River Heights	1050
Smithfield	3500
Trenton	400
Wellsville	1300

The state-of-the-art in geotechnical engineering has advanced significantly in the last several decades. Accordingly, the design standards for most facilities constructed in recent years were much more rigorous than the standards used during the construction of older structures. Since this evaluation involved the study of geotechnical considerations given to the planning, design, and construction of various facilities in light of current standards, present day standards provided the basis for comparison. It was also recognized that certain types of structures require special considerations and individual attention. The design of a vital facility such as a hospital warrants a very detailed and thorough geologic and geotechnical investigation. In contrast, a culinary water storage facility would not warrant the detailed site investigation that a hospital would require. However, these are both critically important facilities which must be designed to assure a high level of dependability.

In reviewing individual facilities, a subjective judgment was required to evaluate the level of geologic and geotechnical expertise which should have been involved in the siting, design, and construction of the facility. Guidelines, as set forth by various state and Federal agencies, private design professionals, and universities, were used in making these judgments.

Chapter 3 discusses many of the important geologic hazards that could affect individual facilities and some of the guidelines that should be employed during siting, design, or construction of a facility. In carrying out the study, the actual geologic and geotechnical expertise that was employed with the design and construction of a facility was compared with the subjective judgment of what should have been required for the facility. A discussion of apparent hazards affecting some facilities is included in Chapter 4. The purpose of the discussion of Chapter 4 is to indicate that certain geologic hazards do exist in Cache County and may influence the safety of some critically important structures. The discussion of Chapter 4 is not intended to reflect negatively on any community or organization nor is it intended to indicate that better alternatives to siting design or construction were available in all cases. It is intended to indicate that certain geologic hazards may pose a threat to vital utilities and structures and that the hazards must be acknowledged and studied as necessary for the safe operation of the facility.

This study considered only the geologic and geotechnical features affecting a site and did not evaluate such factors as hydraulic design, political or social impacts, or economic considerations. The proper siting, design and construction of a facility must consider all of these factors.

CHAPTER 2

GEOLOGIC SETTING

General Features

Cache Valley is a north-south trending elongate basin located partly in Utah and partly in Idaho. The valley floor is about 60 miles (97 kilometers) in length with approximately 35 miles (57 kilometers) in Utah and 25 miles (40 kilometers) in Idaho. The width varies roughly from 8 to 16 miles (12.8 to 25.7 kilometers), with the widest point being at the Utah-Idaho border. The valley's drainage basin which is part of the Bear River Basin, includes approximately 1,840 square miles (4765 square kilometers). The lowest point in the valley, where the Bear River exits at Junction Hills, is about elevation 4,400 feet. Mountain ranges surround the county on three sides; the Bear River Range to the east, the Bannock, Malad, and Wasatch Ranges to the west and the South Hills to the south. The valley floor is at an approximate elevation of 4500 feet above sea level and is principally composed of lacustrine sediments deposited in the ancient Lake Bonneville which once flooded the valley.

Cache Valley is a complex graben, bounded by basin and range faults on both sides. The valley is the downthrown fault block and is composed of sediments of Cenozoic Age. The uplifted blocks forming the surrounding mountain ranges are composed mainly of rocks of Paleozoic Age and limestone and sandstone are the predominant rock types. The faults on either side of the valley are steeply dipping normal or gravity faults and are recognized as active. (Refer to Figure 2-1 by Williams, 1962.) The vertical displacements along these fault systems may exceed 10,000 feet (3048 meters) in some locations (Bjorklund and McGreevy, 1971). This horst and graben geologic structure is typical of the basin and range Physiographic Province.

Utah is seismically active and is part of the Intermountain Seismic Belt. Principal active fault zones such as the Cache Valley Faults and the Wasatch Fault are part of this sesimic belt and are discussed in detail in Chapter 3.

Lake Bonneville

During and subsequent to the fault movements the valley has continually received clastic sediments which have backfilled the valley to its present level. The deposition of these sediments was largely controlled by the ancient Lake Bonneville which once occupied the valley. Lake Bonneville existed during the Pleistocene epoch and covered a major portion of Utah and extended into Idaho and Nevada (see Williams, 1962, pp. 131). The Great Salt Lake is the present remnant of the ancient lake and is now approximately 950 feet (290 meters) lower than the maximum Bonneville elevation. The elevation of the present Great Salt Lake has not risen higher than about 110 feet (34 meters) above the current level for over 11,000 years (Williams, 1958).

The level of Lake Bonneville is known to have fluctuated over a wide range of elevations. Two distinguishable levels can be traced in the Cache Valley. The lake is thought to have risen to an approximate elevation of 5135 feet during the maximum cycle, which is known

Lake Bonneville

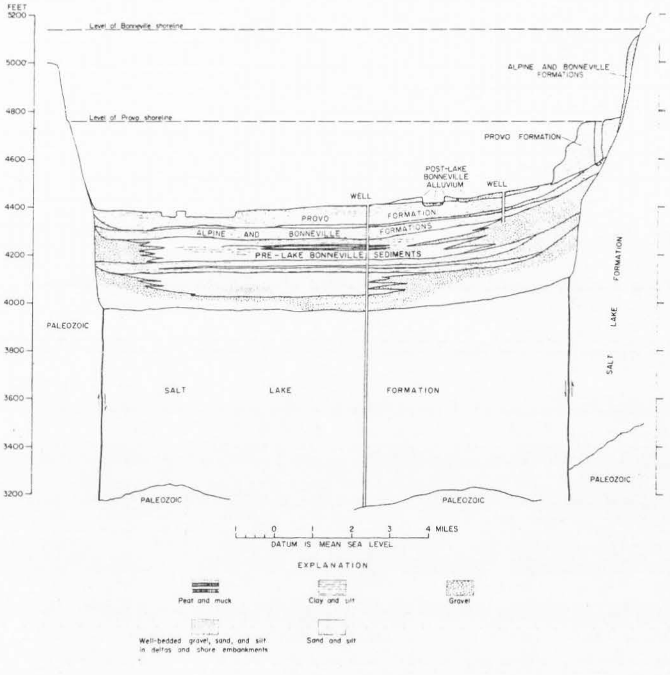

Figure 2-1. Diagrammatic cross-section of Cache Valley from Cache Butte through Amalga to Smithfield (after Williams, 1962).

as the Bonneville level. The lake then receded to a lower level and possibly even dried up for a short geologic time before returning to the Provo level. The Provo level is found at about elevation 4800 feet. Due to fault displacements subsequent to the development of these two beach terraces, these levels are not consistent throughout the valley. It has been indicated that the Bonneville level differs as much as 100 feet (30 meters) at different locations within Cache Valley (Bjorklund and McGreevy, 1971). It is also suggested that the difference in shoreline elevations may be partly due to isostatic rebound due to unloading as Lake Bonneville receded (Bjorklund and McGreevy, 1971).

The Bonneville level sediments cover many of the higher bench areas up to the foothill areas. These sediments range in thickness from about 50 to 100 feet (15 to 30 meters) and are the oldest of the Lake Bonneville unconsolidated sediments. They are composed mostly of silt but also include some gravel in embankments and small deltas.

The Provo level sediments are found extensively in the Cache Valley and they cover the older Bonneville level sediments in many areas. The Provo formations include extensive gravel deposits in spits and river deltas, as well as lacustrine silt and clay sediments that settled from suspension in the lake water onto the lake bottom. The thickness of this formation is as much as 75 feet (23 meters) in some locations but varies from 50 to 75 feet (15 to 23 meters) in thickness (Williams, 1962).

Provo level deposits are most important in the Cache Valley, since they make up the sand and gravel deposits found in this area.

The east side of the valley illustrates this fact, since each of the principle streams entering the valley has formed large sand and gravel delta deposits at the mouths. This can be seen at the mouths of the Little Bear River, Blacksmith Fork, Providence, Logan, High Creek, and Cherry Creek canyons. These large deltas, partly reworked by the parent streams as Bonneville Lake receded from the Provo level, produce the terraced land forms as seen today. Utah State University stands on the major Provo level bench, and the city of Logan occupies three or more of the small recessional benches.

The towns of Lewiston, Cornish, Trenton and Benson have been built on a large sand levee along the Bear River. This levee was formed as the river followed its course during the time when the water was receding from the Provo level. The sand was derived from a large sand delta at the north end of the valley which was formed when the lake stood at a higher elevation. As the lake receded, the delta was disected and the sediments were carried over the new flood plains, toward Junction Hills, where the river presently exits from the valley.

Groundwater

Groundwater is generally abundant in the valley. The source of the water is mainly from the Paleozoic rocks of the mountains, which feed sand and gravel deposits within the valley. Solution within Paleozoic carbonate rocks of the Bear River Range has developed zones of high permeability, especially along joint systems and bedding planes. Although a few large caves have developed as solution channels in these rocks, large solution channels are not found abundantly.

Within the valley areas, below the foothills, most of the developed groundwater systems derive their water from wells. However, where coarse alluvium lies above Lake Bonneville silt and clay deposits contact springs are common. For instance, the major river deltas of the Provo sediments such as the Logan River and the combined deltas of Blacksmith Fork and the Little Bear River lie above the fine lacustrine lake sediments. The groundwater moving into the valley from the mountain sources travels in the pervious zones, above the fine grained lacustrine deposits. Similarly, where post Lake Bonneville deposits extend out on the old lake bed the springs are found to occur along the sides and ends of the deposit.

Typical of lacustrine deposits and the fluctuating level of Lake Bonneville, inter-tongued layers of silt and clay, and sand and gravel was deposited along the sides of the valley in the subsurface strata. The coarse grained sediments in these layers store large quantities of groundwater and provide a high enough permeability that the water is readily available if tapped. Many of these large underground aquifers are confined from near the recharge areas of the foothills to far out into the valley and consequently, widespread artesian conditions are prevalent. These aquifers are probably sheets and channels of coarse grained sediments which grade valleyward into sand (refer to Figure 2-2 by Bjorklund and McGreevy, 1971). The illustration in Figure 2-2 shows the confining nature of the fine-grained sediments and provides an idealistic portrayal of the movement of groundwater from the mountains to the valley. Piezometric heads of as high as 62 feet (18.9 meters) above the land surface have been reported near

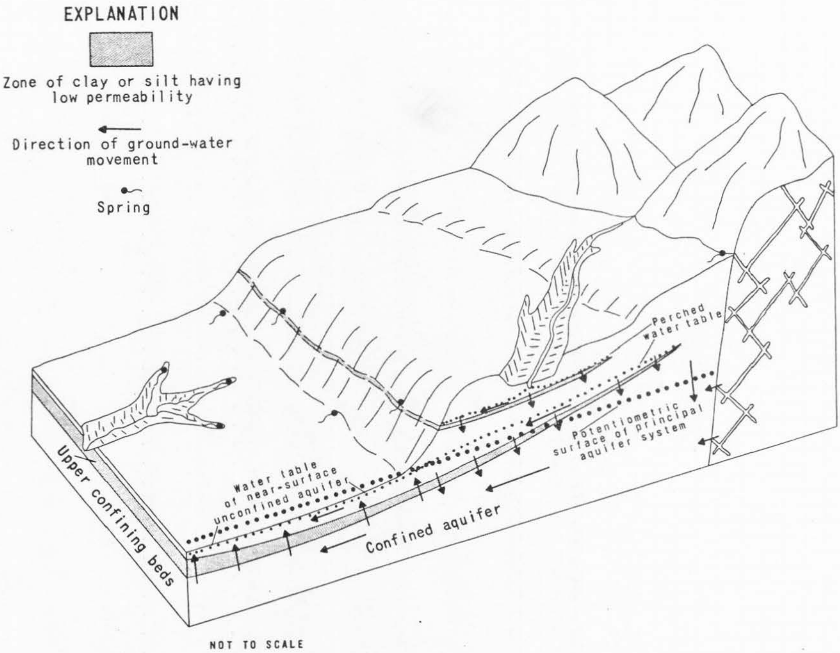

Figure 2-2. Relation of confined, unconfined, and perched groundwater in Cache Valley. (After Bjorklund and McGreevy, 1971.)

Benson (Bjorklund and McGreevy, 1971) however, the head on most wells is 40 feet (12 meters) or less. The confined aquifers of the valley commonly show the deeper beds having slightly higher piezometric heads. This may be due to differences in the permeability of various aquifers and the associated head loss. Also, the recharge area for most aquifers is complex in nature and elevation differences in the source water may influence the varying piezometric level of the different aquifers. The bulk of the artesian conditions generally occurs below the valley floor elevation of 4500 feet (Bjorklund and McGreevy, 1971).

Many springs occur along the base of the mountains and are probably fault controlled. These springs are generally located in a linear fashion along the fault traces and may provide for lateral movement of groundwater along the fractured fault zone. Although the groundwater temperature fluctuates a minor amount throughout the valley from these apparent fault controlled springs, the temperature fluctuation is not enough generally to suggest that the source of the water is deep. Instead, the fault zones may act primarily as a zone for lateral conveyance of the groundwater from the higher mountain sources.

Perched water tables exist in many parts of the Cache Valley region. Several perched water tables can conceivably exist at one location and are formed as the water which percolates downward, is intercepted by soils of lower permeability. The water inflow, above the zone of low permeability is greater than the transmissibility of the fine-grained soil. Perched water tables are encountered in excavations for construction and in wells but are poorly mapped due to seasonal groundwater level fluctuations and lack of wells which tap these zones.

The Bjorklund and McGreevy (1971) report indicates that there has been no upward or downward trend for the groundwater levels in the valley in the 30 years of record, as recorded from wells (other than response to precipitation). Increased amounts of groundwater and overland flow has been diverted for irrigation purposes in recent years. This water is released into perched surface water tables and may be causing a rise in the near surface water table in some parts of the valley.

The Bear River delta is significantly different than many other river delta areas in Cache Valley. The deltas of other streams which enter the valley, are formed by geologically young streams with sufficient energy to transport coarse-grained sediments. The Bear River is an older stream and has a lower energy level. This river delta has deposited sand and silt which is derived from upstream basins, and generally contains poor aquifers.

Post Lake Bonneville

Relatively little geologic change has taken place since Lake Bonneville occupied the valley. The streams entering the valley have continued to cut into their respective deltas and the flood plains and deltas have been reworked and redeposited further out on the old lake bottom.

CHAPTER 3

GENERAL ASPECTS OF GEOLOGIC HAZARDS

Seismic Hazards

General

Earthquakes can cause damage in a variety of ways. This damage can be mitigated only by properly understanding seismic mechanisms and through appropriate planning, zoning, design and construction in hazardous areas. The major seismic hazards considered in this study are described in this chapter and include:

- Strong ground shaking
- Surface fault rupture
- Liquefaction
- Miscellaneous ground failure
- Seiches

Earthquake scales

Intensity and magnitude are terms which are commonly used to describe certain characteristics of an earthquake. Intensity is used to indicate earthquake severity at a specific location. It measures the observable effects of an earthquake as determined through interviews in the quake-stricken area, damage surveys, and earth movement studies.

Magnitude is a term which expresses the total amount of energy release from an earthquake as determined by measuring the amplitudes produced on standard recording instruments. Therefore, it does not consider the effects at any specific location. The equation relating magnitude of an earthquake and the amount of energy which it releases is given by Lew, Leyendecker, and Dikkers (1971) as

$$\log_{10} E = 11.5 + 1.5 M$$

where E is the energy and M is the Richter magnitude. As the magnitude increases, the amount of energy released increases logarithmically. An earthquake of magnitude 8 represents an energy release of about 31.6 times the amount of energy release in a magnitude 7 earthquake, and about 1000 times as much energy as a magnitude 6 earthquake.

The Modified Mercalli Intensity Scale is shown in Table 3-1. The Richter Scale of Magnitude versus equivalent energy in tons of TNT is illustrated in Figure 3-1. The energy released from three local earthquakes are shown on Figure 3-1 and compared with five well known earthquakes and with the energy released from both the Hiroshima Atom Bomb and 1 megaton H-Bomb. Also, shown on Figure 3-1 are estimates of the energy that would be released from maximum credible earthquakes along the Wasatch Fault and the East and West Cache Faults. The maximum credible earthquakes were estimated from data presented by Bonilla (1967).

Strong ground shaking

Characteristics of bedrock motion.

Ground shaking during earthquakes causes the most widespread damage as evidence from recorded earthquakes. When a fault zone ruptures, soil and rock materials

Table 3-1. Modified Mercalli intensity scale of 1930. (Abridged and rewritten.) (After Lew, Leyendecker, and Dikkers, 1971.)

Intensity	Description
I.	Not felt.
II.	Felt by persons at rest, on upper floors, or favorably placed.
III.	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. May not be recognized as an earthquake.
IV.	Hanging objects swing. Vibration like passing of heavy trucks or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. Wooden walls and frames creak.
V.	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move.
VI.	Felt by all. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken visibly, or heard to rustle.
VII.	Difficult to stand. Noticed by drivers of automobiles. Hanging objects quiver. Furnature broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices, also unbraced parapets and architectural ornaments. Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slices and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

Table 3-1. Continued.

Intensity	Description
VIII.	Steering of automobiles affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX.	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated area sand and mud ejected, earthquake fountains, sand craters.
X.	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI.	Rails bent greatly. Underground pipelines completely out of service.
XII.	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

	Quality of Masonry (Brick or Other)
Masonry A	Good workmanship, mortar, and design; reinforced especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
Masonry B	Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Table 3-1. Continued.

	Quality of Masonry (Brick or Other)
Masonry C	Ordinary workmanship and mortar; no extreme weaknesses like failing to tie at corners, but neither reinforced nor designed against horizontal forces.
Masonry D	Weak materials, such as adobe; poor mortar, low standards of workmanship; weak horizontally.

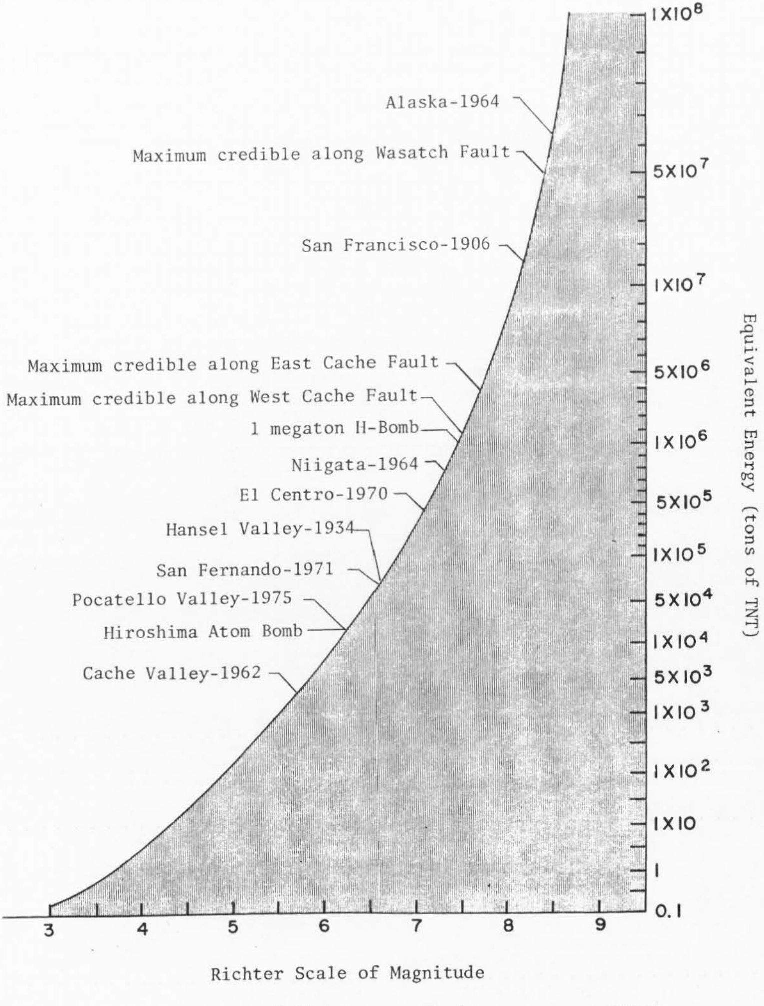

Figure 3-1. Comparison of Richter magnitude versus equivalent energy of TNT (1 ton = 908 Kg).

transmit the associated vibrations by means of waves propagating through the earth's crust. Four basic types of seismic waves cause ground motion:

- Primary wave (P wave)
- Secondary wave (S wave)
- Love wave (Surface wave)
- Rayleigh wave (Surface wave)

The P wave is a longitudinal or compression wave which travels at about 4 miles per second (6.4 kilometers per second) (Lew, Leyendicker, Dikkers, 1971). Particle motion for a P wave is in the direction of the wave propagation. S waves travel about half the velocity of P waves. Particle movement of an S wave occurs at right angles to the direction of propagation. The Love and Rayleigh wave travel about 2.5 and 2.25 miles per second (4.0 and 3.6 kilometers per second) respectively. These waves travel only along the earth's surface and have much longer periods than S and P waves. Love waves produce lateral shear forces in a horizontal plane and Rayleigh waves produce an elliptical motion similar to wind driven ocean waves (Lew, Leyendicker, Dikkers, 1971).

The P and S waves pass through dense subsurface layers of the earth's crust (bedrock) and then propagate vertically upward from the bedrock through less dense soil deposits to cause horizontal ground shaking at the ground surface. Figure 3-2 provides a diagramatic sketch of the propagation of seismic waves from the bedrock surface up through the soil profile. Earthquake damage is caused by the horizontal motion at the base of structures. This motion can have

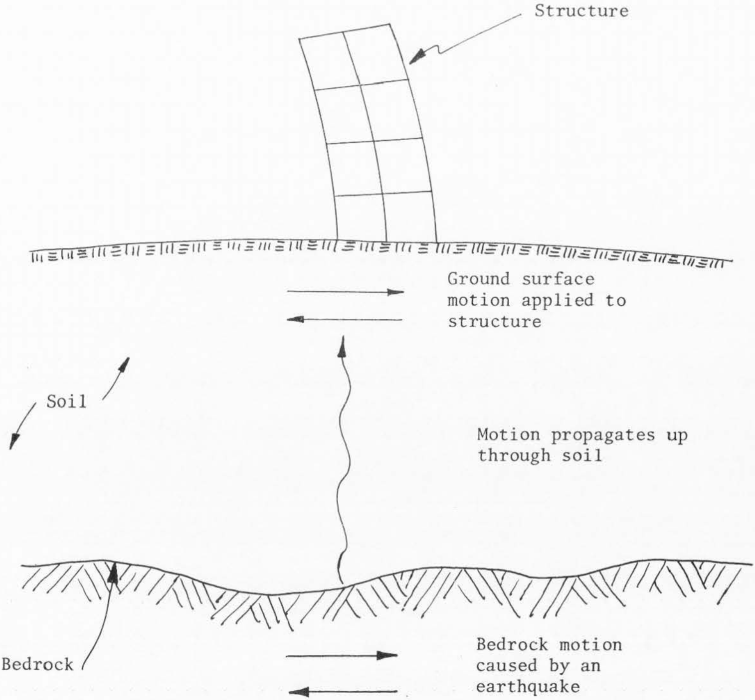

Figure 3-2. Diagrammatic sketch of the propagation of motion through soils during ground shaking.

a detrimental effect on structures located many miles from the causitive fault.

Characteristics of ground surface motion. The characteristics of the ground surface motion to be expected at any particular site is dependent on several factors:

- The amount of energy released during the earthquake which may be described by the Richter Magnitude.
- The distance from the site under consideration to the zone of rupture of the earthquake.
- The character of the site subsurface conditions.

The amount of energy released during a seismic event has been related to the length of the fault rupture (Bonilla, 1967). This provides an estimate of the maximum credible earthquake along a fault by assuming that rupture could occur along the entire fault. Smaller magnitude earthquakes may occur if rupture only occurs along a portion of the fault. Also, the amount of energy released may be very dependent upon the state of stress along the shear zone and the elastic properties of the rock. Rock types which allow the accumulation of strain energy under increasing shear stress, can release violent vibrations when movement in the fault zone eventually occurs.

The distance between the site and the causitive fault and the magnitude of an earthquake influence the characteristics of the bedrock motion. Both the maximum acceleration and the predominate period of the bedrock motion are a function of the distance from the causitive fault. For an earthquake of any given magnitude, maximum accelerations will generally decrease with increasing distance from the causitive fault zone while predominant periods of motion will increase (Kiefer, 1968; and Seed, Idriss, Kiefer, 1969). The maximum bedrock acceleration and the predominate period of the bedrock motion both increase with earthquake magnitude.

While the above relationships generally apply for bedrock motion the response at a specific site is dependent on the properties of the subsurface profile. Kiefer (1968); Seed and Idriss (1969); and Seed, Idriss and Kiefer (1969) discuss the characteristics of ground motion during earthquakes in more detail. Seed and Schnabel (1972) discuss accelerations in rock and the various effects for areas of the Western United States.

Damage potential from ground shaking. Local soil deposits may greatly modify the intensity of the ground motion, as measured by the maximum acceleration and the fundamental period of the motion. Experience has been gained by studying high shaking damage in areas of San Francisco, Santa Rose, and San Jose, during the 1906 San Francisco Earthquake and parts of Caracas, Venezuela, during a 1967 earthquake. The following accout from Seed (1975b) illustrates how soil conditions may effect the ground motion characteristics during earthquakes.

During the Caracas Earthquake, which had a Richter Magnitude of about 6.4 and a fault zone located about 35 miles (56 kilometers) from the city, intense shaking caused the total collapse of four 10- to 12 story apartment buildings. A correlation of depth of underlying soils to structural damage showed that for 3-to-5 story buildings located on soil depths of 98 to 164 feet (30 to 50 meters), the damage was many times greater than for similar structures located where soil depth was 328 feet (100 meters) or more. For 5-to-9 story structures, the most damage was found where the soil depths ranged from 164 to 230 feet (50 to 70 meters). However, for structures greater than 10 stories, the structural damage was several hundred percent greater where the soil depths underlying the structure exceeded 525 feet (160 meters) than for soil depths less than 459 feet (140 meters). This study demonstrated that soil conditions have a significant affect on the ground motion characteristics, even for the same earthquake and within the same city (Seed, 1975b).

The response of a structure to ground shaking is largely dependent upon the relationship between the fundamental period of the building and the predominate period of the ground surface motion. The predominate period of the ground surface motion for a given earthquake is a function of the fundamental period of the site. A critical state can develop when the fundamental period of the site. A critical state can develop when the fundamental building period matches the fundamental period of the site. Both theory and experience indicates that the fundamental site period is dependent on the intensity of the bedrock motion, sediment thickness, soil firmness, and degree of saturation. The fundamental period of the building is related to its weight, material properties, geometry, and structural details. Taller buildings generally possess longer fundamental periods as to deep, saturated, soil deposits. Short rigid structures generally exhibit short fundamental periods as do shallow, very dense, or rocky subsurface conditions. This suggests that the damage potential of an earthquake would be maximized when tall flexible buildings are located on deep soft soil deposits or low rigid buildings are located on shallow stiff soil deposits. Thus, the damaging affects of an earthquake are maximized when there is a similarity in the natural periods of the structure and the ground which it rests on. The 1976 Uniform Building Code considers the relationship between the fundamental site period and the fundamental period of the building in establishing the design forces to be used for the design of the building. The ratio of these two periods is used as a lateral force coefficient in establishing the lateral design force which acts on a structure.

Figures 3-3 through 3-7 from Lew, Leyendecker and Dikkers (1971) are examples of the type of destruction that can result from earthquake ground shaking hazards. These photographs were taken of the aftermath of the 1971 San Fernando Valley Earthquake. Earthquakes of an equal or greater magnitude than the 1971 San Fernando Valley earthquake can be expected in Utah, and the earthquake resistance of structures in Utah should not be expected to be any greater than those of Southern California. Indeed, because of the extensive amount of masonry construction, the resistance of many structures in Utah may be considerably less than those of Southern California. Thus, earthquake damage in Utah due to ground shaking is a very serious geologic hazard. The type of destruction in Utah from a moderately strong earthquake such as occurred in the San Fernando Valley in 1971, can be expected to be very similar to that as shown in Figures 3-3 through 3-7. The fact that earthquakes of a greater magnitude than the San Fernando Earthquake could likely occur in Utah and the fact that such a high

Figure 3-3. Olive View Medical Center, showing extensive damage resulting from the 1971 San Fernando Earthquake (after Lew, Leyendecker, and Dikkers, 1971).

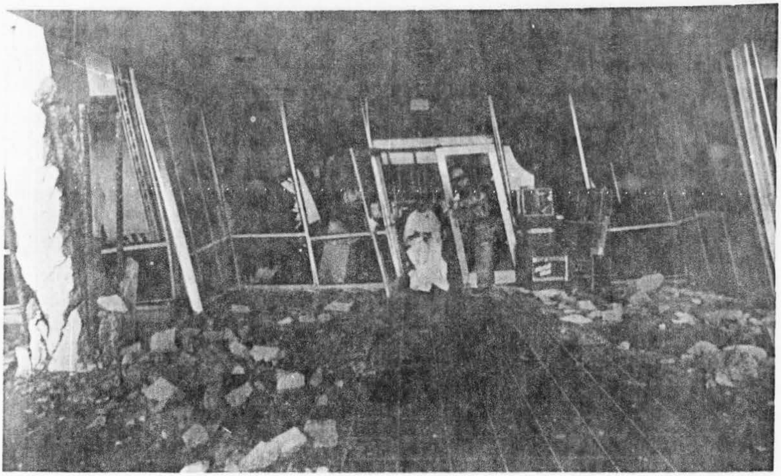

Figure 3-4. Lateral displacement of first floor of Olive View Medical Center (after Lew, Leyendecker, and Dikkers, 1971).

Figure 3-5. Main business district of the city of San Fernando (after Lew, Leyendecker, and Dikkers, 1971).

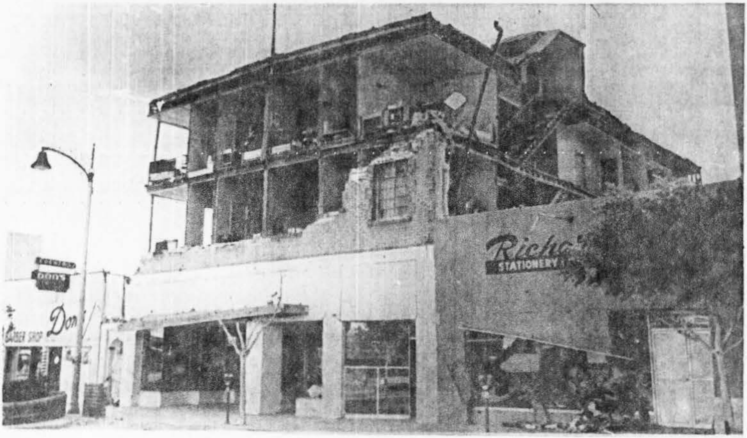

Figure 3-6. Total collapse of brick masonry wall surrounding three-story wood frame building (after Lew, Leyendecker and Dikkers, 1971).

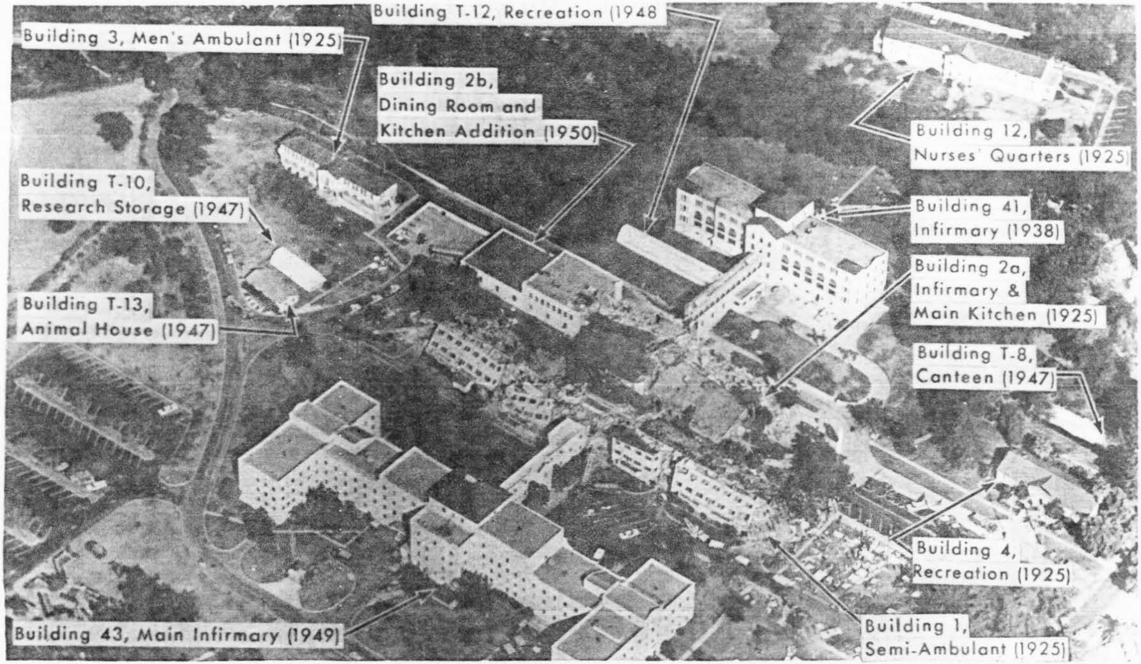

Figure 3-7. Aerial view of the San Fernando Veterans Administration Hospital. Collapsed building (No. 1 and 2a) constructed in 1925, where 46 patients and hospital workers were killed. Many of the buildings, also constructed in 1925 (buildings 3, 4, and 12), although still standing, were severely damaged (after Lew, Leyendecker and Dikkers, 1971).

percentage of the developments in Utah are in very close proximity to major active faults makes the earthquake hazard from ground shaking in Utah very high.

Surface fault rupture

A second well known seismic hazard is that of fault displacement and surface rupture. If a structure is located astride a fault where movement occurs, it is highly probable that total destruction will result. The design of such a structure, to withstand the destructive forces that are induced by displacement or rupture, would be very complex and costly. Thus, especially for the siting of lifelines, emergency service structures, high occupancy structures and certain other important public facilities, it is imperative that both a professional geologist and a professional geotechnical engineer review the site in detail. This should help assure that the facility will not be placed at a location where faulting is probable.

Many faults are known to be inactive and should not be of as much concern to development as active faults. The definition of an active fault, however, is subject to varied opinion. For example, the Nuclear Regulatory commission places a higher risk on the possibility of renewed movement along an old fault for the design of a nuclear facility than would be considered for the design of a relatively minor structure. The type of land use and the importance of the structure should govern the consideration given to possible movement along a fault. An active fault can be defined as one that has moved in recent geologic times. Many geologists would include at least the Holocene Epoch in this period, or about 10,000 years (±) (Wiegel, 1970).

Movement may occur along one fracture surface or along a wide zone involving many fractures (fault zone). Each fracture shear zone may range in width from less than an inch to many tens of feet. The fracture itself is commonly not a plannar surface but rather a curved and irregular surface of sliding. A fault trace may commonly exhibit an en echelon[1] pattern of rupture, however, this is dependent upon the state of stress acting in the crust of the earth and the type of earth materials.

Movement along fracture surfaces can be in virtually any orientation. In order to distinguish the type of movement of faults, a steeply dipping fault is classed as a high angle fault, while a shallow dipping fault is known as a low angle fault. If movement of two points is roughly along strike, it is classed as a strike-slip fault and if movement is along the dip, it is classed as a dip-slip fault. Faults of the Basin and Range Province, such as the Wasatch and East Cache Faults of Northern Utah, are the dip-slip type. The type of movement along a fault is extremely important in estimating the amount and type of damage that might be expected to occur.

As discussed previously, movement commonly does not occur along a single fault plane, but rather within a fault zone. Any one of many fracture surfaces may slip. Generally, within such a fault zone, an area of "most likely" slippage may predominate. Often, short secondary faults may branch out of the main fault zone. Slippage along these minor faults may only be a fractional of the amount of the slippage

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[1] en echelon is a term used to describe a group of parallel ruptures, oriented in a steplike pattern, at an angle to the general direction of fault rupture.

along the main fault. Such secondary faults may form an en echelon pattern of rupture from the main fault zone and would usually be no more than a few miles long.

Although faults with many thousands of feet of past total displacement are not uncommon, the displacement probably represents the summation of a very large number of separate movements over a very long period of time. The individual movements are probably no more than a few inches to a few feet. One of the largest single fault displacements known to have occurred in recorded history of the United States, took place near Salt Lake City, Utah. A single vertical fault movement of 20 feet (6 meters) was estimated to have occurred along the Wasatch Fault near the mouth of Little Cottonwood Canyon. This was estimated to have occurred within the past 300 years (U.S. Senate, 1975, pp. 32). Measurements by Bruce Kaliser of the Utah Geological and Mineral Survey indicate that displacements near the area of Little Cottonwood Canyon range from 20 to 45 feet in height, and that the total vertical displacement, as seen in 6 separate adjacent fault scarps, totals about 188 feet (57 meters) (U.S. Senate, 1975, pp. 32). Another large displacement occurred in 1899, at Yakutat Bay, Alaska, where a single displacement amounted to 47 feet (14 meters) (Tarr and Martin, 1912).

Not all faults extend to the surface of the earth. Movements may occur at depth but due to plastic or elastic deformation of the subsurface strata, the displacements may not propagate to the surface. Northern Utah faults have commonly exhibited this type of diastrophism in the recorded history and only a single seismic event in the recorded history of the state has produced surface ruptures. In recent geologic times, however, many feet of displacement as well as other geomorphic evidence serves to illustrate the geologically recent surface disruptions along all of the major fault zones. Several thousand feet of vertical displacement has occurred during a long fault history in northern Utah.

Lifeline facilities, such as gas and water lines, are particularly exposed to fault zone hazards since they frequently must cross active fault zones to service a region. Proper consideration given to the methods of crossing this zone and to the sense of earth movement along the fault zone is helpful in reducing the geologic hazard (Ford, 1977).

Geologic investigations may include a regional analysis to determine the type of movement along a fault, the probable fault patterns and locations, and the relative degree of activity along a fault. Seismic or micro-seismic earthquake records will also indicate the degree of activity of a fault zone.

Liquefaction

Cause of liquefaction. When a loose, saturated, fine sandy deposit is subjected to vibratory motion, the sand can liquefy and thus, loose essentially all of its shear strength. Relatively large land masses with ground surface slopes as slight as two or three percent have liquefied and flowed horizontally for great distances. This phenomenon has received much attention recently due to several rather spectacular failures such as the building foundation failures in Niigata, Japan (Seed and Idriss, 1967, 1968); the Turnagain Heights landslide in Anchorage, Alaska, the landslide in Valdez, Alaska (Seed, 1974);

the Juvenile Hall landslide in southern California (Nichols and Buchanan, 1974); and the failure of the lower San Fernando Dam (Seed et al. 1975). Figures 3-8 and 3-9 are photographs take from Seed (1975a) of the Niigata building foundation failures and the Turnagain Heights landslide, Anchorage, Alaska, that resulted from liquefaction. Figure 3-10 from Lew, Leyendecker and Dikkers (1971) shows the liquefaction damage resulting from the partial collapse and near catastrophic failure of the lower San Fernando Dam in 1971.

Sand particles when in a loose dry condition will decrease in volume when disturbed. However, if the voids within the sand mass are filled with pore water, the volume cannot immediately decrease upon disturbance. Instead, the load is transferred to the pore water and there is an abrupt increase in the pore water pressures and decrease in the intergranular stress. During an earthquake the sand is repeatedly disturbed. Each disturbance tends to cause a decrease in void volume as described above. Since a decrease in volume cannot occur immediately, there is a transfer of load from the sand grains to the pore water. The pressure induced in the pore water in this manner is an excess hydrostatic pressure. If the disturbance persists, the pore pressure continues to increase until the intergranular stress in the sand is reduced to zero. This is termed as a condition of "initial liquefaction" (Seed, 1976).

Factors affecting liquefaction potential. Several significant factors affect the development of a liquefaction condition, including soil properties, initial stresses, and the characteristics of the earthquake. The following factors are listed as most important:

Figure 3-8. Foundation failures in Niigata, Japan (1964) (after Seed, 1975a).

Figure 3-9. Turnagain Heights landslide, Anchorage, Alaska (1964) (after Seed, 1975a).

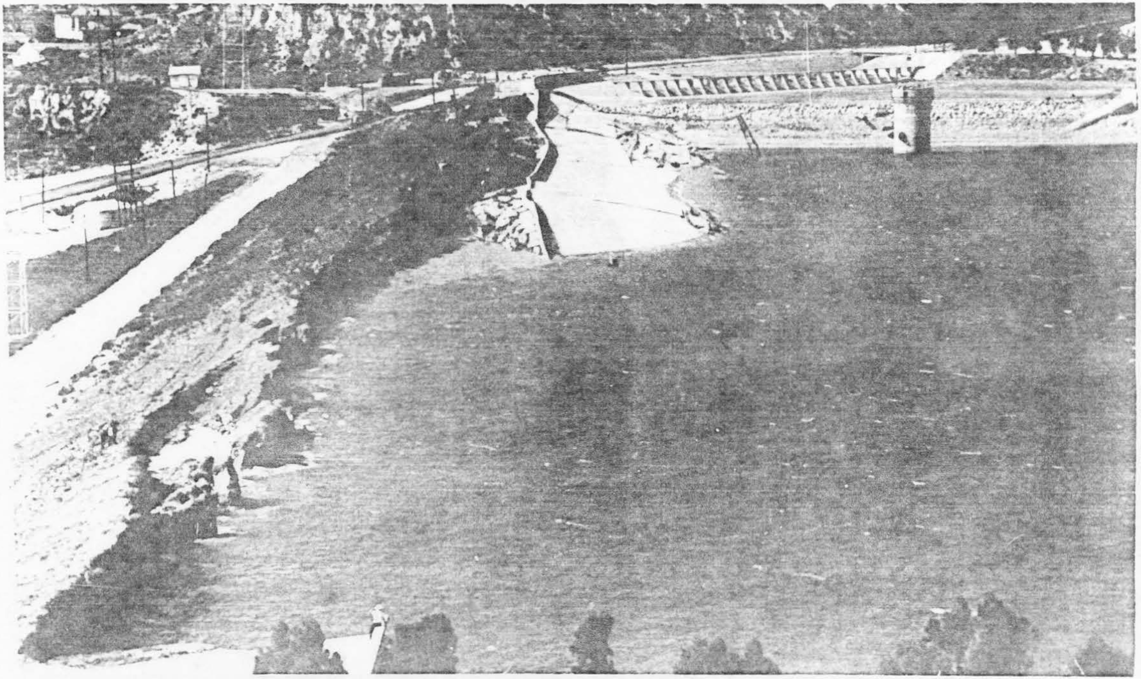


Figure 3-10. Collapsed crest and near failure of the lower San Fernando Dam as a result of liquefaction (after Lew, Leyendecker, and Dikkers, 1971).

- Soil type
- Relative density
- Initial confining pressure
- Intensity of ground shaking
- Duration of ground shaking

Soil type has a significant influence on liquefaction potential. Fine to medium grained sand with a rather uniform grain size has been found to be most susceptible. If the sand contains too many fine particles (minus No. 200 sieve size) or if it is too coarse, the liquefaction potential may not be great.

Relative density of the sand is very significant. Very loose sand is highly susceptible to liquefaction while dense sand has a very low liquefaction potential.

Investigations have shown that the stress required to initiate a liquefaction condition increases with the initial confining pressure. This effect has been shown in field cases such as at Niigata where soil under nine feet of embankment fill remained stable, while similar soils surrounding the embankment liquefied (Seed, Lee, and Idriss, 1967).

The intensity of the ground motion caused by an earthquake is also a very important factor. The susceptability of soil to liquefaction under a given confining pressure and relative density is related to the magnitude of shear forces induced by the earthquake. This effect can again be illustrated by the Niigata earthquake which had a Richter magnitude of 7.3. Records of the past 370 years indicate only slight liquefaction problems at Niigata. During this period, 22 of the major earthquakes affecting the city produced calculated values of ground surface acceleration of 0.12 g or less. Of these, only two earthquakes caused observable liquefaction near Niigata. These two earthquakes are believed to have caused ground surface accelerations of about 0.13 g.

It wasn't until 1964, when maximum recorded accelerations of 0.16 g occurred, that extensive liquefaction in Niigata was observed. Thus, even though a long history of seismic stresses had occurred at the site, they did not cause a critical condition until the 1964 earthquake (Seed, Lee, Idriss, 1967).

Duration of strong shaking and consequently, the number of significant stress cycles to which the soil is subjected influences the extent of the build-up of excess hydrostatic pore pressures. Even though this process begins at the onset of the ground motion, instability will not result until a state of "initial liquefaction" is reached or the intergranular strength becomes less than the forces acting on the land mass. The Turnagain Heights landslide in Alaska did not occur until after approximately 90 seconds earthquake shaking. At this time the stability of the mass had decreased sufficiently to allow movements (Seed, 1974).

Another condition affecting the liquefaction potential of sand is that of the influence of the seismic history on the sand deposit. Experiments by Seed, Mori, and Chan (1975) showed that disturbed sand specimens with a given density, subjected to cyclic stresses, liquefied much sooner than similar undisturbed sand subjected to repeated minor seismic events prior to failure. In a test intended to produce a simulated seismic history, cyclic stresses were mechanically applied to a remolded sand and water sample. The sample was allowed to build small residual pore pressures, then application of the cyclic stress was ceased. The pore pressure in the sample was then allowed to dissipate completely. This series of events was intended to simulate one seismic event such as an earthquake in which a natural soil deposit is subjected to cyclic stresses but liquefaction does not occur. The procedure described above was repeated five or six times, never allowing the sample to liquefy and allowing complete dissipation of the pore pressure between applications of cyclic stress. Next, the sample was allowed to liquefy and the number of applied stress cycles to failure was recorded. The relative density of the sand during this test changed very slightly from 54.0% to 54.7%. Similar tests were run on sand samples with no simulated seismic history. In these tests, cyclic stresses were mechanically applied to remolded sand and water samples. The pore pressure was allowed to build during the first cycle until liquefaction occurred. The samples with the simulated seismic history withstood eight times as many cycles of shear stress to cause failure as similar sand samples with no seismic history (Seed, Mori, and Chan, 1975).

The effect of seismic history on liquefaction potential is believed to be most pronounced in sands possessing very low relative densities. Therefore, a saturated sand fill having no history of seismic disturbance and having a low relative density, may pose an especially acute liquefaction hazard.

The development of a liquefied zone normally occurs between 10 and 80 feet (3 to 24 meters) below the ground surface. If a liquefied layer occurs near the ground surface, structures may loose foundation support and tilt or gradually sink downwards as occurred during the Niigata earthquake of 1964. Also, buried tanks may float out of the ground due to buoyant forces (Seed, Lee, and Idriss, 1967).

Frequently, sand boils, sand ridges, and volcanoes develop in a liquefied area after an earthquake. This is caused by the upward movement of ground water from the liquefied layers, carrying sand particles with it. Often the sand will be removed unevenly from the subsurface and the resulting differential settlement of the ground surface can be catistrophic to a building.

Methods to evaluate liquefaction potential. Two methods of evaluating liquefaction potential are commonly used in design practice. One of these methods involves the use of a chart, developed by Seed, Mori, and Chan (1975) which is based on data from performance observations of many sites during past earthquakes. This chart allows the comparison of the ratio of shear stress and effective overburden pressure to the standard penetration resistance for any site under consideration. By comparing typical values for the site under consideration to Seed's chart, a degree of liquefaction hazard can be identified. Figure 3-11 is a reproduction of that chart.

The second method requires an evaluation of the level of stress which will be induced in the soil by an earthquake. This stress level must be compared with the level of stress in the soil, necessary to cause liquefaction. The zone where these two curves overlap, as shown in Figure 3-12 is the zone where liquefaction may occur (Seed and Idriss, 1975).

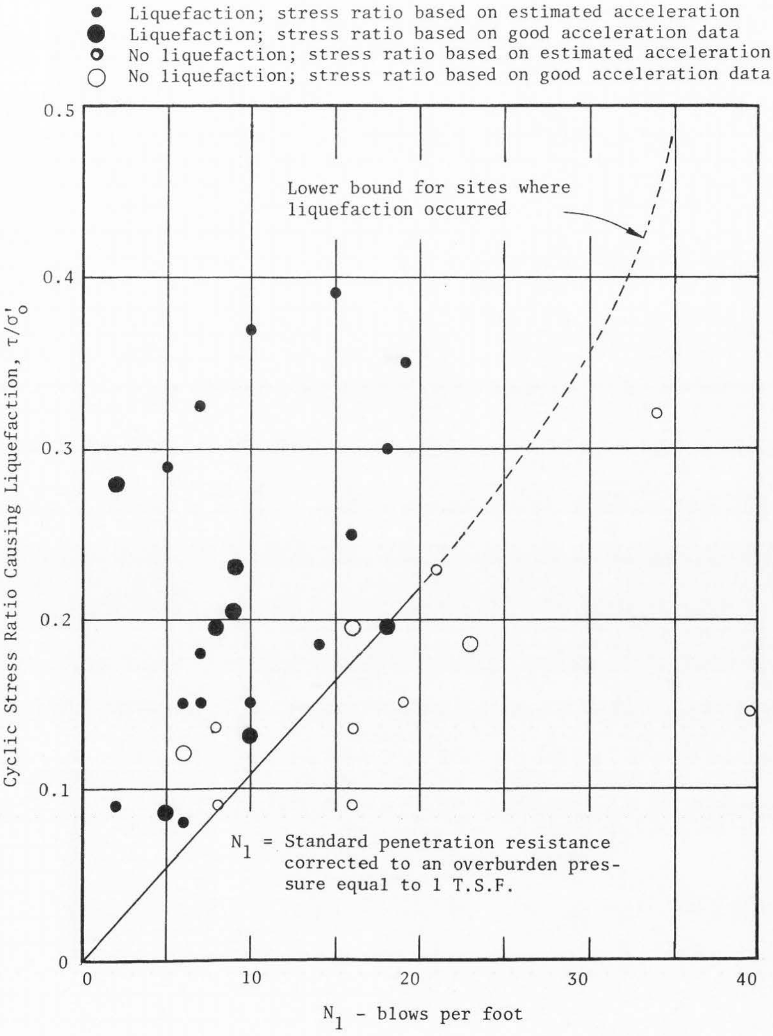


Figure 3-11. Correlation between stress ratio causing liquefaction in the field and penetration resistance of sand (after Seed, Mori, and Chan, 1975).

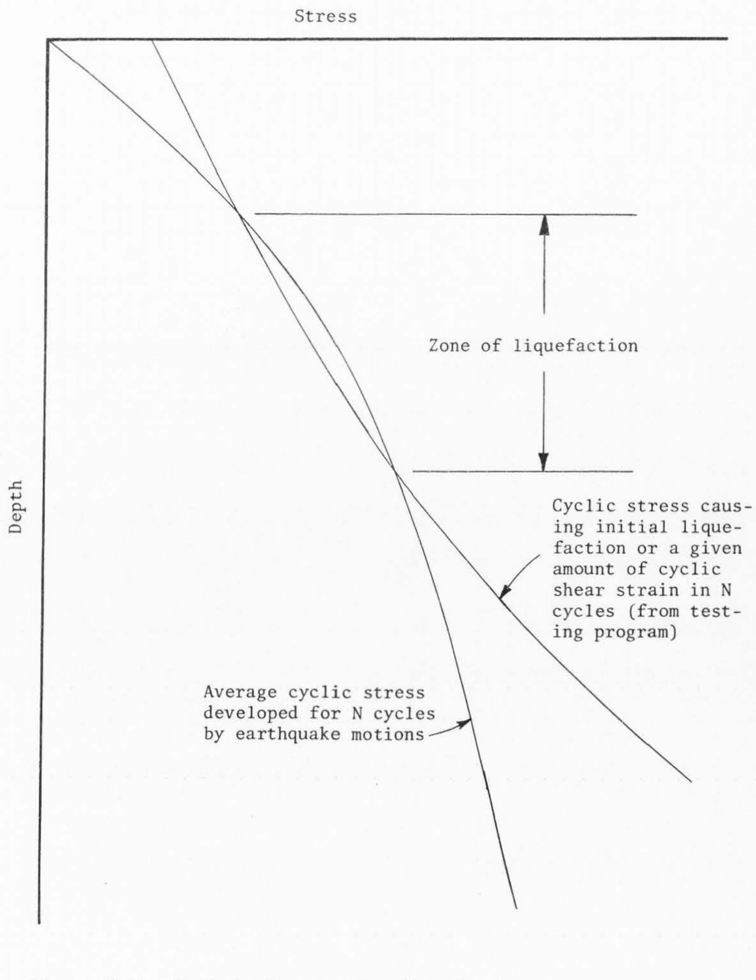


Figure 3-12. Method of evaluating liquefaction potential (after Seed and Idriss, 1971).

Miscellaneous ground failure

Stresses induced in the earth's crust during an earthquake are generally greater than the static forces normally acting on a land mass. Thus, many types of ground failures occur during earthquakes when static forces are augmented by dynamic forces, causing rapid changes in the state of the earth materials. Landslides, ground lurching and cracking, differential settlement, tilting, and loss of strength of loose sand and sensitive cohesive soils are a few of these failures.

Great devastating landslides resulting from earthquakes, have occurred in the past. They can result from faulting and in affect, the natural oversteepening of slopes, or simply by loss of strength upon application of stresses induced by an earthquake. Liquefiable soils or sensitive cohesive clays are examples of soils that can loose strength during an earthquake. Sensitive clays can loose strength due to particle rearrangement when disturbed, and fine sands can liquefy as described previously. These failures can occur on relatively flat slopes.

Landslides can also develop days after an earthquake occurrence as a result of disruption of the natural groundwater flow regime. If the natural groundwater flow channels are severed or blocked, changes in the seepage conditions will occur, often resulting in decreased stability. A later section on slope failures offers an additional discussion about landslides.

Rockfall and snow or rock avalanches can be triggered by ground vibrations. Developments located below steep slopes may be threatened by this type of geologic hazard.

A site may experience large undulating surface waves especially if it is located near the zone of energy release and is supported by soft saturated soil. These waves may cause cracking and the development of compression ridges in concrete or other stiff construction materials. Cracking, related to earthquakes, may also be found in areas where relatively stiff soil or construction materials are found near the ground surface. During a liquefaction condition, for example, as the subsurface spreads laterally, the surface may tend to move in blocks, sometimes resulting in large cracks.

Differential settlement may arise from removal of fine sand by the upward movement of groundwater after an earthquake. Settlement of this type can cause excessive stresses in structures. Subsidence or tilting of the land surface may also result from compaction of the subsurface soil, lateral spreading of soft soils, or sliding of large fault or slide blocks. Utilites may be the most affected by this type of movement since they may likely cross fault zones. Broken utility lines and inverse hydraulic grades are problems that must be considered.

Seiches

A seiche is an earthquake generated standing wave occurring within an enclosed body of water such as a lake or reservoir. These waves are similar to waves produced in a bucket when it is jarred. Often the runup of these waves can be as great as 20 to 30 feet (6 to 9 meters), as observed at Kenai Lake in the March 27, 1964, Alaska Earthquake (Nichols and Buchanan, 1974). Overtopping of dams can cause damage to life and property due to hydraulic forces and innundation.

Landslides cascading into large bodies of water can cause extensive destruction and large loss of life from inundation. The resulting wall of water can be several hundred feet high as observed in Italy in 1963, when a huge landslide fell into Vaiont Reservoir. Nearly 3000 lives were lost (Nichols and Buchanan, 1974). In 1958, in Lituya Bay, Alaska, a similar wall of water 1720 feet (525 meters) high surged out of a coastal bay washing out trees and inundating a very large area. The bay, fortunately, was uninhabited at the time (Nichols and Buchanan, 1974).

General Geologic Hazards

The siting and foundation design of important facilities used by the public should require inspection and approval by a competent geotechnical person. Only a professional geologist and geotechnical engineer is capable of fully assessing the extent of potential hazards which may affect a structure located at a given site. The nature of the structure and its use should govern the extent of the geotechnical investigation required. The knowledge gained from observed failures and problems which may be attributed to insufficient geotechnical investigation and analysis, may be used as a guide to indicate what geologic considerations are necessary.

General

Some major geologic hazards, in addition to seismic hazards, are listed and described below:

- Slope failures
- Flooding
- Erosion
- Expansive soils
- Subsidence

A complete discussion of these hazards, their causes and consequences, and the various effects of modifying conditions is far beyond the scope of discussion in this thesis; however, brief summary of several of the most common hazards is presented.

Slope failures

Slope failure problems. Slope failures cause extensive financial loss in the United States every year. It is estimated that landslides will cause about ten billion dollars worth of damage in California alone during the years 1970 through 2000 (Burer, 1973). Recognizing and avoiding locations where landslides have occurred is of extreme importance in avoiding the hazard in the future. When economically feasible, areas susceptable to slope failures can be stabilized by properly identifying the nature of the instability and making the necessary corrections. The best way to prevent damage is to avoid construction in these areas.

Certain natural and human activities tend to decrease the stability of slopes. Activities which may contribute to instability include oversteepening or overloading slopes, altering the groundwater flow regime to create or worsen a seepage condition, and removal of vegetative cover.

Landslides occur when the driving forces become greater than the stabilizing forces. Oversteepening of slopes has the direct effect of increasing the active forces driving the mass. Overloading a slope with excessive fill also increases the driving forces tending to cause failure.

Categories of slope failure. Slope failures can be classed into many different categories according to type of movement, type of earth materials, and shape of the sliding mass. Rockfalls and soilfalls are land mass movements where the mass travels vertically through air for most of the distance.

Slides may occur in many different varieties. If a slide occurs in rock surfaces, it may be termed a slump if the movement is rotational, or Block Glide or Rockslide if the movement is along a plannar surface. Slope failures in rock are usually controlled by joints, bedding planes or weak layers in the rock mass and the rockslide materials generally come to rest in a very disoriented arrangement.

A slide occurring in soil may be termed a block slide if the mass moves in relatively large undisturbed blocks along a plannar surface. An earthflow is similar; however, it usually involves a rotational surface of sliding.

If slide movement is very rapid, it is generally classed as a flow rather than a slide. High water content characterizes debris flows, sand or silt flows, and mud flows; hence, they usually take the form of a very gentle sloping slide surface.

Rockfall avalanches or debris avalanches may occur in dry conditions, and the mass usually attains high velocities. The soil or rock mass may move up to several miles during this type of movement. The slide at Turtle Mountain near Frank, Alberta in Canada is an example of such a slope failure. Seventy lives were lost when the crest of this mountain broke off and slid to the valley below in 1903 (Legget, 1962).

Identification of landslides by aerial photography. Aerial photography is a significant aid in the detection of landslides. A photo taken near Avon, Utah, (Figure 3-13 and reported by Cluff, Glass, Brogan, 1974), is an illustration of the valuable information such photos can provide. Curved arrows indicate the location of old landslides. A hummocky and wrinkled surface characterizes the ground which has moved and the headwall of the slide or the scarp that remains can be easily identified. Low sun-angle photography, used in this photo, provides an additional aid in recognizing landslide features by accentuating the surface contour of the ground. This method uses shadowing and lighting effects produced by the sun at a low angle to accent unusual landforms. Figure 3-13 also shows prominent linear shadows produced by breaks in slope and probably indicates fault locations.

Aerial photography methods of studying landforms examine changes in photographic tone, changes in ground texture, the pattern of physiographic features such as drainage, and the shape of unusual topographic features. Observations and conclusions stemming from examination of the photographs are interpreted in terms of typical geologic structure of the landforms under review. Photographic investigation can provide

Figure 3-13. Low-sun-angle view of slides near Avon, Utah, (after Cluff, Glass, and Brogan, 1974).

valuable preliminary information about a site; however, it should never be substituted for an actual site investigation.

Flooding

Cache Valley has had a long record of damaging floods, which occur mostly in the agricultural areas. Major floods have occurred six times since the year 1900 (Corps of Engineers, 1973), and studies show that floods larger than those of the past can occur in the future.

Flood studies have been conducted for the Logan River and for the Blacksmith Fork River in Cache County. Construction of vital public facilities should be prohibited below accepted projected flood levels. The type of facility along with its use and occupancy should govern the acceptable level of flood risk to a structure.

If flood studies have not been conducted at a proposed project location and floods may present a problem, either studies should be conducted or an alternate site should be selected.

Erosion

Damage each year due to erosion is very extensive. Losses in California due to erosion have been estimated to be as high as 600 million dollars during the years 1970 to 2000 (Bruer, 1973).

The civil engineer is constantly faced with problems caused by erosion such as stream and river encroachments on valuable property, the erosion of surface soils by wind and rain, siltation behind impoundments, and working with the product of the erosive forces of the past. Neglecting a consideration of the process of erosion on a site may likely result in total failure even though the structure itself is sound.

Removal of the vegetative cover during the construction of civil engineering works enhances the erosion process by allowing wind and water to carry soil particles with it. In many states, very elaborate erosion safeguards are required whenever construction takes place. The State Engineer's office of Virginia and Maryland for instance, require the professional design of erosion mitigation measures for all construction projects. Normally, state agencies govern the soil conservation practices.

Expansive soils

These soils are found mainly in areas of nonsaturated residual soil deposits of fine material containing montmorillonite clay minerals. These minerals are sensitive to changes in humidity and as a result of the addition of water they expand. If construction takes place on soils of this type and later, humidity changes occur which increases the available water supply to the soil, large deformations can result. This causes extensive damage especially if the vertical movement occurs differentially. The maximum expansion occurs when the initial stress or confining pressure is small. It is estimated that expansion of these soils may be as high as five percent (Zeevaert, 1973). When construction takes place on soils of this type, it is essential that appropriate design considerations be taken.

Subsidence

Subsidence is the downward settlement of the ground surface due to consolidation or removal of underlying materials. For many years Mexico City has experienced problems due to subsidence which has been attributed to the lowering of artesian water pressures from pumping. Lowering of the water table causes consolidation of clay deposits because of an increase in the intergranular pressure in the clay.

Consolidation of clay deposits by the addition of surcharge loading usually results in subsidence in areas of soft saturated clays. As the additional weight is applied, the soil becomes more compact. Subsidence may also be caused by removal of soluble materials in the soil structure.

Removal of oil from subsurface has long been known to be a cause of areal subsidence. The best remedy for this situation may be to replace the oil with fluids to maintain equilibrium.

Parts of Cache Valley are underlain with soft saturated soil deposits. Upon loading, very large settlements have been experienced. Subsidence related to extraction of groundwater or surcharge loading is a very important geotechnical consideration.

Seismicity of Utah

Cache Valley is located in a seismically active region, within the intermountain seismic belt. This zone of seismic activity extends in a north-south pattern from Arizona and southern California, through Utah, eastern Idaho, and western Wyoming, and terminates in northwestern Montana. This belt is more than 800 miles (1287 kilometers) long and up to 60 miles (97 kilometers) in width. Seismicity along the intermountain belt has been characterized by Smith (1974) as having:

- en echelon patterned active normal faults
- earthquakes with generally shallow focal depths
- marked areas of low or no seismicity and other areas of earthquake swarms

The seismicity along this zone is associated with the contact and complex movement of the basin and range physiographic province on the west and the North American plate to the east. Movement and stress relief of the two lithospheres creates fracture zones and generates seismic activity.

The seismic history of Utah has been documented since 1850. The most complete study of Utah earthquakes prior to 1950 is a comprehensive report by Williams and Tapper (1953). Their report was based on earthquake data taken from the earliest Utah newspapers and scientific journals, and they assigned modified Mercalli intensities to each event. Since 1950, as better equipment was developed and seismograph stations were installed, much more reliable earthquake data has become available.

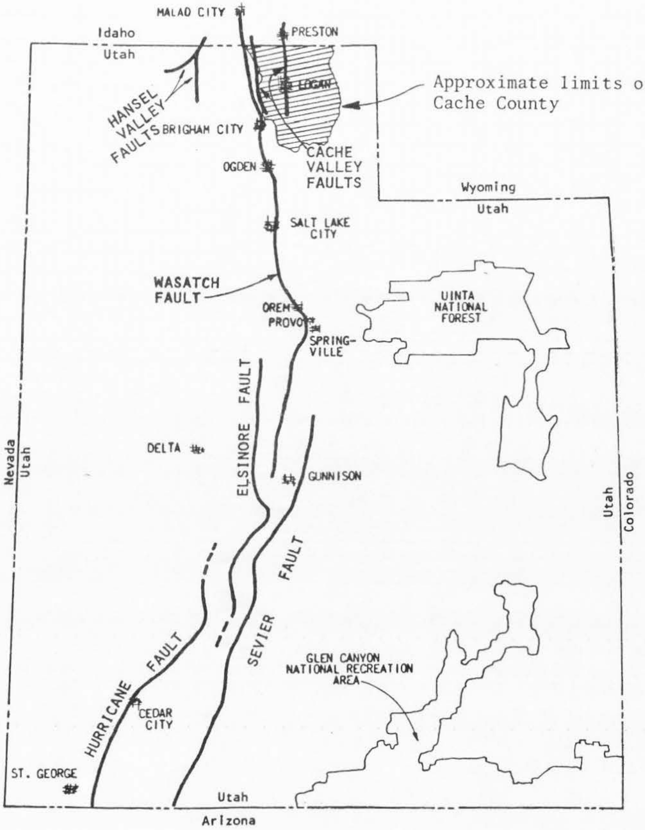
Appendices A and B include information on 824 Intermountain region earthquakes. Appendix A is a list of 609 earthquakes which occured in Utah during the period 1850 through June 1965. The source of data for the period from 1850 through 1949 was Cook and Smith (1967) as taken from a report by Williams and Tapper (1953) and is the most complete list available of early Utah earthquakes. None of the 344 earthquakes listed in their study were recorded by seismograph instruments; however, they were sufficiently intense to be felt and modified Mercalli intensities were assigned based on damage reports. For the period from 1950 through June 1962, data was furnished by the Coast and

Geodetic Survey (CGS), U.S. Department of Commerce as reported by Cook and Smith (1967). This period includes 77 earthquakes which were generally recorded by seismograph instruments and includes earthquakes of magnitude 2.0 and greater. From July 1962 through June 1965, 188 earthquake epicenters were recorded with seismograph instruments by the CGS and the University of Utah (Cook and Smith, 1967) and includes magnitudes 1.4 and greater.

Appendix B includes a list of 418 earthquakes with a magnitude of 2.4 and greater which have occurred within a 186 mile (300 kilometer) radius of Logan, Utah. This list includes earthquake information from 1853 through June 1976, with a great deal of duplication of the listing in Appendix A for the period from 1853 through June 1965. Appendix A is included separately because the Williams and Tapper report is probably the most complete list available of early Utah earthquakes.

Geologists have mapped many surface and subsurface faults in Northeastern Utah. The major faults are shown on Figure 3-14. However, there is no doubt that there are many faults that have not yet been discovered. Several geologically active faults exist in Northeastern Utah and three of the most important, relating to their motion characteristics imposed on Cache County and the surrounding area, are the East and West Cache faults, and the Northern Wasatch Fault shown on Figure 3-14.

The East Cache Fault is a north-south trending fault located along the eastern extremity of the Cache Valley, extending from a mile or more south of Avon, Utah, to well into Southern Idaho. The length



Approximate limits of Cache County

Figure 3-14. Locations of the major active faults in Utah by Cluff, Glass, Brogan (1974).

of this fault is about 70 miles (113 kilometers). Many scarps are visible along its length where it displaces the ancient Lake Bonneville sediments. The maximum credible earthquake for this fault is estimated to have a Richter magnitude of about 7.7 (from Bonilla, 1967, as presented by Seed, Idriss, and Kiefer, 1969).

The West Cache Fault, located generally along the western extremity of the Cache Valley is estimated to be about 55 miles (88 kilometers) in length and trends north-northwest. The maximum credible earthquake for this fault is estimated to be a magnitude of 7.5 (after Bonilla, 1967, as presented by Seed, Idriss and Kiefer, 1969).

The Northern Wasatch Fault is located along the western base of the Wasatch Mountain Range. It extends from near Gunnison, Utah, to Malad, Idaho, a length of about 215 miles (346 kilometers). Movement along this fault is more easily discerned than along the Cache Valley Faults and may indicate more recent movement (Cluff, Glass, and Brogan, 1974). This fault trends north-south and the maximum credible earthquake for this fault is magnitude 8.4 (after Bonilla, 1967, as presented by Seed, Idriss, and Kiefer, 1969). The energy that would be released from the maximum credible earthquakes along these three faults is shown on Figure 3-1.

A critical earthquake hazard exists in the State of Utah and presently, public officials are only beginning to perceive its seriousness. The close proximity of the majority of the population of Utah to major fault zones, particularly along the Wasatch Front, creastes a serious potential for not only an economic catastrophe, but also a tremendous loss of life. Approximately 85 percent of Utah's population is located within 5 miles (8 kilometers) of the Wasatch Fault (Kaliser, 1957). Additionally, nearly 100 percent of the population of Cache County is located within 5 miles (8 kilometers) of the East or West Cache Faults. In an effort to reduce the earthquake hazard, the general session of the 1977 legislature created an 11-member Seismic Safety Advisory Council. The purpose of the council is to recommend safety programs, review and recommend changes in current standards, promote new standards, and propose legislation.

The Utah Department of Natural Resources, Urban and Engineering Geology Section of the Utah Geological and Mineral Survey listed the following items concerning the earthquake hazard situation in Utah (U.S. Senate, 1975).

- Utah's citizens have experienced earthquakes virtually since settlement.
- At least 40 damaging earthquakes have occurred in the 128-year history since settlement.
- Scores of earthquakes are recorded in Utah each year.
- The earthquakes have generally shallow foci (points of origin within the earth), making them potentially quite destructive.
- Utah is traversed by many active fault zones.
- Approximately 41% of the state is in seismic zone #3 (major destructive damage may occur); 22% is in seismic zone #2 (expected moderate damage).
- There is extensive population density and economic development within the active fault zone in the state.

- Severe ground shaking is likely to be experienced in the state's metropolitan areas from future earthquakes.
- Destruction from one earthquake along in Utah, the August 1962 Cache Valley earthquake of Richter magnitude 5.7, amounted to $1,700,000 (1974 dollars).
- Recent geologic movements along extensive fault breaks is in evidence. Two feet of vertical displacement occurred north of Great Salt Lake in 1934.

The possibility of death and total destruction such as that which has recently occurred in South America, Europe, and Asia is not likely in the United States because of better construction materials and techniques. However, the damage potential of an earthquake in Utah is as great or greater than the damage potential in California and Alaska. The potential in Utah may even be more serious due to the fact that such a high percentage of the population is located in close proximity to the active fault zones. Furthermore, there is a significant amount of unreinforced masonry construction and earthquake vulnerable construction. The intermountain seismic zone has generated large earthquakes in the historic past, and it can be expected by generate major earthquakes in the future.

CHAPTER 4

EVALUATION OF STRUCTURES

During this study, over 100 facilities were investigated from a geotechnical viewpoint. Many of these facilities were constructed with inadequate geotechnical considerations and consequently, are now subject to some degree of geologic hazard. In many cases, no evidence was found of geotechnical involvement in projects of vital public importance and the siting criteria was established by non-technical personnel.

Method of Evaluation and Limitations

As discussed previously, each structure included in the investigation was studied to determine the present exterior conditions and if possible, to identify any problems. Plans, specifications, design or construction notes, and reports on the facility were reviewed when available. In many cases, especially in the study of older structures, little or no information or documentation was available to indicate the design considerations. In these cases information was obtained from persons who were knowledgeable about the design, construction, or maintenance of the structure when possible. When information regarding a facility was not available, no judgement could be made concerning the level of geotechnical input other than by noting obvious deficiencies as assessed by examining the exterior of the structure and studying its geologic environment.

Cooperation and accurate reporting of information about a facility from knowledgeable persons was vitally important for proper evaluation in this study. In some cases, the owners, maintenance personnel, and design professionals were very reluctant to cooperate and provide meaningful information. The effect of this reluctance may be that the evaluations made on the facility reflect less geotechnical input to design and construction than may actually have been provided.

As stated previously, the geotechnical evaluations presented in this study are based on present day standards for design and construction. Many significant geotechnical engineering advances have been made in recent decades and accordingly, the design standards for most facilities constructed in recent years are more rigorous than the standards used in the construction of older facilities. However, geologic hazards are not mitigated by age of the structure; therefore, in order to evaluate the current hazard exposure the study was based on present day standards.

The study involved the consideration of a wide variety of influencing factors. For example, the construction of certain facilities sometimes require special considerations which other structures may not need. The type and extent of the investigation necessary is governed by the type of structure, its use, the risk involved, and its association with similar facilities. For critical facilities, the service which is provided must not only be reliable during normal periods of use, but also during emergency situations or during the time of need.

Suggested guidelines to be followed when conducting geologic and geotechnical investigations have been adopted by many states and

Federal Agencies, by private design professionals, and by universities. Duke (1975), Slosson and Amimoto (1974), Torgerson (unverified date), Huber (1970), California Division of Mines and Geology (1973), and Ford (1977) are a few of the references available which provide guidelines for hazard investigations.

Many facilities of public importance were studied during this investigation. In order to illustrate the nature of some of the hazards, the facilities were divided into several categories such as schools, culinary water tanks, dams, etc.

Each category of structure is followed by a discussion of hazards of a general nature which may affect it. Examples of facilities exposed to geologic hazards are discussed individually in order to help illustrate the nature of the hazards. The discussion of individual facilities is also intended to indicate the types of future investigation necessary to mitigate the hazards.

Culinary Water Storage Tanks

General

A total of 34 culinary water storage reservoirs were studied. Nearly all of the water tanks serving Cache Valley communities are circular in shape and constructed of reinforced concrete. Many of the tanks are either entirely or partly buried. The foundations for these tanks are typically circular perimeter footings supporting the exterior walls with interior column footings supporting reinforced concrete columns. Reinforced concrete roof slabs are supported by the walls and columns. The capacities of these water storage tanks range from about 20,000 gallons (76 cubic meters) to 1,000,000 gallons (3800 cubic meters).

Most of the county's communities are located on the foothill benches and nearly all derive at least a portion of their potable water from the surrounding mountains. In order to utilize gravity flow to maintain a desirable water pressure for public use, the ideal locations for storage tanks are generally found on the highest benches near the base of the mountains. Unfortunately, major fault zones are also located near the mountain bases, thereby exposing many culinary water tanks and water distribution lines to an inherent geologic hazard. At least seven culinary water tanks are apparently located very near or within the fault zones of the East Cache or the West Cache Faults.

Unfortunately, many recently constructed water storage tanks in Cache Valley are exposed to certain geologic hazards, especially seismic hazards. Water storage facilities are structures which are critically important in the event of a major earthquake. The San Francisco Earthquake of 1906 and the fires that resulted, emphasize the need for water supply systems that are capable of providing an adequate volume of water under acceptable pressure both during and after an earthquake. Also, Kaliser (U.S. Senate, 1975, pp. 254) points out that each of the intergral parts of a city's water system deserves individual consideration as to its placement. Then, if any of several fault zones move, the reservoir and arterial system can still function adequately. The same faults which constitute hazards to some of the water tanks in Cache Valley show displacement and active movements of many feet in some locations.

Other storage tanks examined during this study may also be located near fault zones, however, without a subsurface investigation such as trenching, the relative position of the faults cannot be easily identified.

Nearly every community of the valley is served by waterlines that cross the active fault zones. Measures can and should be taken to mitigate the danger of disruption of these lines due to fault movement. The fault zones could perhaps be easily identified when the trenches are excavated to lay new water transmission lines. Currently, however, no program is underway to identify or correct any hazard of this type.

Hyrum culinary water storage tank

In 1973, Hyrum constructed a new 1,000,000 gallon (3800 cubic meter) storage facility. This structure is located adjacent to an older tank with a capacity of about 260,000 gallons (980 cubic meters). Both water reservoirs appear to be founded on the steep face of a fault scarp. This is evidenced by the linear fashion of the scarp to the North and South and the abrupt change from unconsolidated soil deposits immediately west of the site, to rock outcrops immediately east of the site.

These two water storage facilities are also subject to erosion and possible landslide hazards. The soil surrounding the tanks is a fine, yellow-brown sandy silt. This soil is highly erodable and the deposit is cut by numerous erosion gullies. Soils surrounding the old reservoir tank have become stabilized over a period of years by the accumulation of vegetation growth; however, two six-foot deep gullies were noted directly beside the new tank. Several deep, narrow erosional gullies which extend up to and possibly under the tank were noted.

Minor mud flows have occurred on the steep (1.3 horizontal to 1 vertical) construction cut slope above the tank. Continued unchecked erosion of this face may constitute a problem to the new tank. Training ditches located on each side of the construction slope have helped check the erosion of this area.

Cracks were noted in the west face of the new tank. The cracks are predominantly vertical and horizontal and spaced three to four feet (0.9 to 1.2 meters) apart. Leakage from these cracks was very minor. The precipitation of calcium carbonate from the water in the tank, has nearly sealed the fissures. The design engineer for this facility indicated that the cracks were probably caused from shrinkage of the concrete upon drying. Consideration was given to the possibility that water from the tank may be leaking out of cracks not observable externally. Several very narrow erosional gullies which were several feet deep were found to extend directly from the side of the tank and one area was found to be quite damp. The assumption that leakage of water may be causing the erosion is probably not valid because of the large quantity of water that would be necessary to form the gullies. It may be concluded, however, that at least some minor leakage is occurring underground as suggested by the cracks above the ground level.

Regardless of the source of the water, the erosion is a serious problem and should be checked to avoid future problems.

Cracking of the soil and signs of the initial stages of a landslide were observed 80 feet (±) (24 meters) below the tank along the side of the access road. This was occurring on a very steep cut slope of about 1.3 horizontal to 1 vertical.

Due to the nature of some of the problems identified above, an immediate inspection of the facility was recommended to the Hyrum City personnel. The site of this water tank presents special geologic and geotechnical problems. Although many different criteria must be considered in selecting a site for a given facility, it must be recognized that locating an important public facility such as this on an active fault scarp could present very serious problems. The degree of risk from possible movement along a known active fault should be thoroughly considered during the early planning stages of a project. A safer alternative location for this facility could probably have been selected.

Millville culinary water storage tank

Millville constructed a new 300,000 gallon (1140 cubic meter) reservoir in 1976. This structure is located approximately 200 feet (61 meters) south of an old 72,000 gallon (274 cubic meter) storage tank. Both facilities are located near the East Cache Fault zone. Several minor fault traces were recorded within the excavation for the tank and in a trench for one of the distribution pipelines. These were only minor traces and indicated slippage of probably less than one inch. A study of the landform and aerial photographs suggests the site is in close proximity to the major active zone of slippage. The inherent danger of locating the tank in a fault zone was probably not studied adequately for this vital public facility.

There is no evidence that trenching or other subsurface investigation was conducted prior to siting and design of the facility even though the facility is located near a known geologically hazardous area (the East Cache Fault). The Millville City Mayor and the design engineer were notified about the minor fault traces at a time when the hazard could have been easily investigated further. The significance of the selected location, possible very close to a zone of major slippage, was apparently not realized and the facility was constructed with no additional investigation.

Providence culinary water storage tank

Similar fault hazards exist near two Providence City storage tanks. A new 1,000,000 gallon (3800 cubic meter) tank was constructed in 1976 adjacent to an old 130,000 gallon (494 cubic meter) tank at the entrance to Providence Canyon. A large sag depression and many linear fault scarps extending a few hundred feet north and south of the tank attest to the presence of active faulting very close to or possibly at the location of the tank. Rock outcrops suggest that the tank location may be slightly to the east of a major zone of slippage; however, a subsurface investigation such as trenching would be required to confirm the fault location.

An additional geologic hazard may exist from flooding. Both storage tanks are located in the flood plain produced by the incision of Providence Creek into the ancient Lake Bonneville deltaic deposits.

It was not determined if a study of the flooding potential was undertaken.

Wellsville culinary water storage tank

This 600,000 gallon (2280 cubic meter) tank was constructed in 1974 and is located in a very hazardous fault zone. Faults are located near two sides of the tank. One is located about 150 yards (137 meters) below the tank and the other is located about 80 feet (24 meters) (±) above the tank. Both fault traces exhibit large linear sag depressions several hundred feet long and 20 to 25 feet (6 to 8 meters) deep. A spring is located along the lower fault trace and may be associated with the fault. Some continuity can be seen between these faults and other possible scarp features farther to the north and south.

Culinary Water Supply Wells

Many of the valley communities supplement spring water supplies with drilled wells. The wells usually pump directly into the water distribution systems and may only operate during the months when the additional water is needed most. The water rights to many springs are shared jointly by municipalities and irrigation companies. In some cases, more than the legal share of water is drawn from the springs for public use which is then replaced by an equal quantity of water pumped directly into the canals from shallow wells.

The culinary water supply wells are essentially free of problems. The Bear River Health Department usually requires approval of the design for a proposed well. This usually includes the drillers log of the boring, the proposed locations of perforations, and the zones which will be sealed to prevent contaminated surface water from entering the system. The design is usually executed by the driller. Hyrum City reported that the infiltration of sand in one of their wells is a minor problem.

Culinary Water Supply Springs

General

Sixteen culinary water supply springs were evaluated during this study. Most of the springs have been in use for many years. The water rights are generally well established and most communities have made minor improvements periodically. The sources of water for many of the springs have not been studied and can only be inferred from knowledge of the geologic structure of the area. Contamination and apparent loss of water has prompted investigations such as dye testing in a few cases.

Most of the collection systems incorporate buried perforated lateral pipes which lead to collector boxes. From there, the water is usually gravity fed or pumped to storage reservoirs. The areas around the collector systems are generally fenced to prevent the infiltration of surface contaminants. In some cases, fences are not maintained and/or are not adequate.

Currently, a few of the culinary water supply springs probably do not meet minimum public health standards because of obvious contamination problems. The Environmental Protection Agency has recently (1977) adopted regulations which requires that any public water system meet minimum public health standards.

Providence culinary water supply spring

Providence obtains its water from a spring located approximately 2 miles (3.2 kilometers) above the entrance to Providence Canyon. A possibility of contamination of this spring exists because of a large open pit limestone mining operation located about 1 mile (1.6 kilometers) upstream. Dye tests indicate that the source of water from this spring originates above the mine and that the dye released at the mine reaches the spring very rapidly through groundwater flow channels. Currently, it appears that no particular measures are being taken to avoid the contamination hazard at the mine. At the time of this investigation the spring area was fenced; however, livestock had recently been grazing near the lateral collector pipes inside the fence.

A county ordinance adopted in 1977 states that no point sources of groundwater pollution may be discharged within a 1500 foot (457 meter) distance above a culinary water supply (springs and shallow wells). These pollution sources include septic tank leach fields, drainage from livestock grazing areas, or drainage from any other sources of pollution. This distance was arbitrarily chosen and is not always conservative. The Providence spring provides an example of a situation where contamination of the water from a source approximately 1 mile (1.6 kilometers) above the spring can readily contaminate the culinary water supply. This example illustrates that an individual evaluation of each proposed water supply development by a competent professional is necessary to ensure greater safety from contamination.

Cove culinary water supply spring

North Cove has had a long record of contamination problems with their water supply. The spring areas that supply the town's water are not adequately fenced and it was noted that cattle were allowed to graze directly within the water collection area.

Dams and Reservoirs

A total of ten dams were evaluated. At the present time, only five of these dams are considered as potentially dangerous to life and property in the event that they should fail. These are Porcupine, Hyrum, Logan First Dam, Newton, and Wellsville Dams.

Porcupine Dam

The largest dam in Cache Valley is Porcupine which is an earthfill dam. It is approximately 160 feet (49 meters) in height at the maximum section and retains 12,800 (15,788,600 cubic meters) of water. It is located on the East Fork of the Little Bear River and the town of Avon, the nearest community, is located about 3½ miles (5.6 kilometers) downstream.

The dam was constructed in 1961 by the Utah Power and Water Board. Since its construction, several problems which are summarized below, have developed:

- Hydrostatic pressure caused the collapse of the original reinforced concrete retaining wall which served as a crest for the spillway inlet structure.
- Originally the spillway chute was constructed in bedrock. After the collapse of the inlet structure, it became apparent that because of erosion of the channel, it would need to be lined.

- Severe vibrations and cavitation of the outlet butterfly valve required that modifications be made.
- A series of leaks developed in the rock abutment on the south side of the dam. The leaks emerged from the lower part of the spillway at several locations.
- A horizontal pervious zone appeared in the embankment about 75 feet (23 meters) below the spillway crest. The downstream face was saturated until the reservoir was later drawn down to make the necessary repairs.
- At a distance of approximately 1/3 the way across the top of the dam from the left abutment, a slide developed near the top of the upstream slope. The slide was approximately 40 feet (12 meters) wide, 10 feet (3 meters) deep, and was estimated to be 50 or 60 feet (15 to 18 meters) long as measured down the upstream slope.
- Piezometers which were installed in 1962 need repair work in order to be operational. Vandals have broken security locks and reportedly dropped rocks down some wells.
- An area of incompetent rock located near the inlet to the spillway is currently undermining a 100 foot (±) (30 meters) high rock cliff. The overhanging rock mass is jointed and fractured and if it should collapse, is capable of significantly damaging and possibly plugging the spillway inlet structure.

Repairs to the spillway included the design and construction of a lined tunnel spillway. A design using a square, reinforced concrete culvert was selected. Repairs to the spillway have also included reconstruction of the reinforced concrete retaining wall which serves as a crest for the spillway inlet structure. Weep holes were provided to reduce hydrostatic pressure on the wall, rock bolts were used to anchor the south wall, and three steel pipe struts were installed to span across the inlet to provide additional lateral support for the wall. Also, pipe drains were installed along either side of the spillway to collect and drain seepage water from the spillway area.

The butterfly valve previously mentioned was moved to the extreme downstream end of the access tunnel serving the outlet pipeline. This was done to enhance the safety of the dam even if the vibration and cavitation problems with the valve were not eliminated. By providing a specially fabricated air intake, which allowed the introduction of large quantities of air into the pipeline, the vibration and cavitation problems were completely eliminated.

The leaks in the south abutment were sealed by grouting. The foundation was grouted to a depth of 160 feet (49 meters) forming a continuous curtain which tied into the existing grout curtain along the centerline of the dam. In order to help provide a water-tight condition, grout was also pumped under the spillway inlet structure. The grouting program was considered successful. The flow of water through the abutments was decreased from about 2 cubic feet per second (0.06 cubic meters per second) to about 1 cubic foot per second (0.03 cubic meters per second) (Palmer, 1964). Also, piezometers installed in the rock abutment, provided information that indicated the hydrostatic pressure would not be hazardous to the abutment.

In order to alleviate the seepage through the dam, a grout curtain was constructed. This grout curtain was constructed at approximately 75 feet (23 meters) upstream from the centerline of the dam and between the 40 and 90 foot (12 and 27 meter) depths below the dam crest. A horizontal, pervious, clayey gravel zone existing downstream from the grout curtain, was used as a blanket drain to carry seepage water to the downstream face where it is collected in drain pipes and carried away from the dam. The construction of the grout curtain did not seal off the seepage completely; however, it is believed that it is functioning properly and has reduced the quantity of seepage water by a factor of perhaps five or ten (Palmer, 1964). Piezometers were installed and inspection revealed that the hazardous condition was checked.

The existence of the slide on the face of the dam was reported by the state engineer several seasons ago. It has been alleged that the owners were notified of the condition. No action had apparently been taken yet at the time of this investigation.

The loss of the piezometers which were installed in 1962 could be detrimental to the proper monitoring of the structure. These piezometers can provide valuable information regarding the seriousness of future stability problems which may arise for unknown reasons. Very little effort would be required to repair and protect these installations.

The damage caused by a rockfall in the vicinity of the spillway could be very significant. Sloughing has occurred over the past several years and continued undermining of the rock cliff presents a very real and present danger. An earthquake shock could possibly trigger such a collapse.

Hyrum Dam

This dam was constructed in 1934 by the U.S. Bureau of Reclamation. The dam is located at Hyrum and the community of Wellsville is situated approximately 3 miles (4.8 kilometers) downstream. The dam is of earthfill construction and is approximately 85 feet (26 meters) high at the maximum section. The impounded water is used primarily for irrigation and recreational purposes. The facility has performed well during its 40 years of service.

No particular geologic hazards effecting this structure were noted during this study. Hydrology studies have been conducted by the U.S. Bureau of Reclamation recently and the results have concluded that the present spillway is probably not adequate. Increasing the spillway capacity is currently being studied.

First Dam, Logan River

First Dam is a concrete gravity dam about 25 feet (8 meters) high. This is an old structure and is estimated to have been constructed in the early part of this century. The dam is located at the entrance to Logan Canyon. The reservoir capacity is roughly estimated to be less than 100 acre feet (123,000 cubic meters). Its capacity has been significantly reduced by siltation behind the dam over the years of operation.

Very little information was available concerning this structure. A field examination indicated that the dam is exposed to a fault hazard. Traces of slippage along the East Cache Fault can be observed short distances north and south of the dam. Any fault movement in this zone would result in almost certain damage or destruction of the dam and subsequent inundation of parts of the densely populated area directly downstream from the dam. The loose, saturated accumulation of silt within the reservoir would probably be transported by the flooding waters and cause additional damage.

Geomorphic evidence also indicates the presence of a fault zone in the vicinity of the dam. The Logan River runs in a westerly direction a short distance upstream from the dam. Downstream from the dam, the river also follows a westerly course, but is oriented north-south along the East Cache Fault zone for several hundred yards, directly upstream and downstream from the dam. The sharp offset in the river channel is probably the result of erosion along the fault zone.

A highway cut several hundred yards north of the dam revealed approximately 12 feet (3.7 meters) of vertical displacement along the fault and aerial photographs (Cluff, Glass, and Brogan, 1974) indicated the extension of the fault to the north and south. Although no fault movements have occurred along this zone in recent history, the displacement revealed in the highway excavation suggests that the potential for surface rupture in the future is high.

Newton Dam

Newton Dam was constructed in 1946 by the U.S. Bureau of Reclamation. This dam is a zoned earthfill structure and is approximately 101 feet (31 meters) in height at the maximum section. The reservoir capacity is 5500 acre feet (6,780,000 cubic meters). The dam is located on Newton Creek, 3½ miles (5.6 kilometers) north of Newton. The primary function of the facility is to impound irrigation and recreational water.

This study identified no geologic hazards influencing this facility. The right abutment of the dam is founded on an ancient landslide which occurred on the west side of Little Mountain, however, the slide shows no evidence of any recent geologic activity resulting from construction of the dam.

Wellsville Dam

This dam is located within the Wellsville City limits. It is a very old earthfill structure and very little is known about it. The dam is approximately 20 feet (6 meters) high at the maximum section, 300 feet (91 meters) in length along the crest and about 10 feet (3 meters) wide at the top. The side slopes were roughly measured with a hand held inclinometer and found to be between 1.1:1 to 1.4:1 (horizontal: 1 vertical). These side slopes are considered to be very steep but no sign of instability is apparent. Several wet areas below the dam may be attributed to minor seepage through the base or under the dam. Heavy vegetative cover has grown on the side slopes of the embankment. The freeboard was measured and found to be approximately 1½ feet (0.46 meters) below the crest elevation. It is controlled by an overflow spillway on the left abutment of the dam. The reservoir capacity is unknown but roughly estimated to be less than 50 acre feet (61,700 cubic meters).

Schools

Two high schools, 3 junior high schools and 14 elementary schools, in the Cache County and Logan School Districts were reviewed during this study. Very little information was available to assess most of the schools; hence, the information collected was based largely on field observations and on reports from persons with knowledge of history of the structures.

Perhaps the most critical hazard to which the schools are exposed, is that of ground shaking from earthquakes. Many of the older structures are showing some signs of deterioration and distress. While these schools may be safe with only static forces acting on them, dynamic forces induced by an earthquake may exceed their reserve strength and cause extensive damage. Problems stemming from the August 1962 Cache Valley Earthquake serves as an appropriate example of the hazards that may exist. During this earthquake, ominous cracks developed in the Lewiston Elementary School, Park Elementary School in Richmond, and the old Logan Junior High School. The old Logan Junior High School was later razed as a result of this damage. Other damage to the schools included window breakage at some schools, cracking of the smoke stack at the Logan High School, and destruction and collapse of a portion of the stone capping on the North Cache Junior High School at Richmond. After the earthquake, steel tie rods were placed in the Lewiston Elementary School to help reinforce the structure.

The magnitude of the August 1962 earthquake was rated as 5.7 on the Richter scale; however, an earthquake of much greater magnitude is possible in the Cache Valley. Experience suggests that great damage can be expected from an earthquake of magnitude greater than the 1962 Cache Valley event.

The hazard exposure due to locating schools in fault zones is another important consideration. Although Cache County schools are not currently faced with this hazard exposure, it was found that site selection processes of the past have not considered proximity of the site to fault zones.

Four exploratory drill holes were bored at the site of the Sky View High School at Smithfield in 1962. An examination of the boring logs suggests that the liquefaction potential of the underlying soil should be studied. The density of underlying fine, silty sand layers is quite low as indicated by standard penetration tests. The height of the static water table could not be determined from the boring records, however, if the water table is near the surface, a critical liquefaction hazard may exist.

The indication that liquefaction could be a hazard is important since many other areas, especially along the Bear River, are probably underlain by similar soils. During the August 1962 Cache Valley Earthquake, the development of sand boils in several areas along the Bear River indicated that a condition of initial liquefaction had occurred. Earthquakes with greater magnitudes and longer durations may cause extensive liquefaction in the locations that displayed the characteristics of initial liquefaction.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Purpose of Study

The purpose of this study was to review existing and proposed publicly used facilities in Cache County, Utah, with regard to geologic hazards and to study the present level of geologic and geotechnical input involved in the siting, design and construction of these structures. The study was intended to indicate the present general level of geologic hazard existing in Cache County. It was also intended to provide information that would help define the nature of problems stemming from these geologic hazards and to encourage the review and revision of currently inadequate public policies pertaining to the siting, design, and construction of critical public facilities.

Limitations

The cooperation from owners, designers, constructors, and anyone knowledgeable about individual facilities was vitally important for a complete and proper review of the facilities. Some or all of these individuals, in some cases, were reluctant to provide meaningful information. In other cases, especially those pertaining to many older structures, little or no information or documentation was available to indicate the design considerations or thoroughness of the geotechnical investigation. Therefore, it was frequently the case, that only the surficial geologic environment could be studied to indicate any problems. A knowledge of the subsurface conditions such as those provided by a proper geologic and geotechnical investigation, may indicate either a greater or lesser exposure to geologic hazards than can be deduced from surficial evidence.

The scope of this study did not permit investigations of the structural capability of facilities to withstand strong ground shaking motion. The study was limited to critical public facilities within Cache County. Facilities associated with Utah State University, however, were not investigated.

Conclusions

Earthquake hazards probably constitute the greatest geologic hazard threat to publicly used facilities in Cache County. Major damage related to strong ground shaking, surface fault rupture, liquefaction or miscellaneous ground failure may result from movement along any one of at least three major faults in or near Cache Valley. These faults and the maximum credible earthquake associated with each are indicated below:

- The East Cache Fault, having a north-south orientation and located along the eastern edge of Cache Valley, is estimated to be capable of producing a maximum credible earthquake magnitude of 7.7 on the Richter scale.
- The West Cache Fault, having a north-south orientation and located at the western margin of Cache Valley, is estimated to be capable of producing a maximum credible earthquake magnitude of 7.5 on the Richter scale.
- The Wasatch Fault, having a north-south orientation, extending for over 200 miles (322 kilometers) and located about 6 miles

> (9.7 kilometers) west of Cache Valley, is estimated to be capable of producing a maximum credible earthquake magnitude of 8.4 on the Richter scale.

A large magnitude earthquake occurring along any of these three major faults would probably cause a considerable amount of damage to many of the structures reviewed during this study, especially many older structures.

Strong ground shaking resulting from earthquakes is considered to be the greatest seismic hazard affecting facilities. Other seismic hazards, such as fault rupture, may present critical problems to some structures. Many past earthquakes in the United States, in areas with similar construction to that of Cache Valley, and even the records of damage in recent Utah and Cache Valley earthquakes supply ample evidence to support the fact that strong ground shaking is usually the major cause of damage. Kaliser (U.S. Senate, 1975, pp. 242) reports that the ground shaking damage from the August 1962 Cache Valley Earthquake alone was $1,700,000 (1974 dollars). This earthquake had a Richter magnitude of 5.7 and mainly affected areas of Logan, Smithfield, Richmond and Lewiston.

Some facilities in Cache County are exposed to surface fault rupture hazards. If a structure is located astride a fault which displaces more than a few inches, extensive damage or total destruction is likely to occur. The surest way to avoid this hazard is to identify the fault zone and avoid construction there.

The active faults are located near the base of the mountain ranges in Cache County. Certain critical facilities such as culinary water supply storage tanks, because of economic considerations stemming from hydraulic design considerations, are also typically located on sites near the base of the mountain ranges. Thus, an inherent geologic hazard exists at virtually all of these otherwise desirable sites. This condition dictates the need for careful individual investigation of all sites in close proximity to known fault zones.

Major geologic hazards other than those related to earthquakes do not appear to affect most structures included in this study. Most of the county's communities have been developed on recessional benches produced by ancient Lake Bonneville as it receded. The soil types found in these benches, especially the higher benches, is generally dense sand and gravel and is usually well suited for construction. However, some problems such as erosion and the development of minor landslides have occurred at or near some of the facilities studied in the bench areas. These problems have generally developed in areas possessing steep slopes and/or excessive groundwater.

Although the structures reviewed do not indicate problems arising from subsidence due to compressible clay strata, many areas of the valley (generally, those below elevation 4500 feet) are underlain by such soils. Since the construction of major structures in these areas has been minimal, problems have usually not been encountered. The soft clays of the valley are highly compressible and extensive groundwater mining could lead to land subsidence problems. This hazard should be thoroughly investigated before extensive groundwater use is allowed.

Many critical facilities were found to be subjected to some degree of geologic hazard during this study. In an effort to emphasize the critical need for adequate geologic and geotechnical investigations and analysis for important public structures, some of the hazards that threaten existing structures have been identified in Table 5-1. It is hoped that this identifcation will illustrate the nature of the hazards and indicate where additional future investigations are necessary in order to mitigate the hazards.

It was not possible, within the scope of this study, to properly assess the structural hazard resulting from strong ground shaking. Based on the reported damage from past Utah earthquakes and the reported damage from past earthquakes in other areas where construction techniques were similar, the hazard is considered to be high. This is especially true for many older structures.

General Recommendations

The "state-of-the-art" in earthquake engineering has advanced significantly in the last decade. It has come about largely as a result of the impact of several catastrophic earthquakes in California. Duke (1975) describes the impact of these earthquakes as follows:

- San Francisco, 1906 -- led to improvements in water supply systems, principally for fighting fire. The importance of system redundancy was emphasized.
- Long Beach, 1933 -- resulted in general adoption of lateral force provisions in California building codes. Several California electrical utilities adopted a seismic design criteria for important facilities which exceeded those required by local building codes.
- Kern County, 1952 -- electric utilities improved criteria for anchoring and bracing electrical equipment. Some earthquake resistive criteria were developed for tanks located on the ground and the importance of flexibility in connected piping was emphasized.

Table 5-1. List of structures with hazardous conditions.

Facility	Location	Hazard
Culinary Water Storage Tanks		
Hyrum	At mount of Blacksmith Fork Canyon	1. Astride major fault scarp 2. Minor landslide below tank 3. Erosive soil
Millville	Extreme S.E. corner of Millville	Very near or within major fault zone
Providence	At mouth of Providence Canyon	Very near or within major fault zone
Wellsville	Approximately 1 mile south of Wellsville	Located a few feet away from and between two major fault scarps
Culinary Water Supply Well		
Hyrum	East end of Main Street, Hyrum	Minor problem with sand infiltration
Culinary Water Supply Springs		
Providence Canyon Spring	2 miles above entrance to Providence Canyon	Contamination of water supply from sources upstream

Table 5-1. Continued.

Facility	Location	Hazard
Cove Springs	Approximately 3/4 miles N.E. of town	Contamination of water supply from infiltration of surface pollutants
Dams and Reservoirs		
Porcupine Dam and Reservoir	Approximately 1½ miles east of the mouth of the East Fork of the Little Bear River	1. Rockfall hazard near spillway 2. Loss of piezometer instrumentation because of vandalism 3. Possible stability problems in embankment
Hyrum Dam	Southwest portion of Hyrum	Spillway capacity is possibly inadequate
First Dam Logan River	At mouth of Logan Canyon	1. Located astride a major fault scarp 2. Extensive populated area downstream
Schools		
Lewiston Elementary School	Lewiston	Cracked walls resulting from ground shaking during Cache Valley Earthquake, 1962

Table 5-1. Continued.

Facility	Location	Hazard
Park Elementary School	Richmond	Minor cracking resulting from ground shaking during Cache Valley Earthquake, 1962
Old Logan Junior High School	Logan	Structural damage resulting from ground shaking during Cache Valley Earthquake, 1962
North Cache Junior High School	Richmond	Window breakage, minor cracks, and architectural damage
Logan High School	Logan	Window breaking, structural damage and near collapse of old smokestack
Sky View High School	Smithfield	Possible liquefaction of subsurface soils

- San Fernando, 1971 -- this shock has had the greatest impact on the development of lifeline earthquake resistive design. Systems with and without aseismic design features were subjected to strong ground shaking and differential earth movements. The behavior of lifelines in this earthquake indicated some glaring hazards. (Duke, 1975)

California has benefited the most from these advances in the state-of-the-art. Other seismically active states have not yet begun to design aseismic capacity into many of their vitally important facilities. Many inexpensive remedies are available to help mitigate the earthquake hazards. However, a complete assessment of public facilities by the operating agency is essential just to determine and rank the hazards to which the facilities may be exposed, before mitigation measures can be initiated. By following the guidelines established by California agencies and by applying more stringent design requirements adapted for specific localities, structures can be made much more earthquake resistant.

As a result of the San Fernando event, the American Society of Civil Engineers was stimulated to organize the Technical Council on Lifeline Earthquake Engineering (TCLEE). It is their goal, "to elevate the level of engineering practice in design of lifelines to survive earthquakes". The council is expected to assume a role similar to that of the Structural Engineers Association of California which has been very instrumental in developing better design standards for that state.

Publically accepted levels of risk should be established for critical facilities in all communities. Legislation may be required to establish these risk levels or acceptable levels of performance.

The development of aseismic design criteria should be guided by professional leadership and upgraded as needed when evaluated by field tests resulting from future earthquakes.

Operating agencies responsible for facilities should set strict guidelines and review procedures to assure the adequacy of assessments of the level of hazard exposure of their facilities. The Public Utilities Commission of California has set some general aseismic guidelines for seismic safety as reported by Duke (1975):

- Provide standby and storage facilities and alternate routes.
- Insure rapid restoration capability
- Provide interconnections with other utilities
- Meet and exceed standard building and safety codes
- Review and modify existing design criteria
- Review older structures
- Install instrumentation to record strong ground motion and monitor damage
- Plan major routes to avoid areas of known seismic hazard
- Recognize possible site amplifications in design criteria
- Coordinate emergency planning with other utilities and agencies (Duke, 1975).

The Earthquake Engineering Research Institute (EERI), is a national society composed of professional people from universities, industry associations, research organizations, professional societies, and many firms and agencies directly involved in the planning, design, construction, and operation of earthquake resistant structures. It is the role of EERI to help communicate and coordinate earthquake mitigation measures among the many organizations interested in the field. By subscribing to the principles established by EERI and becoming actively involved in formal self-education of the hazards, communities will be able to significantly reduce the earthquake hazard exposure of their facilities. Post-earthquake reconnaissance inspection forms for buildings and lifelines are available through EERI and will play an important role in collecting data to mitigate damage from future earth shocks.

Specific Recommendations

Development of public facilities in Cache County is currently proceeding with only minimal aseismic consideration. This should not be allowed to continue. Geologic and geotechnical investigations should be performed for all facilities of public importance. The degree of investigation required is dependent on the site location and should be determined by an individual who is experienced in the field. Geologic as well as geotechnical evaluation of sites should be mandatory whenever the construction takes place in the bench areas along either side of the valley or where surface fault rupture hazards have been identified (refer to Cluff, Glass and Brogan, 1974).

It is extremely important that geologic and geotechnical consideration be incorporated early in the planning stages for a facility. Proper identification and evaluation of hazards during the site selection phase of a project will generally save money in the long run. If a hazardous site is chosen unknowingly and the operating agency becomes committed to the location because of contractual or other reasons, or if problems develop after the construction of a facility is started, the associated costs to correct the problems are likely to be substantially greater than the increased cost associated with a detailed geologic and geotechnical investigation. It must be recognized, however, that only trained, experienced individuals may be capable of fully and correctly assessing the nature of the hazards as they exist.

When a facility must be located in a potentially vulnerable location, the investigation of the hazard should insure that the facility possesses a high order of dependability of performance. Construction should not take place astride active fault traces. However, when a site must, of necessity, be located within a fault zone, the investigation should define the exact location of surface fault ruptures if possible. Finally, a plan of action should be developed to quickly restore necessary services from damaged facilities.

Certain lifelines such as water lines , sewer lines, gas or petroleum lines, and power and communication lines must cross active faults. The location of the fault should be identified and if the competence of the fault cannot be guaranteed, the necessary materials for rapid repair should be provided where they are readily available. Additionally, it is recommended that the lines cross at or near the ground surface to facilitate emergency repair work. Automatic shut-off valves and flexible joints should be incorporated to control the damage resulting from the disruption of the lifeline itself. Figure 5-1 (from Lew, Leyendecker and Dikkers, 1971) illustrates the damage and hazard exposure resulting from the rupture of gas, water, and sewer lines in the same location. The facilities were not only inoperable when needed most, but also a significant problem was created by the lifelines themselves.

Structural damage resulting from strong ground shaking has been identified as an extreme hazard during earthquakes. The Structural Engineers Association of California has been effective in reducing the hazard by the adoption and enforcement of stringent aseismic design criteria. The latest edition of the Uniform Building Code (1976) although significantly superior to previous editions, is regarded by many as providing only minimal earthquake resistive design criteria for structures. In seismically active areas, critical structures such as hospitals and emergency service structures, schools or other high occupancy structures, lifelines, and other important public facilities, may require more stringent design criteria than the criteria set forth by the Uniform Building Code (1976).

Many times minor structural details can help mitigate a significant portion of the total damage. Figures 5-2 through 5-5 from Lew, Leyendecker, and Dikkers (1971) provide glaring examples of the omission of such details. In Figure 5-2, telephone switching equipment at the Sylmar central office of General Telephone Company, is shown to be totally disrupted. If the columns of equipment had been tied together structurally, failure would not have occurred. This situation may be likened to that of rows of bookshelves in a

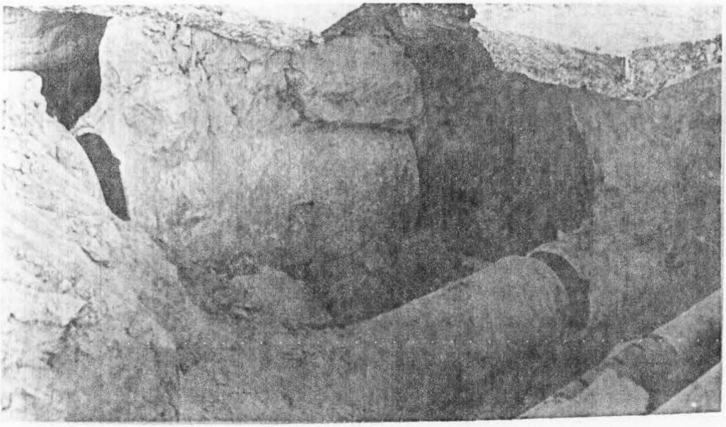


Figure 5-1. Ruptured sewer, water, and gas lines after the San Fernando Earthquake (after Lew, Leyendecker, and Dikkers, 1971).

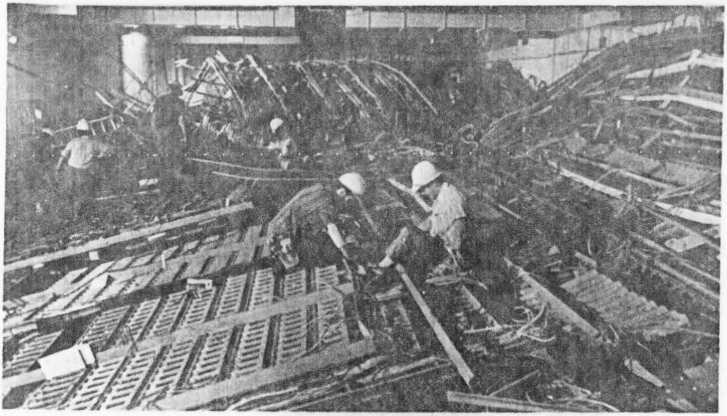


Figure 5-2. Toppled and damaged telephone switching equipment at Sylmar Central Office of General Telephone Company (after Lew, Leyendecker, and Dikkers, 1971).

library. If the rows are tied together to act as a unit rather than each row being supported individually, the unit will become much more stable. Instead, if the rows act individually, and one row topples, the result may be the same as a row of closely spaced dominos falling, each domino upsetting the next one.

Figure 5-3 shows an ambulance which was destroyed as a result of the collapse of a simple port structure. In this case, insufficient lateral support was provided for the relatively massive roof structure. The vertical columns were not capable of transferring the lateral force which was generated by the roof structure as a result of the earthquake. The emergency service vehicles parked in this port were rendered totally useless during the time when needed most.

Figures 5-4 and 5-5 show similar destruction. The electrical power transmission equipment shown in the figures was destroyed simply because of insufficient lateral support. A detailed evaluation of similar critical components of any lifeline system, should suggest many relatively inexpensive measures which can be taken to safeguard the system.

In the past, the governing society has been reluctant to accept the increased costs normally associated with hazard resistance analysis and design. Even in such seismically active areas as California, Alaska, and Japan, the incentive to provide earthquake resistant structures did not occur until after the occurance of major disasters. In Utah, a major disaster has not yet occurred in the densely developed areas. However, the potential exists. By initiating, at this time,

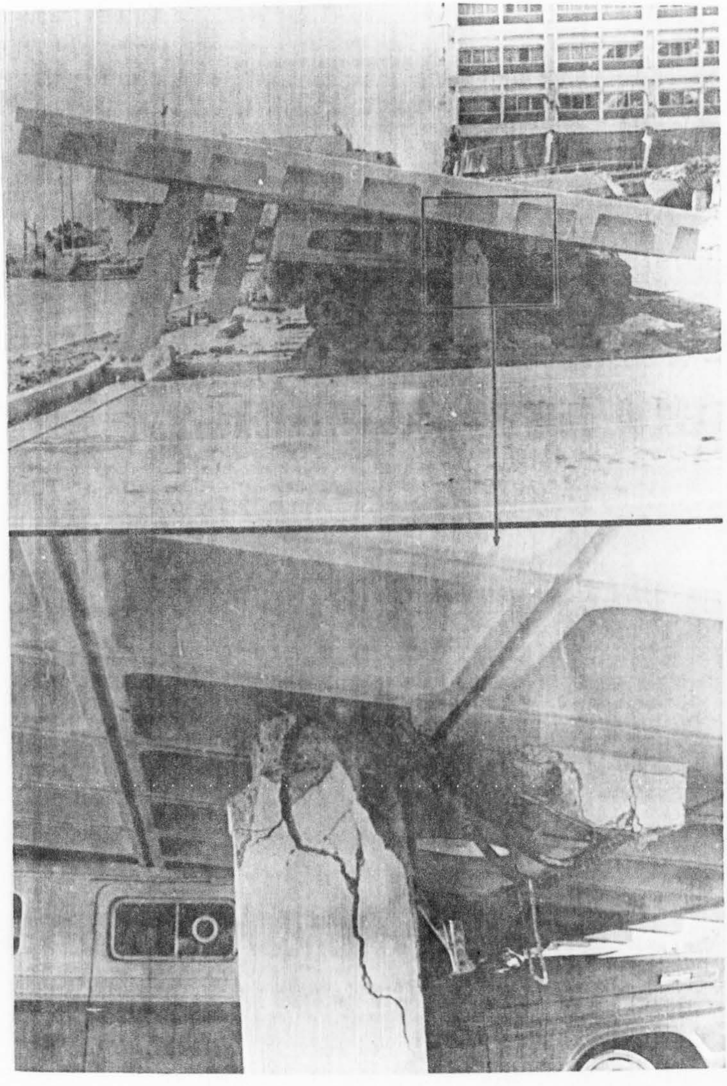


Figure 5-3. Destruction of emergency service vehicles parked in a collapsed ambulance port (after Lew, Leyendecker and Dikkers, 1971).

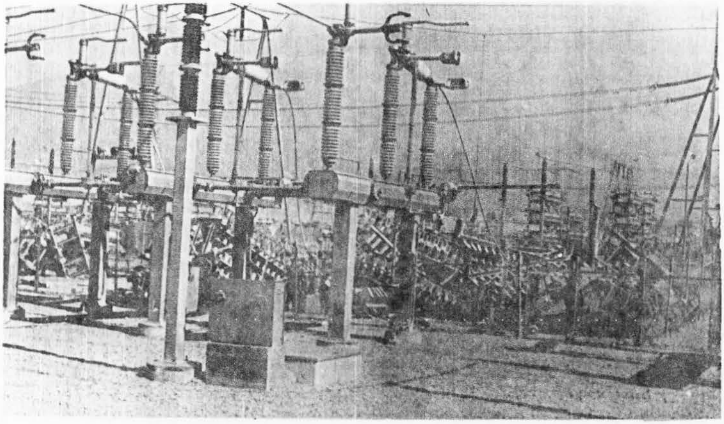


Figure 5-4. Destroyed electrical equipment at Sylmar Converter Station as a result of the San Fernando Earthquake (after Lew, Leyendecker, and Dikkers, 1971).

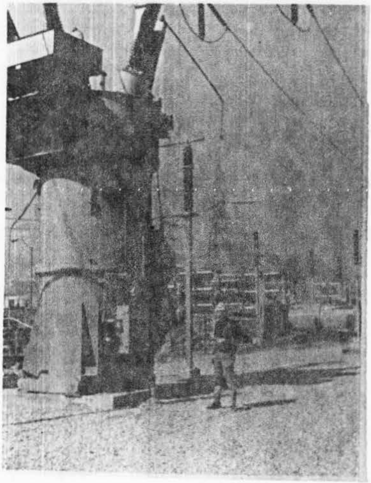


Figure 5-5. Destroyed electrical equipment at Sylmar Converter Station as a result of the San Fernando Earthquake (after Lew, Leyendecker, and Dikkers, 1971).

Programs to help educate the general public about existing geologic hazards, steps can be taken to mitigate a disaster before it occurs.

Providing hazard resistant structures is the responsibility of everyone. No single organization can be expected to carry the burden by itself. First of all, the government should establish a basis for an accepted level of risk to be associated with each type of structure used by the public. Guidelines should be established to help direct future development toward a high order of dependability of performance, and review procedures for existing vulnerable structures should be established.

The public should be responsible for requiring that future development and review of hazardous facilities provides for structures which function to protect life, property, and activities against geologic hazards and against a hazard from the facility itself. The public must realize that additional costs may be associated with earthquake resistant design and must be willing to accept this burden in exchange for safer structures.

The owner of a facility is responsible for providing for proper geologic and geotechnical investigations. The degree of the investigation required should be dependent on the site location and the type of facility. The degree of investigation should also fall within the guidelines as set by government agencies. The owner should obtain an investigation and design which is balanced between economy and risk and falls within the set guidelines.

A geotechnical engineer and/or geologists are responsible for informing everyone of the degree of subsurface investigation necessary for a site. They should suggest to the owner when additional investigation is necessary. The architect and structural engineers are also responsible for requiring that competent personnel and proper subsurface investigations are provided for vital public facilities.

Finally, the constructor is reponsible for seeing that the facility is properly constructed as designed. Adherence to minor details during the construction of a facility can provide for a much safer structure.

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APPENDICES

Appendix A

The data in this appendix includes a list of 609 earthquakes which occurred in Utah during the period 1850 through June 1965 (from Cook and Smith, 1967)

Appendix A

KEY TO EARTHQUAKE DATA

Time of earthquake occurrence -- (year, month, day, hour, minute, second) given in Greenwich Civil Time (GCT)[1].

Earthquake location -- North latitudes (LAT-N) and West longitudes (LONG-W) are listed with the following accuracy: University of Utah data - nearest 0.01 degree; Coast and Geodetic Survey Data - nearest 0.1 degree; and Non-instrument recorded data - geographical location, usually where greatest intensity was reported.

Richter magnitude -- (MAG). Magnitudes of earthquakes occurring prior to 1950 were obtained by converting the intensities, (modified Mercalli scale) which were reported by Williams and Tapper (1953), to Richter magnitudes. Magnitudes of earthquakes occurring from 1950 through June 1962 were as listed by the Coast and Geodetic Survey. Magnitudes of earthquakes occurring from July 1962 through June 1965 were as listed by the University of Utah.

Focal depth -- (DEP) given in kilometers, as listed by the Coast and Geodetic Survey. When the Coast and Geodetic Survey focal depths were not available, the depth was arbitrarily and approximately placed at 20 km.

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[1] Greenwich Civil Times are seven hours later than Mountain Standard Times.

Source of data -- (S) is listed as follows:

C -- Coast and Geodetic survey data
U -- University of Utah data
W -- Williams and Tapper (1953)

Epicenter determination -- (D) was made by both the Coast and Geodetic survey and the University of Utah when the letter "D" was included.

Remarks -- This column gives general information about each event.

YEAR	MO	DAY	HR	MN	SEC	LAT-N	LONG-W	MAG	INT	DEP	S	D	REMARKS
1853	DEC	01	14	15	----	-----	------	4.3	V		W		NEPHI WASATCH FAULT
1853	DEC	01	18	45	----	-----	------	4.3	V		W		PROVO WASATCH FAULT
1859	AUG	28	--	--	----	-----	------	3.7	IV		W		PAROWAN HURRICANE FAULT
1868	OCT	17	10	30	----	-----	------	3.1	III		W		EPHRAIM THOUS LAKE FAULT 3 SHOCKS
1872	MAR	27	07	52	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1873	JUL	31	03	15	----	-----	------	4.3	V		W		BEAVER HURRICANE FAULT DAMAGE
1873	DEC	18	14	00	----	-----	------	3.7	IV		W		BEAR LAKE VALLEY BEAR LAKE FAULT
1873	DEC	27	03	00	----	-----	------	3.7	IV		W		FARMINGTON SEVERE SHOCK WASATCH FLT
1874	JUN	18	06	00	----	-----	------	3.7	IV		W		SALT LAKE CITY
1874	JUN	18	07	00	----	-----	------	3.7	IV		W		FELT SALT LAKE CITY TO MIDWAY
1876	MAR	22	--	--	----	-----	------	4.9	VI		W		MT PLEASANT AND MORONI 3 SHOCKS
1876	MAR	24	--	--	----	-----	------				W		SAN PETE VALLEY SEVERAL SHOCKS
1876	APR	06	--	--	----	-----	------				W		BEAR LAKE VALLEY BEAR LAKE FAULT
1876	APR	06	--	--	----	-----	------				W		BEAR LAKE VALLEY BEAR LAKE FAULT
1876	NOV	30	05	00	----	-----	------	3.1	III		W		CEDAR CITY HURRICANE FAULT
1876	DEC	30	05	15	----	-----	------	3.1	III		W		RICHFIELD COVE CREEK TUSHAR FAULT
1877	JAN	01	--	--	----	-----	------	3.7	IV		W		RICHFIELD FELT 3,000 SQ MI TUSHAR FLT
1877	JAN	15	12	00	----	-----	------	3.1	III		W		SEVIER CITY TUSHAR FAULT 2 SHOCKS
1877	MAR	05	09	00	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1878	JUL	21	12	00	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1878	AUG	14	--	--	----	-----	------	4.3	V		W		COVE CREEK HURRICANE FAULT
1878	AUG	15	13	40	----	-----	------	2.0	II		W		COVE CREEK HURRICANE FAULT
1878	AUG	15	14	40	----	-----	------	2.0	II		W		COVE CREEK HURRICANE FAULT
1878	AUG	16	02	44	----	-----	------	3.7	IV		W		COVE CREEK HURRICANE FAULT
1878	AUG	21	12	--	----	-----	------	3.1	III		W		NORTH OF SALT LAKE CITY WASATCH FLT
1878	SEP	07	19	--	----	-----	------	3.1	III		W		SALT LAKE CITY WASATCH FAULT
1878	DEC	02	--	--	----	-----	------	2.0	II		W		PANGUITCH SEVIER FLT SEVERAL SHOCKS
1880	JUL	12	05	00	----	-----	------	4.3	V		W		BOX ELDER CO PORTAGE 2 SHOCKS
1880	SEP	16	06	27	----	-----	------	3.7	IV		W		SALT LAKE CITY WASATCH FAULT
1880	DEC	27	--	--	----	-----	------	3.1	III		W		KELTON HANSEL VALLEY FLT 2 SHOCKS
1881	MAR	26	02	15	----	-----	------	3.1	III		W		HEBRON DAMAGE
1881	AUG	04	04	30	----	-----	------	3.1	III		W		BEAVER HURRICANE FAULT 5 SHOCKS
1881	AUG	04	18	30	----	-----	------				W		BEAVER HURRICANE FAULT
1881	OCT	16	07	00	----	-----	------	3.1	III		W		MOUNT PLEASANT THOUSAND LAKE FAULT
1883	SEP	28	11	00	----	-----	------	3.7	IV		W		SILVER CITY
1883	NOV	04	--	--	----	-----	------				W		MILLARD CO COVE CREEK
1884	NOV	10	08	50	----	-----	------	6.1	VIII		W		NORTHEASTERN UTAH SEVERE DAMAGE
1884	NOV	10	09	10	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	10	09	19	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	10	09	48	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	10	10	45	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	11	08	55	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	11	14	00	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	12	08	50	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	12	09	35	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	12	12	05	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	13	08	55	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	NOV	13	10	40	----	-----	------	2.0	II		W		BEAR LAKE VALLEY CRAWFORD MTN FAULT
1884	DEC	08	--	--	----	-----	------	3.1	III		W		OGDEN HANSEL VALLEY FLT MANY SHOCKS
1885	SEP	05	03	35	----	-----	------	3.1	III		W		KANAB HEAVY SHOCK SEVIER FAULT
1885	OCT	26	06	10	----	-----	------	3.1	III		W		MINERSVILLE 4 EVENTS MINERAL MTS FLT
1885	OCT	26	08	00	----	-----	------	3.1	III		W		BEAVER CO FRISCO BEAVER MTN FAULT
1885	OCT	26	09	00	----	-----	------	3.1	III		W		BEAVER CO FRISCO BEAVER MTN FAULT
1885	DEC	17	01	00	----	-----	------	3.7	IV		W		CIRCLEVILLE TUSHAR FAULT
1885	DEC	17	03	20	----	-----	------	3.1	III		W		TEASDALE THOUSAND LAKE FAULT
1887	DEC	05	15	30	----	-----	------	5.5	VII		W		KANAB SEVIER FAULT DAMAGE
1889	DEC	07	11	00	----	-----	------	3.7	IV		W		MANTI THOUSAND LAKE FAULT
1891	APR	20	13	55	----	-----	------	4.9	VI		W		WASHINGTON CO HURRICANE FAULT DAMAGE
1891	SEP	13	04	48	----	-----	------	3.1	III		W		CEDAR CITY HURRICANE FAULT
1893	AUG	30	23	30	----	-----	------	3.7	IV		W		SNOWVILLE HANSEL VALLEY FAULT
1894	JAN	08	18	00	----	-----	------	4.3	V		W		FISH SPRINGS FISH SPRINGS FAULT
1894	FEB	05	03	30	----	-----	------	3.7	IV		W		KANOSH HURRICANE FAULT
1894	FEB	06	15	00	----	-----	------	3.1	III		W		KANOSH HURRICANE FAULT
1894	JUL	18	22	50	----	-----	------	4.3	V		W		OGDEN WASATCH FAULT DAMAGE
1895	JUL	27	22	25	----	-----	------	3.7	IV		W		MT PLEASANT THOUS LAKE FAULT DAMAGE
1896	JUN	07	05	30	----	-----	------	3.1	III		W		SANPETE CO GUNNISON SEVIER FAULT
1896	SEP	13	01	30	----	-----	------	3.7	IV		W		NEPHI WASATCH FAULT
1896	OCT	03	15	50	----	-----	------	3.1	III		W		LOGAN EAST CACHE FAULT
1896	OCT	14	14	00	----	-----	------	2.0	II		W		HANKSVILLE FELT 3,000 SQ MI
1897	SEP	18	17	45	----	-----	------				W		BRIGHAM CITY

YEAR	MO	DAY	HR	MN	SEC	LAT-N	LONG-W	MAG	INT	DEP	S	D	REMARKS
1898	FEB	21	00	00	----	-----	------				W		CORINNE
1899	NOV	10	09	00	----	-----	------	3.7	IV		W		BEAVER HURRICANE FAULT
1899	DEC	13	13	50	----	-----	------	3.7	IV		W		SALT LAKE CITY WASATCH FAULT
1900	AUG	01	07	45	----	-----	------	5.5	VII		W		EUREKA DISTRICT DAMAGE
1900	AUG	01	07	55	----	-----	------	2.0	II		W		EUREKA DISTRICT
1900	AUG	01	09	00	----	-----	------	2.0	II		W		EUREKA DISTRICT
1900	AUG	01	16	30	----	-----	------	2.0	II		W		EUREKA DISTRICT
1901	AUG	11	16	00	----	-----	------	3.1	III		W		SALT LAKE CITY WASATCH FAULT
1901	AUG	11	18	00	----	-----	------	3.1	III		W		PROVO WASATCH FAULT DAMAGE
1901	NOV	14	--	--	----	-----	------	2.0	II		W		RICHFIELD SHOCKS NOV 14 TO NOV 30
1901	NOV	14	04	39	----	-----	------	6.7	IX		W		RICHFIELD ABOUT 35 SHOCKS TUSHAR FLT
1902	JAN	05	01	14	----	-----	------	3.1	III		W		BEAR LAKE VALLEY BEAR LAKE FAULT
1902	JUN	01	--	--	----	-----	------	3.1	III		W		BEAVER SEVERAL SHOCKS HURRICANE FLT
1902	JUL	31	07	00	----	-----	------	4.3	V		W		BEAVER CO BEAVER HURRICANE FAULT
1902	NOV	17	19	50	----	-----	------	6.1	VIII		W		PINE VALLEY 2 SHOCKS DAMAGE
1902	DEC	05	--	--	----	-----	------	4.9	VI		W		PINE VALLEY MANY SHOCKS
1903	JUL	12	16	30	----	-----	------	3.1	III		W		RICHFIELD TUSHAR FAULT
1903	JUL	23	08	34	----	-----	------	3.1	III		W		OGDEN-SLC AREA WASATCH FAULT
1903	NOV	04	23	40	----	-----	------	3.1	III		W		WASHINGTON CO ST GEORGE
1903	NOV	23	10	00	----	-----	------	4.3	V		W		WASHINGTON CO ST GEORGE
1905	NOV	11	23	00	----	-----	------	4.3	V		W		SNOWVILLE HANSEL VALLEY FAULT
1906	FEB	21	05	30	----	-----	------				W		SEVIER CO ELSINORE TUSHAR FAULT
1906	MAY	24	21	10	----	-----	------	4.3	V		W		OGDEN 3 SHOCKS WASATCH FAULT
1908	APR	15	--	--	----	-----	------	4.9	VI		W		MILFORD BEAVER MTS FLT 5 SHOCKS
1909	OCT	06	02	50	----	-----	------	6.7	IX		W		NORTHWESTERN UTAH FELT 30,000 SQ MI
1909	OCT	06	03	24	----	-----	------				W		NORTHWESTERN UTAH HANSEL VALLEY FLT
1909	NOV	17	06	30	----	-----	------	4.3	V		W		GARLAND HANSEL VALLEY FLT DAMAGE
1909	NOV	17	07	00	----	-----	------	4.3	V		W		GARLAND MANY AFTERSHOCKS OCT TO DEC
1910	JAN	10	13	00	----	-----	------	4.9	VI		W		ELSINORE TUSHAR FAULT
1910	JAN	10	13	30	----	-----	------	4.9	VI		W		ELSINORE TUSHAR FAULT
1910	JAN	10	18	45	----	-----	------	4.9	VI		W		ELSINORE TUSHAR FAULT
1910	JAN	10	20	25	----	-----	------	4.9	VI		W		ELSINORE TUSHAR FAULT
1910	JAN	10	21	30	----	-----	------	4.9	VI		W		ELSINORE TUSHAR FAULT
1910	JAN	11	04	00	----	-----	------	4.9	VI		W		ELSINORE TUSHAR FAULT
1910	JAN	12	03	00	----	-----	------	4.9	VI		W		ELSINORE TUSHAR FAULT DAMAGE
1910	JAN	12	03	15	----	-----	------	4.9	VI		W		ELSINORE TUSHAR FAULT
1910	MAY	03	00	10	----	-----	------	2.0	I		W		SALT LAKE CITY 2 SHOCKS WASATCH FLT
1910	MAY	22	14	28	----	-----	------	5.5	VII		W		SALT LAKE CITY WASATCH FAULT DAMAGE
1910	MAY	22	15	38	----	-----	------	5.5	VII		W		SALT LAKE CITY WASATCH FAULT
1910	MAY	22	18	26	----	-----	------	5.5	VII		W		SALT LAKE CITY WASATCH FAULT
1910	MAY	23	15	45	----	-----	------	3.1	III		W		SALT LAKE CITY WASATCH FAULT
1910	MAY	26	06	05	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1913	OCT	20	10	00	----	-----	------	3.7	IV		W		PANGUITCH SEVIER FAULT
1914	APR	03	16	06	----	-----	------	4.3	V		W		WASATCH FRONT SALT LAKE TO OGDEN
1914	MAY	13	17	15	----	-----	------	5.5	VII		W		N WASATCH FRONT WASATCH FAULT DAMAGE
1914	DEC	14	05	30	----	-----	------	4.3	V		W		ENTERPRISE
1914	DEC	21	05	25	----	-----	------	3.1	III		W		HURRICANE, PINE VALLEY, AND PINTO
1915	FEB	12	19	50	----	-----	------	3.7	IV		W		ENTERPRISE
1915	FEB	13	08	30	----	-----	------	3.7	IV		W		ENTERPRISE
1915	APR	26	04	30	----	-----	------	2.0	II		W		EMERY JOES VALLEY FAULT
1915	JUL	15	22	00	----	-----	------	4.9	VI		W		SPRINGVILLE-SLC WASATCH FAULT
1915	JUL	30	18	50	----	-----	------	4.3	V		W		BEAR RIVER VALLEY HANSEL VALLEY FLT
1915	AUG	11	10	20	----	-----	------	6.1	VIII		W		STANSBURY RANGE
1915	SEP	20	01	28	----	-----	------	3.1	III		W		THISTLE
1915	OCT	02	23	41	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1915	OCT	03	01	50	----	-----	------	3.1	III		W		SALT LAKE CITY WASATCH FAULT
1915	OCT	03	06	56	----	-----	------	4.9	VI		W		N UTAH HANSEL VALLEY FAULT
1915	OCT	04	12	00	----	-----	------	3.1	III		W		CLARKSTON CLARKSTON FAULT
1915	OCT	05	08	00	----	40.00	114.00	5.5	VII		W		IBAPAH
1915	OCT	25	17	13	----	-----	------	3.1	III		W		JOSEPH TUSHAR FAULT
1916	FEB	05	06	25	----	-----	------	4.3	V		W		UTAH COUNTY WASATCH FAULT
1918	OCT	16	12	45	----	-----	------	3.1	III		W		CLARKSTON AND TREMONTON WASATCH FLT
1919	MAY	07	23	30	----	-----	------	3.7	IV		W		MORONI THOUSAND LAKE FAULT
1920	AUG	18	08	20	----	-----	------	3.1	III		W		BEAVER HURRICANE FAULT
1920	SEP	18	20	10	----	-----	------	4.3	V		W		BRIGHAM CITY WASATCH FAULT
1920	SEP	19	13	50	----	-----	------	4.3	V		W		BRIGHAM CITY WASATCH FAULT
1920	NOV	20	04	35	----	-----	------	4.3	V		W		BRIGHAM CITY WASATCH FAULT
1920	NOV	26	00	00	----	-----	------	4.9	VI		W		ST GEORGE
1920	DEC	17	09	55	----	-----	------	3.7	IV		W		BRIGHAM CITY WASATCH FAULT
1920	DEC	17	10	05	----	-----	------	3.7	IV		W		BRIGHAM CITY WASATCH FAULT

YEAR	MO	DAY	HR	MN	SEC	LAT-N	LONG-W	MAG	INT	DEP	S	D	REMARKS
1921	JUN	02	21	30	----	-----	------	3.1	III		W		CEDAR CITY HURRICANE FAULT
1921	SEP	12	10	18	----	-----	------	3.7	IV		W		RICHFIELD TUSHAR FAULT
1921	SEP	12	10	22	----	-----	------	3.7	IV		W		RICHFIELD TUSHAR FAULT
1921	SEP	12	13	27	----	-----	------	3.7	IV		W		RICHFIELD TUSHAR FAULT
1921	SEP	13	09	30	----	-----	------	4.3	V		W		RICHFIELD TUSHAR FAULT 2 SHOCKS
1921	SEP	28	--	--	----	-----	------	2.0	II		W		ELSINORE TUSHAR FLT MANY SHOCKS
1921	SEP	29	14	12	----	-----	------	6.1	VIII		W		ELSINORE TUSHAR FAULT DAMAGE
1921	SEP	30	02	30	----	-----	------				W		ELSINORE SEVIER VALLEY
1921	SEP	30	13	30	----	-----	------				W		ELSINORE
1921	OCT	01	02	00	----	-----	------	2.0	II		W		ELSINORE TUSHAR FAULT
1921	OCT	01	15	32	----	-----	------	6.1	VIII		W		ELSINORE TUSHAR FAULT DAMAGE
1921	OCT	01	17	30	----	-----	------	2.0	II		W		ELSINORE TUSHAR FAULT
1921	OCT	02	01	05	----	-----	------	2.0	II		W		ELSINORE TUSHAR FAULT
1921	OCT	04	03	00	----	-----	------	2.0	II		W		ELSINORE TUSHAR FAULT
1921	OCT	04	17	25	----	-----	------	2.0	II		W		ELSINORE TUSHAR FAULT
1921	OCT	08	20	30	----	-----	------	2.0	II		W		ELSINORE TUSHAR FAULT
1921	OCT	10	08	30	----	-----	------	2.0	I		W		ELSINORE TUSHAR FAULT
1921	OCT	10	09	45	----	-----	------	2.0	I		W		ELSINORE TUSHAR FAULT
1921	OCT	15	11	15	----	-----	------	3.1	III		W		ELSINORE TUSHAR FAULT
1921	OCT	15	12	27	----	-----	------	3.1	III		W		ELSINORE TUSHAR FAULT
1921	OCT	27	14	15	----	-----	------	5.5	VII		W		ELSINORE TUSHAR FAULT 2 SHOCKS
1921	DEC	20	09	45	----	-----	------	3.7	IV		W		ELSINORE TUSHAR FAULT
1921	DEC	20	10	35	----	-----	------	3.7	IV		W		ELSINORE TUSHAR FAULT
1921	DEC	20	12	15	----	-----	------	3.7	IV		W		ELSINORE TUSHAR FAULT
1921	DEC	20	13	00	----	-----	------	3.7	IV		W		ELSINORE TUSHAR FAULT
1921	DEC	20	14	50	----	-----	------	3.7	IV		W		ELSINORE TUSHAR FAULT
1921	DEC	20	15	15	----	-----	------	3.7	IV		W		ELSINORE TUSHAR FAULT
1923	MAY	14	12	15	----	-----	------	4.3	V		W		NADA
1923	JUN	07	04	15	----	-----	------	4.3	V		W		LOGAN EAST CACHE FAULT DAMAGE
1923	JUN	09	02	37	----	-----	------	2.0	II		W		RICHMOND EAST CACHE FAULT
1923	SEP	07	18	39	----	-----	------	3.7	IV		W		RICHMOND EAST CACHE FAULT
1924	JAN	01	23	15	----	-----	------	3.1	III		W		KANE CO ORDERVILLE SEVIER FAULT
1925	JUL	14	13	47	----	-----	------	3.7	IV		W		MODENA
1925	DEC	01	07	30	----	-----	------	3.1	III		W		SALT LAKE CITY
1925	MAY	03	--	--	----	-----	------	2.0	II		W		SALT LAKE VALLEY WASATCH FAULT
1926	MAY	15	19	51	----	-----	------	3.1	III		W		KANE CO ORDERVILLE SEVIER FAULT
1926	JUN	01	05	20	----	-----	------	2.0	II		W		ORDERVILLE SEVIER FAULT
1926	JUN	05	11	00	----	-----	------	3.1	III		W		ORDERVILLE SEVIER FAULT
1926	JUN	22	03	40	----	-----	------	2.0	II		W		ORDERVILLE SEVIER FAULT
1925	JUN	28	06	00	----	-----	------	2.0	II		W		ORDERVILLE SEVIER FAULT
1926	JUL	12	05	20	----	-----	------	3.1	III		W		ORDERVILLE SEVIER FAULT
1926	JUL	15	--	--	----	-----	------	2.0	II		W		ORDERVILLE SEVIER FAULT
1926	JUL	28	04	25	----	-----	------	3.1	III		W		LEWISTON EAST CACHE FAULT
1925	JUL	29	18	50	----	-----	------	3.1	III		W		LEWISTON EAST CACHE FAULT
1925	OCT	01	15	15	----	-----	------	3.1	III		W		ORDERVILLE SEVIER FAULT
1925	OCT	04	20	30	----	-----	------	3.1	III		W		ORDERVILLE SEVIER FAULT
1925	OCT	23	00	00	----	-----	------	3.1	III		W		ORDERVILLE SEVIER FAULT
1925	NOV	12	03	40	----	-----	------	3.1	III		W		ORDERVILLE SEVIER FAULT
1926	NOV	16	14	15	----	-----	------	3.1	III		W		ORDERVILLE SEVIER FAULT
1926	DEC	19	03	30	----	-----	------	3.7	IV		W		ELBERTA
1927	MAY	22	05	00	----	-----	------	3.1	III		W		RICHFIELD TUSHAR FAULT
1927	NOV	23	02	45	----	-----	------	2.0	II		W		ORDERVILLE SEVIER FAULT
1927	NOV	23	09	30	----	-----	------	3.1	III		W		ORDERVILLE SEVIER FAULT
1928	JUN	02	09	00	----	-----	------	2.0	II		W		PRICE
1931	MAR	09	04	29	----	-----	------	2.0	II		W		ELSINORE TUSHAR FAULT
1931	APR	10	08	30	----	-----	------	2.0	I		W		CEDAR CITY HURRICANE FAULT
1931	JUN	03	04	25	----	-----	------				W		LUND
1932	MAY	22	06	00	----	-----	------	2.0	I		W		VENICE
1932	JUN	18	20	50	----	-----	------	2.0	II		W		PAROWAN HURRICANE FAULT
1932	NOV	11	10	00	----	-----	------	3.7	IV		W		MIDWAY
1932	DEC	21	06	13	----	-----	------	3.1	III		W		SALT LAKE CITY WASATCH FAULT
1933	JAN	20	13	10	----	-----	------	4.9	VI		W		PAROWAN HURRICANE FAULT DAMAGE
1934	JAN	30	20	21	----	-----	------	3.1	III		W		SALT LAKE CITY WASATCH FAULT
1934	JAN	30	21	32	----	-----	------	3.1	III		W		SALT LAKE CITY WASATCH FAULT
1934	MAR	12	15	06	----	41.7	112.8	6.1	VIII		W		KOSMO HANSEL VALLEY FAULT DAMAGE
1934	MAR	12	18	20	----	-----	------				W		KOSMO NW UTAH HANSEL VALLEY FAULT
1934	MAR	17	22	40	----	-----	------	3.1	III		W		COLLINSTON WASATCH FAULT
1934	APR	07	02	15	----	-----	------	3.1	III		W		SALT LAKE CITY
1934	APR	14	21	28	----	-----	------	5.5	VII		W		KOSMO HANSEL VALLEY FAULT
1934	MAY	06	20	10	----	-----	------	4.9	VI		W		KOSMO HANSEL VALLEY FAULT

YEAR	MO	DAY	HR	MN	SEC	LAT-N	LONG-W	MAG	INT	DEP	S	D	REMARKS
1934	JUN	02	12	49	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1934	JUL	04	00	30	----	-----	------	3.7	IV		W		SNOWVILLE HANSEL VALLEY FAULT
1934	DEC	25	10	00	----	-----	------	3.7	IV		W		KANAB SEVIER FAULT
1935	MAY	30	05	00	----	-----	------	2.0	II		W		NEWTON DAYTON FAULT
1935	JUN	04	17	09	----	-----	-------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1935	JUL	09	10	59	----	-----	------	3.7	IV		W		SALT LAKE VALLEY WASATCH FAULT
1935	JUL	09	11	49	----	-----	------	3.7	IV		W		SALT LAKE VALLEY WASATCH FAULT
1935	OCT	05	03	00	----	-----	------	3.7	IV		W		BOULDER
1935	NOV	06	08	12	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1935	DEC	05	21	15	----	-----	------	2.0	II		W		TROPIC PAUNSAGUNT FAULT
1936	MAY	09	10	25	----	-----	------	4.3	V		W		ZION NATIONAL PARK 2 SHOCKS
1936	SEP	02	23	37	----	-----	------	3.1	III		W		KIMBERLY
1937	FEB	13	04	15	----	-----	------	3.7	IV		W		PANGUITCH, PAROWAN, AND CEDAR CITY
1937	FEB	18	06	30	----	-----	------	3.7	IV		W		PANGUITCH, PAROWAN, AND CEDAR CITY
1937	FEB	18	09	00	----	-----	------	3.7	IV		W		PANGUITCH SEVIER FAULT
1937	FEB	21	08	30	----	-----	------	3.1	III		W		PANGUITCH SEVIER FAULT
1937	FEB	26	01	30	----	-----	------	3.7	IV		W		PANGUITCH SEVIER FAULT
1937	MAR	13	11	40	----	-----	------	2.0	II		W		PANGUITCH SEVIER FAULT
1937	APR	01	04	41	----	-----	------	2.0	II		W		PANGUITCH SEVIER FAULT
1937	NOV	18	23	50	----	-----	------	3.7	IV		W		LUCIN
1938	MAR	18	--	--	----	-----	------	3.1	III		W		THISTLE
1938	JUN	30	13	37	----	-----	------	4.3	V		W		SALT LAKE VALLEY WASATCH FAULT
1938	JUL	01	18	14	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1938	DEC	03	22	00	----	-----	------	2.0	II		W		SALT LAKE CITY WASATCH FAULT
1939	MAR	31	06	40	----	-----	------	3.7	IV		W		SALT LAKE CITY WASATCH FAULT
1940	FEB	29	04	47	----	-----	------	2.0	II		W		LOGAN EAST CACHE FAULT
1940	NOV	23	13	00	----	-----	------	3.7	IV		W		MANTI THOUSAND LAKE FAULT
1940	NOV	23	13	22	----	-----	------	3.7	IV		W		MANTI THOUSAND LAKE FAULT
1940	NOV	25	12	30	----	-----	------	2.0	II		W		MANTI THOUSAND LAKE FAULT
1940	NOV	25	13	10	----	-----	------	2.0	II		W		MANTI THOUSAND LAKE FAULT
1940	NOV	25	14	25	----	-----	------	3.7	IV		W		MANTI THOUSAND LAKE FAULT
1941	JUN	20	15	20	----	-----	------	3.1	III		W		LOGAN EAST CACHE FAULT
1942	MAR	28	14	10	----	-----	------	3.7	IV		W		CIRCLEVILLE TUSHAR FAULT
1942	MAR	28	16	00	----	-----	------	3.7	IV		W		CIRCLEVILLE TUSHAR FAULT
1942	APR	18	06	45	----	-----	------	4.3	V		W		HANSEL VALLEY HANSEL VALLEY FAULT
1942	JUN	04	23	04	----	-----	------	4.3	V		W		SANPETE CO EPHRAIM TO NEPHI
1942	AUG	30	23	08	----	-----	------	4.9	VI		W		CEDAR CITY HURRICANE FAULT DAMAGE
1942	SEP	18	01	00	----	-----	------	3.1	III		W		CEDAR CITY HURRICANE FAULT
1942	SEP	18	03	00	----	-----	------	3.1	III		W		CEDAR CITY HURRICANE FAULT
1942	SEP	18	06	20	----	-----	------	3.7	IV		W		CEDAR CITY HURRICANE FAULT
1942	SEP	26	08	00	----	-----	------	2.0	II		W		CEDAR CITY HURRICANE FAULT
1942	SEP	26	12	16	----	-----	------	4.3	V		W		CEDAR CITY HURRICANE FAULT
1942	SEP	26	12	36	----	-----	------	2.0	II		W		CEDAR CITY HURRICANE FAULT
1942	SEP	26	15	50	----	-----	------	4.9	VI		W		CEDAR CITY HURRICANE FAULT DAMAGE
1942	SEP	28	14	30	----	-----	------	3.7	IV		W		ZION NATIONAL PARK
1943	JAN	16	11	50	----	-----	------	3.7	IV		W		CEDAR CITY HURRICANE FAULT DAMAGE
1943	FEB	22	14	20	----	-----	------	4.9	VI		W		SALT LAKE VALLEY WASATCH FAULT
1943	FEB	23	04	50	----	-----	------	2.0	II		W		HUNTER, MAGNA, AND GARFIELD
1943	MAR	12	13	45	----	-----	------	3.7	IV		W		EPHRAIM THOUSAND LAKE FAULT
1943	APR	10	23	42	----	-----	------	4.3	V		W		SALT LAKE VALLEY WASATCH FAULT
1943	APR	11	20	32	----	-----	------	3.1	III		W		SALT LAKE VALLEY WASATCH FAULT
1943	NOV	03	10	30	----	-----	------	4.3	V		W		SEVIER TUSHAR FAULT
1943	NOV	03	12	30	----	-----	------	3.1	III		W		SEVIER TUSHAR FAULT
1943	NOV	04	03	00	----	-----	------	3.1	III		W		SEVIER TUSHAR FAULT
1943	DEC	09	17	06	----	-----	------	3.7	IV		W		CEDAR CITY HURRICANE FAULT
1943	DEC	09	19	21	----	-----	------	3.7	IV		W		CEDAR CITY HURRICANE FAULT
1943	DEC	10	02	17	----	-----	------	3.7	IV		W		CEDAR CITY HURRICANE FAULT
1943	DEC	10	08	30	----	-----	------	2.0	II		W		CEDAR CITY HURRICANE FAULT
1944	MAY	04	00	45	----	-----	------	3.7	IV		W		ST GEORGE
1944	JUN	05	15	45	----	-----	------	2.0	II		W		MONROE SEVIER FAULT
1944	JUN	13	11	48	----	-----	------	2.0	II		W		CEDAR CITY HURRICANE FAULT
1945	MAR	28	10	40	----	-----	------	2.0	II		W		NEPHI WASATCH FAULT
1945	NOV	18	01	15	----	-----	------	4.9	VI		W		GLENWOOD SEVIER FAULT DAMAGE
1946	FEB	19	21	15	----	-----	------	2.0	II		W		PARK VALLEY HANSEL VALLEY FAULT
1946	FEB	20	03	00	----	-----	------	2.0	II		W		PARK VALLEY HANSEL VALLEY FAULT
1946	MAY	05	02	30	----	-----	------	4.3	V		W		BEAR RIVER VALLEY AND LOGAN
1946	OCT	25	16	53	----	-----	------	3.1	III		W		MAGNA
1947	MAR	07	14	14	----	-----	------	3.1	III		W		SALT LAKE CITY WASATCH FAULT
1947	MAR	28	11	02	----	-----	------	3.7	IV		W		MURRAY WASATCH FAULT
1948	NOV	04	13	18	----	-----	------	4.3	V		W		MANTI THOUSAND LAKE FAULT

YEAR	MO	DAY	HR	MN	SEC	LAT-N	LONG-W	MAG	INT	DEP	S	D	REMARKS
1949	MAR	07	06	50	----	-----	------	4.9	VI		W		SALT LAKE CITY WASATCH FAULT
1949	MAR	07	06	54	----	-----	------	4.9	VI		W		SALT LAKE CITY WASATCH FAULT
1949	MAR	07	07	09	----	-----	------	3.7	IV		W		SALT LAKE CITY WASATCH FAULT
1949	MAR	07	08	06	----	-----	------	3.7	IV		W		SALT LAKE CITY WASATCH FAULT
1949	MAR	07	08	16	----	-----	------	3.7	IV		W		SALT LAKE CITY WASATCH FAULT
1949	NOV	02	02	30	----	-----	------	4.9	VI		W		WASHINGTON CO HURRICANE FAULT
1950	JAN	02	19	53	04.0	41.5	112.0	3.7	IV		C		NORTHERN UTAH
1950	JAN	18	01	55	31.0	40.5	110.5	5.5			C		NORTHERN UTAH
1950	FEB	19	--	--	----	----	-----				C		PAYSON
1950	FEB	20	14	59	----	----	-----	3.7	IV		C		PAYSON
1950	FEB	25	13	37	37.0	40.0	112.0				C		CENTRAL UTAH SOUTH OF SALT LAKE
1950	MAY	05	07	35	----	----	-----	3.7	IV		C		PIUTE COUNTY
1950	MAY	08	19	40	----	----	-----				C		EUREKA
1950	MAY	08	22	35	----	----	-----	4.3	V		C		PAYSON DAMAGE
1950	JUL	21	19	25	----	----	-----	3.7	IV		C		LOGAN
1951	JAN	23	13	29	----	----	-----	3.7	IV		C		NEPHI
1951	JAN	23	13	33	----	----	-----	3.7	IV		C		NEPHI
1951	MAR	05	23	00	----	----	-----	3.7	IV		C		FREDONIA ARIZONA AND KANAB UTAH
1951	AUG	12	00	25	----	----	-----	4.3	V		C		PROVO
1952	MAY	02	10	15	----	----	-----	3.1	III		C		TOQUERVILLE
1952	MAY	02	15	15	----	----	-----	3.1	III		C		TOQUERVILLE
1952	JUL	21	01	00	----	----	-----	3.7	IV		C		SANTAQUIN
1952	JUL	23	19	28	----	----	-----	3.7	IV		C		SALT LAKE CITY
1952	SEP	28	20	00	----	----	-----	4.3	V		C		LEHI
1953	APR	16	05	15	----	----	-----	3.7	IV		C		MONROE
1953	MAY	24	02	54	29.0	40.5	111.5	4.3	V		C		NORTH-CENTRAL UTAH SALT LAKE CITY
1953	JUL	30	05	45	----	----	-----	4.3	V		C		GREENRIVER
1953	AUG	16	15	37	----	----	-----	3.7	IV		C		SALT LAKE CITY ROSE PARK AREA
1953	AUG	16	16	00	----	----	-----	3.7	IV		C		SALT LAKE CITY ROSE PARK AREA
1953	AUG	16	16	36	----	----	-----	3.7	IV		C		SALT LAKE CITY ROSE PARK AREA
1953	OCT	22	03	00	----	----	-----	4.3	V		C		PANGUITCH DAMAGE
1953	OCT	24	20	50	----	----	-----				C		PANGUITCH
1954	MAR	09	11	58	----	----	-----	2.0	II		C		SALT LAKE CITY
1954	MAR	31	14	00	----	----	-----	3.7	IV		C		GREENRIVER
1954	MAY	12	--	--	----	----	-----				C		SALT LAKE CITY
1954	MAY	13	--	--	----	----	-----				C		SALT LAKE CITY
1954	NOV	01	07	45	----	----	-----				C		LOGAN AND VICINITY
1955	FEB	02	19	23	----	----	-----	4.3	V		C		SALT LAKE CITY REGION DAMAGE
1955	MAR	27	12	13	----	----	-----	3.7	IV		C		SOUTH CENTRAL UTAH FRUITA AND TORREY
1955	MAY	12	22	57	----	----	-----	4.3	V		C		CENTERVILLE DAMAGE
1955	JUN	25	05	00	----	----	-----	3.7	IV		C		MORGAN
1955	NOV	29	10	57	00.9	37.1	113.9	3.7	IV		C		SOUTHWEST UTAH
1956	FEB	12	03	00	----	----	-----	3.7	IV		C		VERNAL
1956	FEB	12	04	15	----	----	-----	3.7	IV		C		VERNAL
1957	JUL	18	15	24	20.0	40.0	110.5	3.7	IV		C		CENTRAL UTAH
1957	OCT	25	16	25	47.0	40.0	111.0				C		CENTRAL UTAH
1957	OCT	26	01	45	41.0	40.0	111.0				C		CENTRAL UTAH
1958	JAN	05	17	00	07.4	40.72	112.43			20	U	D	TOOELE CO, 15 MI NW OF TOOELE
1958	FEB	13	22	52	00.0	40.5	111.5	4.9	VI		C		10 MILES NW OF WALLSBURG DAMAGE
1958	MAR	22	16	47	31.8	39.72	110.33			20	U		CARBON CO, 9 MI N OF SUNNYSIDE
1958	NOV	29	13	30	39.0	----	-----	4.3	V		C		NEPHI
1958	DEC	01	20	50	49.1	40.28	112.48	4.3	V	20	U	D	TOOELE CO, ST. JOHN AREA DAMAGE
1958	DEC	01	22	30	16.5	40.45	112.56	3.7	IV	20	U	D	TOOELE CO, 6 MI NW OF ST. JOHN
1958	DEC	01	22	30	16.5	40.45	112.56	3.7	IV	20	U		·TOOELE CO, 6 MI NW OF ST. JOHN
1958	DEC	02	03	23	15.7	40.46	112.61	4.3	V	20	U	D	TOOELE CO, 8 MI W OF ST. JOHN
1958	DEC	11	09	30	----	----	-----	3.7	IV		C		WATTIS
1958	DEC	14	21	00	----	----	-----				C		NEPHI
1959	JAN	04	00	22	54.0	----	-----	4.3	V		C		SE IDAHO N OF BEAR LAKE DAMAGE
1959	FEB	27	22	19	52.0	38.0	112.5	4.9	VI		C		SE UTAH PANGUITCH DAMAGE
1959	JUL	21	17	39	29.0	37.0	112.5	5.7			C		UTAH-ARIZONA BORDER KANAB DAMAGE
1959	JUL	27	11	15	----	----	-----	3.7	IV		C		KANARRAVILLE
1959	SEP	17	06	20	----	----	-----	3.7	IV		C		MARYSVALE
1960	MAY	06	20	28	42.9	39.84	110.88			20	U	D	CARBON CO, 10 MI SE OF SOLDIER SUMMIT
1960	JUL	09	21	36	40.0	41.5	112.0				C		NORTHWESTERN UTAH
1960	SEP	12	03	40	57.5	39.1	111.7			25	C		CENTRAL UTAH
1961	FEB	21	05	39	51.0	38.9	111.5			25	C		CENTRAL UTAH
1961	APR	16	05	02	39.3	39.33	111.65	4.9	VI	40	U	D	6 MI NW OF EPHRAIM DAMAGE
1961	MAY	06	16	12	20.7	39.6	110.2	4.3	V	25	C		COLUMBIA AND SUNNYSIDE DAMAGE
1961	MAY	25	13	28	03.2	42.2	111.9			33	C		UTAH-IDAHO BORDER
1961	OCT	15	21	05	01.8	39.25	111.56			20	U	D	SAN PETE CO, 6 MI E OF MANTI

YEAR	MO	DAY	HR	MN	SEC	LAT-N	LONG-W	MAG	INT	DEP	S	D	REMARKS
1961	OCT	16	19	13	06.5	39.2	111.5			18	C		CENTRAL UTAH
1961	OCT	17	00	59	41.6	39.2	111.5			21	C		CENTRAL UTAH
1961	OCT	17	03	54	39.3	39.23	111.57			20	U	D	SAN PETE CO, 5 MI SE OF MANTI
1962	FEB	15	07	12	42.9	36.9	112.4	4.5		26	C		UTAH-ARIZONA BORDER
1962	FEB	15	09	06	45.1	37.0	112.9			21	C		UTAH-ARIZONA BORDER SW OF KANAB
1962	FEB	17	03	29	26.9	38.6	111.6			33	C		NE OF PANGUITCH
1962	JUN	03	19	15	62.0	38.0	113.0			33	C		NW OF PAROWAN
1962	JUN	05	00	17	09.0	37.5	113.0			33	C		SOUTHERN UTAH
1962	JUN	05	22	29	45.0	38.0	112.1			33	C		NE OF PANGUITCH
1962	JUN	08	19	14	07.0	37.5	113.0			33	C		SE OF CEDAR CITY
1962	JUN	08	19	21	27.0	37.5	112.5			33	C		S OF PANGUITCH
1962	JUN	13	12	14	10.0	39.5	110.5			33	C		SW OF SUNNYSIDE
1962	JUN	19	00	47	32.0	37.5	112.5			33	C		S OF PANGUITCH
1962	JUL	09	07	03	07.0	40.24	111.89			20	U		UTAH CO, LAKE MTNS.
1962	JUL	15	02	07	57.0	40.78	112.20			0	U		SALT LAKE CO, 16 MI W OF SLC
1962	AUG	10	00	53	44.6	38.96	111.27			20	U		EMERY CO, 6 MI S OF EMERY
1962	AUG	10	04	05	3.4	39.00	111.28	3.4		20	U		EMERY CO, 6 MI NW OF EMERY
1962	AUG	19	17	32	42.9	38.15	111.56			20	U		WAYNE CO, 12 MI S OF LOA
1962	AUG	21	02	35	43.6	39.3	111.0			33	C	D	CENTRAL UTAH N OF CASTLE DALE
1962	AUG	30	13	35	28.8	41.92	111.79	5.7		40	U	D	1 MI E OF RICHMOND DAMAGE
1962	AUG	30	22	51	15.6	41.73	111.86	3.8		20	U		CACHE CO, 1 MI W OF LOGAN
1962	AUG	31	10	33	32.2	42.13	111.97	3.9		20	U		S IDAHO, FRANKLIN CO
1962	AUG	31	18	41	35.7	39.94	112.20			20	U		TOOELE CO, 6 MI W OF EUREKA
1962	AUG	31	21	15	58.2	40.01	112.21			20	U		TOOELE CO, 6 MI NW OF EUREKA
1962	SEP	02	23	19	41.7	40.08	112.16			20	U		UTAH CO, 6 MI NE OF EUREKA
1962	SEP	05	16	04	29.1	40.73	112.11	5.2		10	U	D	SALT LAKE CO, MAGNA AREA DAMAGE
1962	SEP	06	03	05	33.7	41.38	112.01			10	U		SALT LAKE CO, KEARNS AREA
1962	SEP	07	08	47	19.0	40.0	111.0			33	C		SE OF STRAWBERRY RESEVOIR
1962	SEP	07	16	50	28.0	39.5	110.0			33	C	D	SE OF PRICE
1962	SEP	08	17	03	47.6	42.15	112.03			20	U		S IDAHO, FRANKLIN CO
1962	SEP	09	11	44	43.4	41.09	112.48			10	U		WEBER CO, GREAT SALT LAKE
1962	SEP	09	14	38	12.1	41.76	111.79	4.0		40	U	D	CACHE CO, 1 MI NE OF LOGAN
1962	SEP	13	18	56	38.4	39.65	112.04	2.0		20	U		JUAB CO, 12 MI SW OF NEPHI
1962	SEP	14	00	29	53.1	41.26	112.51			20	U		BOX ELDER CO, PROMONTORY POINT AREA
1962	SEP	14	13	16	59.1	42.03	111.76	3.9		40	U	D	S IDAHO, 8 MI NE OF RICHMOND, UTAH
1962	SEP	30	09	37	28.3	41.29	111.98	2.3		20	U		WEBER CO, 6 MI N OF OGDEN
1962	OCT	14	07	35	52.7	39.47	111.10	2.5		20	U		EMERY CO, W OF HIAWATHA
1962	NOV	24	13	14	23.6	40.38	111.96			20	U		UTAH CO, W OF AMERICAN FORK
1962	NOV	27	18	00	54.7	39.91	112.46			20	U		TOOELE CO, 18 MI W OF EUREKA
1962	DEC	06	16	05	37.0	40.2	110.6			33	C		NORTHEASTERN UTAH
1962	DEC	11	10	28	18.8	39.62	110.63	4.3		0	U	D	CARBON CO, 12 MI E OF PRICE
1963	JAN	10	13	51	29.6	39.54	110.78			0	U		CARBON CO, 3 MI W OF WELLINGTON
1963	FEB	17	17	34	29.0	37.7	113.2	4.0		33	C		WEST OF CEDAR CITY
1963	MAR	03	00	40	12.0	41.01	112.22			0	U		DAVIS CO, ANTELOPE ISLAND
1963	MAR	12	23	47	23.7	39.55	110.78			0	U	D	CARBON CO, S OF PRICE
1963	MAR	17	11	11	37.2	39.27	111.90			20	U	D	SAN PETE CO, 14 MI W OF MANTI
1963	APR	04	15	36	27.1	42.2	111.2			33	C		SOUTHERN IDAHO
1963	APR	15	22	18	24.6	39.31	110.64	4.2		0	U	D	CARBON CO, 16 MI E OF HUNTINGTON
1963	APR	24	13	33	07.1	39.69	110.47	4.6		0	U	D	CARBON CO, 12 MI N OF DRAGERTON
1963	MAY	06	05	09	00.1	39.6	110.0			33	C	D	CARBON CO, PROBABLE ROCKBURST
1963	MAY	24	14	30	20.5	40.52	111.72			10	U		SALT LAKE CO, 15 MI SE OF SALT LAKE
1963	JUN	19	08	38	47.6	37.9	112.5	4.2		36	C		NW OF PANGUITCH
1963	JUN	20	23	47	22.8	41.02	112.05	3.0		20	U		DAVIS CO, 5 MI SW OF KAYSVILLE
1963	JUL	07	19	20	42.4	39.55	111.92	4.9		30	U	D	JUAB CO, 2 MI W OF LEVAN DAMAGE
1963	JUL	09	15	20	46.9	39.83	111.93	3.6		20	U	D	JUAB CO, 12 MI NW OF NEPHI
1963	JUL	09	20	25	26.7	40.01	111.23	4.1		10	U	D	UTAH CO, S OF STRAWBERRY RESERVOIR
1963	JUL	10	12	07	34.5	39.54	112.16	3.4		20	U	D	JUAB CO, 12 MI W OF LEVAN
1963	JUL	10	18	32	50.5	40.01	111.32	4.2		10	U	D	UTAH CO, SW OF STRAWBERRY RESERVOIR
1963	AUG	01	05	00	17.1	39.63	110.44	3.7		0	U	D	CARBON CO, 6 MI N OF DRAGERTON
1963	AUG	14	12	30	04.1	41.70	112.23	3.7		20	U	D	BOX ELDER CO, NEAR TREMONTON
1963	AUG	16	03	21	08.0	39.62	111.99	3.9		20	U	D	JUAB CO, 12 MI SW OF NEPHI
1963	AUG	16	07	01	02.9	41.54	112.19	3.6		20	U	D	BOX ELDER CO, 7 MI NW OF BRIGHAM CTY
1963	AUG	17	05	09	09.8	41.55	112.20	3.5		20	U	D	BOX ELDER CO, 12 MI NW OF BRIGHAM CTY
1963	AUG	17	10	23	10.0	40.38	111.04	3.9		20	U	D	WASATCH CO, 12 MI NE STRAWBERRY RES.
1963	SEP	02	17	40	06.2	39.03	110.15	3.8		0	U		CARBON CO, GREEN RIVER
1963	SEP	07	09	38	45.2	39.62	110.81	2.2		10	U		CARBON CO, PRICE
1963	SEP	29	20	17	52.9	39.57	112.28			20	U		JUAB CO, 2 MI N OF LEAMINGTON
1963	SEP	30	09	17	41.9	38.09	111.29	4.5		20	U	D	GARFIELD CO 14 MI NE OF BOULDER
1963	NOV	13	06	17	32.8	38.25	112.72	3.8		20	U	D	BEAVER CO, 5 MI SW OF BEAVER
1963	NOV	15	02	33	56.4	40.73	112.26	2.8		20	U		TOOELE CO, 8 MI W OF MAGNA

YEAR	MO	DAY	HR	MN	SEC	LAT-N	LONG-W	MAG	INT	DEP	S	D	REMARKS
1963	NOV	25	11	54	57.0	39.57	111.02	2.0		0	U		CARBON CO, 13 MI W OF PRICE
1963	DEC	19	09	07	22.9	39.55	111.09	2.1		0	U		CARBON CO, 16 MI W OF PRICE
1963	DEC	20	20	02	23.0	39.3	114.3	3.3		33	C		UT-NEV BORDER, LEHMAN CAVES
1963	DEC	21	03	02	23.0	39.3	114.3	3.3	IV		C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	22	15	43	13.4	39.3	114.3	3.3		33	C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	24	14	51	09.2	39.59	110.36	4.1		0	U	D	CARBON CO, SUNNYSIDE
1963	DEC	25	23	55	14.5	39.2	114.2	3.6	IV		C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	26	14	40	04.3	39.75	110.49	3.7		0	U	D	CARBON CO, 14 MI NW OF DRAGERTON
1963	DEC	28	14	25	19.5	39.2	114.3	3.4	IV		C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	28	15	19	58.0	39.0	114.0			33	C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	28	15	50	14.2	39.1	114.1	3.3		33	C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	29	04	02	03.8	39.1	114.2	3.5	IV		C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	29	04	05	12.2	39.1	114.2	3.4	IV		C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	29	04	15	04.1	39.08	114.17	4.0		20	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	29	06	38	58.2	39.1	114.2	3.7	IV		C		UT-NEV BORDER, LEHMAN CAVES AREA
1963	DEC	29	01	42	13.7	39.1	114.2	3.4		33	C		UT-NEV BORDER, LEHMAN CAVES AREA
1964	JAN	01	16	43	07.9	37.55	112.72			20	U	D	IRON CO, SE PANGUITCH LAKE
1964	JAN	05	13	57	21.3	41.10	109.35	3.9		20	U	D	SW WYOMING, SWEETWATER CO
1964	JAN	07	11	55	34.6	39.14	114.13	3.6		30	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1964	JAN	07	12	53	47.8	39.11	114.23	3.5		20	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1964	JAN	17	00	15	05.1	38.16	112.69			20	U	D	BEAVER CO, 8 MI S BEAVER
1964	JAN	17	00	15	37.3	38.18	112.72			20	U	D	BEAVER CO, 6 MI S BEAVER
1964	JAN	17	20	15	17.1	39.05	114.13			20	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1964	JAN	20	10	10	01.0	41.85	111.81			20	U		CACHE CO, SMITHFIELD
1964	JAN	21	23	31	42.1	39.16	114.22	3.3		20	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1964	JAN	27	20	21	52.3	40.64	111.81			0	U		SALT LAKE CO, MURRAY AREA
1964	FEB	02	06	58	17.8	39.41	114.26	2.9		20	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1964	FEB	06	07	53	48.8	37.5	113.2			15	C		SOUTH OF CEDAR CITY UTAH
1964	FEB	06	08	02	30.1	41.90	112.28			20	U	D	BOX ELDER CO, 15 MI NW OF TREMONTON
1964	FEB	06	11	13	38.9	41.73	112.33			20	U	D	BOX ELDER CO, 6 MI NW OF TREMONTON
1964	FEB	07	13	20	11.8	41.82	112.35			20	U	D	BOX ELDER CO, 11 MI NW OF TREMONTON
1964	FEB	15	22	33	31.2	41.10	111.70	2.2		20	U		MORGAN CO, 4 MI NW OF MORGAN
1964	FEB	20	20	19	49.7	39.42	114.23	3.7		10	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1964	MAR	02	07	29	24.4	39.66	111.91	3.9		20	U	D	JUAB CO, 4 MI SW OF NEPHI
1964	MAR	03	03	24	54.1	38.59	112.28			20	U		SEVIER CO, 18 MI SW OF RICHFIELD
1964	MAR	05	12	40	52.5	39.14	114.21	3.4		20	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1964	MAR	26	22	01	39.1	38.57	112.47	2.4		20	U		MILLARD CO, 5 MI E OF COVE FORT
1964	APR	01	15	59	54.4	40.52	112.31			0	U		TOOELE CO, TOOELE
1964	APR	06	22	00	45.3	40.30	112.42			20	U		TOOELE CO, 4 MI S OF ST. JOHN
1964	APR	09	22	57	39.6	38.66	113.88			20	U		BEAVER CO, SE OF GARRISON
1964	APR	10	21	09	35.5	42.01	112.63	2.3		10	U		UT-IDAHO BORDER, HANSEL MTS
1964	APR	17	20	36	51.3	39.62	111.99			20	U		JUAB CO, 12 MI SW OF NEPHI
1964	APR	21	10	29	25.2	39.06	112.71			20	U		MILLARD CO, 20 MI S OF DELTA
1964	MAY	06	22	21	03.0	39.63	112.15	1.9		20	U		JUAB CO, 18 MI SW OF NEPHI
1964	MAY	09	05	04	05.1	40.46	111.34	2.4		20	U		WASATCH CO, 5 MI SE OF HEBER
1964	MAY	11	00	17	25.9	39.23	110.94	2.4		20	U		CARBON CO, 3 MI NE OF CASTLE DALE
1964	MAY	17	20	02	58.0	41.85	111.98			20	U		CACHE CO, NEWTON AREA
1964	MAY	21	20	12	57.0	41.92	111.86	2.2		20	U		CACHE CO, 2 MI W OF RICHMOND
1964	MAY	22	12	11	49.4	41.84	112.15	2.3		20	U	D	BOX ELDER CO, 12 MI NE OF TREMONTON
1964	MAY	29	22	45	54.6	42.25	112.14			20	U		SE IDAHO
1964	JUN	06	06	44	35.2	39.5	110.3	4.5		33	C		CARBON CO, PROBABLE ROCKBURST
1964	JUN	06	12	47	1.5	39.94	110.51			0	U	D	CARBON CO, S DUCHESNE
1964	JUN	19	00	37	20.6	42.02	111.14			20	U		SE IDAHO, E OF BEAR LAKE
1964	JUN	25	19	44	51.5	40.81	111.80			10	U		SALT LAKE CO, E SALT LAKE CITY
1964	JUN	27	19	53	24.3	41.43	113.77	2.5		20	U		BOX ELDER CO, 8 MI NE LUCIN
1964	JUN	27	20	26	21.4	40.87	113.15	2.2		20	U		TOOELE CO, 12 MI NE OF KNOLLS
1964	JUN	27	23	10	39.4	41.27	113.45	3.0		20	U	D	BOX ELDER CO, N END NEWFOUNDLAND MTS
1964	JUL	01	01	11	24.3	41.73	111.50			20	U		CACHE CO, 17-MI E OF LOGAN
1964	JUL	06	19	27	35.7	38.35	112.27			20	U		PIUTE CO, 7 MI SW OF MARYSVALE
1964	JUL	07	21	16	13.4	38.89	111.05	3.1		20	U		EMERY CO, NE OF EMERY
1964	AUG	04	03	08	22.7	41.16	111.86			20	U		WEBER CO, SE OF OGDEN
1964	AUG	04	10	43	23.6	41.53	111.81	3.1		20	U		CACHE CO, AVON
1964	AUG	05	15	17	58.6	38.97	110.89	3.2		20	U		EMERY CO, 18 MI NE OF EMERY
1964	AUG	05	19	55	09.8	41.11	112.82			20	U		BOX ELDER CO, LAKESIDE MTS
1964	AUG	12	05	04	52.5	39.42	112.04	3.8		20	U	D	JUAB CO, N SEVIER BRIDGE RESERVOIR
1964	AUG	21	05	34	40.3	37.65	111.89			20	U		GARFIELD CO, 12 MI E OF TROPIC
1964	AUG	24	01	41	17.6	38.92	112.28			20	U		MILLARD CO, 6 MI SE OF FILLMORE
1964	AUG	24	01	51	02.9	38.76	112.23	3.2		20	U	D	MILLARD CO, 14 MI NE OF FILLMORE
1964	AUG	24	01	55	37.2	39.09	112.08	3.0		20	U	D	MILLARD CO, SCIPIO LAKE
1964	AUG	28	06	50	46.6	37.0	113.1			33	C		ESE OF ST GEORGE

YEAR	MO	DAY	HR	MN	SEC	LAT-N	LONG-W	MAG	INT	DEP	S	D	REMARKS
1964	SEP	06	19	03	37.7	39.26	111.59	3.3		20	U	D	SAN PETE Co, 3 MI E OF MANTI
1964	SEP	12	02	32	32.7	40.84	111.74			10	U		SALT LAKE CO, 10 MI NE SALT LAKE CITY
1964	SEP	21	00	36	25.9	38.88	112.30	3.4		20	U		MILLARD CO, 7 MI S OF FILLMORE
1964	OCT	02	20	48	02.4	38.46	112.59			20	U		BEAVER CO, 14 MI N OF BEAVER
1964	OCT	09	09	33	51.3	39.39	111.16	2.8		20	U	D	CARBON CO, 14 MI NW OF CASTLE DALE
1964	OCT	15	06	57	23.0	40.94	111.41			20	U		SUMMIT CO, ECHO JUNCTION
1964	OCT	18	18	33	20.7	41.88	111.81	4.4		10	U	D	CACHE CO, 3 MI S OF RICHMOND
1964	OCT	18	18	46	26.8	42.14	111.93			20	U		S IDAHO, FRANKLIN CO
1964	OCT	19	00	36	05.7	40.59	112.14			30	U		SALT LAKE CO, 4 MI N OF BINGHAM
1964	OCT	21	02	04	03.8	41.81	112.68			20	U		BOX ELDER CO, HANSEL VALLEY
1964	NOV	04	08	42	54.3	39.55	110.29	3.2		0	U	D	CARBON CO, 3 MI E OF SUNNYSIDE
1964	NOV	04	23	30	37.2	39.64	111.00			20	U		CARBON CO, 6 MI W OF HELPER
1964	NOV	08	03	08	56.5	41.92	111.75			10	U		CACHE CO, 2 MI E OF RICHMOND
1964	NOV	29	09	31	41.3	39.33	112.10			20	U		MILLARD CO, 25 MI E OF DELTA
1964	NOV	30	22	36	00.8	40.53	112.20			0	U		TOOELE CO, 8 MI E OF TOOELE
1964	DEC	01	01	16	13.2	37.81	110.94			20	U		GARFIELD Co, 26 MI E OF BOULDER
1964	DEC	12	13	14	03.5	39.52	114.24			20	U	D	UT-NEV BORDER, LEHMAN CAVES AREA
1964	DEC	13	18	06	17.4	39.59	110.34	2.3		0	U		CARBON CO, 2 MI N OF SUNNYSIDE
1964	DEC	16	21	39	27.4	38.96	110.88	3.1		20	U		EMERY CO, 21 MI E OF EMERY
1964	DEC	19	06	53	05.2	41.80	112.55			20	U		BOX ELDER CO, E SIDE HANSEL VALLEY
1964	DEC	26	20	55	16.8	39.57	110.32	3.9		0	U	D	CARBON CO, 4 MI E OF SUNNYSIDE
1965	JAN	14	12	30	11.9	39.56	110.34	4.5		0	U	D	CARBON CO , 2 MI E SUNNYSIDE
1965	JAN	18	20	05	15.2	37.70	113.02	4.1		20	U	D	IRON CO, NE CEDAR CITY
1965	JAN	25	04	43	39.7	41.39	111.32	2.5		20	U		RICH CO, 20 MI SW RANDOLPH
1965	JAN	27	09	49	20.0	41.76	112.18	2.7		20	U		BOX ELDER CO, GARLAND
1965	JAN	30	13	48	55.4	37.49	113.14			20	U		IRON CO 13 MI S CEDAR CITY
1965	FEB	03	20	15	43.9	38.54	112.10			20	U		SEVIER CO, 16 MI S RICHFIELD
1965	FEB	26	03	03	33.1	39.84	110.45	2.8		0	U		CARBON CO
1965	MAR	09	06	41	34.2	39.89	111.30	3.5		20	U	D	UTAH CO, 20 MI S STRAWBERRY RESERVOIR
1965	MAR	14	13	18	05.3	39.6	110.3	3.9		0	C		CARBON CO, SUNNYSIDE
1965	MAR	16	05	37	14.6	38.65	112.45	3.4		20	U	D	SEVIER CO, 21 MI WSW RICHFIELD
1965	MAR	21	22	56	41.6	39.55	110.31	4.0		0	U	D	CARBON CO, 3 MI E SUNNYSIDE
1965	MAR	26	00	51	26.8	39.53	110.33	4.3		0	U	D	CARBON CO, 3 MI SE SUNNYSIDE
1965	APR	02	05	28	43.8	42.03	111.62			20	U		UTAH-IDAHO BORDER
1965	APR	02	22	38	47.5	40.89	112.37	1.4		20	U		TOOELE CO, GREAT SALT LAKE
1965	APR	11	01	39	34.2	40.86	112.50			20	U		TOOELE CO, STANSBURY ISLAND
1965	APR	23	03	10	44.4	39.47	110.33	2.0		0	U		CARBON CO, 6 MI SE SUNNYSIDE
1965	APR	27	18	51	33.6	41.63	112.85	4.1		20	U	D	BOX ELDER CO, N END GREAT SALT LAKE
1965	MAY	01	01	47	06.7	40.79	111.67	2.7		20	U		SALT LAKE CO, 11 MI E SALT LAKE CITY
1965	MAY	05	20	21	03.7	40.73	111.90			0	U		SALT LAKE CO, S SALT LAKE CITY
1965	MAY	10	18	39	53.4	37.62	113.14			20	U		IRON CO, 5 MI SW CEDAR CITY
1965	MAY	11	00	23	33.2	39.87	111.51			20	U		UTAH CO, 11 MI S THISTLE
1965	MAY	11	01	50	26.3	41.18	111.54	4.1		20	U	D	MORGAN CO, 12 MI NE MORGAN
1965	MAY	12	06	12	12.6	40.34	111.67			20	U		UTAH CO, 7 MI N PROVO
1965	MAY	16	08	50	13.0	42.17	111.69			20	U		SE IDAHO, FRANKLIN CO
1965	MAY	16	19	04	04.6	38.18	112.67	3.4		20	U		BEAVER CO, 7 MI S BEAVER
1965	MAY	24	21	35	22.2	41.17	111.26			20	U		MORGAN CO, 23 MI NE MORGAN
1965	MAY	28	11	04	52.8	41.86	112.13	3.5		20	U		BOX ELDER CO, 10 MI NNE TREMONTON
1965	MAY	28	11	16	39.2	41.47	112.12			20	U		BOX ELDER CO, 6 MI SW BRIGHAM CITY
1965	MAY	28	12	45	22.2	41.60	111.89			20	U		DAVIS CO, 10 MI SE OGDEN
1965	MAY	28	18	01	21.7	41.00	113.31			20	U		BOX ELDER CO, S END NEWFOUNDLAND MTS
1965	MAY	29	12	03	27.7	39.45	110.15	3.2		0	U	D	EMERY CO, 13 MI SE SUNNYSIDE
1965	JUN	09	17	04	28.5	41.03	110.48			20	U		SW WYOMING, S UINTA CO
1965	JUN	09	21	31	13.0	40.73	111.87			0	U		SALT LAKE CO, E SIDE SALT LAKE VALLEY
1965	JUN	13	01	42	39.5	38.86	112.12	2.0		20	U	D	SEVIER CO, 6 MI NW RICHFIELD
1965	JUN	14	00	45	37.9	39.30	112.23			20	U		MILLARD CO, 23 MI NE FILLMORE
1965	JUN	15	21	54	30.4	40.84	111.72			10	U		SALT LAKE CO, 10 MI NE SALT LAKE CITY
1965	JUN	17	15	22	11.4	39.76	111.23			20	U	D	CARBON CO, 5 MI W SCOFIELD RESERVOIR
1965	JUN	21	19	15	44.8	39.08	113.85			20	U		MILLARD CO, 16 MI NE PRUESS LAKE
1965	JUN	27	19	24	09.5	39.67	110.44	4.1		0	U	D	CARBON CO, 9 MI NW SUNNYSIDE
1965	JUN	29	07	46	39.5	39.72	110.40	4.4		0	U	D	CARBON CO, 10 MI N SUNNYSIDE

Appendix B

The data in this appendix includes a list of 418 earthquakes which occurred within a 186 mile (300 kilometers) radius of Logan, Utah.

This data was made available by

The U.S. National Oceanic and Atmospheric Administration (NOAA)

Appendix B

KEY TO EARTHQUAKE DATA

Source: Source of data is listed as follows:

- AEC -- U.S. Atomic Energy Commission
- BCI -- Bureau Central International de Seismologie, Strasbourg, France
- CGS -- Coast and Geodetic Survey
- EQH -- *Earthquake History of the United States*
- ERL -- Environmental Research Laboratories
- G-R -- Gutenborg-Richter
- GS -- U.S. Geological Survey, Denver, Colorado
- NOS -- National Ocean Survey
- PAS -- Pasadena, California
- SLC -- Salt Lake City, Utah
- USE -- *United States Earthquakes*

YEAR, MO, DA: Date

HR, MN, SEC: Origin time

LAT, LONG: Geographic latitude and longitude

DEPTH: Focal depth (km) and depth control factor

- A -- Assigned
- G -- Depth restrained by geophysicist
- N -- Held at 33 km (normal depth), when data not sensitive to depth for a shallow focus

MAGNITUDES: Body- and Surface- (SURF) wave values as determined by Preliminary Determination of Epicenters program. Authority for other magnitudes and local magnitudes according to source codes.

INT MAP: Isoseismal map published and source codes

INT MAX: Maximum intensity

PHENOM DTSUNO: Associated phenomena:

- C -- Coal bump or rockburst in coal mine
- D -- Faulting and uplift/subsidence
- E -- Explosion-accidental, controlled or suspected
- R -- Rockburst

RN: Flinn-Engdahl geographic region

CE: Cultural effects

D -- Earthquake was damaging
F -- Earthquake was felt

Q/S: Quality/number of stations

MAR DG: Marsden Square

DIST: Distance in kilometers between the earthquake location and Logan, Utah.

NOTE: For additional explanation of this key, contact:

U.S. Department of Commerce
National Oceanic and Atmospheric Adminstration
Environmental Data Service
National Geophysical and Solar-Terrestrial Data Center
Boulder, Colorado

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH	MAGNITUDES				INT	INT	PHENOM	PN	CF	G/S	MAR	DG	DIST
									(KM)	BODY	SURF	OTHER	LOCAL	MAP	MAX	DTSVNO						(KM)
EQH	1853	12	01	18	15	00.0Z	39.700N	111.800W							V		478	F		120	91	230.
EQH	1880	07	12	05	00	00.0Z	42.000N	112.300W							VI		457	F		156	22	47.
EQH	1880	09	17	05	27	00.0Z	40.800N	112.000W							V		478	F		156	02	109.
EQH	1884	11	09	09	00	00.0Z	41.500N	111.200W							VI		478	D		156	11	60.
EQH	1894	06	08	18	00	00.0Z	39.900N	113.400W							V		478	F		120	93	246.
EQH	1894	07	18	22	50	00.0Z	41.200N	112.000W							VII		478	D		156	12	65.
EQH	1899	12	13	13	50	00.0Z	41.000N	112.000W							V		478	F		156	12	87.
EQH	1900	08	01	19	45	00.0Z	39.800N	112.200W							VII		478	D		120	92	221.
EQH	1905	11	11	21	26	00.0Z	42.900N	114.500W							VII		033	D		156	24	253.
EQH	1906	05	24	21	10	00.0Z	41.200N	112.000W							V		478	F		156	12	65.
EQH	1906	10	19	02	06	00.0Z	42.500N	111.400W							V		457	F		156	21	89.
EQH	1910	05	22	12	28	00.0Z	40.800N	111.900W							VII		478	D		156	01	108.
EQH	1910	07	26	01	30	00.0Z	41.500N	109.300W							V		460	F		155	19	212.
EQH	1913	04	12	08	25	00.0Z	42.000N	112.000W							V		457	F		156	22	30.
EQH	1914	05	13	17	15	00.0Z	42.000N	112.000W							VII		457	D		156	22	30.
EQH	1915	07	15	22	00	00.0Z	40.300N	111.700W							VI		478	D		156	01	163.
EQH	1915	07	30	18	50	00.0Z	41.800N	112.200W							V		478	F		156	12	31.
EQH	1915	08	11	10	20	00.0Z	40.500N	112.700W							V		478	F		156	02	159.
EQH	1915	10	05	08	00	00.0Z	40.100N	114.000W							V		037	F		156	04	260.
EQH	1916	02	05	06	25	00.0Z	40.000N	111.700W							V		478	F		156	01	197.
EQH	1916	09	10	02	57	00.0Z	43.500N	114.300W							V		033	F		156	34	279.
EQH	1917	12	12	12	00	00.0Z	43.000N	111.300W							V		457	F		156	31	144.
EQH	1920	09	18	21	05	00.0Z	41.500N	112.000W							VI		478	F		156	12	33.
EQH	1920	09	19	13	50	00.0Z	41.500N	112.000W							VI		478	F		156	12	33.
EQH	1920	11	20	05	40	00.0Z	41.500N	112.000W							VI		478	F		156	12	33.
EQH	1923	03	24	04	00	00.0Z	43.600N	110.600W							V		460	F		156	30	227.
EQH	1924	11	25	14	10	00.0Z	42.500N	111.500W							V		457	F		156	21	86.
USE	1928	03	31	15	16	00.0Z	43.700N	110.700W									460	F		156	30	234.
USE	1928	06	02	09	00	00.0Z	39.800N	111.000W									478	F		120	91	229.
USE	1929	10	01	08	00	00.0Z	42.200N	111.200W									457	F		156	21	71.
USE	1930	06	12	09	15	00.0Z	42.600N	111.000W							VI		457	F		156	21	115.
USE	1930	07	28	09	35	00.0Z	41.500N	109.300W									460	F		155	19	212.
USE	1930	11	16	03	15	00.0Z	41.900N	115.400W									037	F		156	15	297.
USE	1930	12	09	06	50	00.0Z	41.800N	115.300W									037	F		156	15	288.
G-R	1934	03	12	15	05	40.0	41.500N	112.500W				6.60PAS		USE	VIII	D	478	C		156	12	63.
G-R	1934	03	12	16	20	13.0	41.750N	112.500W				6.00PAS			VIII		478	D		156	12	56.
G-R	1934	04	14	21	26	32.0	41.500N	112.500W				5.25PAS					478			156	12	63.
G-R	1934	05	06	08	09	49.0	41.750N	113.000W				5.50PAS			VI		478	D		156	13	97.
CGS	1942	04	18	05	45	42.0	41.500N	112.300W									478			156	12	49.
CGS	1943	02	22	14	20	00.0	41.000N	111.500W									478	F		156	11	89.
USE	1948	02	24	02	39	00.0	43.500N	111.000W							VI		457	F		156	31	204.
CGS	1949	06	09	09	33	22.0	42.500N	110.000W									460			156	20	171.
USE	1950	01	02	19	53	04.0	41.500N	112.000W							IV		478	F		156	12	33.
CGS	1950	01	18	01	55	51.0	40.500N	112.500W				5.25PAS			V		478	D		156	00	179.
CGS	1950	02	25	13	37	37.0	40.000N	112.000W									478			156	02	197.
USE	1951	02	21	17	09	56.0	43.000N	110.000W							III		460	F		156	30	207.
USE	1953	05	24	02	54	29.0	40.500N	111.500W							VI		478	F		156	01	143.
CGS	1954	02	01	03	33	19.0	43.000N	114.000W									033			156	34	225.
CGS	1955	05	08	09	38	16.0	42.750N	110.750W									460			156	20	141.
USE	1956	10	03	20	21	40.0	41.500N	110.100W							IV		460	F		156	10	146.

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH	---------MAGNITUDES---------				INT	INT	PHENOM	RN	CE	Q/S	MAR	DG	DIST
									(KM)	BODY	SURF	OTHER	LOCAL	MAP	MAX	DTSVNO						(KM)
CGS	1957	07	21	17	30	02.0	41.500N	113.000W	000							E	478			156	13	102.
CGS	1957	10	25	16	26	47.0	40.000N	111.000W									478			156	01	208.
CGS	1957	10	26	01	46	41.0	40.000N	111.000W									478			156	01	208.
CGS	1957	11	03	16	58	00.0	42.500N	111.500W									457			156	21	85.
USE	1957	11	03	17	36	22.0	42.500N	111.000W							IV		457	F		156	21	106.
CGS	1958	01	05	17	00	04.0	41.000N	112.500W									478			156	12	102.
USE	1958	02	13	22	52	00.0	40.500N	111.500W							VI		478	F		156	01	143.
BCI	1958	02	17	11	57	30.0*	39.500N	113.000W									478			120	93	271.
USE	1958	12	01	20	50	48.0	40.500N	112.500W							V		478	D		156	02	152.
CGS	1958	12	01	22	30	15.0	40.500N	112.500W									478			156	02	152.
BCI	1958	12	02	03	23	15.0	40.500N	112.500W							V		478	F		156	02	152.
CGS	1959	09	02	00	05	05.0	44.000N	110.000W									459	F		156	41	285.
CGS	1960	04	24	20	36	57.0	43.000N	111.500W									457			156	31	140.
CGS	1960	05	06	20	28	42.0	39.500N	111.000W									478			120	91	262.
CGS	1960	07	09	21	36	40.0	41.500N	112.000W									478			156	12	33.
CGS	1960	07	23	01	31	17.0	42.500N	111.500W									457			156	21	86.
CGS	1960	07	23	04	10	13.0	42.500N	111.500W									457			156	21	86.
CGS	1960	07	23	07	26	49.0	42.500N	111.500W									457			156	21	86.
CGS	1960	07	25	01	30	00.0	42.500N	111.500W									457			156	21	86.
CGS	1960	07	25	01	47	18.0	42.500N	111.500W									457			156	21	86.
CGS	1960	08	07	16	27	16.2	42.400N	111.500W	049						VI		457	D		156	21	75.
CGS	1960	08	07	19	20	15.1	42.500N	111.400W	049								457	F		156	21	89.
CGS	1960	08	10	07	41	35.3	42.500N	111.500W	018						V		457	D		156	21	86.
CGS	1960	08	20	07	14	41.7	42.500N	111.700W	030								457			156	21	82.
CGS	1960	08	20	07	24	48.2	42.600N	111.700W	032								457			156	21	93.
CGS	1960	08	20	08	11	54.3	42.300N	111.300W	041						V		457	F		156	21	73.
CGS	1960	08	20	10	11	40.9	42.500N	111.600W	051								457	F		156	21	84.
CGS	1960	08	20	10	13	14.9	42.600N	111.400W	014								457			156	21	99.
CGS	1960	08	20	11	01	59.0	42.400N	111.500W	049								457	F		156	21	75.
CGS	1960	08	20	14	46	51.3	42.500N	111.600W	029								457	F		156	21	84.
CGS	1960	08	21	05	04	07.3	42.400N	111.600W	025								457			156	21	73.
CGS	1960	08	26	01	22	39.6	42.400N	111.200W	032								457			156	21	87.
CGS	1960	09	12	03	40	57.5	39.100N	111.700W	025								478			120	91	297.
CGS	1961	02	15	09	10	49.4	43.300N	111.400W	025N								457			156	31	174.
CGS	1961	04	11	08	57	52.7	43.400N	111.200W	033N								457			156	31	185.
CGS	1961	04	16	05	02	39.3	39.300N	111.500W	035						VI		478	D		120	91	276.
CGS	1961	05	06	16	12	20.7	39.600N	110.200W	025N								478	D		120	90	277.
CGS	1961	05	25	18	28	03.2	42.200N	111.900W	033N								457			156	21	40.
CGS	1961	10	15	21	05	02.0	39.200N	111.400W	033N								478			120	91	288.
CGS	1961	10	16	19	13	06.5	39.200N	111.500W	018								478			120	91	287.
CGS	1961	10	17	00	59	41.8	39.200N	111.500W	021								478			120	91	287.
CGS	1961	10	17	03	54	46.7	40.000N	112.500W	028								478			156	02	205.
CGS	1962	08	21	02	36	43.6	39.300N	111.000W	033								478		007	120	91	287.
CGS	1962	08	30	13	35	28.7	41.800N	111.800W	037			5.70PAS		USE	VII		478	D	025	156	11	4.
PAS	1962	09	05	16	04	29.0F	40.700N	112.000W	016A				5.10PAS		VI		478	D		156	02	120.
CGS	1962	09	09	14	38	13.0	41.600N	111.800W	037								478	F	007	156	11	15.
CGS	1962	09	14	13	17	02.9	41.800N	111.500W	033								478		008	156	11	27.
CGS	1962	10	06	09	28	17.4	43.600N	110.800W	033						IV		460	F	010	156	30	220.
CGS	1962	12	06	16	05	37.0	40.200N	110.600W	033								478		005	156	02	202.
CGS	1962	12	11	10	28	17.5	39.400N	110.300W	033								478		006	120	90	293.

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH	---------MAGNITUDES---------				INT	INT	PHENOM	RN	CE	G/S	MAR	DG	DIST
									(KM)	BODY	SURF	OTHER	LOCAL	MAP	MAX	DISVNO						(KM)
CGS	1963	02	25	18	45	16.5	42.600N	109.200W	033	4.30					V		460	F	014	155	29	235.
CGS	1963	03	05	01	30	38.7	42.600N	111.300W	033						III		457	F	009	156	21	102.
CGS	1963	03	12	23	47	18.2	39.600N	110.500W	000							R	478		005	120	90	266.
CGS	1963	03	27	07	22	09.4	44.300N	110.700W	033								459		018	156	40	296.
CGS	1963	04	04	15	36	26.3	42.300N	111.200W	033								457		006	156	21	79.
CGS	1963	04	15	22	18	22.7	39.500N	110.200W	000							R	478		008	120	90	287.
CGS	1963	04	16	10	41	08.9	39.700N	110.500W	000							R	478		005	120	90	256.
CGS	1963	04	24	13	33	02.9	39.500N	110.300W	000							R	479		010	120	90	283.
CGS	1963	05	06	05	09	00.1	39.600N	110.000W	033								478		006	120	90	286.
CGS	1963	05	19	08	10	18.5	44.400N	112.000W	015								457		005	156	42	293.
CGS	1963	06	25	15	51	49.6	44.000N	110.000W	033								459		018	156	40	289.
CGS	1963	07	07	19	20	42.4	39.600N	111.900W	033	4.90					VI		478	D	054	120	91	241.
CGS	1963	07	09	15	20	47.1	39.900N	111.900W	033								478		005	120	91	208.
CGS	1963	07	09	20	25	27.5	40.000N	111.200W	033								478		014	156	01	227.
CGS	1963	07	10	18	32	53.6	39.900N	111.400W	033	4.20							478		008	120	91	211.
CGS	1963	08	02	09	45	41.9	43.400N	114.500W	050						IV		033	F	006	156	34	284.
CGS	1963	08	14	12	30	06.0	41.500N	112.200W	033	3.70					IV		478	F	007	156	12	47.
CGS	1963	08	16	03	21	08.7	39.700N	112.100W	033	3.40					IV		479	F	008	120	92	231.
CGS	1963	08	16	07	01	03.7	41.500N	112.200W	033	3.60							478		006	156	12	47.
CGS	1963	08	17	05	09	11.1	41.400N	112.200W	033	3.50							478		005	156	12	51.
CGS	1963	08	17	10	23	15.5	40.400N	110.700W	033	3.50							478		006	156	[illegible]	179.
CGS	1963	08	24	03	15	49.8	40.800N	112.600W	033	3.50							478		006	156	02	109.
CGS	1963	08	28	00	13	12.9	40.900N	111.900W	033	3.40							478		006	156	01	97.
CGS	1963	09	02	17	40	15.4	39.600N	110.100W	033								478		010	120	90	281.
CGS	1963	09	09	18	55	46.9	43.900N	113.300W	033								457		005	156	33	266.
CGS	1963	09	11	23	40	46.9	40.700N	112.100W	000							E	478		008	156	02	121.
CGS	1963	09	22	04	37	15.1	43.300N	111.400W	033								457		008	156	31	174.
CGS	1963	09	22	08	58	10.5	43.300N	111.500W	033								457		005	156	31	177.
CGS	1963	09	22	09	56	44.0	43.300N	111.600W	033								457		007	156	31	171.
CGS	1963	09	22	17	06	07.1	43.200N	111.200W	033								457		008	156	31	167.
CGS	1963	09	22	21	30	55.8	43.200N	111.500W	033								457		006	156	31	162.
CGS	1963	09	22	21	32	17.0	43.200N	111.400W	033								457		008	156	31	163.
CGS	1963	09	23	01	30	32.7	43.200N	111.300W	033								457		005	156	31	165.
CGS	1963	09	23	23	27	10.5	43.300N	111.500W	033								457		005	156	31	173.
CGS	1963	09	24	17	05	27.9	43.200N	111.200W	033								457		005	156	31	167.
CGS	1963	09	28	19	08	02.7	43.300N	111.300W	033								457		006	156	31	176.
CGS	1963	09	29	05	58	23.7	43.400N	111.400W	033								457		009	156	31	185.
CGS	1963	09	29	06	05	32.5	43.300N	111.400W	033								457		008	156	31	174.
CGS	1963	10	11	23	09	53.1	43.400N	111.100W	030								457		007	156	31	191.
CGS	1963	10	12	06	58	25.7	43.300N	110.900W	030								460		008	156	30	187.
CGS	1963	10	12	21	59	01.9	43.100N	111.100W	033								457		008	156	31	160.
CGS	1963	10	12	22	34	01.6	43.100N	111.300W	033	3.90							457		006	156	31	154.
CGS	1963	10	13	17	55	47.1	43.200N	111.200W	030								457		007	156	31	167.
CGS	1963	10	14	08	31	23.0	42.200N	108.300W	030								460		005	155	28	295.
CGS	1963	10	26	20	20	14.5	43.100N	111.200W	037								457		015	156	31	157.
CGS	1963	10	29	05	39	33.0	43.100N	111.600W	033	4.00							457		005	156	31	149.
CGS	1963	10	29	07	42	11.8	43.200N	111.300W	030								457		005	156	31	165.
CGS	1963	10	31	06	08	52.0	43.000N	111.300W	033	3.00							457		005	156	31	144.
CGS	1963	11	03	18	26	02.0	43.100N	111.300W	033								457		006	156	31	154.
CGS	1963	11	05	03	44	39.7	43.100N	111.200W	033								457		005	156	31	157.

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	---------MAGNITUDES---------				INT MAP	INT MAX	PHENOM DTSVNO	PN	CE	Q/S	MAR	DG	DIST (KM)
										BODY	SURF	OTHER	LOCAL									
CGS	1963	12	09	01	45	18.2	43.600N	110.100W	033								460		017	156	30	248.
CGS	1963	12	14	12	55	07.9	43.610N	110.300W	033								460		011	156	30	239.
CGS	1963	12	24	14	51	58.0	39.500N	110.200W	000							R	478		009	120	90	287.
CGS	1963	12	26	14	40	06.2	39.600N	110.100W	033								478		006	120	90	281.
CGS	1964	01	05	13	57	21.0	41.000N	109.500W	015								460		009	155	19	212.
CGS	1964	01	28	12	57	07.9	43.200N	111.400W	041	4.20							457		008	156	31	167.
CGS	1964	01	30	22	23	19.4	43.300N	111.400W	033								457		007	156	31	174.
CGS	1964	02	02	12	15	11.0	43.300N	111.400W	030								457		008	156	31	174.
CGS	1964	02	03	05	55	44.3	43.200N	111.100W	030								457		016	156	31	170.
CGS	1964	02	06	08	02	28.3	42.000N	112.300W	030								457	F	010	156	22	47.
CGS	1964	02	06	11	13	34.8	42.100N	112.400W	030								457		010	156	22	67.
CGS	1964	02	07	13	20	08.1	42.100N	112.400W	025								457		008	156	22	67.
CGS	1964	02	28	01	09	43.1	43.600N	110.200W	030								460		009	156	30	243.
CGS	1964	03	02	07	29	23.4	39.600N	111.900W	033	3.90							478			120	91	241.
CGS	1964	04	12	15	37	49.6	43.200N	111.400W	015								457		005	156	31	167.
CGS	1964	04	13	11	36	30.4	43.300N	110.800W	015	3.70							460		005	156	30	190.
CGS	1964	04	15	13	37	02.7	43.100N	111.500W	033								457		005	156	31	151.
CGS	1964	05	02	03	24	24.1	43.600N	110.400W	033								460		008	156	30	235.
CGS	1964	05	04	05	40	35.2	39.400N	110.800W	033								478		018	120	90	277.
CGS	1964	05	07	11	42	30.4	43.300N	110.400W	033								460		008	156	30	207.
CGS	1964	05	08	01	35	08.2	43.300N	111.300W	033								457		005	156	31	176.
CGS	1964	05	22	12	11	49.3	41.900N	112.100W	033								478		005	156	12	27.
CGS	1964	06	05	04	52	04.3	43.200N	111.300W	033	3.70							457		006	156	31	165.
CGS	1964	06	06	06	44	31.8	39.500N	110.300W	000							R	478		018	120	90	283.
CGS	1964	06	06	12	46	59.9	39.400N	110.200W	030								478		007	120	90	297.
CGS	1964	06	27	23	10	41.9	41.000N	113.400W	033								478		005	156	13	157.
CGS	1964	07	01	03	41	15.0	42.600N	111.800W	033								457		005	156	21	97.
CGS	1964	07	11	02	47	25.3	42.900N	111.700W	033								460		005	156	20	156.
CGS	1964	08	12	05	04	50.9	39.400N	112.000W	015	3.90							478		006	120	92	264.
CGS	1964	08	15	17	38	05.1	44.300N	110.700W	033								459		006	156	40	296.
CGS	1964	08	24	01	55	38.3	39.100N	112.200W	033								478		005	120	92	298.
CGS	1964	09	06	19	03	35.3	39.200N	111.500W	015								478		009	120	91	287.
CGS	1964	09	17	22	17	20.0	42.800N	110.800W	033	4.00							460		006	156	20	142.
CGS	1964	10	15	00	37	30.0	43.900N	113.500W	033								457		005	156	33	274.
CGS	1964	10	18	18	33	19.9	41.900N	111.800W	010	4.30							478	F	018	156	11	15.
CGS	1964	11	04	08	42	53.8	39.600N	110.300W	000	4.00						C	478		008	120	90	273.
CGS	1964	12	26	20	58	14.4	39.600N	110.300W	000	3.90						R	478		008	120	90	277.
CGS	1965	01	14	12	30	11.1	39.600N	110.200W	000	4.50						C	478		011	120	90	277.
CGS	1965	03	09	06	41	34.4	39.900N	111.300W	033	3.50							478		006	120	91	212.
CGS	1965	03	14	13	18	05.3	39.600N	110.300W	000	3.90						R	478		006	120	90	273.
CGS	1965	03	21	22	56	39.7	39.500N	110.300W	000	4.00						R	478		017	120	90	283.
CGS	1965	03	26	00	51	24.5	39.500N	110.300W	000	4.30						R	478		009	120	91	283.
CGS	1965	03	27	23	17	38.5	42.600N	111.500W	033								457	F	009	156	21	96.
CGS	1965	04	02	03	06	51.1	42.600N	111.500W	033								457			156	21	96.
CGS	1965	04	02	05	19	25.5	42.500N	111.500W	033	4.50							457			156	21	86.
CGS	1965	04	02	05	25	29.0	42.500N	111.500W	033								457			156	21	86.
CGS	1965	04	27	18	51	36.6	41.300N	112.800W	033								478		005	156	12	96.
CGS	1965	05	11	01	50	25.3	41.900N	111.500W	015	4.10							478		005	156	11	89.
CGS	1965	05	24	12	05	17.6	42.800N	111.400W	033								457		005	156	21	120.
CGS	1965	05	29	12	03	29.2	39.500N	110.000W	033	3.20							478		007	120	90	295.

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	MAGNITUDES BODY	SURF	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DISVNO	RN	CE	Q/S	MAR	DG	DIST (KM)
CGS	1965	06	17	15	22	09.8	39.700N	111.300W	033								478		005	120	91	234.
CGS	1965	06	27	19	24	07.1	39.600N	110.400W	000	4.60						R	478	F	005	120	90	269.
CGS	1965	06	29	07	46	28.2	39.600N	110.300W	000	4.30						R	478		010	120	90	277.
CGS	1965	07	05	17	17	09.1	39.300N	111.500W	033								478		009	120	91	276.
CGS	1965	07	18	03	55	51.4	39.500N	109.900W	033	3.10							478		006	119	59	300.
CGS	1965	07	29	08	25	52.7	43.200N	111.800W	033	4.00							457		006	156	31	159.
CGS	1965	08	17	07	09	34.4	41.700N	112.750W	033								478			156	12	73.
CGS	1965	08	22	17	54	33.3	42.300N	110.600W	033	3.30							460		005	156	20	117.
CGS	1965	08	23	01	03	05.8	42.500N	111.300W	033	3.60							457		011	156	21	92.
CGS	1965	11	04	12	08	22.2	39.500N	111.100W	029	3.90							478		012	120	91	259.
CGS	1965	11	28	06	16	47.3	42.600N	111.300W	033								457		006	156	21	102.
CGS	1965	12	05	06	24	52.0	44.000N	113.800W	033								457		006	156	43	296.
CGS	1965	12	24	10	05	34.6	42.800N	110.700W	033	3.90							460		017	156	20	148.
CGS	1966	02	11	20	36	26.9	42.100N	111.400W	033	3.50							457	F	009	156	21	51.
CGS	1966	02	12	09	52	38.5	42.300N	111.200W	033	3.20							457		006	156	21	79.
CGS	1966	03	17	11	47	59.0	41.700N	111.500W	045	4.40					V		478	F	029	156	11	28.
CGS	1966	04	17	09	58	57.5	40.900N	113.300W	033								478		006	156	03	156.
CGS	1966	04	23	20	20	54.5	39.200N	111.400W	033	4.40							478		010	120	91	288.
CGS	1966	04	24	02	59	38.6	39.200N	111.400W	033	3.60							478		007	120	91	288.
CGS	1966	04	28	10	26	45.5	39.600N	110.300W	000	3.70						R	478		013	120	90	273.
CGS	1966	04	30	18	29	14.1	39.600N	110.400W	000	3.40						R	478		008	120	90	269.
CGS	1966	06	10	19	45	47.9	43.100N	111.100W	033	3.70							457		006	156	31	160.
CGS	1966	06	11	05	35	51.3	43.100N	111.000W	033								457		007	156	31	163.
CGS	1966	06	11	09	02	14.2	43.200N	111.300W	033								457		005	156	31	165.
CGS	1966	06	11	09	32	49.1	43.100N	111.200W	033								457		006	156	31	157.
CGS	1966	06	11	09	36	53.3	43.200N	111.200W	033								457		005	156	31	167.
CGS	1966	06	11	10	19	27.4	43.200N	111.100W	033	3.40							457		008	156	31	170.
CGS	1966	06	11	10	46	40.8	43.100N	111.400W	033								457		005	156	31	152.
CGS	1966	06	11	10	53	10.9	43.100N	111.400W	033								457		005	156	31	152.
CGS	1966	06	14	15	41	29.1	41.500N	110.600W	033								460		005	156	10	106.
CGS	1966	06	19	07	38	22.3	42.700N	111.400W	033								457		006	156	21	109.
CGS	1966	07	05	18	26	13.0	40.200N	109.000W	005	3.70							478		010	155	09	294.
CGS	1966	07	05	20	02	41.3	40.200N	109.000W	008								478		007	155	09	294.
CGS	1966	07	30	03	25	30.8	39.400N	110.300W	000	4.10						R	478		012	120	90	293.
CGS	1966	10	04	15	34	36.0	41.600N	110.600W	000	3.80						F	460		005	156	10	103.
CGS	1966	10	08	15	29	53.8	43.200N	111.600W	033								457		008	156	31	177.
CGS	1966	10	14	21	09	38.9	41.800N	110.700W	000							F	460		005	156	10	93.
CGS	1966	10	20	09	19	15.3	39.600N	111.100W	033								478		006	120	91	249.
CGS	1966	10	27	17	15	11.0	43.200N	111.600W	033	3.70							457		007	156	31	173.
CGS	1966	11	11	16	45	34.6	39.600N	110.500W	015	3.20							478		005	120	90	266.
CGS	1966	11	12	06	06	40.9	41.900N	112.600W	033								478		006	156	12	82.
CGS	1966	11	14	14	30	52.2	41.700N	112.700W	033								478		007	156	12	73.
CGS	1967	01	05	22	42	01.4	41.848N	112.557W	005G								478		008	156	12	61.
CGS	1967	01	22	10	01	01.7	39.640N	111.929W	033N								478		010	120	91	237.
CGS	1967	02	05	10	07	16.6*	39.549N	110.697W	033N	3.60							478		005	120	90	286.
CGS	1967	02	15	03	28	03.6	40.100N	109.072W	005G	4.50					V		478	F	024	155	09	296.
CGS	1967	02	16	19	21	35.1	41.336N	112.351W	014	4.00							478		015	156	13	136.
CGS	1967	02	18	15	21	33.9	40.378N	109.569W	033N								478		008	155	09	244.
CGS	1967	02	26	02	58	20.0*	41.611N	111.773W	033N								478		006	156	11	19.
CGS	1967	02	27	22	53	36.6	41.586N	110.630W	000G	3.70						F	460		006	156	10	101.

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH	---------MAGNITUDES---------				INT	INT	PHENOM	RN	CE	Q/S	MAR	DG	DIST
									(KM)	BODY	SURF	OTHER	LOCAL	MAP	MAX	DTSVNO						(KM)
CGS	1967	03	05	05	40	23.9	41.334N	111.669W	011	3.50					IV		478	F	008	156	11	50.
CGS	1967	03	10	02	20	35.4	42.035N	110.238W	033N	3.70							460		011	156	20	135.
CGS	1967	03	10	05	34	59.8	42.775N	111.899W	005G						IV		478	F	007	156	01	110.
CGS	1967	04	03	21	17	12.0	39.493N	111.118W	004	3.40							478		011	120	91	260.
CGS	1967	04	08	21	42	13.8	42.869N	111.307W	033N	4.20							457		009	156	21	130.
CGS	1967	04	24	17	07	28.4*	41.535N	110.618W	000G	3.40						F	460		006	156	10	164.
CGS	1967	05	01	07	37	47.3*	43.512N	111.708W	033N	3.20							457		005	156	31	194.
CGS	1967	06	26	22	31	02.8	43.000N	111.000W	033	4.00							457		006	156	31	153.
CGS	1967	07	21	15	27	58.0	41.300N	113.400W	019								478		010	156	13	141.
CGS	1967	08	24	11	53	53.2	42.900N	111.300W	033								457		009	156	21	133.
CGS	1967	09	02	10	04	07.6	41.100N	111.600W	006								478		008	156	11	77.
CGS	1967	09	11	04	10	46.5	43.000N	111.000W	033	3.50							457		009	156	31	153.
CGS	1967	09	11	14	29	06.4	43.000N	111.200W	033								457		006	156	31	146.
USE	1967	09	24	04	46	48.8	40.700N	112.100W				3.70			V		478	D		156	02	121.
CGS	1967	09	24	05	00	28.1	40.700N	112.100W	004	3.70							478		007	156	02	121.
CGS	1967	10	25	00	56	12.2	39.500N	110.400W	000	3.10							478		008	120	90	279.
CGS	1967	10	25	01	33	00.4	39.500N	110.300W	000	3.50							478		013	120	90	287.
CGS	1967	10	25	02	17	45.9	39.500N	110.400W	000	3.50							478		010	120	90	279.
CGS	1967	10	25	02	41	34.4	39.400N	110.300W	000	4.00							478		016	120	90	293.
CGS	1967	10	25	05	53	08.4	39.400N	110.300W	000	4.00							478		019	120	90	293.
CGS	1967	10	31	06	21	52.6	42.500N	111.500W	033								457		007	156	21	96.
CGS	1967	11	04	21	06	31.9	39.200N	111.700W	033								478		006	120	91	286.
CGS	1967	11	16	00	09	48.1	39.600N	110.200W	000	3.90							478		013	120	90	277.
CGS	1967	11	28	15	46	54.7	44.300N	110.600W	033								459		005	156	41	295.
USE	1967	12	07	13	33	22.5	41.300N	111.700W	009	4.30							478	F	017	156	11	57.
CGS	1967	12	09	19	35	43.2	41.600N	111.800W	001								478		012	156	11	19.
CGS	1967	12	18	22	12	50.1	43.400N	109.800W	033								460		005	155	39	246.
CGS	1967	12	20	07	13	23.6	43.600N	110.400W	033								460		009	156	31	254.
CGS	1968	01	16	06	09	22.4	42.800N	111.600W	022	3.90							457		014	156	21	116.
CGS	1968	01	16	08	58	44.0	39.300N	112.100W	033	4.10							478		018	120	92	275.
CGS	1968	01	16	09	17	52.3	39.300N	112.100W	033	3.90							478		014	120	92	275.
CGS	1968	01	16	09	20	12.1	39.300N	112.100W	033								478		008	120	92	275.
CGS	1968	01	16	09	39	54.1	39.200N	111.900W	033								478		005	120	91	286.
CGS	1968	01	16	09	42	54.2	39.200N	112.000W	033	4.00							478		006	120	92	286.
CGS	1968	01	17	04	27	16.1	39.300N	112.200W	033	2.80							478		005	120	92	276.
CGS	1968	01	19	11	19	28.3	39.300N	112.100W	033								478		015	120	92	275.
CGS	1968	02	15	07	31	26.0	42.800N	111.700W	033								457		007	156	21	115.
CGS	1968	02	20	06	34	30.2	41.500N	110.600W	033	3.70							460		007	156	10	105.
CGS	1968	02	26	18	16	10.5	39.600N	111.000W	007	3.20							478		010	120	91	251.
CGS	1968	03	06	18	34	29.7	39.400N	110.300W	004								478		009	120	90	293.
CGS	1968	03	07	04	17	12.5	41.900N	112.700W	033								478		008	156	12	74.
CGS	1968	03	28	04	48	12.6	41.100N	113.300W	033								478		006	156	13	144.
CGS	1968	05	11	08	53	48.8	42.349N	111.335W	033N								457		006	156	21	76.
CGS	1968	06	02	18	59	28.0	39.512N	110.351W	000G	3.80							478		012	120	90	280.
CGS	1968	08	02	07	07	02.5	39.524N	111.044W	006								478		009	120	91	258.
USE	1968	08	04	06	23	36.4	39.100N	111.400W	015	4.00					II		478	F	008	120	91	288.
CGS	1968	08	05	23	07	04.7	39.489N	110.990W	008								478		008	120	90	263.
CGS	1968	08	05	23	10	28.7	39.515N	110.948W	005G								478		009	120	90	261.
CGS	1968	08	29	09	31	48.1	39.484N	110.248W	000G	4.20						C	478		011	120	90	287.
CGS	1968	09	10	00	52	53.5*	42.682N	111.899W	004								457		006	156	21	102.

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH (KM)	MAGNITUDES BODY	SURF	OTHER	LOCAL	INT MAP	INT MAX	PHENOM DTSVNO	RN	CF	Q/S	MAR	DG	DIST (KM)
CGS	1968	10	11	05	00	17.7	39.568N	110.384W	005G	3.20							478		009	120	90	273.
CGS	1968	11	16	03	51	22.4	43.663N	110.213W	033N	3.90							460		019	156	30	248.
CGS	1968	11	17	14	33	37.5	39.501N	110.986W	006	4.60							478		022	120	90	262.
CGS	1968	12	18	11	33	45.5	44.345N	110.860W	033N	3.50							459		006	156	40	297.
CGS	1969	02	01	11	55	38.4*	42.012N	111.652W	033N								457		007	156	21	31.
CGS	1969	02	25	11	11	09.7	43.872N	111.049W	033N	3.60							457		007	156	31	242.
CGS	1969	02	28	15	30	24.4	43.902N	111.811W	033N								457		005	156	31	237.
CGS	1969	03	13	07	03	14.8	39.444N	110.226W	002	4.10							478		011	120	90	291.
CGS	1969	04	05	10	56	35.4	43.996N	111.321W	033N								457		007	156	31	153.
CGS	1969	06	30	12	05	52.3	42.690N	111.169W	033N	3.70							457		012	156	21	116.
USE	1969	08	27	15	59	28.4	42.900N	110.800W	001G	4.20			4.10CGS		III		460	F	012	156	20	152.
CGS	1969	08	27	18	35	18.9	43.002N	110.724W	001G	3.90			3.90CGS				460		016	156	30	164.
CGS	1969	08	30	02	01	02.5*	43.072N	110.670W	001G	3.90			3.60CGS				460		005	156	30	177.
CGS	1969	09	19	09	31	45.9	43.066N	111.420W	005G	4.10			4.40CGS				457		010	156	31	148.
CGS	1969	09	19	13	33	15.0	42.987N	111.429W	005G	4.50			4.90CGS				457		014	156	21	140.
CGS	1969	09	19	19	57	18.7	43.019N	111.266W	005G	4.30			4.40CGS				457		014	156	31	146.
CGS	1969	09	19	23	58	06.5	42.964N	111.493W	005G	3.90			4.10CGS				457		013	156	21	136.
CGS	1969	09	20	09	12	06.7*	43.122N	111.409W	005G	3.60			3.80CGS				457		006	156	31	154.
CGS	1969	09	23	12	58	13.5	42.923N	111.474W	005G	3.90			3.80CGS				457		010	156	21	130.
CGS	1969	09	25	03	19	45.0*	42.871N	111.698W	005G				3.90CGS				457		006	156	21	123.
CGS	1969	10	06	04	03	51.6	44.157N	110.426W	033N	3.90							459		010	156	40	289.
CGS	1970	01	22	12	49	23.0	39.607N	110.416W	001	4.00						C	478		013	120	90	269.
CGS	1970	02	21	06	13	45.9	39.350N	110.561W	000G	4.10						C	478		007	120	90	289.
USE	1970	03	29	12	40	41.2	41.600N	113.700W	010G	4.60					V		478	D	018	156	13	157.
CGS	1970	04	14	10	40	54.2	39.665N	110.787W	013	4.20							478		010	120	90	250.
CGS	1970	09	21	07	04	36.9	43.177N	110.759W	015G	4.40							460		019	156	30	190.
NOS	1970	10	17	08	06	33.3	42.697N	111.115W	015G	4.30							457		006	156	21	119.
NOS	1970	10	25	07	46	42.1*	39.152N	111.385W	005G	4.30			3.00NOS				478		014	120	91	293.
NOS	1970	10	27	06	11	51.5	39.103N	111.355W	005G				2.60NOS				478		009	120	91	299.
NOS	1970	11	13	00	45	45.1*	44.049N	110.409W	033N	3.90							459		019	156	40	279.
NOS	1971	02	24	07	08	22.8	39.405N	110.164W	005G				3.60NOS				478		010	120	91	298.
NOS	1971	04	22	23	01	03.2	39.424N	111.978W	005G				3.40NOS				478		007	120	91	261.
ERL	1971	06	23	05	01	50.5*	44.040N	110.422W	015G								459		005	156	40	277.
ERL	1971	07	10	17	22	37.2*	40.403N	109.566W	008	3.80							479		007	155	09	243.
ERL	1971	07	16	16	54	19.7	42.215N	111.392W	005G	3.60							457	F	005	156	21	61.
ERL	1971	12	03	05	35	02.3*	42.257N	110.413W	005G	4.10							460		009	156	20	129.
ERL	1971	12	03	07	44	59.0	42.472N	110.257W	005G	4.20							460		012	156	20	151.
ERL	1972	03	06	13	33	24.5*	41.873N	111.616W	005G	4.60							478	F	015	156	11	91.
ERL	1972	10	01	19	42	29.2	40.581N	111.302W	005G	4.70							478	D	025	156	01	139.
ERL	1972	10	16	21	49	32.4	40.415N	111.039W	010G	4.10							478	F	009	156	01	164.
ERL	1972	11	24	05	36	06.9	42.505N	111.158W	033N	4.40					IV		457	F	016	156	21	99.
ERL	1973	02	14	13	57	53.0	43.923N	111.187W	016								457		008	156	31	245.
ERL	1973	03	24	23	20	04.5*	43.986N	110.228W	010G								460		007	156	30	279.
ERL	1973	03	25	09	56	21.5*	44.052N	110.233W	010G								459		008	156	40	285.
ERL	1973	03	28	15	38	43.0*	44.196N	110.360W	010G								459		006	156	40	295.
ERL	1973	03	29	10	40	26.3*	44.081N	110.166W	010G								459		006	156	40	291.
ERL	1973	03	30	14	36	25.2*	44.087N	110.271W	010G								459		006	156	40	287.
ERL	1973	04	07	19	16	49.9*	44.066N	110.217W	005G								459		008	156	40	287.
ERL	1973	04	09	10	30	58.7	44.140N	110.485W	005G	3.60							459		005	156	40	286.
ERL	1973	04	13	06	56	37.3	42.090N	112.643W	010G								457		007	156	22	77.

SOURCE	YEAR	MO	DA	HR	MN	SEC	LAT	LONG	DEPTH	----------MAGNITUDES----------				INT	INT	PHENOM	RN	CF	Q/S	MAR	DG	DIST
									(KM)	BODY	SURF	OTHER	LOCAL	MAP	MAX	DTSVNC						(KM)
ERL	1973	04	14	06	45	49.2	42.051N	112.525W	024	4.40			4.75ERL		IV		457	F	036	156	22	66.
ERL	1973	04	20	19	06	54.1*	43.653N	111.063W	017								457		006	156	31	240.
ERL	1973	06	14	21	59	40.6*	42.831N	108.534W	005G							F	460		005	155	28	295.
GS	1973	07	16	06	36	42.8*	39.149N	111.508W	010G	4.20							478		036	120	01	292.
GS	1973	10	27	00	44	07.9*	42.770N	111.109W	011								457		007	156	21	126.
GS	1973	11	20	23	36	30.0	42.042N	112.690W	010G								457		011	156	22	78.
GS	1974	07	04	03	10	56.2*	44.414N	111.112W	005G								458		9	156	41	300.
GS	1974	08	30	19	33	20.5*	44.361N	111.053W	005G						III		458		6	156	41	295.
GS	1974	10	20	02	19	29.5*	44.241N	111.137W	005G								458		7	156	41	281.
GS	1975	03	27	04	48	51.6U	42.070N	112.545W	006	4.40			4.20SLC				457	F	59	156	22	68.
GS	1975	03	28	02	31	05.7U	42.061N	112.548W	005	6.10	6.0		6.20PAS		VIII		457	D	258	156	22	68.
GS	1975	03	28	13	11	16.6U	42.051N	112.481W	002	4.30			3.00SLC				457		16	156	22	63.
GS	1975	03	28	16	15	06.9U	42.030N	112.534W	007	4.10			3.80SLC				457		36	156	22	66.
GS	1975	03	29	05	44	32.6U	42.080N	112.453W	003	4.30			3.20SLC				457		20	156	22	63.
GS	1975	03	29	13	01	19.8U	42.016N	112.521W	004	4.70			4.70SLC				457	F	80	156	22	64.
GS	1975	03	30	06	56	28.6U	42.020N	112.578W	005	4.30			4.10SLC				457		45	156	22	66.
GS	1975	03	30	07	22	00.6U	42.028N	112.620W	002	4.00			2.93SLC				457		6	156	22	72.
GS	1975	03	30	07	32	12.7U	42.023N	112.605W	001	4.30			3.40SLC				457		24	156	22	71.
GS	1975	03	30	10	06	48.2U	42.097N	112.644W	005	3.90			2.82SLC				457		7	156	22	77.
GS	1975	03	30	12	17	59.7U	42.039N	112.537W	003	4.00			2.61SLC				457		5	156	22	66.
GS	1975	03	30	12	56	33.4U	42.014N	112.594W	006	4.00			3.23SLC				457		13	156	22	69.
GS	1975	03	30	14	02	26.3U	42.011N	112.605W	003	4.00			3.60SLC				457		32	156	22	70.
GS	1975	03	31	10	30	56.2U	42.063N	112.500W	006	4.30			3.50SLC				457		27	156	22	65.
GS	1975	03	31	13	23	58.3U	42.008N	112.497W	007	4.40			3.00SLC				457		7	156	22	62.
GS	1975	03	31	13	45	51.5U	41.981N	112.411W	007	4.50			3.19SLC				457		8	156	12	54.
GS	1975	04	02	21	06	45.9U	42.094N	112.444W	007	4.70			3.20SLC				457		16	156	22	63.
GS	1975	04	04	13	46	03.4U	42.008N	112.477W	005				2.90SLC				457		8	156	22	60.
GS	1975	04	06	21	05	34.0U	42.022N	112.493W	004				3.20SLC				457		17	156	22	62.
GS	1975	04	07	13	42	34.5U	42.041N	112.492W	004	4.60			3.10SLC				457		21	156	22	63.
GS	1975	04	07	14	01	42.2U	42.147N	112.585W	002				3.10SLC				457		20	156	22	76.
GS	1975	04	07	14	43	54.3U	42.039N	112.498W	003	4.40			3.00SLC				457		20	156	22	63.
GS	1975	04	08	03	48	03.7U	41.880N	112.374W	005	4.00			2.90SLC				478		5	156	12	47.
GS	1975	04	10	10	21	00.5U	42.012N	112.554W	005				3.20SLC				457		22	156	22	66.
GS	1975	05	30	03	25	49.2*	41.832N	108.770W	010G	3.2							460		14	155	18	253.
GS	1975	06	07	04	36	21.7	41.912N	108.804W	005G	3.7							460		5	155	18	251.
GS	1975	06	16	23	30	54.9	40.873N	114.003W	005G	4.3							037		23	156	04	260.
GS	1975	06	18	05	42	29.2*	43.367N	110.959W	005G	3.3							457		10	156	30	192.
GS	1975	06	30	03	26	47.2U	42.112N	112.466W	005				3.00SLC		II		457	F	16	156	22	65.
GS	1975	07	17	19	04	54.3*	43.507N	110.591W	005G	3.3			3.30ERD				460		7	156	30	218.
GS	1975	08	16	21	20	53.6U	42.124N	112.448W	019				3.60SLC				457		34	156	22	65.
GS	1975	09	08	11	56	44.9*	44.200N	111.282W	019				2.50ERD				458		12	156	41	274.
GS	1975	09	12	18	26	06.4	42.072N	112.571W	005G				4.00SLC		III		457	F	24	156	22	70.
GS	1975	09	12	18	57	22.7*	42.086N	112.469W	005G								457		8	156	22	65.
GS	1975	09	14	04	13	24.2	41.871N	112.426W	005G						III		478	F	23	156	12	51.
GS	1975	09	22	10	42	30.2U	42.075N	112.453W	013	4.2			3.60SLC		IV		457	F	34	156	22	62.
GS	1975	10	02	14	58	29.2*	40.691N	114.710W	005G								037		6	156	04	269.
GS	1975	10	06	09	41	58.1*	40.914N	114.533W	005G								037		11	156	04	276.
GS	1975	10	12	09	47	03.9*	40.879N	114.896W	005G				3.70ERD				037		6	156	04	275.
GS	1975	10	13	06	55	25.2*	42.000N	112.556W	005G								457		5	156	22	66.
GS	1975	11	09	08	55	46.9	41.992N	112.517W	005G								457		7	156	12	63.

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SOURCE YEAR  MO DA HR MN SEC      LAT      LONG   DEPTH ---------MAGNITUDES---------       INT  INT PHENOM  RN CE Q/S  MAR DG   DIST
                                                  (KM)  BODY   SURF   OTHER   LOCAL      MAP  MAX DTSVMO                     (KM)

  GS   1975  11 11 00 19 16.3* 41.822N 110.595W 010G                                                    460      5  156 10   102.
  GS   1975  11 17 08 21 11.1U 41.955N 112.533W 007                          3.00SLC                    457     33  156 12    62.
  GS   1975  12 05 11 06 40.5  44.417N 111.443W 010G                         2.40ERD                    458     12  156 41   296.
  GS   1975  12 20 01 44 12.9  42.001N 112.528W 005G               2.70ERD   2.70GS                     457     11  156 22    64.
  GS   1975  12 27 21 53 09.8* 43.154N 110.752W 005G                         3.10ERD                    460      9  156 30   179.
  GS   1976  02 11 03 28 14.7U 41.270N 111.843W 013                          2.70SLC         III        478 F   72  156 11    55.
  GS   1976  02 14 13 11 11.0* 42.719N 111.272W 005G                         3.40AEC                    457      7  156 21   115.
  GS   1976  02 21 14 12 47.0  41.589N 112.553W 005G                         3.30AEC                    457      9  156 12    65.
  GS   1976  02 23 01 01 18.2* 42.010N 112.523W 005G                         2.80AEC                    457      7  156 22    64.
  GS   1976  02 27 07 18 16.4* 41.240N 111.275W 005G                         2.40SLC                    478 F   11  156 11    74.
  GS   1976  03 07 07 23 11.1  42.059N 112.571W 005G                                                    457     12  156 22    70.
  GS   1976  03 15 02 28 34.5* 43.253N 110.732W 005G  3.7                    3.20AEC                    460     13  156 30   198.
  GS   1976  03 17 08 02 46.3* 43.243N 110.684W 005G  3.9                    3.50AEC                    460     13  156 30   199.
  GS   1976  03 21 07 52 33.3* 43.258N 110.692W 005G                                                    460     11  156 30   198.
  GS   1976  03 21 08 03 07.3* 43.272N 110.683W 017                                                     455     11  156 30   192.
  GS   1976  03 22 09 18 45.7* 42.050N 112.642W 005G                                                    457     14  156 22    75.
  GS   1976  06 14 09 37 57.8U 42.118N 112.495W 007                          3.60SLC                    457 F   34  156 22    67.
  GS   1976  06 15 02 08 10.4U 41.886N 112.442W 001                          3.10SLC                    478     25  156 12    53.

                            TOTAL NUMBER  127089 NUMBER OF HITS  418
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