1981

Preliminary inventory of lifeline systems and evaluation of seismic hazards in Reno and Sparks, Nevada

Barbara Priest
Portland State University

Recommended Citation

Priest, Barbara, "Preliminary inventory of lifeline systems and evaluation of seismic hazards in Reno and Sparks, Nevada" (1981). *Dissertations and Theses.* Paper 3187.
https://doi.org/10.15760/etd.3178

AN ABSTRACT OF THE THESIS OF Barbara Priest for the Master of geography presented February 18, 1981.

Title: Preliminary Inventory of Lifeline Systems and Evaluation of Seismic Hazards in Reno and Sparks, Nevada.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

[redacted]

Fritz L. Kramer

[redacted]

Daniel M. Johnson

[redacted]

James G. Ashbaugh

The Reno-Sparks community is in a seismically hazardous area. Recent research indicates that a Richter 7.0 or greater magnitude earthquake could affect the area. Many of the emergency and essential facilities are situated in dangerous geological locations and are housed in outdated structures which could be severely damaged in the event of a major earthquake. Detailed site evaluations need to be made with respect to location of new structures and of existing building safety. The 1979 Unified Building Code seismic provisions should be adopted without exception; Nevada Revised Statute 278.160 needs to be revised to require a seismic safety plan; Alquist-Priolo legislation should be implemented, and creation of a comprehensive civil defense plan for seismic hazards is essential.

PRELIMINARY INVENTORY OF LIFELINE SYSTEMS AND EVALUATION OF SEISMIC HAZARDS IN RENO AND SPARKS, NEVADA

by

BARBARA PRIEST

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

MASTER OF SCIENCE
in
GEOGRAPHY

Portland State University

1981

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

The members of the Committee approve the thesis of Barbara Priest presented February 18, 1981.

[redacted]

Fritz L. Kramer

[redacted]

Daniel M. Johnson

[redacted]

James G. Ashbaugh

APPROVED:

[redacted]

D. Richard Lycan, Chairman of Geography

[redacted]

Stanley E. Rauch, Dean of Graduate Studies and Research

DISCLAIMER

This report relied on geophysicists, engineers and geologists for estimates of seismic risk and location of works of man relative to faults. Most information on utility line sizes and location came from Sierra Pacific Power Company in 1973. Sierra Pacific Power, a privately owned utility company, has chosen to withhold additional maps on utility lines built since 1973, owing to fear of sabotage.

The assessment of hazard potential for individual sites must be based on detailed site-specific evaluations. This preliminary report is to help identify areas which need such detailed evaluations, but is not, itself, intended for site-specific planning.

ACKNOWLEDGEMENTS

I am indebted to many people for assistance and encouragement during the course of this investigation. I wish to thank all those who patiently answered my questions during interviews which provided much of the data for this thesis. I am particularly thankful to Dennis Trexler, Dr. E. C. Bingler, Dr. Allan Ryall, John Bell, and Dr. H. F. Bonham for making maps, unpublished articles and reprints available to me. Special thanks go to the Sierra Pacific Power Company for their maps and technical explanations, and to Washoe County Civil Defense for supplying additional data.

I could not have written this thesis without the patient, behind the scene's help of my husband who listened to and reviewed my ideas.

I am especially grateful to my advisor, Dr. Fritz Kramer for his admirable patience and encouragement during my work.

TABLE OF CONTENTS

PAGE

CHAPTER PAGE

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

* See back pocket.

CHAPTER I

INTRODUCTION

STATEMENT OF THE PROBLEM

Recently major earthquakes in the western United States, such as at Prince William Sound, Alaska in 1964, and San Fernando, California during 1971, have brought public attention to this natural hazard. Earthquakes cannot be prevented, but measures can be taken to limit the amount of damage done. This has prompted earthquake hazard studies for seismically active areas.

The urban complex of Reno-Sparks, Nevada, lies in one of the seismically most active areas of the United States. This area is in the fault-shattered transition zone between the eastern Sierra Nevada and the Basin and Range Province. The study area occupies the structural basin bounded by the Virginia Range on the east, the Carson Range on the west, Steamboat Hills to the south, and the eastern part of the uplifted Peavine Mountain block to the north (Figure 1). The area is surrounded by active fault zones: the Walker Lane on the east, the Steamboat Hills complex to the south, the Carson Range fault and Olinghouse fault zone on the west, and the Peavine Mountain fault to the north.

Although in historic time (i.e., since 1800 A.D.), no major earthquakes have occurred in the study area, ten large historic earthquakes have occurred in nearby western central Nevada (see Figure 2). Ryall

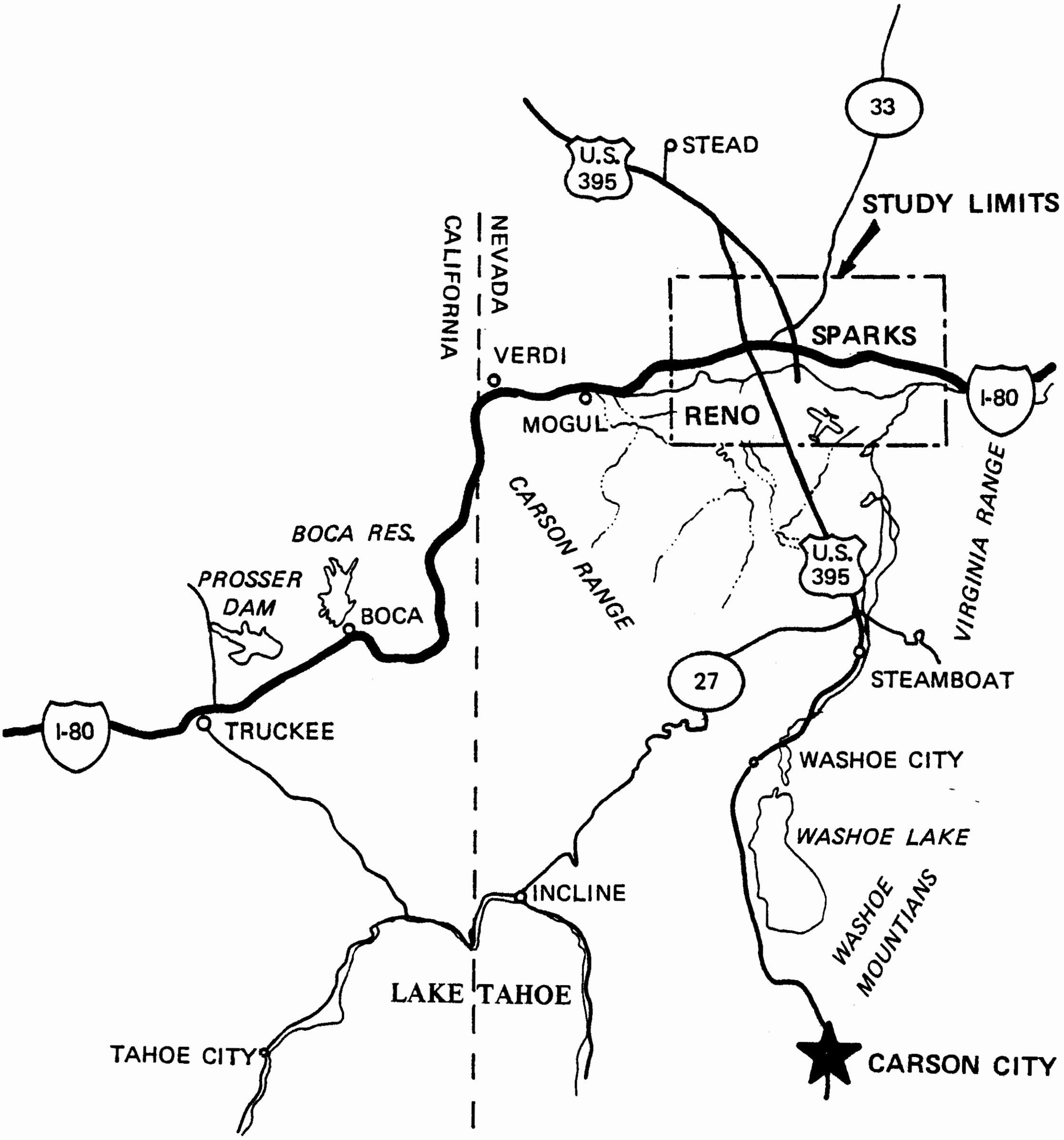


Figure 1. Location map

(From Exxon map of California and Nevada, 1972)

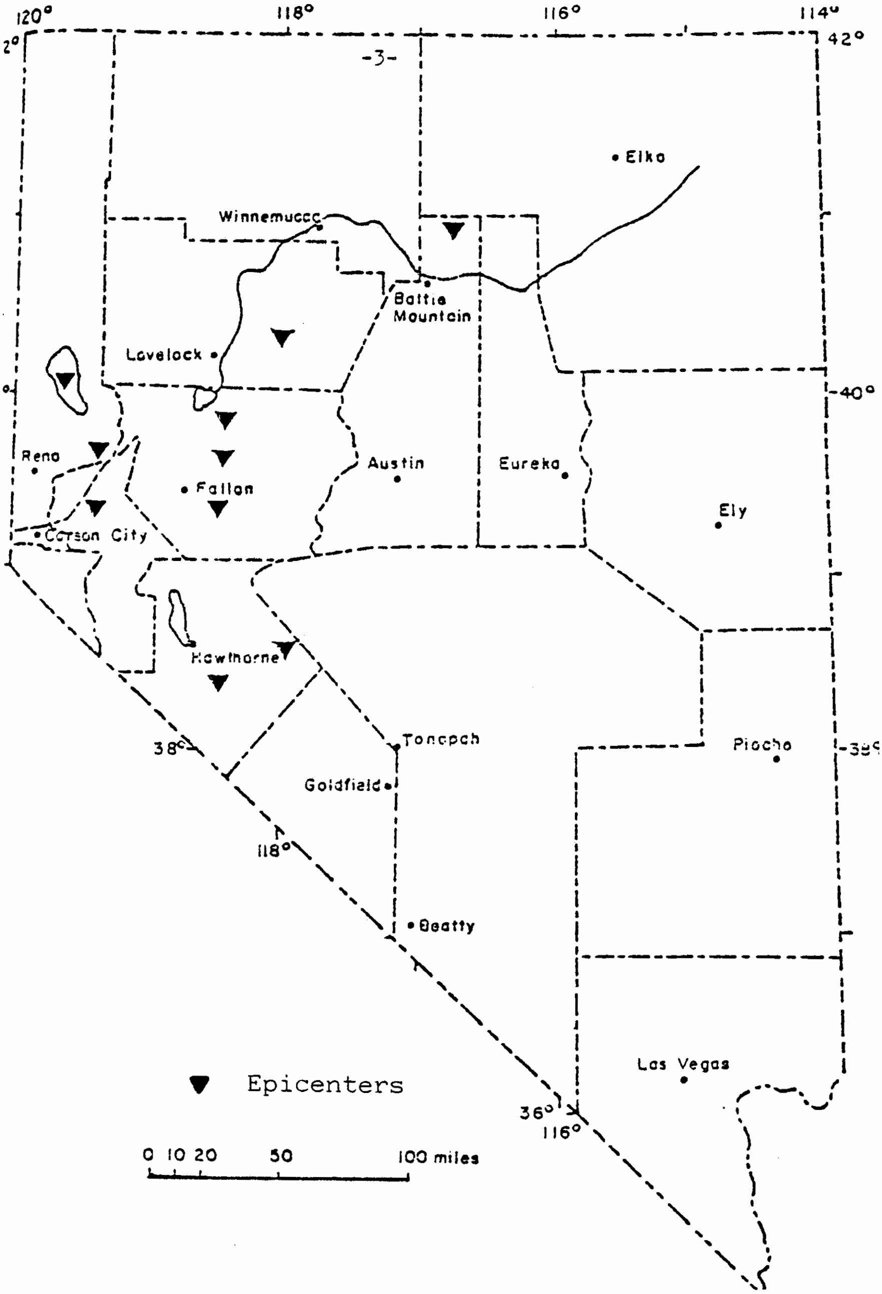


Figure 2. Historic earthquakes in Nevada

(From Ryall, 1973)

TABLE I

RICHTER SCALE

(From Leet et al, 1978)

Earthquake magnitude	*Approximate energy released*
1.0	6 ounces T.N.T.
1.5	2 pounds T.N.T.
2.0	13 pounds T.N.T.
2.5	63 pounds T.N.T.
3.0	397 pounds T.N.T.
3.5	1,990 pounds T.N.T.
4.0	6 tons T.N.T.
4.5	32 tons T.N.T.
5.0	199 tons T.N.T.
5.5	1,000 tons T.N.T.
6.0	6,270 tons T.N.T.
6.5	31,550 tons T.N.T.
7.0	199,000 tons T.N.T.
7.5	1,000,000 tons T.N.T.
8.0	6,270,000 tons T.N.T.
8.5	31,550,000 tons T.N.T.
9.0	199,000,000 tons T.N.T.

et al. (1973) have predicted the maximum possible earthquake within 100 kilometers of the Reno-Sparks area as having a magnitude of seven or greater on the Richter Scale (see Table I) with a return period of 80 years. The expected maximum ground acceleration would be 0.64 gravities (g.) having a predominant period of 0.3 seconds and 30 seconds of strong ground motion. It is also likely that an event of magnitude equal to or greater than 5.5 Richter could occur with a return period of 30.4 years and would have a maximum ground acceleration of 0.18 g. with a predominant period of 0.2 seconds and 6 seconds of strong ground motion.

Fortunately, no extensive damage to life and/or property has recently been recorded in Nevada, but this is only because major earthquakes have occurred in remote areas. Within a major metropolitan center, such as Reno-Sparks, there are a number of emergency and essential facilities which serve the public, such as the police department, fire departments, utility companies, hospitals, communication systems, transportation networks, National Guard and Civil Defense. In the event of an earthquake, it is imperative that these facitilites continue to function, since they are the lifelines for a disaster-struck community.

It is the purpose of this paper to evaluate the adequacy of these facilities to deal with a probable earthquake which could occur in this metropolitan area. It is intended to be an aid to planners, government units and the general public for evaluating works of man as they are distributed in this seismically active area.

BACKGROUND

To date, several reports have been done on individual problems related to a potential earthquake in the Reno-Sparks area by geology and civil engineering classes at University of Nevada in Reno. They have been working on a catalog of building parapets and have also studied some schools, utilities and emergency facilities. The Nevada Bureau of Mines in 1976 published an Environmental Folio, including a series of maps showing slope, soils, hydrology, land use, geology, physical properties and other geologic hazards. The Reno-Sparks Civil Defense is preparing a disaster plan for earthquake hazards, the Army Corps of Engineers has conducted a reservoir survey in the Truckee Meadows area and a study is underway to evaluate the possible seismic response of bridges and over-passes in the Reno-Sparks area by Dr. Bruce Douglas, Engineering Department, University of Nevada.

METHOD OF STUDY

This report will integrate all the previous specialized reports and new data. Information in this report is based on research conducted from 1973 through 1980. Personal interviews with numerous authorities in the area formed an important part of this study. Historical seismic activity in the study area and similar areas is used to predict the impact of a possible earthquake upon the cities of Reno and Sparks. All data will be summarized and presented as maps with overlays at a scale of 1:24,000. The end result will be quantified hazard maps pinpointing specific problem areas in the event of an earthquake.

PRELIMINARY CONCLUSIONS

Since the San Fernando earthquake of 1971, an increasing awareness of earthquake hazards has grown, but most Reno-Sparks residents give little credence to the possibility of a major earthquake in their area. This is due to the fact that Reno-Sparks has never experienced a large earthquake in historic times. This is also the main reason why these cities lag behind California cities in prevention of earthquake damage. It will be shown that Reno could sustain major damage in the event of a large earthquake. Many of the emergency and life-sustaining facilities are on geologically dangerous structures. Most agencies also lack specific post-earthquake plans of action. Sparks, however, being a younger town, can probably cope with an earthquake within the city. Both towns, however, have no specific codes on building design or location other than the Uniform Building Code. This writer recommends a complete rewriting of the present building codes along the lines of those routinely used in seismically active areas of California.

CHAPTER II

EARTHQUAKES AND SEISMICITY

THE CAUSE OF EARTHQUAKES

Earthquakes are caused by movement of crustal materials as the rocks of the earth adjust to tectonic forces. The basic idea of plate tectonics is that the earth's outermost part, the lithosphere, consists of several large rigid plates. Each plate is about 80 km deep, moves horizontally relative to neighboring plates and "floats" on a plastic zone of denser rock material. At the edge of a plate, where contact with other plates occurs, deforming or tectonic processes operate on the rocks, causing physical and chemical changes. The frequency of earthquakes is highest in a zone where two plates are being pushed against each other or where one plate overrides another. Earthquakes also take place within plates, but at a lower frequency.

The major plates are the Indian, Pacific, Antarctic, American, African, and Eurasian. The boundaries of these plates are the loci of present-day earthquakes and volcanic activity. Ocean ridges, in general, have shallow earthquakes. In areas marked by oceanic trenches and arcs, both shallow and deep earthquakes are found.

Plate motion with respect to other adjacent plates results in three main types of boundaries. _Divergent_ boundaries result where plates move away from one another; if they move toward each other, a _convergent_ boundary exists; and when a plate moves past another plate in a parallel fashion, _transform_ boundaries occur (Leet et al, 1978).

Divergent boundaries exhibit tension interaction which results in shallow-focus earthquakes. Convergent plate boundaries are characterized by compression which results in trenches and island-arc volcanoes with shallow, intermediate and deep-focus earthquakes along ocean-ocean plate contacts. When continental plates meet, young mountain ranges result from the piling up of continental masses and shallow-focus earthquakes are common (e.g., Himalayas).

Intracontinental transform boundaries are characterized by fault zones and shallow focus earthquakes over a broad zone. Fracture zones with shallow focus earthquakes in narrow belts mark ocean-ocean transform boundaries.

The most active zone of seismicity is the Circum-Pacific belt. It accounts for over 80% of the total seismic energy released throughout the world. Most of the remaining energy released (15%) occurs in the Alpine or Mediterranean and trans-Asiatic zones (Leet et al, 1978). Earthquakes in these zones have foci aligned along mountain chains. Other parts of the world generally seem to experience only occasional earthquakes. There are also huge continental areas lacking earthquakes (aseismic regions) such as the Canadian shield, Brazilian shield, Fenoscandian shield, northern Asia, the African Massif, western Australia, peninsular India and Greenland.

In 1961, the U.S. Coast and Geodetic Survey began establishing a worldwide network of seismograph staions. Knowledge of earthquakes has rapidly expanded, owing to the quantity and quality of records obtained. Currently, 6,000 earthquakes per year are located. Computerization has helped data processing in determining earthquake location, depth of foci, and size (Leet et al, 1978).

EARTHQUAKE FOCUS

In the study of earthquakes, the term focus designates the source of a given set of earthquake waves. These earthquake waves are, in general, generated from rupture of the earth at some depth. Most source dimensions are around 50 km in length and breadth and, on a world-wide average, the frequency of occurrence decreases rapidly with depth.

Earthquakes are classified as to depth of focus: shallow or S quakes emanate from above 70 km, intermediate or I quakes from 70-300 km, and those below 300 km are termed deep (Bolt, 1976). Shallow-focus earthquakes are the most devastating and make up three-fourths the total energy released in earthquakes throughout the world (Leet, 1978). Moderate to large shallow earthquakes are usually followed by numerous smaller quakes, called aftershocks, in the same area. A major earthquake is often preceded by small quakes or foreshocks from the source area, and aftershocks are nearly universal after a major quake.

The epicenter of an earthquake is the area on the surface directly above the focus point. This area usually experiences the greatest surface shaking.

TYPES OF SEISMIC WAVES IN EARTHQUAKES

There are three basic types of elastic waves that make up the shaking that is felt and causes damage in an earthquake. These waves are similar in many important ways to waves in water. Of the three types, only two propagate within a body of rock. The faster of these body waves is called primary or P wave. Its motion is the same as that of a sound wave in that, as it spreads out, it alternately compresses and dilates the rock. The slower wave through a body of rock is called a secondary or S wave. As an S wave propagates, it shears the rock sideways at right angles to its direction of travel. The actual speed of P and S waves depends on the density and elastic properties of the rock and soil through which they pass. In most earthquakes, P waves are felt first; the effect is similar to sonic boom. Seconds later, the S waves arrives, which shakes the ground with an up-and-down and side-to-side motion. It is the S waves which effect most of the damage to structures. The third type of earthquake wave is called a surface wave, because its motion is near the ground surface. Surface waves correspond to ripples of water that travel across a lake. Surface wave motion is located at the surface itself, and as the depth below the surface increases, the wave displacements become less. Surface waves can affect foundations of structures and can affect bodies of water.

Body waves (the P and S waves), as they move through rock layers, are reflected or refracted at interfaces of rock types. Whenever either is reflected or refracted, energy is converted from one type to waves of the other type. So, after the first few shakes on land occur, a combination of body waves is usually felt in strong ground motion. When body waves reach the ground surface, most of their energy is reflected back into the crust, which results in simultaneous up-and-down-moving waves on the surface. This creates amplification of shaking at the ground level, which increases shaking damage.

Heavy shaking near the center of a large earthquake consists of a mixture of wave types that cannot be distinctly separated.

Earthquake waves are affected both by soil conditions and by topography. In alluvium and water-saturated soil, the amplitude of seismic waves can be increased or decreased as they pass to the surface from more rigid basement rock. Ridge tops and bottoms can have intensified shaking, depending on the direction from which the waves are coming and on wavelength.

Seismic waves are recorded on seismographs which, in turn, enable us to measure the period (time between passing waves) of an earthquake. a seismograph consists of three basic parts: an inert member, a transducer and a recorder. The inert member is a weight suspended by a wire so that it acts like a pendulum but is made to move in only one direction and is damped so that it will not swing freely. A transducer picks up relative motion between the pendulum and the ground and converts it into a recordable form. To record motion in all directions, it is necessary to use three seismographs, one to record vertical motion, and two to record horizontal motion at right angles to each other.

If the ground under the instrument oscillates with a short period, the mass will stay essentially still; it then serves as a reference point to measure the earth's motion. The inert members are made to stand still during the passage of waves of a selected period range. Usually, two sets are used, one for short period waves and one for long. The motion is finally recorded on a cylindrical drum around which a sheet of paper is wrapped. The drum rotates at a constant speed, and a pen sketches out displacements, producing a continuous record.

Three types of waves are recorded on seismographs. The first to arrive at the station, P (Primary) waves, the second to arrive, S (Secondary) waves, and the last to arrive are the long (L) waves. Since the difference in arrival times increases as the distance from the source increases, the difference between the arrival of P and S waves gives a measure of the distance to the focus. It generally takes at least three widely separated stations to accurately locate a focus with this method.

INTENSITIES OF EARTHQUAKES

Earthquakes are generally measured by intensity and magnitude. Magnitude attaches a number to an earthquake which is independent of the distance from the earthquake focus and independent of the geology and soil condition. Intensity is a rating of the severity of the ground motion at a specific location. It is assigned a value by observation and description of damage. Intensity is of especial importance to evaluation of earthquake hazards at the surface of the earth.

The scale intensity of measurement is based upon personal sensations, the behavior of natural objects and physical damage to natural and man-made objects. In the U.S., the most widely used and accepted scale is the 1931 modified version of the Merccalli Scale. It has twelve degrees of intensity and takes into account various construction types (Table II, Cluff et al, 1970). From careful observation of earthquake effects, investigators attempt to determine what places have been shaken by equal amounts of energy. These amounts are then plotted with the points of equal intensity connected to make an isoseismic map. Unfortunately, relying upon subjective impressions of an earthquake is an inaccurate way to compile information. Therefore, in 1935, the Richter scale was devised, based on instrumental records of seismographs (Table I).

TABLE II

MERCALLI SCALE

(From Bolt, 1978)

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Practically all works of construction are damaged greatly or destroyed. Waves seen on ground surface. Lines of sight and level are distorted. Objects are thrown into the air.

MAGNITUDE

Magnitude is based on ground motion as recorded by seismographs at varying distances. The most used method in the U.S. for calculating magnitude is that of C. T. Richter. Richter's scale is based on the amount of motion in certain waves expressed as a number. In 1967, an international commission on magnitude redefined the scale. The measurement on this scale is measured on a logrithmic basis, each higher whole number on the scale represents an earthquake ten times stronger than the next lower number.

GROUND FAILURE

Widespread damage can occur during ground shaking in an earthquake when surface deposits fail. This ground failure can take the form of landslides, liquifaction and settling. Steep slopes with unstable rock or soil are especially vulnerable to landslides during shaking, although slide blocks can move on even gentle slopes when liquifiable or unstable clays underlie the area. Severe damage resulted from such sliding on low slopes in both the Alaskan earthquake of 1964 (Bolt et al, 1977) and the San Fernando earthquake of 1971 (R. Yeats, personal communication date 1978).

Liquifaction, a change of soil into a dense liquid-like medium during shaking, is one of the most destructive types of ground failure. Liquifaction can occur wherever loose water-saturated sediments or soils are subjected to cyclic shaking. When water-saturated sands are subjected to shaking, individual grains cease to be in stable contact and become partially suspended in water, so that interstitial pore water bears the weight of the overlying material. Such material has the shear strength of a dense liquid and solid structures will float or sink in liquified sediment according to the density of the structure relative to the bulk density of sediment and water. Sewer lines and septic tanks tend to float, while buildings tend to sink in liquified sediments. The low shear strength of liquified material accounts for landslides on low slopes and for failure of some earthen dams, where liquifiable material is involved. An example of earthen dam failure is the partial collapse which occurred in the San Fernando Dam, during the 1971 San Fernando earthquake, when hydraulic fill in the dam's interior liquified (Bolt et al, 1977).

After severe shaking, surface sediment may settle differentially, creating changes in the local shape of the land surface. Such changes can destabilize structures.

FAULTING

Faults are normally associated with seismic activity, although earthquakes may occur in association with volcanic activity, as well. Displacement along surface faults and attendant shaking can cause severe damage by truncating pipelines and disclocating man-made structures. The activity of faulting lends a clue to seismic activity in an area. It is therefore important to consider types of fault movement and their occurence in the Reno-Sparks area.

Faults are classified according to type of movement and level of activity (Table III). Convergent plate boundaries like the Alaskan Coast and the Himalayas have high-angle <u>reverse faults</u> or low-angle <u>thrust faults.</u> These faults are characterized by compressive movements and crustal shortening and thickening. Divergent plate boundaries

TABLE III

SYSTEM FOR CLASSIFICATION OF FAULT ACTIVITY

(From Cluff, 1972)

ACTIVITY CLASSIFICATION AND DEFINITION	CRITERIA		
	HISTORIAL	GEOLOGICAL	SEISMOLOGICAL
ACTIVE - A FAULT WHICH HAS EXPERIENCED DISPLACEMENT OF SUFFICIENT GEOLOGIC RECENCY TO SUGGEST THAT THERE IS POTENTIAL FOR DISPLACEMENTS IN THE NEAR FUTURE.	(1) SURFACE FAULTING AND ASSOCIATED STRONG EARTHQUAKES, (2) TECTONIC FAULT CREEP, OR GEODETIC INDICATIONS OF FAULT SLIP.	(1) GEOLOGICALLY YOUNG* DEPOSITS HAVE BEEN DISPLACED OR CUT BY FAULTING, (2) FRESH GEOMORPHIC FEATURES CHARACTERISTIC OF ACTIVE FAULT ZONES PRESENT ALONG FAULT TRACE, (3) PHYSICAL GROUND-WATER BARRIERS PRODUCED IN GEOLOGICALLY YOUNG* DEPOSITS. *THE EXACT AGE OF THE DEPOSITS WILL VARY WITH EACH PROJECT AND DEPENDS UPON THE ACCEPTABLE LEVEL OF RISK AND THE TIME INTERVAL WHICH IS CONSIDERED SIGNIFICANT FOR THAT PROJECT.	EARTHQUAKE EPICENTERS ARE ASSIGNED TO INDIVIDUAL FAULTS WITH A HIGH DEGREE OF CONFIDENCE.
POTENTIALLY ACTIVE - A FAULT WHICH HAS NOT RUPTURED IN HISTORIC TIME, BUT FOR WHICH AVAILABLE EVIDENCE INDICATES THAT RUPTURE MAY HAVE OCCURRED IN THE RECENT GEOLOGIC PAST AND THE RECURRENCE PERIOD COULD BE SHORT ENOUGH TO BE OF ENGINEERING SIGNIFICANCE.	NO RELIABLE REPORT OF HISTORIC SURFACE FAULTING.	(1) GEOMORPHIC FEATURES CHARACTERISTIC OF ACTIVE FAULT ZONES SUBDUED, ERODED, AND DISCONTINUOUS. (2) FAULTS ARE NOT KNOWN TO CUT OR DISPLACE THE MOST RECENT ALLUVIAL DEPOSITS, BUT MAY BE FOUND IN OLDER ALLUVIAL DEPOSITS. (3) GROUND-WATER BARRIER MAY BE FOUND IN OLDER MATERIALS. (4) GEOLOGICAL SETTING IN WHICH THE GEOMETRIC RELATIONSHIP TO ACTIVE OR POTENTIALLY ACTIVE FAULTS SUGGESTS SIMILAR LEVELS OF FAULT ACTIVITY.	ALIGNMENT OF SOME EARTHQUAKE EPICENTERS ALONG FAULT TRACE, BUT LOCATIONS ARE ASSIGNED WITH A LOW DEGREE OF CONFIDENCE.
ACTIVITY UNCERTAIN - A FAULT FOR WHICH INSUFFICIENT EVIDENCE IS AVAILABLE TO DEFINE ITS RECENT DEGREE OF ACTIVITY OR ITS RECURRENCE INTERVAL. NO FAULT SHOULD BE CONSIDERED TENTATIVELY ACTIVE, UNTIL PROVEN OTHERWISE, IF IT MAY BE SIGNIFICANT TO THE PROJECT.	AVAILABLE INFORMATION IS INSUFFICIENT TO PROVIDE CRITERIA THAT ARE DEFINITIVE ENOUGH TO ESTABLISH FAULT ACTIVITY. THIS LACK OF INFORMATION MAY BE DUE TO THE INACTIVITY OF THE FAULT OR DUE TO A LACK OF INVESTIGATIONS NEEDED TO PROVIDE DEFINITIVE CRITERIA.		
INACTIVE - A FAULT ALONG WHICH IT CAN BE DEMONSTRATED THAT SURFACE FAULTING HAS NOT OCCURRED IN THE RECENT GEOLOGIC PAST, AND THAT THE RECURRENCE INTERVAL IS LONG ENOUGH TO BE OF NO ENGINEERING SIGNIFICANCE.	NO HISTORIC ACTIVITY	GEOMORPHIC FEATURES CHARACTERISTIC OF ACTIVE FAULT ZONES ARE NOT PRESENT AND GEOLOGICAL EVIDENCE IS AVAILABLE TO INDICATE THAT THE FAULT HAS NOT MOVED IN THE RECENT PAST AND RECURRENCE IS NOT LIKELY DURING A TIME PERIOD CONSIDERED SIGNIFICANT TO THE SITE. AGE OF MOST RECENT FAULT OFFSET SHOULD BE DOCUMENTED: HOLOCENE, PLEISTOCENE, QUATERNARY, TERTIARY, ETC.	NOT RECOGNIZED AS A SOURCE OF EARTHQUAKES.

create high-angle *normal faults* which are associated with crustal extension and thinning. The Reno-Sparks area and the Basin and Range Province in general is characterized by normal faults (Bingler, 1976). Transform plate boundaries like the San Andreas fault zone of California are characterized by vertically dipping *lateral* or *strike-slip faults.* These faults chiefly have horizontal displacements along vertical fault planes. Dip-slip and oblique-slip faults (Figure 5) have significant vertical components of movement and may produce *fault scarps* in areas of normal and reverse faulting. Careful study of the morphology of fault scarps can reveal the number of distinct episodes of movement which have occurred. Analysis of the ages of displaced soil and rock units dates the movements on faults.

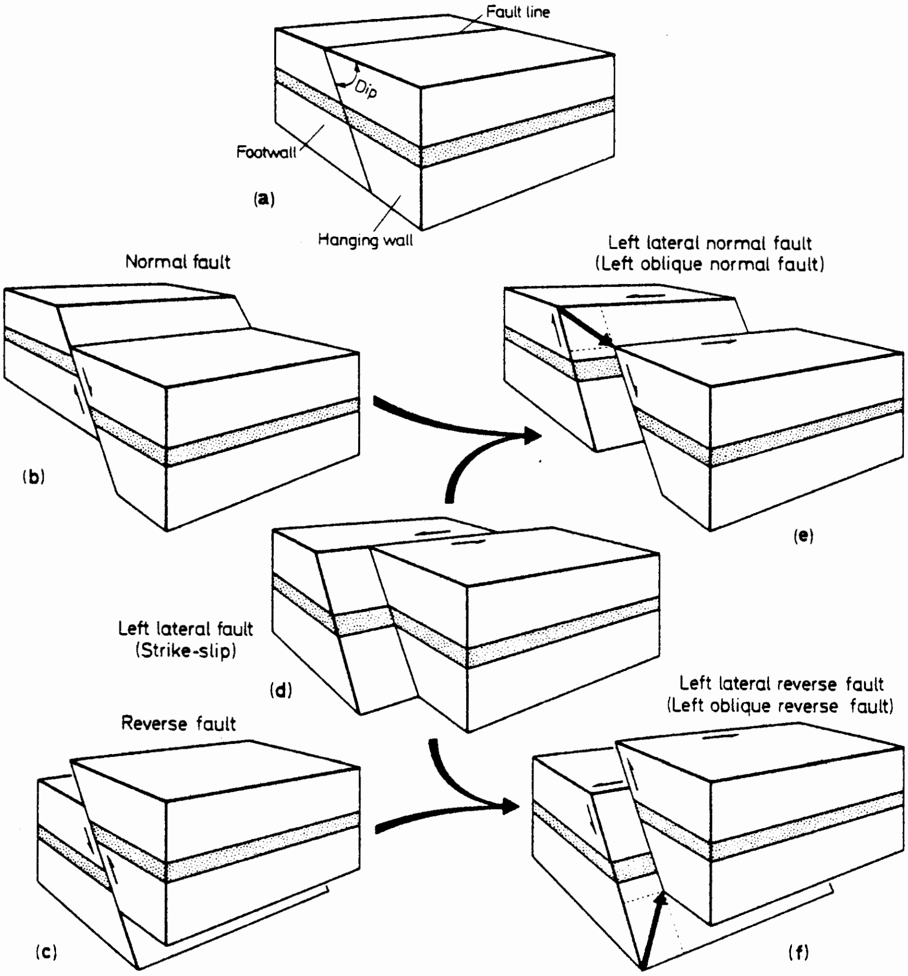
Table IV of Slemmons and McKinney (1977) illustrates the close relationship between surface fault activity and earthquake magnitude and recurrence. This figure dramatically illustrates the importance of quantitative measurements of deformation rates and consequent fault activity. Ryall and Van Wormer (1980) have determined the following relationship between fault-zone length and earthquake magnitude for fault ruptures of eight historic earthquakes in the Western Great Basin:

$\log L \text{ (km)} = 0.4329M \;\; 1.388;$

L = Fault zone lenght; M Richter magnitude.

Quantitative values of the lenghth of fault zones which might rupture in a single event are thus critical for prediction of the magnitude of potential earthquakes.

It is imperative that planners have concrete quantitative definitions of terms like "active fault" and "capable fault". Slemmons and



Diagrammatic sketches of fault types (a) names of components, (b) normal fault, (c) reverse fault, (d) left-lateral strike-slip fault, (e) left-lateral normal fault, (f) left-lateral reverse fault.

<u>Figure 3.</u> Fault types

(From Bolt et al, 1977)

TABLE IV

FAULT ACTIVITY AND EARTHQUAKE REOCCURRENCE

(From Slemmons and McKinney, 1977)

SOURCE FAULT (DISTANCE FROM SITE)	MAXIMUM HISTORIC EARTHQUAKE (DATE, MAGNITUDE, LOCATION)	PROJECTED EARTHQUAKE ACTIVITY	
		MAGNITUDE	ESTIMATED RECURRENCE IN YEARS***
FAULT A 34 MILES FROM SITE	MARCH 12, 1939 8.1 38 MILES FROM SITE INTENSITY X	8-1/2**	
		8	100-500
		7-1/2	60-150
		7	50-100
		6-1/2	25-50
		6	10-30
		5-1/2	5-10
		5	2-5
FAULT B 14 MILES FROM SITE	JULY 12, 1840 6.5-7.0 (ESTIMATED) 20 MILES FROM SITE INTENSITY IX-X OCTOBER 21, 1868 6.0-6.5 (ESTIMATED) INTENSITY IX-X	7-1/2**	
		7	100-500
		6-1/2	50-100
		6	25-50
		5-1/2	10-20
		5	5-10
FAULT C 11 MILES FROM SITE	JULY 4, 1864 6.5-7.0 (ESTIMATED) 16 MILES FROM SITE INTENSITY VIII-IX	7-1/2**	
		7	100-500
		6-1/2	50-100
		6	25-50
		5-1/2	10-25
		5	5-10
FAULT D 4 MILES FROM SITE	DECEMBER 17, 1890 7.0-7.5 (ESTIMATED) 31 MILES FROM SITE INTENSITY IX-X OCTOBER 24, 1955, MAGNITUDE 5.4 6 MILES FROM SITE	7-1/2**	
		7	250-500
		6-1/2	100-200
		6	50-100
		5-1/2	20-50
		5	10-20

*FAULTS AND RECURRENCE DATA ARE HYPOTHETICAL, INTENDED FOR ILLUSTRATIVE PURPOSES ONLY.

**MAXIMUM CREDIBLE EARTHQUAKE: THE MAXIMUM EARTHQUAKE THAT IN OUR JUDGMENT APPEARS CAPABLE OF OCCURRING UNDER THE PRESENTLY KNOWN GEOLOGIC FRAMEWORK.

***THE RECURRENCE INTERVALS ARE A NUMERICAL COMPARISON OF PAST FAULT ACTIVITY AND ARE NOT A PREDICTION OF FUTURE ACTIVITY; THEY DO INDICATE THE RELATIVE ACTIVITY BETWEEN DIFFERENT FAULT ZONES.

McKinney (1977) define the following essential attributes of an Active Fault:

> "1. Active faults have been offset during the present seismotectonic regime [present type of deformation].
>
> 2. Active faults have the probability or potential for future renewal or recurrence of offset.
>
> 3. Active faults have evidence of recent activity, as may be shown by physiographic evidence.
>
> 4. Active faults may have associated earthquake activity."

In addition to these elements, most workers specify that an active fault have Holocene displacement (within the last 10,000 years), according to Slemmons and McKinney (1977). A capable fault is defined by the U.S. Nuclear Regulatory Commission (1975) as a fault displaced once during the last 500,000 years. A dead fault is a fault that "was active during an earlier orogenic period, but is not active within the present tectonic regime and accordingly does not offset late Cenozoic deposits or surfaces, and is not seismically active" (Slemmons and McKinney, 1977). Other definitions of all these terms are exhaustively summarized by Slemmons and McKinney (1977) in their excellent review of the subject.

Workers such as McKinney (1976), Trexler (1976) and Bingler (1974) in the Reno-Sparks area have classified the faults according to most recent sedimentary erosion surface or deposit cut. Such classifications can only put maximum ages on particular faults but are an honest presentation of the uncertainty of the data.

CHAPTER III

GEOLOGIC HISTORY

TECTONIC SETTING

The Reno-Sparks area lies at the fault-shattered contact between the Basin and Range and the Sierra Nevada Tectonic provinces. West of the area, a westerly tilted, north-south trending block of thick Sierra Nevadan crystalline rocks forms the majestic Sierras of Eastern California (Slemmons, 1967). East of the area, much lower elevations prevail over a vast region of Nevada, Utah and Arizona which are collectively called the Great Basin (Longwell et al, 1969). The prevalence of numberous small NW to N-trending closed basins and adjacent mountain ranges has caused the Great Basin to be referred to also as the Basin and Range Province. The ranges are generally up-thrown fault blocks (horsts), while basins are almost invariably down-dropped fault blocks (grabens) with bounding faults of late Cenozoic age. The faults are thought to be the result of both tensional and lateral forces associated with the San Andreas transform plate boundary (Slemmons, 1967). These forces have tended to pull apart and thin the crust of the Basin and Range Province, creating the lower elevations characteristic of the Great Basin.

ROCK UNITS

Areas uplifted in the northern and northwest part of the Reno-Sparks area are composed of Mesozoic metamorphic and intrusive rocks, whereas younger rocks characterize the down-thrown central and south-eastern parts of the area. The oldest rocks are Triassic and or Jurassic-aged metavolcanic and metasedimentary rocks of the Peavine sequence which are intruded by younger Mesozoic granodiorities and quartz monzonites. Cenozoic volcanic rocks overlie the older crystal-line rocks and dominate outcrops adjacent to the sediment-filled basin which holds the main cities.

Volcanism in the area began with eruption of great sheets of ash-flow tuff of the Hartford Hill Rhyolite Tuff about 29 million years ago (latest Oligocene; Bingler and Bonham, 1976). Sedimentary breccias, formed by erosion of the Hartford Hill rocks, were covered in the middle Miocene by pyroxene andesite lava flows and volcanic mudflows of the Alta Formation. Granitic and rrhyolitic plugs intruded the Alta Formation prior to emplacement of hornblende-biotite andesite flows and intrusives of the late Miocene Kate Peak Formation (Bonham, 1969):(Bingler and Bonham, 1976). By late Miocene or early Pliocene, significant movement on Basin and Range faults produced numberous intermontane lake basins where diatomites of the sandstone of Hunter Creek accumulated. Pleistocene deposits filled in the developing basins during melting of mountain glaciers in interglacial times and these gravels and sands serve with Holocene alluvial deposits to demarcate intervals of Quaternary of faulting (see Bingler and Bonham 1976 for detailed description of these deposits).

STRUCTURAL GEOLOGY

The latest deformation episode in the Reno-Sparks area began in the late Miocene and has continued into the present. Deformation has occurred chiefly by normal faulting (Bingler, 1976) but also includes upwarping of mountain blocks and downwarping of basins with faults at the flexures of these movements (Bingler and Bonham, 1976). The Truckee River crosses through the downwarped structural basin of the Truckee Meadows which separates the anticlinal uplift of the northern Carson Range from the dome-like upwarp of the Peavine block. Dominant fault sets trend N20°E to N45°E in a zone 3 km (2 mi) wide extending NW-SE through the area (Bingler and Bonham, 1976). A secondary set at N30°W to N60°W and north- and east-trending faults also occur in the area. Quaternary movements on a few faults in these zones can be demonstrated and a very few cut younger Quaternary or Holocene deposits (Bingler, 1976). Maximum total offset in the Quaternary deposits was 11m (35 feet) in the Virginia Lake Graben (Bingler and Bonham, 1976). Lengths of individual fault's range from 0.4 km (0.25 mi) to 0.65 km (0.4 mi) with 90% less than 3 km (1.86 mi) in lenghth with dip-slip displacements of a few meters. A large number of these small faults may have formed in a single major seismic event (Bingler and Bonham, 1976). Bingler (1976) concludes that few fault scarps in the area are the result of recurrent offsets on the same fault plane and that fault activity younger than 80,000 years old has decreased somewhat relative to activity between latest Miocene and 80,000 years ago.

Trexler (personal communication, 1980) and Cordova (1969), however, note that continuations of fault zones of Reno-Sparks further south have evidence of multiple movements. In view of the excellent exposures of fault scarps to the south of Reno-Sparks relative to scarps in urbanized areas, their observations may be more accurate than those of Bingler.

SEISMIC HAZARD MAPS

Plate 1 is a composite of four seismic hazard maps prepared by the Nevada Bureau of Mines for the Reno-Sparks area. These maps were produced for general planning purposes and each has a disclaimer stating that they are not intended for geologic hazard potential for individual sites. They do, however, show areas of potentially unstable ground which might be sensitive to earthquake activity. Each map also summarizes the entent of fault scarps with some indication of the maximum age since the last movement on the faults. The two southerly parts of the composite map and the east section were prepared by Trexler (1976) and McKinney (1976). They classify faults only as potentially active (i.e., Quaternary in age or approximately, post-two million years) or as pre-Quaternary in age. The northern-most map, which takes in the most populous part of the Reno-Sparks area, was produced by E.C. Bingler (1974) and shows a much more detailed classification of maximum age of last fault movements. Bingler's map also contains a much more detailed classification of shaking potential of various foundation materials. Viewing the maps as a composite allows one to see with a little extrapolation how Bingler's detailed classification might apply to adjacent parts of Trexler and McKinney's maps.

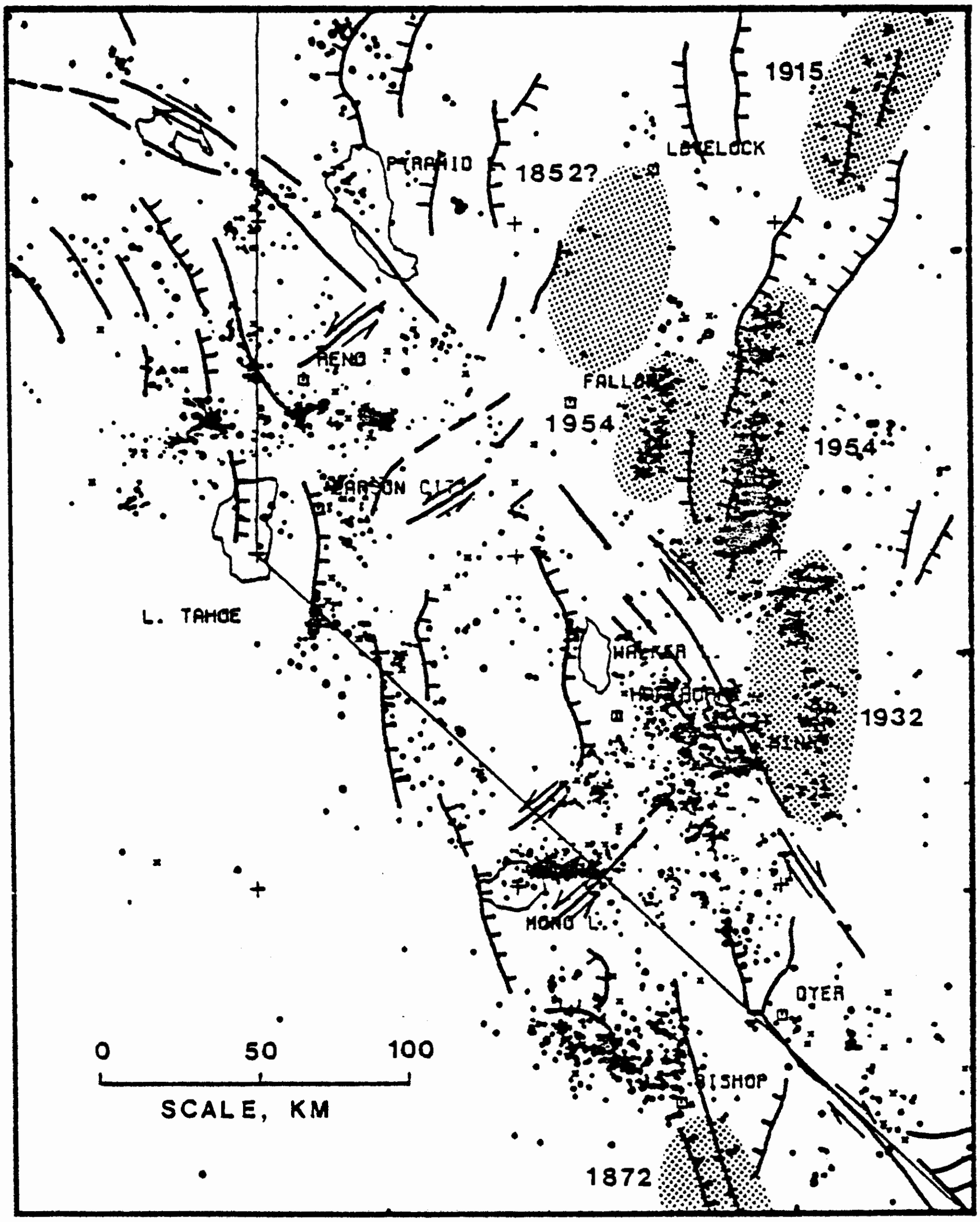
The utility of the composite is thus much greater than the individual maps taken alone.

Bingler's (1974) seismic hazard map classifies the faults according to the youngest deposit that they cut. Faults which cut older deposits are not, however, necessarily older than faults which cut younger deposits. In all likelihood, many of the faults in a particular zone formed at about the same time, regardless of what age deposit they happen to cut. The weakness of Bingler's map and of all the maps is that none of them makes an attempt to classify the faults according to freshness of scarp morphology. Also, none of the maps indicate whether fault scarps show evidence of multiple movements. Bingler (1974) makes the observation that few faults in the Reno quadrangle area appear to be the result of multiple movements. Apparently he could find little tendency for ground rupture to occur preferentially along established fault planes. One might conclude that they very weak Quaternary deposits which form the cover over much of the Reno-Sparks area, are so easily deformed that fault planes are not markedly weaker than adjacent unbroken ground. Cordova (1969) in his study of faults in the Mount Rose area to the south of Reno found three to five movements on individual faults in Holocene time. Trexler (personal communication, 1978) noted multiple offsets on individual faults in his map area, as well. This casts doubt on Bingler's (1974) conclusions.

It may be profitable for planning purposes to assume that ground failure from faulting and from severe shaking near a fault may occur anywhere in a particular zone of faults. A zone could be defined as an area containing a swarm of surface faults sharing approximately the same trend. This approach carries the tacit assumption that swarms of surface faults in weak sediments overlie a deep fault or faults which tend to move along established fault planes in strong bedrock. This assumption makes it necessary to consider broad areas on individual faults. While inconvenient to builders, such a conservative approach may be justified in areas where a great many lives may be lost if ground failure and severe shaking were to occur.

Three highly active zones or swarms of faults are immediately apparent on the hazard map. Each zone contains individual faults which cut sediments younger than the last glacial deposits. Zone I may be called the Veterans Hospital - State Hospital Zone and contains six scarps with subparallel trends at N60°E. Zone I faults cut the youngest alluvium on the map at the Truckee River and near the Sparks High School. Zone II may be called the Virginia Lake - Anderson School Zone and contains about fifteen north-trending scarps in populated areas. The youngest alluvium in the map area is cut at Virginia Lake by two faults of Zone II. Zone III may be called the Peavine School-Clayton High School Zone. It contains about seven scarps in populated areas with a general trend of N45°E (see Plate 1). Post-Pleistocene pediment gravels are cut by faults of Zone III at the Towler School, Clayton High School and the Warner School. (See Plate 1).

Zones I and II intersect in the Billinghurst Jr. High School - Veterans Hospital area. It is likely that this may be a very high-risk area for severe shaking, although it is mostly underlain by sediments with only moderate tendencies toward ground failure (Luza, 1974). Similar moderately competent sediments underlie most of Zone I and much of Zone II (Luza, 1974). Zone III, however, is underlain by less compentent sediments than those of Zones I and II, and has much steeper slopes.



Generalized map of late Cenozoic structural features of the western Great Basin (Wright, 1976), together with epicenters of small earthquakes for 1969 to 1978 (dots) and approximate rupture zones of major historic earthquakes (stippled areas, with year of main shock). Note: seismic network coverage was not uniform for the period of observation; best coverage was in areas around Reno and between Walker and Mono lakes.

Figure 4. Major fault zones of Nevada

(From Ryall and Van Wormer, 1980)

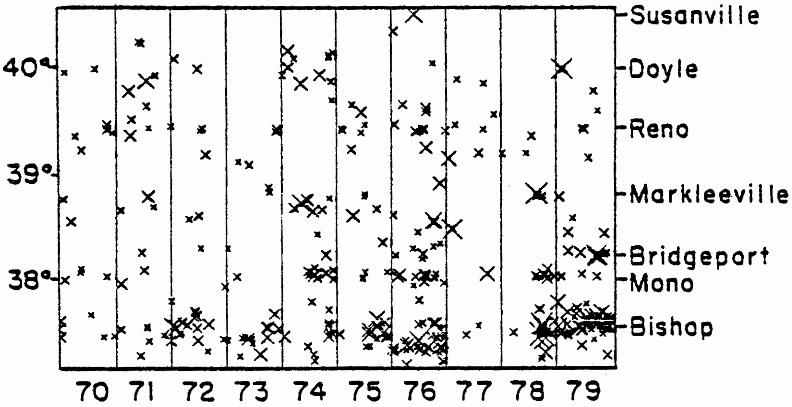
LIKELIHOOD OF A LARGE EARTHQUAKE

Most seismologists consider earthquakes of magnitude 7 and greater to be "major" earthquakes, capable of causing severe damage to works of man. It is very important to quantify the probability of occurrence of such major earthquakes in the Reno-Sparks area in order to achieve a realistic assessment of the risk engendered by the faults shown in Plate I.

The major fault zones of Figure 6 are part of the very active Eastern Sierra Zone. Ryall (1977), Wallace (1978), and Ryall and Van Wormer (1980) have identified this zone as one with a potential for a large earthquake in the near future. Ryall (1977) and Ryall and Van Wormer (1980) conclude that large earthquakes in the Basin-and-Range province have a recurrence interval on the order of thousands of years. While this may seem reassuring, they point out that the Reno-Sparks area is in a dangerously active phase of this cycle of movement which occurs every 2,000 to 4,000 years, according to fault morphology studies by Cordova (1969) on faults of Zone II in the Mount Rose area. The Reno-Sparks area occupies an anomalous "gap" in the pattern of historic seismicity in the Western Great Basin (Ryall and Van Wormer, 1980). This may indicate that stress has been building up to a dangerous level here, so that release in the form of a large earthquake is imminent. Pease (1979) estimates that the most recent major movement on faults parallel to those of Zone II in the Carson City area to the south was just over a century ago, but Ryall and Van Wormer (1980) allude to other evidence placing the event at times ranging from 1,000 to 2,000 years ago. If the latter hypothesis is true, then Zone II faults, and possibly other faults, could be ready for a major movement in the near future.

Recent statistical analyses of earthquake frequency in the Sierra Nevada-Great Basin boundary zone (SNGBZ) by Ryall and Van Wormer (1980) and Van Wormer and Ryall (1980) lend additional support to the hypothesis that this zone may be ready for a large earthquake. They show that historic earthquakes in the Basin and Range have been preceded by a moderate increase in seismicity within or in the vicinity of an impending rupture zone. Figures 5 and 6 show plots of the frequency of earthquakes along various parts of the SNGBZ from 1970 to 1979. Van Wormer and Ryall (1980) suggest that overall increase in earthquake frequency in the SNGBZ with time and dramatic increase in frequency of earthquakes during 1978-1979 could correspond to foreshocks signaling that a major earthquake is imminent along the SNGBZ. They point out that the 70-km-long fault zone along the eastern flank of the Carson Range south of Reno has clusters of earthquakes at both ends and could generate a major earthquake (Figure 6). Putting 70 km into the equation of Ryall and Van Wormer (1980) yields a maximum earthquake magnitute of 7.5. The Dog Valley fault in the Truckee area west of Reno is 25 km long and could generate a magnitude 6.4 earthquake (Ryall and Van Wormer, 1980).

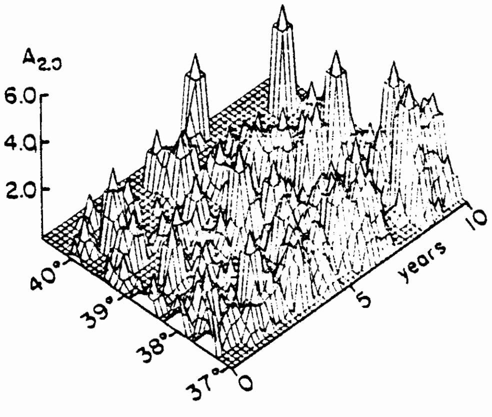
Whereas Ryall and Van Wormer (1980) and Van Wormer and Ryall (1980) discuss earthquake magnitudes in all fault zones surrounding Reno-Sparks, they do not treat individual zones within the cities. Using Ryall and Van Wormer's (1980) equation and fault zone lengths from the seismic hazard maps, Zone I faults (9.6 km; 6 miles long) can have a 5.5 magnitude earthquake; Zone II faults (17.6 km; 11 miles



Earthquake occurrence in the Sierra Nevada-Great Basin boundary zone as a function of time and latitude. Size of symbols is proportional to magnitude; location of zone shown on Figure 11.

Figure 5. Earthquake occurrence in the SNGBZ

(From Van Wormer and Ryall, 1980)



Energy released by earthquakes in the Sierra Nevada-Great Basin boundary zone as a function of time and distance toward the northwest along the zone. $A(2.0)$, logarithm of the number of $M2.0$ earthquakes that would be equivalent to total energy released by earthquakes within grid square. Number of earthquakes were smoothed with a triangular filter before log $N(2.0)$ was calculated. Energy was determined for each earthquake using log $E = 11.8 + 1.5\ M$ (Richter, 1958).

Figure 6. Earthquake energy in the SNGBZ

(From Van Wormer and Ryall, 1980)

long) can have a 5.6 magnitude earthquake; Zone III faults (11.2 km; 7 miles long) can have a 5.5 magnitude earthquake and, should all three zones become involved in a single seismic event, their combined lengths (38.4 km; 24 miles) would yield a maximum probable earthquake of magnitude 6.9.

Fault zone lengths for all of these estimates are limited by the map coverage. Because nearly all of these zones probably entend out of the map area, larger maximum magnitudes are probable. A conservative planner would be wise to assume that a Richter 7 or greater magnitude earthquake is possible in the Reno-Sparks area.

ESTIMATES OF GROUND ACCELERATION

Owing to lack of published data on site-specific ground accelaration estimates for the Reno-Sparks area, no definitive estimates are listed here. Ideally, possible accelerations attributable to maximum credible earthquakes from all fault zones in and around the Reno-Sparks urban complex should be estimated for each geologic setting. Ryall (1973) estimates that a maximum ground acceleration of 0.64 gravities is possible in the region within 100 kilometers of Reno-Sparks from a Richter 7 or greater magnitude earthquake. Such an earthquake would probably have a predominant period of 0.3 seconds and 30 seconds of strong ground motion (Ryall, et al., 1973).

Should an earthquake of this magnitude occur in Reno-Sparks, these ground motion estimates may be used as a rough guideline. Van Wormer and Ryall (1980), however, indicate that the method of estimating these ground motions probably leads to high estimates for areas geologically similar to Reno-Sparks.

MOGUL LANDSLIDE - TRUCKEE RIVER

West of Reno, outside the study area, is the Mogul landslide complex, which foots into the Truckee River. (See Figure 1). This area has been active in 1940 and 1964 and is currently active, according to Trexler (personal communication, 1978). If this slide area were reactivated during an earthquake, the river could become dammed by the landslide. Water would build up until it overtopped the landslide, releasing a torrent of water and debris which could cause a large-scale flood in the Reno-Sparks area.

CHAPTER IV

STATUS OF EARTHQUAKE CONTINGENCY IN NEVADA

Earthquakes are natural hazards having a potential for impact in terms of damage to life, property, and economic loss. Based on an analysis of geologic data of earthquakes, the U.S. has been divided into seismic "risk zones". Zone values range from 0 (least risk) to 4 (highest risk). Risk zones for the U.S. are shown in Figure 9. Most of western Nevada is in zone 3 and 4. The last major earthquake (magnitude 7.1) in Nevada occurred in 1954 in the Dixie Valley area, but due to its remote location, little damage was done. If it had occurred in an urban area, more attention would have been paid to the problem of seismic hazards in Nevada. However, in 1971, a large earthquake occurred in San Fernando, California, which caused over one-half billion dollars worth of damage and alerted the public, at least in the West, to the realities of earthquake hazards.

To date, there is no known way to prevent earthquakes. All that we can do is try to reduce the hazards that they pose to life and property.

Due to the rapid urban growth in western Nevada, where the seismic risk potential is high, Governor Mike O'Callaghan created an Ad Hoc Panel in 1978 to study ways of lessing the damage that might be caused by an earthquake. The Ad Hoc Panel came to several broad conclusions regarding seismic hazards in Nevada:

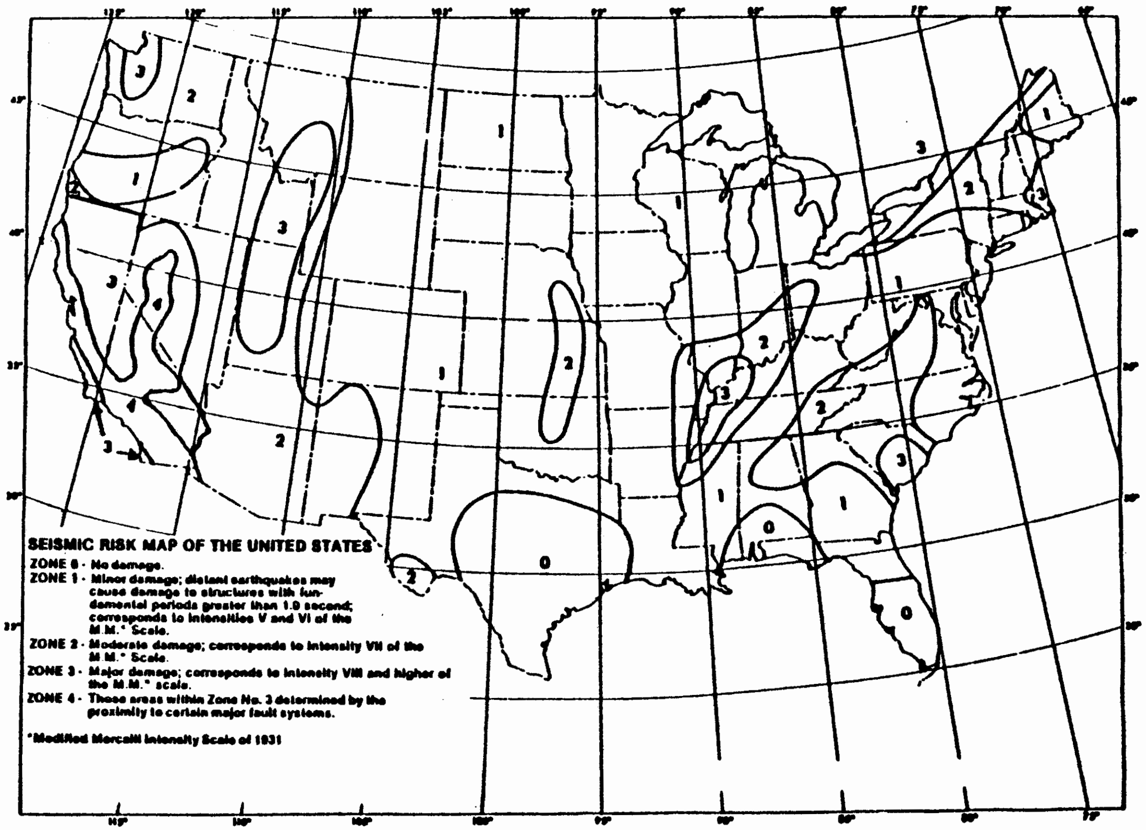


Figure 7. Seismic risk zones of the United States

(From Ad Hoc Panel on Seismic Mitigation, 1979)

1. Nevada lies in a region of high seismic activity. The extent of the hazard is growing because of the rapidly growing population, living and working in structures that are not adequately designed for a seismic event.

2. With few exceptions, earthquake hazard-related planning in Nevada is inadequate. The high-risk potential demands effective plans for disaster preparedness, disaster response, mitigation and land use.

3. There is no overall program focusing on seismic research and data collection. The University system through federal funding has done significant work, but much more is needed.

4. There is no coordinated program related to earthquake hazards between public and private entities in Nevada. The Ad Hoc Panel provided a temporary focal point, and its activities served to highlight just how serious the communication and coordination problems are.

5. The manner and extent to which the counties of Nevada and private enterprise deal with the earthquake problem is inadequate. The State Legislature and Executive Branch should give serious consideration to this matter and take appropriate actions; failure to do so could, in the event of a major earthquake, make State and counties liable for damage and loss of life.

The Ad Hoc Panel at the end of its ten-month study recommended:

1. Establishment of an independent interdisciplinary Seismic Safety Council;

2. Revision of NRS 278.160 to require preparation of a seismic safety plan as an element of city, county or regional master plans;

3. Increased funding for the Nevada Bureau of Mines and Geology to accelerate the Bureau's seismic hazard mapping program. If the State

is to have a serious program to reduce earthquake hazards, this type of data is urgently needed;

4. The State of Nevada should adopt as State law all the seismic provisions of the 1979 Uniform Building code. To date, each county has adopted the Uniform Building Code with exceptions, so it is not uniformly applied;

5. Establishment of a center for seismic hazard assessment data to achieve and make available all date developed by public and private entities within Nevada;

6. To adopt "Alquist-Priolo Geological Hazards Act" legislation. This California act came about as a result of studies of California seismic safety problems by the Legislative Joint Commission on Seismic Safety and the Governor's Earthquake Council. Experience of losses in San Fernando's 1971 earthquake added impetus. The act provides mechanisms to reduce loss from surface fault displacement by

(a) requiring the state geologist to delineate special study zones (1/4 mile wide areas on active faults) through a 10 year mapping program.

(b) requiring affected local jurisdictions to regulate development programs within the defined zone by withholding development permits or change of occupancy permits until geological investigations demonstrate that the site is not threatened by surface displacement from future faulting

(c) requiring sellers of any property in special study zones to disclose that fact to any prospective buyer

(d) requiring the owner/developer of zoned lands to obtain the required geological reports

(e) requiring a fifty-foot standard setback for stuctures and regulating the types of buildings permitted (i.e. wooden framed ones or two-story homes)

(f) specifically prohibiting the location of structures of human occupancy across active fault traces.

7. Increase the seismographic station network in order to make possible accurate epicenter location of future earthquakes and to improve seismic zoning.

In response to the Ad Hoc Panel, the State Legislature of 1979 adjourned without holding even a hearing on the above recommendations. The Panel urged Governor List to officially continue the Ad Hoc Panel as an interim measure, but this too, fell on deaf ears.

HAZARD MITIGATION

Mitigation of seismic hazards includes prevention of new hazards and elimination of existing hazards as part of the overall disaster preparedness response. Seismic hazards can be related to: (1) unstable geologic conditions, (2) unsafe structures and (3) inadequately designed utility systems.

The most effective hazard reduction program would be to avoid building in areas of high seismic risk. However, this is a very difficult problem because urban growth tends to force development of potentially hazardous locations, even as awareness of the hazard grows more acute. Much can be accomplished by recognition of seismic hazards at the planning level.

Mitigation of seismic hazards can be accomplished by use of (1) mapping of geologic hazards, (2) land-use planning, (3) zoning, (4) building code requirements, (5) insurance programs, and (6) assessment of economic impacts.

It is important to inventory vital critical, crucial and dangerous facilities already within a jurisdiction so that they can be incorporated in a plan to eliminate seismic hazards. Vital facilities are defined as those required to remain in service following an earthquake to care for the safety or health of the public. Examples of such facilities are the police and fire departments, hospitals and communications centers. These facilities require more design considerations, because their failure will not be tolerated in a disaster. Critical facilities are those whose failure would result in loss of life, large economic losses and degradation of the environment. Such facilities are: electrical power lines and plants, natural gas lines, water lines, sewage lines, water and sewage treatment plants, dams, and transportation systems. High-occupancy facilities such as schools and high-rise buildings are considered to be crucial, while older buildings having parapets and facades are seen as dangerous.

GUIDELINES FOR SITING FACILITIES

In many cases the safety of a facility can be enhanced by careful design criteria and siting. To select a site, certain geological and seismic parameters must be known, and this knowledge, in turn, can play an important role in the design of the facility. The following are considered of paramount importance to aid siting: (1) the regional geology, (2) degree of activity seismically--how large and how often a movement will occur on local faults, amount of displacement associated with an event, slip rate, and reccurrence interval of associated earthquakes at various magnitudes; (3) history of faulting, (4) detailed geology at the site, (5) soils and investigation of the general area and site, and (6) potential seismic response of the site. It should be recognized that there is a difference between hazard and a perceived hazard. In some cases, the potential hazard can be controlled by care and consideration used in site selection and design. In the past, this has not been done, because the hazard has been judged to be lower than it is, owing to lack of knowledge and understanding. This results in perceived hazards which may be very different from the potential hazard (White and Haas, 1975).

The extent of damage to a structure by ground motion of a given intensity will depend on how well the structure was designed to resist the induced forces. There is a lack of seismic design standards for the utilities and a lack of seismic performance criteria for critical facilities which should be remedied. The UBC also does not cover systems such as water or electrical distribution; it only covers structures such as buildings and tanks. In addition, the utilities in Washoe County are privately owned, and self regulation seriously hampers application of seismic standards.

All vital, critical and crucial facilities and routes should be required to have a geological investigation. This includes both existing and proposed facilities. To date, due to Federal requirements, on-site seismic assessments are currently performed on certain structures such as nuclear power facilities and dams. These site-specific studies are essential for evaluating seismic hazards prior to the approval of designs. Buildings and structures need to be inspected during construction to check the implementation of the design, and the quality of the design can be partially regulated by licensing of architects and engineers.

Formulation of a land-use plan that is acceptable should be based on the economic, social, and political considerations of the area involved. Land and building use should generally be based on (1) the type of occupancy, (2) the type of construction and design, (3) structural system and building height, and (4) the risk from ground deformation.

Urban areas near faults and in zones of potential seismic risk should be zoned for restricted building purposes. Construction in such areas needs to be regulated at the state or federal level. Controls should be designed to minimize potential casualties and property damage whenever economically feasible. There are several options at present for the use of such land: (1) wooden frame homes, (2) recreational, (3) greenbelts for farms or dairies, or (4) use as natural open spaces.

During the Alaskan Earthquake of 1964, frame buildings withstood a series of shocks that collapsed or damaged beyond repair many other buildings. Even under severe circumstances, when ground settlement left homes hanging on cliffs, the frame houses did not usually break up. Brick chimneys, however, generally broke at the roof line.

In the Reno-Sparks area, there is, as yet, no seismic zoning. Currently, the City Building Departments require that the builder prove that the building, if in a potentially dangerous area of strong ground motion, will continue to stand. Dr. Douglas, at the University of Nevada (in Reno) Engineering School, is presently working with the Building Codes Inspector, Mr. Harrington, on rewriting the building code. It is felt that vital and critical facilities in the Reno-Sparks area, built prior to 1976, may be unable to continue functioning after a major earthquake.

BUILDING CODES

Most loss of life, injuries, and property damage during earthquakes results from structural failures. Building codes represent the minimum design and construction standards needed to ensure public health and safety. Building codes are the primary tool governments possess to reduce seismic risk in structures. The basic philosophy behind the Uniform Building Code (UBC) is that buildings be so constructed as to resist without collapsing--but with some structural and non-structural damage--major earthquakes of the intensity or severity of the strongest earthquakes experienced in California. The intent was to minimize the hazard to life and restrict property damage and loss of life to reasonable limits.

Every major destructive earthquake in the U.S. has exposed deficiencies in the design criteria which has subsequently led to modifications of the UBC. The 1976 UBC code calls for a 50% increase in lateral seismic loads over that required in the 1970 UBC owing to lessons learned from the San Fernando Earthquake of 1971. Older structures (pre-1950's) were not built to withstand the lateral stress imposed by strong ground shaking during major earthquakes. These older structures need to be catalogued. Generally, the older the structure (except possibly single-story wooden frame buildings), the less likely it is to resist an earthquake. This applies especially to buildings having walls of non-reinforced brick held together by sand-lime mortar, but in general to all multi-storied buildings that do not have steel reinforcements (U.S. Department of Commerce, 1973). Steel reinforcements and shear walls are the most commonly used lateral force resistant systems to date in multi-storied buildings.

High-rise buildings (over 75 feet in height) are most vulnerable to violent seismic stresses. Design of these buildings is critical, because failure of these buildings could result in great loss of life (Ad Hoc Panel, 1978). In Washoe county, fire codes require buildings over 75 feet tall, or having five stories, to have a sprinkler system or an alarm system with heat and smoke detectors directly tied into the fire station. This code applies to all new and existing high-rise buildings.

In the Reno metropolitan area, there are many different types of buildings. Past designs fall into three general categories (1) those with no considerations for seismic loads, (2) those where some risk was recognized, and some increase in the lateral load design was made, and (3) those which were specifically designed for a site, taking into account the seismic loads as established by a geological investigation. At any intensity of shaking not all older buildings will respond in the same way; it is necessary to check each building's seismic resistance individually.

The Ad Hoc Panel suggested that the requirement of remodeling permits be used to implement the correction of deficiencies found in older structures. The Ad Hoc Panel further stated that to insure successful application of the latest seismic design criteria in the UBC, the use of registered architects and engineers be required. Nevada statutes require only public works facilities costing over $150,000 to be designed by registered professionals.

In Washoe County, soil investigations are required for large subdivisions and commercial buildings (Harrington, 1976). The lack of geological and soil investigations prior to building of vital and critical facilities is a major problem which must be remedied, if these facilities are to be relied upon during a major earthquake. It is imperative that the 1979 UBC be adopted without exceptions. The new code's seismic design provisions are considered to be the best available.

CHAPTER V

LIFELINE INVENTORY

There are a number of essential and emergency facilities in the Reno-Sparks community which serve the public. In the event of a natural disaster, such as a high-magnitude earthquake, it is imperative that these facilities continue to operate since they would be the lifelines of the stricken community. The term lifeline for the purposes of this paper is considered to include: fire stations, police departments, hospitals, ambulance services, communications, electrical power, gas, water, sewage treatment and transportation.

The Ad Hoc Panel of Nevada on seismic hazard mitigation divided the lifelines into four classes:

1. Vital: fire department, police department, hospitals and communications
2. Critical: electrical power lines and plants, natural gas pipelines and storage plants, water and sewage lines and treatment plants, transportation and dams
3. Crucial: schools and hi-rise buildings
4. Dangerous: older buildings, and buildings with parapets and facades

Little attention has been given to the design of lifelines until the recent disasters in Anchorage and San Fernando, where large earthquakes struck urban areas. The amount of useful data collected on life-line performance is small compared to the volumes of research done on earthquake engineering. The 1971 San Fernando Earthquake disaster has brought earthquake planning and mitigation to the public attention, and has led to many improvements in building codes and design.

This paper is meant to be an inventory of vital, critical and crucial facilities. Facilities will be evaluated in terms of general problems which occurred in past earthquakes, the number of facilities available, the capabilities of the facilities, the buildings housing them, and their location relative to known faults, and other features which could be potentially hazardous during seismic shaking. Emergency action plans and agencies will be discussed in a separate section.

VITAL FACILITIES

Vital facilities are those required to sustain life and property during and after a seismic condition.

Fire Stations and Services

When an earthquake occurs in a metropolitan area, subsequent fires can be a greater hazard than the strong ground motion felt during the earthquake. In both the San Francisco earthquake of 1906 and the Tokyo earthquake of 1923, fires caused significantly more damage than did the earthquake's shaking. In the 1906 event, the fire broke out immediately after the earthquake and raged for three days, burning 508 blocks of the city (Bolt, 1978). To date, this fire has been the only major fire disaster associated with an earthquake in the United States.

The rapid spread of fire after an earthquake is due to: (1) strong ground motion disrupting the water system, (2) lowered water pressure, and (3) the highly combustible nature of buildings lacking fire protection devices, such as ceiling water sprinklers.

Fire fighting capabilities and rescue can be hampered by debris blocking streets adjacent to the fire and by the rupturing of major access routes. The season and weather can also act to either intensify or help to mitigate a fire with high winds, rain and the availability of water. Today's high-rise structures pose specific problems in fire control, especially when elevators become inoperative, debris fills the stairways and fire ladders cannot reach the upper stories (EERI, 1977).

Fire hazard can be reduced by planning and fire drills. Extra equipment should be stored in a seismically safe building in an area having easy, quick access in the event of a disaster. It is also important for fire fighters to be able to get to their station, and imperative that the station remain functional after an earthquake.

Reno. Reno has nine fire stations within its city boundaries. In the event of a major disaster, they could be supplemented by the Stead Facility fire station (ten miles to the northwest), Truckee Meadows Fire District (Washoe County), and by outlying volunteer fire departments (Miller, 1978).

Station 1 was located in downtown Reno at 136 W. Commercial Row. Until 1976, it was the main station and housed the communications network for the city. The building, a two-story unreinforced brick structure, was approximately 75 years old. Portions of the building were designated unsafe by the city Building Inspector, since it was considered to be a prime candidate for collapse in the event of strong ground motion. Collapse of this structure could have led to the loss of trained personnel, the city's communication network and fire fighting equipment (two pump trucks and one aerial ladder truck). Therefore, a new main station was built in 1976.

The new station, at 200 Evans Street (part of the Reno Public Safety Center) is in a three-story reinforced concrete building poured-in-place, having shear walls and a basement. It is built with a 50% higher lateral force than required in the 1970 Uniform Building Code (Van Meter, 1976). A soils investigation carried out on the site found that the liquefaction potential for the area was nil (Van Meter, 1976). This facility is located on the north side of the Truckee River, giving it quick access to most of the downtown Reno business area. The building also houses the Communication office for the city.

Station 2, situated at 495 Morril Avenue, is a two-story reinforced concrete building approximately 28 years old. It is equipped with two pump trucks and one aerial ladder truck. This station is not close to any known faults, but is on potentially unstable outwash deposits (Bingler, 1974). There is some potential for damage, due to the age of the building (see Uniform Building Code section) and the soils.

Station 3, at 532 South Virginia Street, is approximately 63 years old. It is a one-story brick building resting on a mortared stone foundation. The station is located within 100 feet (30 meters) of a potentially active fault scarp (fault number 26) and sits on potentially unstable out-wash deposits. Due to the age of the station, it could collapse during strong ground motion or be severely damaged. This station houses one pumper truck, and would be the main station to respond to fires in the south central part of Reno, because the bridges crossing the Truckee River are expected to collapse during a major earthquake (Hay, 1978).

Station 4 at 1090 Ralston near the University of Nevada, is approximately 26 years old. It is a one-story reinforced brick structure which houses two pump trucks. Fault number 5 lies one mile to the northwest and the soils at the station are moderately stable (Bingler, 1974). This station is expected to survive a major earthquake relatively undamaged.

Station 5 at Mayberry Drive is a one-story reinforced cinder block building with an adjoining four-story tower. It is 18 years old and houses two pump trucks. This station is within one-half mile of two potentially active faults (fault number 13 and 14) and is on potentially unstable outwash deposits (Bingler, 1974). Some damage could occur, especially to the towers, during strong ground motion.

Station 6, located at 969 Gentry Way, is approximately 15 years old and houses two-pump trucks. The building is a one-story reinforced cinder block structure. In 1976, station 9 was built adjacent to Station 6. It is a two-story reinforced concrete and shear-wall structure. The exterior of the new building has a ceramic glaze which is brittle. While falling pieces could harm people outside the building during an earthquake, the glaze will not affect the structural strength of the building (Miller, 1978). The soils underlying this station are composed of potentially liquefiable fine sand silt (Bingler, 1974) which could undergo severe ground motion and surface dislocation during a major earthquake. This station could, in addition, be subjected to flooding by the Truckee River. (See section on transportation, regarding airport location.)

Station 7 is a reinforced one-story brick structure situated at 300 Skyline Boulevard. It is approximately 14 years old and is equipped with one pumper and one aerial ladder truck. The station is within 100 feet (30 meters) of a potentially active fault (fault number 19) on relatively stable soils (Trexler, 1976). Damage incurred here would probably be minor.

Station 8 was constructed in 1971, at 3600 Kings Row. The station has one pumper truck and is a single-story reinforced concrete building. The service area is composed of homes. The station sits on relatively stable bedrock near fault number 2 (Bingler, 1974).

Except for station 3, all the fire stations in both Reno and Sparks were constructed in conformance with the Uniform Building code requirements for lateral forces (relating to earthquakes) at the time of their construction (Van Meter, 1976).

In general, stations located in the northwest parts of Reno could become isolated if fracturing occurred along the older fault lines. Other stations could have the double problem of low water pressure in addition to access problems caused by street fracturing. The fire hydrants in the Reno-Sparks community are connected to Sierra Pacific Power Company's water tanks (Firth, 1978). In the event of a fire, these tanks could supply 75,000 gallons per minute of water if they remain functional. The fire department could reduce the flow of water around ruptured mains by closing and opening the proper valves (see waterpipe section under Sierra Pacific Power). There are contingency plans to pump directly from the river if no water is available in the pipelines.

Sparks. The city of Sparks has three fire stations. The department headquarters are located on "C" Street and 12th Avenue. This station is a two-story reinforced concrete building which underwent major remodeling in 1970 (Richards, 1976). The potentially active faults are within one-half mile (800 meters) of this station (fault numbers 45 and 44) and the soils in this area according to C. E. Bingler's map (1974) are potentially unstable. It is possible under wet conditions or with amplified ground motion that damage to this building could occur during a major seismic event.

Station 2, at the corner of Baring and N. Truckee Lane, built in 1975, is a single-story reinforced masonry building. This station is situated in an area of high ground water where liquefaction could be a problem.

Station 3, on South 21st Street, at present is unmanned and is used for storage of reserve fire trucks and equipment (Brown, 1978). This station was built in 1953, and is a one-story reniforced masonry building with an adjoining three-story tower. In the event that the I-80 bridge collapsed, this station, if manned, could be the only Sparks station serving the southern part of the town. The station is within 200 yards (200 meters) of a potentially active fault (number 45) and is on potentially unstable outwash deposits. It is likely that this station would sustain damage during strong ground motion.

The Sparks Fire Department has the following emergency equipment: one aerial ladder truck and five pump trucks. It employs approximately 39 full-time people with 15 active volunteers. In addition to the fire department equipment, local construction firms have been contracted to supply heavy equipment to enhance the rescue capabilities, and to aid in clearing major escape routes under the direction of the fire department. Any building built in Sparks which is higher than the aerial ladder truck's capabilities of 75 feet (12 meters) is required by law to have internal sprinkler systems. The older buildings in Sparks represent few problems because they are only one and two stories high (Richards, 1976).

The presence of a tank storage farm (oil and gas) in Sparks has prompted the fire department to implement special plans and methods to handle any fire or tank rupture within the tank farm. Fire drills are held three days each year in cooperation with the Southern Pacific Pipeline Company (Richards, 1976).

A written procedure exists specifically for an earthquake emergency including ways to obtain medical aid (for those rescued or burned), food, shelter and for additional aid from other agencies outside the City of Sparks (Truckee Meadows Fire Protection District and the City of Reno), (Brown, 1978).

Police Departments

In the event of a major earthquake, the main function of the police department will be (1) traffic control coordination with the hospitals, ambulance services and fire department, (2) prevention of looting, and (3) aid in helping to extricate the injured and dead from debris. The police department is considered to be vital and it must remain functional after a seismic disaster. It is therefore imperative that the buildings housing this facility be designed to withstand strong ground motion.

Reno. The Reno Police Department was built to the Uniform Building Code of 1950 at the northwest corner of High and Second Streets. It across the Truckee River from the new Public Safety Center. The building is constructed of reinforced concrete and shear walls. Adjoining the north side of the older building is a newer three-story reinforced concrete structure with shear walls, built in 1975. This addition was designed for a 50% increase in the lateral force load above the 1970 Uniform Building Code requirements (Roguemore, et al, 1976). Both buildings are located fairly close to the Truckee River and could be subject to flooding. The soils according to Bingler (1974) are potentially unstable outwash deposits. A potentially active fault (number 27) is within 1,000 feet (300 meters). It is possible that the older part of this building could sustain damage during strong ground motion.

A second police station is located next to Fire Station 7, on Skyline Boulevard, in the southwest end of Reno (Roguemore, et al 1976). Due to its location on stable soils near a fault, it may sustain only moderate damages.

Sparks. The Sparks police headquarters is located at the corner of 12th and "C" Street, alongside the fire department. This building, completed in 1970, is a two-story, reinforced masonry, and shear wall structure. It also contains the Sparks Communication Department (Walker, 1974). There are two potentially active faults within one-half mile of this structure, and the soils are potentially unstable. An on-site soils investigation should be made and the building should be inspected and brought up to 1976 seismic standards, at least. This would insure that it remain functional.

Hospitals

Damage to medical facilities was an outstanding feature of the 1971 San Fernando earthquake. Four major hospitals suffered severe damages--the Veterans Administration Hospital, Olive View Hospital, Pacoima Memorial Lutheran Hospital, and the Holy Cross Hospital. Damages to these hospitals incurred three main internal problems: (1) search and rescue of patients and staff, (2) transferral of patients to a safe location, and (3) caring for those who were injured at the site. In terms of community response, problems were encountered with: (1) inoperative emergency rooms, (2) failure of electrical power and the back-up emergency power, (3) blockage of stairways and elevators by debris, and (4) the loss of supplies, communications and utilities, compounded the problems. In addition, the lack of communications led to an abundance of patients being sent to overcrowded hospitals instead of being sent to hospitals further away who were not crowded; this was especially bad when it involved a hospital that was damaged (U.S. Dept. of Commerce, 1973).

Structural designs which were supposedly seismic-resistant sometimes were proved to be inadequate; such was the fate of the Olive View Hospital which suffered partial to complete collapse in various structural parts.

St. Mary's Hospital - Reno. St. Mary's Hospital is located at 235 West 6th street. It is a complex of three- and five-story sections, constructed with a steel frame having non-bearing reinforced concrete. Parts of the complex date back to 1944, the most recent being a five-story building finished in 1967 (Erskine, 1978). The hospital is located approximately one mile from any faults. Due to the age of this hospital, damage is to be expected, especially in portions older than 1950. This hospital's geographic location makes it very important, since it might be possible that it would the only hospital able to serve the entire north side of town, should the bridges over the Truckee River collapse (Hay, 1978). This hospital does have emergency generating capabilities.

Veterans Hospital - Reno. The Veterans Hospital administration building, at 1000 Locust, consists of two parts: (1) a three-story and (2) a five-story rectangular hospital, constructed of reinforced concrete shear walls. The main parts were built in 1947, and an adjacent one-story concrete block building houses the emergency generator (Teats, 1974). In 1974, an accelerograph was installed by the state on the first floor of the complex as part of the seismic monitoring network. There are three potentially active faults within one quarter of a mile (fault numbers 28, 29, and 30), which are Part of Zone I. Owing to the close proximity of these faults, the age of construction and local soils, this facility is likely to be severely damaged and possibly rendered useless.

Washoe Medical Center - Reno. The Center, at the junction of Mill and Kirman Avenues, consists of an older two- and three-story reinforced masonry building used for storage and a newer (1968) seven-story wing constructed of reinforced concrete shear walls. This newer section met the 1968 Uniform Building Codes for emergency facilities; however, at that time, a dynamic soils analysis was not required. The newer building also houses the city's emergency equipment (Gribbon, 1974).

This center is within one-half mile of a potentially active fault (number 28), is on potentially unstable outwash deposits and is close to the Truckee River, which could flood. Washoe County Civil Defense expects some damage to occur to this facility, but the hospital should remain functional. In 1978, work was being done on a new annex. This author noted that the new facility looked much like the Olive View Hospital of San Fernando. Further investigation led to the conclusion that the design and construction type was the same. The design flaw appears to be that the first floor acts as a rigid box and does not flex (personal communication, 1978--from an informant who requested to remain unnamed). If this information is correct, Washoe Medical Center could have serious problems in a major earthquake.

Nevada State Mental Institute - Sparks. There is only one hospital within the City of Sparks, the Nevada State Mental Hospital, located in the southwest corner of town. The institution consists of a cluster of 30 buildings whose dates of construction range from 1882 up to 1967. A seismic survey during the 1970's found three buildings to be unsound; six others are no longer in use and are scheduled to be removed (Walker, 1974). None of the buildings are over two stories high. Construction appears to be of brick, concrete block and cinder block.

The staff is aware of the seismic hazard; however, the existing evacuation plan is primarily for fire. The plan is to move the patients to another part of the building complex or bus them elsewhere (no specific destination). The patient complement ranges from 320 to 370. The staff number varies with the shift from 400 to 550 people.

This hospital's proximity to a known active fault zone, combined with the age and construction of its buildings and high number of people (some of whom are incapable of helping themselves) may add up to disaster in the event of a strong earthquake.

Local convalescent centers and medical offices can be used in both towns as emergency facilities for outpatient treatment if needed. It is apparent that all the hospital facilities in the Reno-Sparks area need retrofitting for seismic resistance.

Ambulance service. In 1976 there were two ambulance services in the Reno-Sparks area. The Alert Ambulance Company in Reno is at 395 S. Wells Avenue. A fault lineament appears to cut through the lot where the ambulances are parked. The lineament runs parallel to three faults one mile to the south (fault numbers 28, 29, 30) and fault number 27 is also within one-half of a mile. The local soils are potentially unstable outwash deposits. In Sparks, the service is located at 680 Greenbrae Drive. The two services together have five units available.

Other units from Carson City, Fernley, Tahoe and the Air National Guard could be made available in the event of a major disaster. Travel time from these areas is approximately one hour, given passable access routes.

Serving the community is also Medic Air Service at 647 N. Arlington Avenue. Between this service and local commercial companies, there are eight available helicopters. The Air National Guard and Stead Facility have seven helicopters which bring the total in the immediate area up to fifteen. If the highway system is severely damaged by collapsing bridges over the Truckee River, these helicopters could be vital to the area (Hay, 1976), since the major hospitals are all located south of the river.

Communications Systems

Failures of communication systems after earthquakes have in the past been due to: (1) damaged buildings, (2) broken lines, (3) equipment damage resulting from lack of bracing, (4) system failure due to overloading, and (5) lack of commercial electrical power and failure of emergency power sources owing to inadequate bracing of equipment (U.S. Department of Commerce, 1973).

Nevada Bell Telephone Company. Within Nevada, there are three routes over which calls can be directed: (1) microwave station, (2) underground cross-country cable, and (3) above-ground pole lines. In Reno, there is a microwave station situated on First Street in the downtown area. This facility has been designed to withstand extreme earthquake shaking and strong lateral winds (Upton, 1978). It has emergency power generation capabilities and battery supplies (Penner, 1976). Should this station become inoperative, the Reno-Sparks community could be without telephone communications.

Cross-country cables and above-ground lines are susceptible to ground movement and should not be relied upon. The Sparks switch station is located on Prater Way, west of Pyramid Way. It is a concrete block building with a flat roof. If this building were lost, the entire city of Sparks would lose its telephone service.

City of Reno Communications Department. The Communications Department is located in the Reno Public Safety Building on the northeast corner of Evans and Second Street. It was built in 1976, conforming to the Los Angeles Building Code, which calls for a 50% increase in lateral force over the 1970 UBC requirements for emergency facilities. It is a reinforced three-story concrete building having shear walls and a basement. A soil investigation was made at this site and little potential for liquefaction is present here. This stucture also houses the new main fire station, vehicle and communication repair facilities, a data bank containing maps of all the utility lines throughout Reno and floor plans of high rises. A computer is used to monitor local fire alarms and keep track of mobile units.

(Police communication facilities will be considered under Police Stations.)

Public Broadcast Facilities

The performance of television and radio after an earthquake depends on the damage suffered by the buildings housing the studios and transmitters. Many stations have mobile ground and air units; however, failure of emergency power supplies at the main station could curtail transmissions. Usually, several stations in the local area are part of the Emergency Broadcast System. These stations, according to federal requirements, are seismically designed and should be able to operate during and after a disaster (U.S. Department of commerce, 1973).

The average height of local radio and television broadcast towers is 200 feet and they are secured by guy wires. Only two towers within the study area posed any potential hazards. These were KOLO tower near Pyramid way, and KOH tower at the east end of Prater Way. Both areas are subject to seasonal flooding. This, coupled with strong ground motion, could perhaps loosen the guy wires, causing the towers to topple.

Hospital Emergency Communications. The hospital emergency assistance radio network (HEAR) played a key role in minimizing the immediate post-earthquake medical problems in the San Fernando earthquake (U.S. Department of Commerce, 1973). Although some equipment was destroyed in certain hospitals, such as the Olive View Hospital and Veterans Administration Hospital, this California system enabled medical teams, supplies and equipment to be ordered from other hospitals, and it permitted the coordination of patient transfers to alleviate patient overloading problems. The network often became the hospitals' only link to outside community agencies. Such a system needs to be set up for the Reno-Sparks area, tying the hospitals directly into each other, the ambulance services, the police, fire departments and Civil Defense disaster center.

Others. Ham operators, local CB, and two-way mobile radio systems of the local population could also be helpful in rescue and disaster response if coordinated with the local communications system.

CRITICAL FACILITIES

Critical facilities are defined by the Ad Hoc Panel as those required to continue life and protect property with the vital facilities intact. Critical facilities are considered to be: electrical power lines and generation plants, natural gas lines and storage facilities, water and sewage lines, and treatment plants, dams, reservoirs and the transportation system.

Electrical Lines and Power Plants

Damage to electrical power generating plants, as well as to transmission and distribution systems following destructive earthquakes in the United States, has let this industry to use earthquake design criteria, which have resulted in the relatively good performance of these facilities in large earthquakes (EERI, 1977). During the 1971 San Fernando shock, weakness in large pieces of electrical equipment became apparent. Changes in lateral force criteria for electrical equipment were made, and considerable research is currently underway. Existing equipment needed to be modified to conform to the new criteria. The ability of power plants to continue operation after a destructive earthquake is essential.

The Sylmar Converter in San Fernando sustained over $28 million in damages, not including the loss of revenue due to the inoperative condition of the station. A summary of conclusions for electrical power systems in the U.S. Department of Commerce publication of the 1971 San Fernando Earthquake states: "(1) Power system facilities, equipment and supports were designed for .20 g ground acceleration according to the current UBC in use. In view of the high ground acceleration within the area of intense ground shaking, the practice of designing electrical facilities for .20 g requires reappraisal. (2) Brittle porcelain components of electrical equipment are extremely vulnerable to earthquake shaking, damping should be considered and supports installed. (3) Inadequate anchorage resulted in overturned equipment, and (4) flexible leads are needed for equipment."

Transmission lines have been disrupted by landslides. Conductors have swung together, causing short-circuiting and power outages. Damages to the overhead electrical distribution system have been severe when older non-earthquake resistant buildings were in use, and fires have resulted.

Underground systems are affected by differential soil movement. Unbraced transformers on pole-supported platforms have proven to be especially vulnerable to strong ground motions during earthquakes.

Sierra Pacific Power Company. The Sierra Pacific Power Company is the sole supplier of electricity, natural gas and water for the Reno-Sparks community. The main power generating sources of the utility company lie outside of the study area: (1) Tracy steam plant 13 miles to the south in the Steamboat area, (2) the Churchill coal-fired plant in Yearington, 50 miles to the southeast, and (3) tie lines with Utah Power and Light, PGE and Idaho (under construction), (Fagg, 1978). All together, the total megawatt capacity will be approximately 1,030 megawatts. There are several diesel-fired units dispersed outside the study area which could be used in an emergency to produce an extra 50 megawatts. Several stations are capable of using gas or oil for power generation and have on hand fuel supplies for one month's use. In 1981, a 500 megawatt unit is scheduled to go in at Valley Central station and a second unit is to go in sometime in 1983. The power company feels that it would be able to lose one generating station and still be able to provide power for the Reno-Sparks area. However, there is no double contingency plan (Fagg, 1978).

Sierra Pacific's sytem operations center is located on East Mill Street. This building, built in 1976 to seismic design criteria, houses the central office for mobile unit dispatch, service and repairs. From this center, it is possible to cut off electrical power in various areas of the Reno-Sparks complex.

In Reno and Sparks, following the 1971 San Fernando event, earthquake resistant design transformer and condenser hold-downs were installed in all new substations and to new additions of existing substations, but no modifications were made on substations built prior to 1971. The use of flexible connections for lead-in busses also followed the 1971 event.

In 1972, Dennis Trexler wrote a paper on the utility company, outlining problems encountered during past seismic events, and went over the existing conditions in the Reno-Sparks area. He found:

1. The high-voltage transformers would sustain substantial damage during .4 g ground acceleration, approximately .375 to .5 g could overturn the transformer depending upon the height (6 to 8 feet, respectively)
2. Connections began to fail at about .4 g's.
3. The underground distribution system was not designed to be earthquake-resistant.

Trexler recommended (1) placing anchors capable of resisting .4 g's in all substations, (2) having insulator wire connections able to withstand 10 inches of displacement, (3) geological engineering investigations of underground transmission lines in areas of known faults, specifically citing the need for flexible joints at all fault crossings, and (4) updating of disaster preparation plans and placement of distribution plan maps in two separate locations that are earthquake and fire resistant (one person has one set of these maps at this time). Recommendations by Trexler that were economically feasible were eventually implemented by the utility company.

Electrical Inventory. In most areas, electrical lines from the substation are overhead; if enough displacement occurs along any one line, the tension could cause the lines to be pulled down. That could start fires and service could be lost. There is a chance that a line might function even if pulled down. Service lines to the east of Sparks, Raleigh Heights and northwest Reno originate at the Valley road substation (see Plate 3). Before this line enters the study area, the line crosses numerous faults. Service to the west of Highland Reservoir and the intersection of West Seventh Street and Bowman Drive would probably be in danger of being cut off by fault numbers 3, 4, and 5. This area is served by the Highland Substation, Northwest Substation, West Seventh Substation and partially by the Reno Substation, all of which cross at least one or more faults in the area described. Sierra, University, Pickard, Sparks Local, McCarran, Pyra, Airport, Spanish Springs, El Rancho, Mill, Sutro, Alameda and Hidden Valley Substations are all in relatively safe areas.

Service from Mt. Rose Substation: (1) crosses fault numbers 14, 15, 19 and fault set number 18 before reaching Hunter Lake Substation, (2) crosses fault set numbers 18, 19, and number 21 before it gets to Moana Substation, and in the vicinity of South Virginia it crosses fault numbers 32 and 33 then, (3) crosses fault set number 17 and several other faults before reaching Hash Lane where it is crossed by fault number 34. The Moana substation could become totally cut off due to the numerous faults in the service area.

Service from Holcomb Substation crosses fault numbers 24, 25, 26, and 27. This is likely to hamper service to the north of Vassar Street and west of south Virginia. Wheeler Substation lies within 50 feet of fault number 27, and might be disrupted. Electrical service to the north of Hymer Avenue from Sparks Independent Substation and to the south of Sparks Local are crossed by fault number 45.

Damage to any or all of the above substations and transmission lines, which have been noted as potential breakage sites, would be related to the amount and type of movement on each fault. The transmission lines will sustain some increase in tension, but the amount will vary with the size of the lines (Scelero, 1973). Transformers in most substations are placed on concrete piers, but some are mounted on power poles. The surrounding site is covered in 6 to 8 inches of crushed gravel which is designed to contain oil leakage from the transformers, should they topple. Transformers have a high center of gravity and do not tolerate gound motion well (Trexler, 1972). Potential interruption of electrical services would probably be due in large part to disturbance of these transformers at the ten locations cited. The potential for an electrically ignited oil fire at some of these sites is high, especially during the fall, when wind-blown debris gathers on the site.

The majority of underground high voltage lines within the Reno-Sparks area are in relatively stable ground.

Natural Gas

In the San Fernando Earthquake of 1971, the natural gas lines generally sustained little damage except in areas having violent ground displacement. Welded steel mainlines of 3/4, 2, 3, and 4-inch diameters were most affected. Earth movement pulled, compressed, and twisted systems which resulted in broken mains, valves and total loss of service (EERI, 1977).

Gas Lines. Sierra Pacific Power Company buys its gas from the Southwest Gas Company of Idaho. The main gas line enters the Reno-Sparks area through a 12 inch pipe, pressurized to 500 psi (see Plate 4). This line crosses numerous faults before entering the Reno-Sparks area. A second major line from Indian Springs to Verdi under 80 psi crosses many older faults along its course. There are plans to construct a plant to liquify the gas for storage.

The southwest line shares a common carrier for 55 miles from Lovelock to Reno with the power line that supplies electricity to the Reno-Sparks community. The use of a common corridor could lead to a dual disaster. Large surface displacement along the faults which cross the corridor could cause simultaneous loss of gas and electricity, in addition to the danger of an open gas main of relatively explosive high pressure gas. The utility company is aware of this, but is constrained to this corridor by BLM regulations (Fagg, 1978).

Within the Reno-Sparks community, natural gas mains (4-1/2 inches to 16 inches in diameter) rest a minimum of 30 inches below ground in trenches backfilled with sand, compacted to the density of the surrounding soils. The mains are generally made of steel pipe which should sustain little damage unless large ground displacement occurs (Firth, 1978). The gas mains are generally laid out in the same pattern as the water mains (see Plate 5). Regulator stations occur on every line to monitor the gas pressure. These stations are tied into the gas alarm system at the Mill Street operations center. Each mobile unit servicing the system is equipped with detailed maps. Whenever gas lines interconnect, the dresser couplings used are flexible (Firth, 1978).

Shut-off valvues occur in the mains about every block. According to the power company, in the event of a breakage, areas five city blocks square could be isolated. This would leave a 12-hour gas supply residue which would remain in the lines and could burn if ignited (Dobbyns, 1973).

Gas Line Inventory. The main feeder is crossed by fault numbers 43, 46, 47 and 98, before it reaches city gate station number 1. To the north, the 8-5/8 inches O.D. main serving Raleigh Heights and Stead is crossed many times, by fault sets 1 and 50. The northwest 12 inches O.D. line from city gate number 1 to station number 2 crosses six faults; it is likely that Verdi could lose this service. The three 8-5/8 inches O.D. mains in the northwest of Reno are likely to be disrupted by faults numbers 2, 3, 4, 5, and 6. Loss of service to the west of the Highland Reservor and to the southwest is probable, owing to potential rupture of many small 4-1/2 inches O.D. mains throughout the area. Rupturing of the 8-5/8 inches O.D. main at Monana and Lakeside could cut off most gas to the southwest of Reno, along with the 8-5/8 inches O.D. main southeast of Mayberry and California.

Storage Tanks of the Sparks Facility. Damage to surface mounted and elevated tanks has occured in many earthquakes. Tanks resting on the ground have suffered buckled and ruptured walls as well as damaged and collapsed roofs. Tank movement during strong ground motion has resulted in the rupturing of connecting pipes and subsequent leakage of contents (EERI, 1977).

Oil and gas storage facilities during the 1971 San Fernando shock received minor damage as the result of lessons learned in the 1933 Long

Beach earthquake, after which design criteria were raised (U.S. Department of Commerce, 1973).

The Southern Pacific Pipeline Company operates a storage tank farm at the east end of Sparks between Interstate 80 and the Southern Pacific Railroad. Neither information about the total capacity of the facility nor the number, age, or type of tanks, was available to the public. At the time of this study (1973 to 1974 data collected from air photos and binocular views) it was believed that there were 39 tanks with varying capacities. Approximately 12 had floating roofs, indicative of high vapor liquid storage (gas). The rest had conical roofs, usually used for storage of low-vapor liquids such as oil.

The storage tanks were designed according to A.P.I. specifications at the time of their construction, to withstand earthquakes. Some pipe-to-tank connections appeared to be flexible, while others were typical rigid boiler plate and rivet connections. All pipes noted at the site were heavy-duty, with massive collar joints.

In the event of a major earthquake, the tank storage farm could become a disaster area, due to liquefaction and densification of the soils. The tanks could sink into the ground or float up, causing potential rupturing of the tanks and failure of their connections. This might lead to a large oil spill, greater than could be contained by the dike. A spill would possibly back up from the point where I-80 and Southern Pacific Railroad converge. At this neck are two embarkments; should they be breached due to strong ground motion or liquefication, it would then permit a potential spill to wash over the road surface and railroad. Either possibility could close the two major transport routes to the east.

Water Line and Treatment Facilities

In the San Fernando earthquake the water system was extensively damaged. Most underground damage was associated with ground displacement, although damage to older lines occurred owing to pressure variations as well. Pipelines and conduits subjected to ground settlement, ground shaking, liquefication or landslides and crossed fault displacements, experienced breakage of joints, valves, fittings, check valves, meters, and isolator valves (Bolt, 1978).

Steel storage tanks that were surface-mounted or elevated, suffered buckled and ruptured walls as well as damaged and collapsed roofs. Tank movements have resulted in ruptured connection piping, and subsequent loss of contents. Only tanks were specified lateral force-resistive features and have performed well (EERI, 1977).

Pressure boosting and pressure reducing stations, pressure pumps and wells have had anchorage and bracing problems. They have been unable to function due to lack of power, and contamination.

Sierra Pacific Power Company. In the Reno-Sparks area, the water mains in 1973 were 57% to 95% asbestos cement and the remainder were cast iron (Dobbyns, 1973). By 1978 rubber gaskets, steel pipe, and plastic services were being used (Firth, 1978). The water mains will probably break at every fault fracture, since they are mostly rigid and brittle. Wherever the movement is sufficient to break a gas main, the water main will also break (see plate 5). Water mains occur each block, so that a spill area could be isolated if necessary. The fire departments carry redwood plugs, just for this contingency (Miller, 1978).

Water mains from 4 inches to 24 inches O.D. carry water from the older three treatment plants and 10 water tanks on the periphery of the community. The three older plants are (1) Highland, (2) Idelwild and (3) Hunter, all built in the early 1900's. All three of these plants use chemical filters and have large storage facilities (covered under reservoirs). These plants have been renovated (Firth, 1978).

Water storage tanks range from 3/4 to 3 million gallons holding capacity, with a total capacity of 18.7 million gallons (Dobbyns, 1973). Each tank is kept at least two-thirds full in case of emergency. Most lines to the tanks have booster pumps at the top (Firth, 1978). There are currently two types of tanks in use: (1) above ground steel-welded and (2) underground reinforced concrete tanks. The underground tanks appear to be more seismic-resistant, so the utility is in the process of changing over to this newer design (Firth, 1978).

The three water treatment facilities in the area are fed by the Truckee River and 16 community wells. The wells produce 38 million gallons per day. The three plants produce 65 million gallons per day.

These plants were fast approaching their capacity; a new plant, using a mixed media filter, went on-line in 1978, on Glendale Road. It has a capacity of 25 million gallons per day, but has no storage reservoirs. This new plant is built to seismic design criteria of the 1976 UBC. The plant is remotely controlled from the Mill Street operations center, and is believed to be above the potential flood plain.

In the event of an emergency, areas in the community could be temporarily out of portable water, due to possible contamination from ruptured sewage lines and flooding.

Inventory of Water Lines. The two 18 inches O.D. steel water mains running north to Raleigh Heights intersect faults set numbers 1 and 50. This line flows to four booster pumps and three storage tanks which supply both Raleigh Heights and Stead. If this line would rupture, the storage in these tanks might be able to supply the area for a few days, if the tanks were to remain standing and functional.

The main lines serving the northwest Reno area would be ruptured numerous times. The Highlands Tank number 2 is located by fault set number 1 and would be damaged. Rupturing of 12 inches and 18 inches lines in the southwest areas of Reno would cut off service to the west of California and Mayberry Streets, south to West Plum Lane and west of South Virginia.

In downtown Reno, several major lines ranging from 10 inches to 24 inches O.D. could be cut several times by faults numbers 26, 27 and 25. This would cut off the service from pumps to the south and to the downtown area which would be dependent on service from the pumping stations north of the Truckee River.

In Sparks, fault number 45 intersects three mains in the vicinity of the Nevada State Hospital and the area east to Fifteenth Street. A large water storage tank and pump station are located northwest of Pyramid Way. This provides pressure for the Sparks water system.

Sewage Treatment Plants

Ground shaking, differential earth movements, landslides and loss of power, have caused most damage to sewer treatment plants, and have rendered facilities inoperable (EERI, 1977). Sewer lines of vitrified clay tile shatter in fault zones (Trexler, 1972).

Reno/Sparks Facility.

This joint treatment plant is located on the east side of the Truckee Meadows where the Truckee River enters the

Canyon. This plant in 1967 replaced the older Sparks treatment plant, which had sustained pipe damage in the 1966 Truckee, California earthquake (5.4 Richter).

Sewage is carried to the plant by a 30 inch gravity plume from both cities. Reno has several lift stations along the route. A large part of the plant consists of underground concrete tunnels. The plant is built of structural concrete with steel reinforcements which met the 1967 Federal engineering specifications for ground shaking.

The plant has its own water system, while heating and boiler firing use gas (Hancock, 1976). This facility is almost a self-contained unit, purchasing only its electricity from Sierra Pacific Power. The joint plant is part of the utility service which could be severely damaged by a major earthquake due to: (1) the age of the facility and UBC criteria, now outdated, (2) its location on potentially liquefiable fine sand and silteds in an area with a high water table, (3) its geographic location next to the Truckee River and the confluence of Steamboat Creek--both susceptible to local flooding (see section on Truckee River) and (4) the existence of a large, potentially active fault scarp (fault number 39) within one-quarter mile to the south which runs along the base of the Virginia Range by Steamboat Creek.

Sparks Sewer System. The sewer system in Sparks is managed by the Public Works Department of Sparks. All the utility lines, including the sewer lines, are buried. In Sparks, the water table is close to the surface, which decreases the soil strength, especially in areas of compacted fill. This makes the utility lines vulnerable to disruption by possible liquefaction during a major earthquake.

Most lateral lines from 4 inches on up are made of cast iron or fiber pipe. The truck lines are generally made of concrete (see plate number 6). The interceptor sewer line for Sparks crosses potentially active fault number 45; damage, disruption, or severage is possible. The sewer trunk on Pyramid Way, north of the Oddie Boulevard intersection, crosses a recent Holocene fault number 44; damage of the line is likely. Seepage of sewer effluent from broken lines could cause local contamination problems.

Reno Sewer System. In Reno, the sewer system is managed by the Department of Public Works. The utility lines, including the sewers, are buried, and there is potential for liquefication. The airport area and adjacent southeast parts of Reno in the Truckee Meadows are in greatest danger due to their soil type (Bingler, 1974). Sewer lines crossing any potentially active fault are likely to be disrupted, if displacement occurs.

Contamination from broken lines in the faulted area in southwest Reno (fault numbers 13, 14 and 15) could potentially flow into the Virginia Lake and the Last-Chance ditches. In southern Reno, the trunk sewer line that follows Lakside Drive also follows fault number 24. Contamination of Virginia Lake is probable. Local service in the area bound on the south by Pueblo Street and on the west by Holcomb, could be cut off as a result of active fault numbers 25, 26 and 27. Contamination of the Truckee River is possible, especially if consequent flooding occurs, though to what degree, is uncertain.

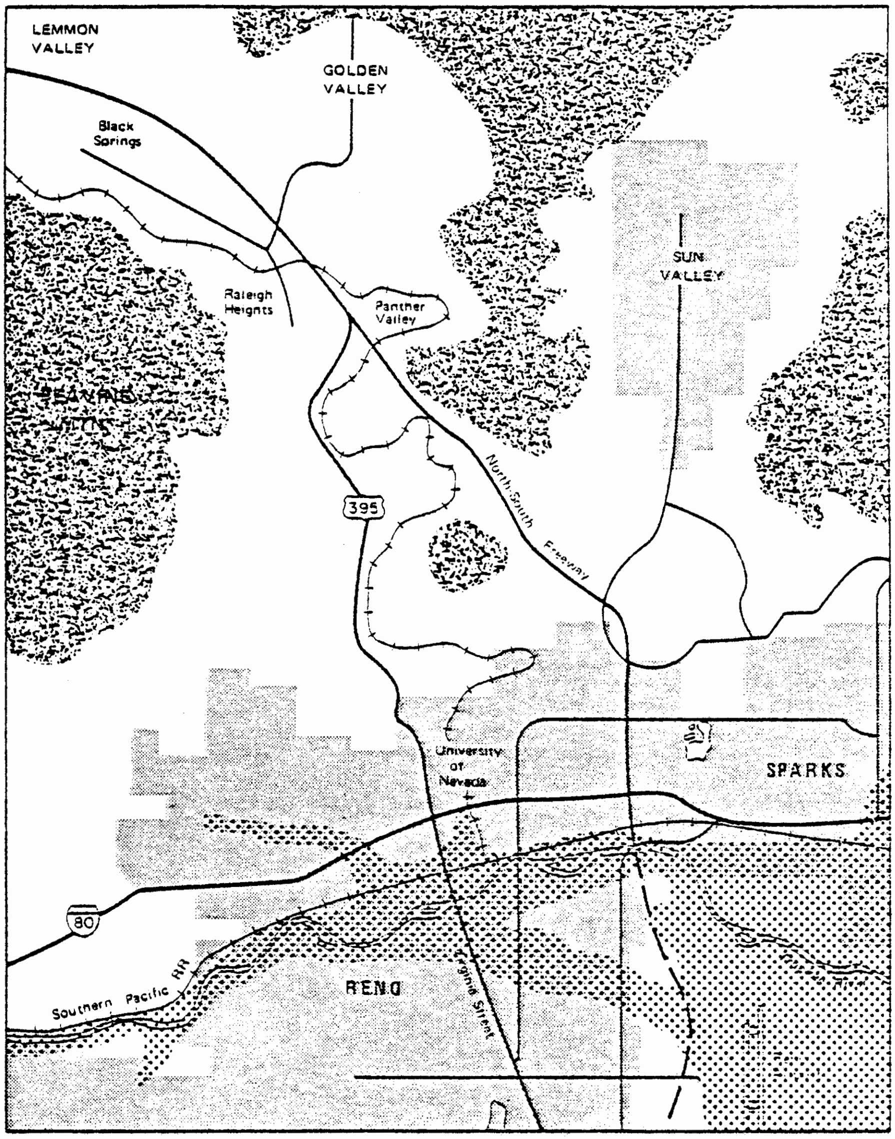
Chlorine treatment stations could be temporarily shut down, owing to electrical power loss in areas of potentially active faults. This would enhance the problems of contamination by sewage.

Surface Water Ways

Earthen and rock-filled dams, using the hydraulic fill method of construction, have sustained serious damages from earthquakes, and some dams have failed. Rolled earthen dams, on the other hand, have withstood high ground acceleration quite well, sustaining only minor damages (EERI 1977). Downstream populations and critical facilities must be considered in evaluating the safety of dams.

Dams. Regional flooding has occurred prior to the 1960's in the Truckee River Drainage. The floods were seasonal, taking place in late fall and winter months when rainstorms accompanied by high temperature caused rapid melting of the snowpack. The flash floods would inundate a 3 to 4-block-wide strip though the downtown Reno area and affect 6,000 to 7,000 acres in the Truckee Meadows (Bingler, 1976), (see Figure 10).

To remedy this problem, four rolled earthen dams were completed between 1960 and 1963 which reduced this type of flood hazard from the Truckee River and its tributary drainages of Prosser and Martis Creeks (Nishikawa, 1980). In the Reno-Sparks area, there are four dams which make up the Peavine Water Shed Project. These four dams are situated in the hilly northwest part of Reno. All four--the Upper Peavine, Lower Peavine, East Wash and West Wash dams--are operated and maintained by the City of Reno for flood control (See Plate 7). Most of the year, the dams are dry (Jones, 1978). The U.S. Army Corps of Engineers surveyed these dams in 1979 and concluded that they represented a minor hazard in the event of a major earthquake.



Heavy dot pattern in southern part of map covers areas subject to inundation by a Standard Project Flood as defined by the U. S. Army Corps of Engineers.

Figure 8. Regional flooding

(From Reno Folio, 1976)

East Wash Dam is crossed by fault number 2 near its crest, and above it is a sequence of post-Tertiary faults. West Wash Dam does not have any faults directly under it. However, faults numbers 2, 3 and 4 lie close to it. The Upper Peavine Dam is cut by two faults of set number 1 and note that one is near the crest. Lower Peavine Dam is underlain by fault number 4. These dams, in general, will contain water during the winter flood season and after thermal summer storms; if a major earthquake occurred while the water level was high in either Upper Peavine or East Wash, failure could occur.

Failure of the East Wash Dam is unlikely; however, if it did contain a large volume of water and there was movement on the fault at its crest, a flood could wash over (1) Van Ness Avenue to Peavine Road where it joins Keystone Avenue, (2) Whitaker Park, (3) I-80, (4) Doten School area until it joined the Truckee River drainage (see Figure 10 showing older flood pattern).

Failure of the Upper Peavine Dam is also unlikely, but if the circumstances were right, the water released would flow into the Lower Peavine Dam, causing it, in turn, to overtop. Water would probably flow down Elmcrest Avenue to Keystone. There, it would wash southeast under I-80 and continue on southeast until joining the Truckee River.

Either event could cause flooding similar to that incurred before the flood control project was established.

Reservoirs. Highland Reservoir, Hunter Lake, and Wheeler Lake are owned by the Sierra Pacific Power Company. Highland Reservoir pools were constructed from 1880 to 1905. The pools contain 10 surface acres with a volume of 54 million gallons. The dam is believed to be earthern fill. Up-slope approximately 600 feet (185 meters) is a fault which cuts middle Quaternary deposits. This same fault runs directly under Lake Park. Both the Reservoir and Lake are in dense residential areas. Liquefaction or rupturing of these structures could cause flooding to the immediate south. Highland Reservoir is considered to be the most hazardous reservoir by the Army Corps of Engineers (Firth, 1978), due to uncertainty regarding the materials and methods used to construct it, its age, large volume and location. Hunter Lake is at the west end of Reno, and contains five surface acres of water and has an 18-million gallon capacity. The dam is an earthen structure with parts dating back to 1863 to 1904. Unfortunately, it is outside the limits of my geological data base.

Wheeler Lake has 46 surface acres, with a capacity of 190 acres/foot. The dam is earth-filled and dates back to 1889. The Wheeler Lake dam is crossed by fault number 23 on its eastern side. Release of water from this point would present a problem mainly to the local golf enthusiasts, as the Lake is in the middle of a golf course.

Virginia Lake is owned by the City of Reno. The Lake holds 140 acre feet and is impounded by earthern fill dam of unknown age. Virginia Lake is bordered on the east and west by active fault numbers 24 and 31. The combined movement of the two faults could produce varied results. The most serious possibility would probably be flooding of the Orchard Trailer Park and Park Lane shopping center.

Paradise Park Lake in Sparks is a very recent earthen structure dating to the mid-1970's. It is not near any faults. The only possible problem could be from earthquake-generated waves (Seichs).

The Truckee River

The Truckee River bisects downtown Reno. West of Reno, two to three miles on the Truckee River, is an older complex of landslides in the Mogul area. If this slide complex were activated during the rainy season by an earthquake, the river could become dammed by the slide (Trexler, 1973). Water would build up until the slide was topped, the overflowing water would quickly erode the loose unconsolidated alluvial materials, releasing a torrent of water and debris. The destructive force of the torrent would depend upon the magnitude of the landslide and the size of the body of water trapped before overtopping. It is possible that the area from Liberty Street to the airport could be covered by flood waters-compounding the problems of rescue, water contamination from broken sewage pipes and emergency coordination.

The Mogul slide area has been historically active: in 1940, when a landslide covered the Steamboat Ditch and in 1964, during the Boca Earthquake (6.4 on the Richter Scale), (Trexler, 1978). This area was recently monitored by Pease and Trexler for yearly movement, while funding was available. Truckee River is currently undercutting the toe of the landslide (Bureau of Mines Open File Report, 1976).

After passing through Reno, the Truckee River is intersected by fault number 45 near Glendale Road, within Sparks. Movement on this fault could cause some localized flooding to the west, if the movement on the fault raised the land to the east of the intersection. Below this point, there are two diversion dams which protect the airport from flooding.

To the east, the Truckee River flows into a canyon area (past the Vista Freeway exit) where, during the rainy season steep slopes, combined with rapid ground acceleration, could cause landslides. This would back up water into the Vista and Glendale Road areas, flooding I-80 and the railroad. Flood water from the west could be blocked thus worsening the flooding situation. The time of year in which an earthquake occurred would make a difference in the amount of flooding of both the reservoirs and Truckee River.

No information about the effect of seismic activity on slumps to the west in the Mustang area is available as yet (Bell, 1978; Trexler, 1980). Areas of poorly consolidated material on steep slopes could, however, pose a hazard.

The Reno area experiences its heaviest rainfall from December through March with runoff from melting snowpack peaking in May. The Truckee's flow is highest in April. The amount of water available during the year would also affect the fire stations because if water mains were broken or if no pressure existed, the Truckee could be the only source of water (see Plate 7).

Creeks. To the southeast of Sparks, near the Virginia Range Front Fault, Steamboat Creek flows into the Truckee River. This is a low-lying area that has a high liquefaction and flooding potential.

Other local drainages known to be subject to local flooding are: (1) Hunter Creek, (2) Evans Creek, (3) Alum Creek and (4) the Sun Valley drainage along Orr ditch in northern Sparks.

Ditch System. There are seven ditches in the Reno-Sparks area, all eventually connect to the Truckee River, and to each other via an aqueduct system. The ditches are: (1) Orr Ditch, (2) Steamboat Ditch, (3) Last Chance Ditch, (4) Lake Ditch, (5) Pioneer Ditch (6) Cochran and (7) Highland Ditch (owned by Sierra Pacific Power Company). The Orr Ditch is undercut by fault number 43 in western Reno by a steep road embankment which could collapse during an earthquake, letting water flow into the Truckee River. Lake Ditch is crossed by faults numbers 13 and 14; spillage here would cause minor damage. Lake Ditch is also underlain by fault number 25 near the County Golf Course; flooding there would cause little damage. Last Chance Ditch is cut several times by fault number 13, 14, 15 and 25. Some damage by flooding is likely to occur there. Pioneer Ditch in Sparks has a low flood potential.

The aqueduct in downtown Reno is repeatedly crossed by faults numbers 24, 25, 26 and 27 before it enters Virginia lake. This is the only aqueduct in serious danger from an earthquake.

All the ditches have spill facilities for handling overflows and the amount of water in the ditches is regulated (Dukes, 1978). The significant problem with the ditch system is that of possible sewage contamination, which could rapidly lead to a serious health hazard.

Transportation

The first real test of freeway structures occurred in the 1971 San Fernando earthquake. The main deficiency was the inadequate tying together of spans and structural elements of bridges and overpasses. Since then, the design criteria have been modified and other structures in California have been retrofitted to increase their lateral-load carrying abilities. The 1976 Guatemala earthquake provided evidence that structures with this new design could survive a major earthquake (EERI, 1977). Damage to road beds has been associated mainly with permanent ground displacement. To date, highway tunnels in the United States have not been tested under severe ground motion.

Highways. In the Reno-Sparks community, there are three major highway systems; (1) U.S. 395, (2) Interstate 80 and (3) U.S. 40.

U.S. 395, before entering Reno from the south crosses seven post-tertiary faults, (Fault sets 1 and 50) some are associated with steep road embankments which could be subject to minor slumping and rockfalls. Within Reno, Highway Alt 395 (BUSN) crosses potentially active faults numbers 25, 26 and 24 north of Virginia Lake. Alt 395 then crosses faults numbers 35, 36 and near 31 and 29 from Mays Lane southward. Most of the Reno area is underlain by unconsolidated outwash deposits with potential for liquefaction. Locally, these soils could amplify strong ground motion during a major seismic event.

Highway 40 comes into Reno along the Truckee River from the west and, at the eastern end of Sparks, rejoins Interstate 80. Upon entering west Reno, it crosses fault number 12 by a road cut. Minor slumping could occur here in a major earthquake.

Interstate 80 crosses a complex of faults at its entrance to Reno from the west, and the soils there are prone to slumping along road cuts. In Sparks, I-80 encounters potentially active fault number 45.

There are two other minor highways, State Highway 33 to Pyramid Lake, and State Highway 34, which converges with State Highway 33, and crosses fault number 44 in a potentially hazardous area (see water tanks section).

There are numerous overpasses and underpasses on the I-80 and U.S. 395 system. In 1976 an investigation of Ramp number 13 in Reno for seismic response was sponsored by the U.S. Department of Transportation under the supervision of Dr. Bruce Douglas of the Civil Engineering Department, University of Nevada at Reno. Ramp number 13 is a six-span composite girder bridge built in 1961, located at the interchange complex of U.S. 395 and I-80. This ramp provides access to U.S. 395 south for east-bound traffic on I-80. The interchange complex also crosses over the southern Pacific Railroad line. The investigation revealed that during a minor earthquake of 5.5 some structural damage would occur, and that during a maximum probable earthquake of 7.2 the bridge would probably collapse. Another study is currently underway at the University of Nevada to determine the earthquake response of other briges and overpasses. Data from that study by Dr. Douglas should be published later in 1981.

Bridges. Mr. Hay of the Washoe Civil Defense in an interview in 1978 was of the opinion that it is possible that all the bridges over the Truckee River could be damaged and lost during a major earthquake. Bridges which could possibly sustain damage and still be usable are (1) Arlington, (2) Southern Rock Boulevard, (3) North McCarron and (4) Kietzke. The Keystone Bridge collapsed in 1977 after the passage of a truck with a load of strawberries and has not yet been rebuilt.

Railroads. Damage to railways has occurred in numerous earthquakes, generally as a consequence of permanent ground subsidence, displacement, or landslides. In general, railroad bridges have performed better in earthquakes than have highway bridges, because the structures are tied together by rails (EERI, 1977). There have been no recent design changes as a result of earthquakes for railroads and railway bridges.

The Southern Pacific Railroad bisects Reno's downtown area; this causes massive traffic problems at grade crossings whenever a train goes by or stops at the Amtrak station. The railroad line is crossed several times by bridges and overpasses associated with the U.S. 395 and I-80 system, failure of any of these spans could block the rail system. The entrance to the Sparks switch yard is crossed by potentially active fault number 45. This is the only fault scarp crossed by the railroad in the Reno-Sparks area, but it could cause enough displacement to render the east-west rail system temporarily useless.

To the north of the Reno Amtrak depot is a spur line of the Western Pacific Railroad which meanders to the north towards Stead where it crosses several faults. It is doubtful that this line would be usable in the event of a major earthquake.

Airport. Aside from damage to buildings and collapse of control towers, most damage to airports has been to runways and utility connections. The loss of electrical power for communications and other services has crippled operations.

The Cannon International Airport is in no apparent danger from known fracturing. The entire area is, however, underlain by alluvial material that could mask fault traces. There are two major potential hazards associated with earthquakes which could severely affect the airport: (1) the soil is extremely susceptible to liquefaction and (2) flooding danger due to the low elevation and to reactivation of the Mogul slump block upstream near Verdi. If this slide were triggered by a major earthquake, disastrous flooding could occur (see Reservoirs and Rivers section) which would cover the entire airport area.

CHAPTER VI

CRUCIAL AND DANGEROUS FACILITIES

Crucial facilities are those, both public and private, which have high occupancy rates. Non-structural damage is expected to occur; however, failure of the buildings would incur large loss of life, which is not an acceptable situation. The public schools, and high-rise buildings fall into this category.

WASHOE COUNTY SCHOOL DISTRICT

At the time of my preliminary survey in 1973, there were five schools known to be structurally inadequate. All were built before 1930, and were expected to collapse or fail to some degree during an earthquake. The school district had tentative plans to close the unsafe schools whenever it became economically feasible. The five schools were: (1) Mary S. Doten, (2) Orvis Ring Grammar School, (3) McKinley Park, (4) Mt. Rose Grammar School and (5) D.B. Billinghurst Jr. High. Orvis Ring was the last to be condemned in June of 1978. The School District is considering renovating Mt. Rose Grammar School to current standards, if funding can be found (Robb, 1978).

The Washoe County School District has been aware of the local earthquake potential since the early 1950's. Facilities built since then have been designed with safety factors above those required in the Uniform Building Code current at the time of their construction (Dr. Piccolo, 1976).

In 1956, the responsibility for design approval was delegated to the State Planning Board. Once the designs are approved, it is left up to each county school district to carry out construction inspections.

The State Planning Board does require a foundation study to assure adequate bearing capacity for soils at the site, but no fault study is required. There are no codes specifying resistance to lateral forces, as generated by earthquakes, for a private or public structure in the state of Nevada; only federal laws are enforced. There are no state code requirements regarding site inspection near an active fault scarp and no state agency is apparently responsible for checking the existing structure for earthquake safety. Safety inspections are performed only when the facility undergoes a change in use or when a complaint is filed concerning the building safety with the Nevada Industrial Commission.

Currently, there are 22 elementary schools, six middle schools and three secondary schools in Reno. The seismic resistance of each building needs to be determined individually by a specialist. The last known report on the structure and safety of schools was compiled by John, Webster and Brown, civil and structural engineers, in October of 1971. In light of new research and building techniques which resulted from the San Fernando Earthquake of 1972, a new study is needed to re-evaluate school facilities.

In Reno, there are several schools in potentially dangerous sites, should an earthquake occur: (1) Anderson, (2) Peavine, (3) Towler, (4) St. Alberts, (5) Clayton Jr. High, (6) Warner, (7) Swobe Jr. High, (8) Vaughn, (9) Reno Jr. Academy and (10) Elmcrest. Both Elmcrest and Peavine are either on or within one block of number 5 while the others are located within two blocks of known faults or in the Zones previously noted on page 29-30 (see Plate 2).

In Sparks there are nine elementary schools, two middle schools, and two high schools. Three schools are in hazardous sites on a fault trace located diagonally between Greenbrae Elementary, Sparks High and Mitchel Elementary School (see Plate 2).

HIGH-RISE BUILDINGS

In the past, buildings of over five stories have been more susceptible to seismic damage than one and two story buildings. Damage has been concentrated on the exits, entrances, stairways, elevators and interior wall partitions. High-rise buildings have posed special problems in fire control, because ladders can only be extended to 75 feet. As previously mentioned, Washoe County does require specific fire control systems for these buildings. High-rise buildings which pre-date the 1976 UBC need to be reevaluated in terms of seismic response, owing to changes made in lateral loading requirements.

DANGEROUS OLDER BUILDINGS

Reno has undergone extensive development in the last decade; over 50% of the downtown area has been rebuilt (Bonham, 1978). This has helped to mitigate the hazards of older buildings but has increased the problems encountered with high-rise buildings.

Students from the University of Nevada at Reno have catalogued in term papers dangerous older structures having parapets and facades from 1974 to 1978. Parapets are structures that extend above the roofline of a building which aid in fire control and prevent water from falling onto the street below. Historically, parapets and facades have fallen during seismic events, killing pedestrians in the streets below. The bulk of older parapets occur in downtown Reno. Most of these parapets are over 20 years old, made of brick and may not be adequately tied to the buildings. A second dangerous area has been identified along South Virginia, East Second, East Fourth and East Sixth streets in Reno. Some older parapets also occur along "B" street in Sparks. All of the above mentioned streets are the most heavily traveled in the Reno-Sparks complex. Tourism (casino's) is concentrated almost soley in the areas of maximum parapet hazard.

In Reno and Sparks, building inspections are made only when there is a change in occupancy or business within a structure. Once inspection has been made, the cities lack the means to have a building brought up to code, except by beginning the lengthy and complicated process of condemnation. The Ad Hoc Panel in 1979 suggested the use of a remodeling permit to correct deficiencies. Charging an extra fee added to the property tax was further suggested for structures having dangerous parapets and facades.

Sparks is a younger city which, until recently, functioned basically as a bedroom community for Reno. Sparks has experienced rapid urban growth and subsequent appearance of numberous shopping centers. Large wholesaling, warehousing and storage establishments have sprung up in the Truckee Meadows area, giving Sparks an economic base for continued growth. Structures in Sparks tend to have only one and two stories. While taller buildings do occur, they are rare in comparison to Reno, and the taller structures in Sparks are new. Sparks has few dangerous older buildings to contend with.

CHAPTER VII

CIVIL DEFENSE

The Washoe County Civil Defense agency had its Emergency Operations Center (E.O.C.) in the basement of the Washoe County courthouse, located at the junction of Court and Sierra Streets. In 1976, the Washoe County Civil defense center was moved to 3031 Boington Lane, southeast of the airport. This newer facility is a prefabricated metal building with a concrete pad. It is located in an area of high ground water subject to liquefaction and recurrent flooding. The Washoe County Civil Defense facility has emergency power generating capabilities and a mobile unit which could serve as communications center, if the building were damaged. The E.O.C. has communication ties not only with the fire and police departments but with most government agencies in the area. In the event of an emergency or a natural disaster, preselected individuals in the community would meet under the director of the Civil Defense Agency at the E.O.C. From the E.O.C. disaster analysis teams would travel to stricken areas, analyze the damage and report back to the E.O.C., where decisions would be made regarding the proper course of action. At a later time, State and Federal disaster teams would meet with the Civil Defense officials at the E.O.C. to determine necessary aid for the community.

Since the mid-1970's, emergency seismic simulation exercises have been held on an annual basis assuming a variety of possible epicenters. These exercises have included all public and private agencies who would be involved in a natural disaster. Seismic hazards such as fire mitigation, high-rise building collapse, school evacuations and reservoir flooding have been taken into account in the exercises. Data banks have been established and are maintained to contain information on the utility lines, plans of high rise buildings, location of seismic instruments, geologic and soil maps, and hospital capabilities. In 1979, while interviewing Mr. Hay, director of the agency, it came to the writer's attention that there was no plan for the eventuality of consequent large-scale flooding caused by landsliding (i.e., Mogul or Mustang areas). It is hoped that this has since been remedied.

In 1973, during the first stage of the study it was noted that many Civil Defense shelters were situated in basements of older or high-rise buildings. These shelters would not be usable after a seismic event, and supplies stored in them would be lost. A survey of seismically safe shelters was underway in 1979, and a plan of action specifically for earthquake disaster, existed. Effects of the seasonality, time of day, and tourist season were included in the earthquake disaster plan, as well as a mutual aid plan with the National Guard and State Civil Defense. In conjunction with the E.O.C., the health department had established critical points to place water purification units in the event of contamination.

DISASTER AWARENESS

The Washoe County Civil Defense program's growing awareness of earthquake disaster can be traced to community lectures and research by the University on earthquakes, as well as state and Federal legislation recently enacted. In 1978 and 1979 the State of Nevada Disaster Plan, a part of the State of Nevada Emergency Plan, was revised and updated to include an analysis of earthquake hazards in the state.

Prior to the establishment of the Ad Hoc Panel, there was no state or local entity or program that provided coordination and communication with respect to the full spectrum of seismic hazards. The Civil Defense program was the only one concerned which involved individuals from different governmental agencies.

The perception of the problem of seismic hazards is growing, but as was noted by the Ad Hoc Panel work still remains to be done. Further plans need to made concerning (1) using local contractors of heavy equipment to aid in debris removal and fire fighting, (2) preservation of the underground utilities through modification of construction requirements and possible code changes.

OTHER AGENCIES

Every agency or department contacted between 1973 and 1979 had contingency plans of some sort for disasters. Few had specific plans for a seismic disaster, and the few existing plans were not coordinated with the Civil Defense plan until 1979. The Nevada Bell Telephone Company had the most sophisticated disaster contingency plans for a seismic event of all utility companies investigated. More communication, evaluation and coordination is needed to form a comprehensive seismic plan for Washoe County.

CHAPTER VIII

CONCLUSION AND RECOMMENDATIONS

SPARKS

The City of Sparks can probably cope with the known faults within the city. Small recurrent movements of these faults may disrupt utility and communications lines, but the faults are, for the most part, in residential areas where building damage would not be unduly great. Sparks has few high-rise buildings that will be affected by ground shaking. The older part of Sparks has nearly been replaced with newer single story buildings; such as have the least response to strong ground motion.

Sparks without a doubt will be a metropolitan part of the Truckee Meadows that will continue to grow in years to come. Decisions can be made now that will minimize high-rise building damage from strong ground motion. Sparks is in a unique position with respect to planning for earthquake damage in that it is able to take advantage of new knowledge of seismic risk. It remains to be seem whether responsible people will take the initiative and make the decision to keep potential earthquake damage to a minimum.

Sparks also needs a flood-control plan tied into the seismic hazard plan of Washoe County. Flooding as a consequence of a large earthquake could create a very serious situation, when combined with the seismic shaking hazards.

RENO

In Reno many of the vital and critical facilities are located in hazardous areas. Government and local officials are becoming more aware of the danger through increased publicity, research and awareness of recent increases in seismic activity. This has resulted in the greater design strength required by the new 1979 UBC. It has also caused designers to build above the code minimum, and to use more advanced dynamic analysis in structural designs. This is a good trend in view of the inadequate codes.

Reno has taken the first major step in the improvement of their life sustaining facilities with the completion of the Public Safety Building. More lifeline facilities should however, be relocated and placed in areas of least hazard. Because of the large number of high-rises and older buildings in Reno, it is imperative that these buildings be catalogued by an engineering team and investigated on a site-specific basis. In any case, adequate emergency coordination and communications systems must be implemented.

GENERAL RECOMMENDATIONS

Legislation as recommened by the Ad Hoc Panel is sorely needed, but if nature follows her normal course it will be done only after a seismic disaster. It is inappropriate to list again all of the panel's recommendations (see Pages 37 to 38) but the following minimum actions should be taken with all possible haste: (1) revisions of NRS 278.160 to require preparation of a seismic safety plan as an element of city, county and regional master plans, (2) adoption of all of the 1979 UBC seismic provisions. (3) adoption of Alquist-Priolo legislation requiring seismic site specific planning (see page 44). Creation of a comprehensive civil defense plan to cope with seismic hazards.

BIBLIOGRAPHY

Ad Hoc Committee, 1975, Report of the Ad Hoc Committee on Geologic Hazards submitted to Washington State Legislature, 1975 session: State of Washington publication.

Ad Hoc Panel on Earthquake Prediction, 1965, Earthquake Prediction: Report of the Ad Hoc Panel on Earthquake Prediction of the office of Science and Technology, Executive Office of the President.

Ad Hoc Panel on Seismic Mitigation, 1979, Report on Conclusions, Recommendations and Findings: Governor's Office of Planning and Coordination, Nevada.

Algermissen, S.T., 1969, Seismic Risk Studies : in Proceedings of 4th world conference on Earthquake Engineering: Santiago, Chile, vol. 1, pg. 14-27.

Barkan, D.D., 1962, Dynamics of Bases and Foundations: N.Y., McGraw-Hill

Bell, E.J. Broadbent, R. and Szumigala, A, 1976, Effects of the Dec. 29, 1948 Earthquake at Verdi, Nevada: unpub. paper.

Bingler, E.C., 1974, Earthquake Hazards Map: in Reno Folio: Nevada Bureau of Mines and Geology Environmental Folio Series, Reno Quadrangle, 1:24,000.

Bingler, E.C., 1975, Guide Book to the Quaternary Geology Along the Western Flank of the Truckee Meadows, Washoe County, Nevada: Nevada Bur. Mines and Geology Report 22.

Bingler, E.C. and Bonham, H.F., 1976, Geologic Map, Aereal Distribution and Structural Geology: in Reno Folio: Nevada Bureau of Mines and Geology, Reno, Nevada.

Bingler, E.C. and Trexler, D.T., 1975, Composite Earthquake Hazard Index Map - A Synthesis of Hazard Elements of the Reno Quadrangle: Geological Society of America Abstracts with Programs, vol. 7, no. 7, pg. 998.

Bolt, B., 1978, Earthquakes, A Primer: San Francisco, W.H. Freeman & Co.

Bolt, B., Horn, W., MacDonald, G. and Scott, R., 1977, Geologic Hazards: N.Y., Springer-Verlag.

Bonham, H.F., 1969, Geology and Mineral Deposits of the Washoe and Storey Counties, Nevada: Nevada Bureau of Mines Bull. 70, 140 pg.

Bonilla, M.G., 1970, Surface Faulting and Related Effects: in Wiegel, R. 9th ed., Earthquake Engineering: Prentice Hall.

Borges, J.F., 1968, How to Design Structures to Resist Earthquakes: in International Seminar on Earthquake Engineering Procedings: U.N. Educational Science, pg. 41-49.

Brogan, G.E., Cluff, L.S., Korringa, M.K. and Slemmons, D.B., 1975, Active Faults of Alaska: Tectonophysics, vol. 29, pg. 73-85.

Californian Department of Transportation, 1973, Earthquake Design Criteria for Bridges: Sacramento, California, State Division of Structures.

Califoria State Automobile Association, 1979, Map of Reno-Sparks and Vicinity.

Cluff, L., Hansen, W., Taylor, C., Weaver, K., Brogan, G., McClure, F., Iduss, I. and Blayness, J., 1972, Site Evaluations in Seismically Active Regions-An Interdisciplinary Team Approach: in Proceedings of the International Conference on Microzonation for Safer Construction Research and Application,Seattle, Washington, 33 pg.

Cluff, L., Slemmons, D.B., and Waggoner, E.B., 1970, Active Fault Zone Hazards and Related Problems of Siting Works of Man: in Proceedings of the 4th Symposium on Earthquake Engineering, University of Roorkee, India, pg. 401-410.

Cooley, R.L., Fordham, J.W., and Westphal, J.A., 1971, Hydrology of Truckee Meadows, Nevada: University Nevada System, Center for Water Resources Research, Desert Research Institute, Project Report 15.

Cordova, T., 1969, Active Faults in Quarternary Alluvium and Geology of the Mount Rose Quadrangle, Nevada: M. S. Thesis, University of Nevada at Reno, 53 pg.

Davison, C., 1936, Great Earthquakes: London, Murby.

Office of Emergency Preparedness, 1972, Disaster Preparedness: Report to Congress, pg. 73-83.

Federal Disaster Assistance Administration, 1975, Directory of Disaster-Related Technology: Housing and Urban Development Report 401.

Douglas, B.M., 1976, Quick Release Pullback Testing and Analytical Seismic Analysis of a Six-Span Girder Bridge: Department of Civil Engineering, University of Nevada, Reno, Report no. 44.

Douglas, B., and Ryall, A., 1975, Return Periods for Rock Acceleration in the Nevada Seismic Zone: Bulletin Seismological Society of America, vol. 65, no. 6, pg. 1599-1612.

Douglas, B.M., and Weir, P., 1971, Multistory Building Response Determined from Ground Velocity Records: Bulletin Seismological Society of America, vol., 64, no. 1, pg. 357-367.

Earthquake Engineering Research Institute, 1977, Learning From Earthquakes: Planning and Field Guide of the Earthquake Engineering Research Institute.

Eiby, G.A., 1957, Earthquakes: London, F. Muller.

Freeman, J.R., 1972, Earthquake Damage and Earthquake Insurance: N.Y., McGraw-Hill.

Fung, G. G., LeBeau, R.J., Klien, E., Belvedre, J. and Goldschmidt, A.F., 1971, The San Fernando Earthquake-Field Investigation of Bridge Damage: State of California, Business and Transportation Agency, Dept. of Public Works, Division of Highways, Bridge Dept.

Gedney, P., 1966, Preliminary Study of Focal Mechanisms of Small Earthquakes in Central Nevada: M.S. Thesis, University of Nevada at Reno.

Guilluly, J.A., Waters, A.C., and Woodford, A.O., 1968, Principles of Geology: San Francisco, California, W.H. Freeman & Co.

Gutenberg, B. and Richter, C.F., 1954, Seismicity of the Earth and Association of Phenomena: Princeton, N.J., Princeton University Press.

Haas, J.E. and Mileti, D.S., 1976, Socioeconomic Impact of Earthquake Prediction on Government, Business and Community: Institute of Behavioral Science University of Colorado, Boulder, Colorado.

Hahn, K. and Sowers, R., 1974, Reducing Parapet Hazards in the Reno-SparksCarson City Area: Report for CE 779, University of Nevada at Reno.

Hodgson, J.H., 1964, Eathquakes and Earth Structure: Edgewood Cliffs, N.J., Prentice-Hall.

Iacopi, R., 1964, Earthquake Country, San Francisco, California, Lane Book Co.

Isacks, B., Oliver, J. and Sykes, L., 1972, Seismology and the New Global Tectomics: <u>in</u> Plate Techtonics: American Geophysical Union, Washington, D.C., pg. 186.

Jeffreys, H., 1950, Earthquakes and Mountains: London, Methun.

Joint Commission of Seismic Safety, 1974, Meeting the Earthquake Challenge: State of California Publication.

Joint Panel on Problems Concerning Seismology and Rock Mechanics, 1972, Earthquakes Related to Reservoir Filling: National Academy of Engineering.

Kennedy, B., 1973, Earthquake Hazards to Schools in the Reno Area: Report for CE 779, Civil Engineering Department, University of Nevada at Reno.

Kininmonth, C. and Richins, B., 1973, Parapet Hazards in Reno: Report for CE 779, Civil Engineering Department, University of Nevada at Reno.

Kuan, R.L., 1974, Seismic Risks to Downtown Reno: CE 479 Term Paper, Civil Engineering Department, University of Nevada at Reno.

Lambe, M.E., 1972, Map of the City of Reno and Sparks Sanitary Sewer System: City of Reno Division of Public Works.

Lambe, M.E., 1972, Map of City of Reno and Sparks Showing Electrical Substations and Lines: City of Reno, Nevada, Division of Public Works.

Leet, D. L., Judson S. and Kauffman, M.E., 1978, Physical Geology: New Jersey, Prentice-Hall.

Longwell, C.R., Flint, R.F. and Sanders, J.E., 1969, Physical Geology: N.Y., John Wiley & Sons Inc.

MacFarland, D. and Joslin, B., 1976, Summary of the Parapet Study in Reno, Nevada: Report for CE 779, Civil Engineering Department, University of Nevada at Reno.

Malone, S.D., 1972, Earth Strain Measurement in Nevada and Possible Effects on Seismicity Due to the Solid Earth Tides: M.S. Thesis, University of Nevada at Reno, 139 pg.

McKinney, R.F., 1976, Quarternary Geology Map of the Steamboat Quadrangle, Nevada: Nevada Bureau of Mines and Geology Open File Map.

Medueder, S.R., 1968, Measurements of Ground Motion and Structural Vibrations Caused by Earthquakes: in International Seminar on Earthquake Engineering Proceedings: United Nations Educational, Scientific and Cultural Organization.

Menard, H.W., 1974, Geology, Resources and Society: San Francisco, California, W.H. Freeman and Company, pg. 156-204.

Mileti, D., Drabek, T. and Hass, E., 1974, Human Systems in Extreme Environments: A Summary of Findings on Natural Hazards and Disasters: Boulder, Colorado, Institute of Behavioral Science.

Mock, R.G., 1972, Correlations of Land Surface in the Truckee River Basin Between Reno and Verdi, Nevada: M.S. Thesis, University of Nevada at Reno.

National Academy of Sciences, 1971, The San Fernando Earthquake of February 9, 1971 - Lessons From a Moderate Earthquake on the Fringe of a Densely Populated Region: National Academy of Sciences Report, 24 pg.

Nevada Bureau of Mines and Geology, 1976, Reno Folio: Nevada Bureau of Mines and Geology, Reno, Nevada.

Nevada Bureau of Mines and Geology, 1977, Computer Simulated Composite Earthquake Hazard Model for the Reno Area: In Summaries of Technical Reports, vol. 4, pg. 171.

Nevada Bureau of Mines and Geology, 1976, Earthquake Studies in the Carson City, Nevada Area: In Summaries of Technical Reports, vol. 1, U.S. Department of Interior, pg. 94.

Niazi, M., 1964, Seismicity of Northern California on Western Nevada: Bulletin Seismological Society of America, vol. 54, pg. 845-850.

Oakeshott, G.B., 1976, Volcanoes and Earthquakes: N.Y., McGraw-Hill.

Panel on Earthquake Prediction of the Committee of Siesmology, 1976, Predicting Earthquakes, National Academy of Science, Washington, D.C.

Panel on Strong-Motion Engineering Seismology, 1973, The Key to Understanding and Reducing the Damaging Effects of Earthquakes: National Academy of Science, Washington, D.C.

Panel on the Public Policy Implications of Earthquake Prediction, 1975, Earthquake Prediction and Public Policy: National Academy of Science, Washington, D.C.

Pease, R.C., 1979, Scarp Degradation and Fault History Near Carson City, Nevada: University of Nevada M. S. Thesis, 95 p.

Peck, B., 1974, Earthquake Risk in the Reno Area: Report for CE 779, Civil Engineering Department, University of Nevada at Reno.

Press, F. and Siever, R., 1974, Earth: San Francisco, California, W.H. Freeman and Company.

Priest, B.J., 1973, Possible Seismic Hazards in Reno: Report for CE 701, Civil Engineering Department, University of Nevada at Reno.

Priestly, K.F., 1974, Earth Strain Observed in the Western Great Basin: Doctoral Dissertation, University of Nevada at Reno.

Richter, C.F., 1958, Elementary Seismology: San Francisco, California, W.H. Freeman and Company.

Rikitake, T., 1976, Earthquake Prediction: Amsterdam, Elsevier.

Rogers, W.P., Ladwig, L.R., Hornbacker, A.L., Schwochow, S.D., Hart, S.S., Shelton, D.C., Scroggs, D.L. and Soule, J.M., 1974, Guidelines and Critera for Identification and Land Use Controls of Geologic Hazards and Mineral Resource Areas: Colorado Geological Survey, Department of Natural Resources, Denver, Colorado.

Roguemore, G., Hyytinen, R. and Soeller, S., 1976, An Assessment of the Emergency Facilities in the Reno Area: Term Paper, CE 779, Civil Engineering Department, University of Nevada at Reno.

Rushing, R., 1975, Geology and Related Hazards of the Sparks, Nevada Area: Report CE 479-779, Civil Engineering Department, University of Nevada at Reno.

Ryall, A.S., 1977, Earthquake Hazard in the Nevada Region: Bulletin of the Seismological Society of America, vol. 7, no. 2, pg. 517-532.

Ryall, A.S. and Malone, S.D., 1971, Earthquake Distribution and Mechanism of Faulting in the Rainbow Mountain-Dixie Valley-Fairview Beak Area, Central Nevada: Journal of Geophysical Research, vol. 76, pg. 7241-7248.

Ryall, A.S., Savage, W. and Koizumi, C., 1974, Seismic Potential in the Western Nevada-Eastern California Region: in Proceedings of the 5th World Conference on Earthquake Engineering, vol. 2, pg. 1729-1732.

Ryall, A.S., Slemmons, D.B. and Douglas, B., 1973, Block I Project - Reno, Nevada: Consulting Report.

Ryall, A.S., Van Wormer, J.D. and Jones, A.E., 1968, Triggering of Micro-earthquakes by Earth tides and Other Features of the Truckee, California Earthquake Sequence of September, 1966: Bulletin of the Seismological Society of America, vol. 58, pg. 215-248.

Ryall, A.S. and Van Wormer, J.D., 1980, Estimation of Maximum Magnitude and Recommended Seismic Zone Changes in the Western Great Basin: Bulletin Seismological Society of America, vol. 70, no. 5, pg. 1573-1581.

Sales, J.K., 1966, Structural Analysis of the Basin-Range Province in Terms of Wrench Faulting: Doctoral Dissertation, University of Nevada at Reno.

Seed, H.B. and Schnabel, P.B., 1972, Soil and Geological Effects on Site Response During Earthquakes: in Proceedings of the International Conference on Microzonation for Safer Construction, Seattle, Washington, vol. 1, pg. 61-86.

Shawe, D.R., 1965, Strike-Slip Control of Basin-Range Structure Indicated by Historical Faults in Western Nevada: Geological Society of America Bulletin, vol. 76, no. 12, pg. 1361-1377.

Sierra Pacific Power Company, 1973, Map of the Reno-Sparks Sewer System: From Air and Photo Overlay, unpublished.

Sierra Pacific Power Company, 1973, Map of Reno-Sparks Water System: Sierra Pacific Power Company, unpublished.

Slemmons, D.B., 1957, Geological Effects of the Dixie Valley Fairview Peak, Nevada Earthquake of December 16, 1954: Bulletin Seismological Society of America, vol. 47, pg. 353-375.

Slemmons, D.B., 1967, Pliocene and Quaternary Crustal Movement of the Basin-and-Range Province, U.S.A.: Journal of Geoscience, Oska City University, vol. 10, article 1-11, pg. 91-103.

Slemmons, D.B., Jones, A.E. and Simlett, J.I., 1965, Catalogue of Nevada Earthquakes 1852-1960: Bulletin of Seismological Society of America, vol. 55, no.2, pg. 537-583.

Slemmons, D.B. and McKinney, R., 1977, Definition of an Active Fault: U.S. Army Corp. of Engineers Misc. Paper S-77-8, 22 pg.

State of California Resource Agency, 1964, Earthquake and Geologic Hazards Conference: State of California Resource Agency, San Francisco, California.

Steinbrugge, K., 1968, Earthquake Hazards in San Francisco Bay Area: Institute of Government Studies, University of California at Berkeley, pg. 40.

Stewart, J.H., 1971, Basin-Range Structure; A System of Horst and Grabens Produced by Deep-Seated Extension: Geological Society of America Bulletin, vol. 82, no. 4, pg. 1019-1043.

Teallman, M.A., 1973, Earthquake Hazards to Schools in the Reno Area: Report for CE 779, Civil Engineering Department, University of Nevada at Reno.

Technical Council of Lifeline Earthquake Engineers, 1977, Lifeline Earthquake Engineering: in Proceedings Technical Council of Lifeline Earthquake Engineers Specialty Conference, University of California, Los Angeles, California.

Thompson, G.A. and White, D.E., 1964, Regional Geology of the Steamboat Springs Area, Washoe, County, Nevada: U.S.G.S. Professional Paper 458-A.

Trexler, D., 1973, Seismic Risk to Life Support Systems in the Reno Area: Report for CE 779, Civil Engineering Department, University of Nevada at Reno.

Trexler, D.T. and Pease, R.C., 1980, Geologic Mapping of the Vista and Steamboat 7-1/2 Minute Quadrangles, Nevada: Nevada Bureau of Mines and Geology Technical Report, 32 pg.

University of California, 1977, Proceedings of the Technological Council on Lifeline Earthquake Engineering Specialty Conference: University of California, Los Angeles, California.

U.S. Government, 1976, Earthquake Prediction and Hazard Mitigation Options for USGS and NSF Programs: U.S. Government Printing Office, Washington, D.C., no. 20402.

U.S. Army Corps of Engineers, 1972, Floodplain Information on the Truckee River, Nevada: Regional Planning Commission of Reno, Sparks and Washoe County.

U.S. Department of Commerce, 1973, San Fernando, California Earthquake of February 9, 1971: U.S. Department of Commerce, National Oceanic and Atmospheric Adminstration, Washington, D.C., V., I., II., III.

U.S. Geological Survey, 1969, Reno Quadrangle Topographic Map, 7.5 Minute Series: U.S. Geological Survey Publications.

U.S. Geological Survey, 1969, Mount Rose, N.E., 7.5 Minute Quadrangle: U.S. Geology Survey Publication.

U.S. Nuclear Regulatory Commission, 1975, Reactor Site Criteria: in Code of Regulations-Energy: U.S. Nuclear Regulatory Commission, Title 10, Ch. 1, pg. 100-1 through 100-6.

U.S. Task Force on Earthquake Hazard Reduction, 1971, In the Interest of Earthquake Safety: Institute of Government Studies: University of California at Berkley, 22 pg.

U.S. Geological Survey, 1965, Alaska's Good Friday Earthquake, March 27, 1964: U.S. Geological Survey, vol. 148, no. 3678, pg. 1675-1687.

Van Wormer, J.D. and Ryall, A.S., 1980, Sierra Nevada-Great Basin Boundary Zone: Earthquake Hazard Related to Structure, Active Tectonic Processes and Anomalous Patterns of Earthquake Occurence: Bulletin Seismological Society of America, vol. 70, no. 5, pg. 1557-1572.

Walker, D.M., 1974, Seismic Risks in Sparks: Report for CE 779, Civil Engineering Department, University of Nevada at Reno.

Wallace, R.E., 1978, Patterns of Faulting and Seismic Gaps in the Great Basic Province, U.S. Geological Survey, Open-File Report 78-943, pg. 857-868.

Washoe County Civil Defense and Disaster Agency, 1976, Public Fallout Shelters in Washoe County: Washoe County Report.

White, G.F. and Haas, J.E., 1975, Assessment of Research on Natural Hazards: M.I.T. Press.

Wiegel, R.L., 1970, Earthquake Engineering: Englewood Cliffs, N.J., Prentice-Hall.

Wright, L., 1976, Late Cenozoic Fault Patterns and Stress Fields in the Great basin and Westward Displacement of the Sierra Nevada Block: Geology, N.Y., 489-494.

Yanev, P., 1974, Peace of Mind in Earthquake Country: San Francisco, California, Chronicle Books.

PERSONAL INTERVIEWS AND CORRESPONDENCE

Bell, J. W., 1976, 1978, Engineering Geologist, Nev. Bureau of Mines and Geology.

Bingler, E.C., 1973, 1974, 1976, 1978, Geologist, Nevada Bureau of Mines and Geology.

Bixell, O. E., 1973, Planner, Washoe County Civil Defense.

Bonell, J., 1978, Ad Hoc Panel Chairman, Civil Engineering Dept., University of Nevada, Reno, Nevada.

Bonham, H.F. Jr., 1978, Geologist, Nevada Bureau of Mines and Geology.

Borda, B., 1976, Engineer, Sierra Pacific Power Company.

Brown, S., 1978, Captain, Sparks Fire Department.

Byrom, J., 1978, Transmission Supervisor, Sierra Pacific Power Company.

Classic, D., 1976, 1978, Attorney General's Office, Nevada.

Cleary, P., 1980, U.S. Soil Conservation Service.

Couch, R. W., 1978, Seismologist, Oregon State University, Corvallis, Oregon.

De Crona, D., 1976, Washoe Civil Defense Agency.

Dobbyns, E., 1973, 1979, Engineer, Sierra Pacific Power Company.

Douglas, B.M., 1973, Personal Communication and Classnotes for CE 701, University of Nevada at Reno.

Douglas, B.M., 1978, Chairman, Department of Civil Engineering, University of Nevada.

Dukes, C., 1978, Federal Water Ditch Master, Reno, Nevada.

Erskine, G., 1978, Architect, St. Marys Hospital, Reno, Nevada.

Fagg, R., 1978, Electrical Design Engineer, Sierra Pacific Power Company, Reno, Nevada.

Ferrari, P. A., 1978, Building Inspector, City of Reno.

Firth, R., 1978, Gas and Water Engineer, Sierra Pacific Power Company, Reno, Nevada.

Fredericks, J.H., 1976, Manager of Federal Housing and Urban Development, Reno, Nevada.

Gribbon, C., 1974, 1978, Maintenance Engineer, Washoe Medical Center, Reno, Nevada.

Hancock, B., 1976, 1978, Director, Nevada State Public Works Board, Reno, Nevada.

Hansen, J., 1976, 1978, Planner, Reno and Sparks Regional Planning commission of Washoe County, Nevada, Reno, Nevada.

Harrington, P., 1973, Inspector, Building Department, City of Reno, Nevada.

Hay, R.B., 1976, 1978, Director of the Washoe Civil Defense Agency, Reno, Nevada.

Jones, R. and Hawk, J., 1978, Office of Water Planning, U. S. Army Corps of Engineers.

Kronberg, M., 1976, 1978, Planner, Nevada State Civil Defense, Carson City, Nevada.

Littlefield, J.M., 1973, Deputy of Nevada State Planning Board, Reno, Nevada.

Martin, G., 1976, Director of the Nevada State Civil Defense, Carson City, Nevada.

Miller, S., 1978, Captain of the Reno Fire Department.

Nishikawa, K., 1980, Engineer, Nevada Water Resources Department, Reno, Nevada.

Parker, T., 1976, 1978, Engineering Services Supervisor, Sierra Pacific Power Company, Reno, Nevada.

Pease, B., 1976, Geologist, Nevada Bureau of Mines and Geology, Reno, Nevada.

Penner, W.S., 1976, Senior Engineer, Building and Equipment Section, Nevada Bell Telephone Company, Reno, Nevada.

Piccolo, M., 1973, 1976, Superintendent of Wahoe Co. Schools, Reno, Nevada.

Priest, G.R., 1980, Geothermal Specialist, Oregon Department of Geology and Mineral Industries, Portland, Oregon.

Richards, B., 1976, Captain, Sparks Fire Department, Sparks, Nevada.

Rigsby, B., 1976, Planner, Nevada, State Planning Coordination Office, Carson City, Nevada.

Robb, J., 1978, Administrator, Washoe County Schools, Reno Nevada.

Ryall, A., 1976, Director of Seismological Lab, University of Nevada at Reno.

Scelero, J., 1973, Electrical Egineer, Sierra Pacific Power Company.

Slemmons, D.B., 1972, 1974, 1976, 1978, 1979, Professor, Univ. of Nevada at Reno.

Smith, B., 1978, Personnel Officer, Nevada Bell Telephone Company, Reno, Nevada.

Sparbell, J., 1976, 1978, Planner, Nevada State Planning Coordination Office, Carson City, Nevada.

Spencer, L., 1978, Soil Scientist, U. S. Soil Conservation Service.

Soule, G., 1978, Engineer, Sierra Pacific Power Company, Reno, Nevada.

Teats, F., 1974, Maintenance Engineer, Veterans Administration Hospital, Reno, Nevada.

Trexler, D., 1972 through 1979, Geologist, Nevada Bureau of Mines and Geology, University of Nevada at Reno.

Upton, C. G., 1976, 1978, District Engineer, Equipment and Building Disstric, Nevada Bell Telephone Company, Reno Nevada.

Van Fleet, 1976, Planner, Office of Emergency Preparedness, City of Reno, Nevada.

Van Meter, H.G., 1976, 1978, Chief Engineer, Reno Fire Department, Reno, Nevada.

Van Wormer, D., 1976, Geologist, Nevada Bureau of Mines and Geology, Reno, Nevada.

Waldron, B., 1978, Environmental Division, Washoe County Health Department, Environmental Division.

Yeats, R., 1977, 1978, Chairman, Department of Geology, Oregon State University, Corvallis, Oregon.