Workshop On Post-Earthquake Data Collection

Arkansas State Police Headquarters Office
3 Natural Resources Drive
Little Rock, Arkansas

November 9-10, 1993

An Activity of the International Decade for Natural Disaster Reduction

Sponsors: Arkansas Geological Commission
United States Geological Survey

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I. Objectives and Agenda

Objectives of Post-Earthquake Investigations

Damaging earthquakes are a scientific laboratory for scientists, architects, planners, engineers, and emergency responders. They provide an opportunity to see the physical effects of an earthquake and their impact on buildings and lifeline systems in the stricken community. Every flaw in planning, siting, design, and construction will be exposed by the earthquake, so scientific investigations to determine what happened and why are urgently needed to underpin decisions on earthquake risk management and to improve public policies and professional practices.

Post-Earthquake investigations encompass:

Geologic Studies - These studies use a wide variety of techniques such as over flights, satellite observations, geodynamic measurements, and field mapping to accomplish the goals which encompass: 1) understanding ground shaking, crustal deformation, and ground failure; 2) defining the regional seismotectonic setting; and 3) mapping, assessing, and analyzing **faulting phenomena**, the geometry and physical properties of **soil deposits** and bedrock, **regional tectonic deformation**, **liquefaction**, **landslides**, and **flood-wave inundation**.

Seismological Studies - These studies use a variety of techniques such as fixed local, regional, national, and global seismometer networks and portable instrument arrays to characterize and understand the **main shock and aftershock sequence**. Arrays of portable seismographs are used to locate aftershocks in the epicentral region, determine their spatial and temporal characteristics, define the rupture zone, relate the main shock to the long-term regional seismicity, and explain **precursory geophysical phenomena**, if any, before the main shock.

Engineering Seismology Studies - These studies use techniques such as permanent local and regional strong-motion instrument arrays and portable strong motion instruments to acquire quantitative data (i.e., strong motion accelerograms and spectra, pore water pressure measurements, etc.). These data are used to improve understanding of regional **seismic wave propagation** and local **ground response** and **ground failure** and to relate ground motion effects from both the aftershocks, the main shock, and past earthquakes to parameters of the solid earth system. Strong motion accelerograms and spectra derived from them are used to guide earthquake resistant design.

Engineering Studies - These studies currently use a variety of qualitative (e.g., photos and slides) and quantitative (e.g., accelerograph records and material testing) techniques to ascertain the nature, cause, degree, and spatial distribution of **damage** to a wide variety of **structures** and **foundations** in the stricken community. Technical assistance may also be required after the earthquake to assess the safety of buildings (e.g., to assign "red, yellow, and green" tags to buildings after the earthquake to signify "unsafe," "use caution," and "safe to use"). The structures include: **dwellings, low-**, **medium-**, and **high-rise buildings**, and **industrial facilities**; **lifelines** (i.e., those systems that transport people, distribute resources, and transmit information), **essential facilities** (e.g., schools, hospitals, emergency operations centers), and **critical facilities** (i.e., dams, nuclear power plants)). This information is used to develop and refine architectural, geotechnical and structural engineering, and land-use planning principles and practices. Vulnerability relations are derived in order to refine or revise building and lifeline regulations; improve siting, design, and construction criteria; and advance professional practices.

Casualty Studies - These studies use site-specific determinations of casualties and building damage in the stricken area to correlate deaths and injuries with building type, local geology, and land use and building regulations in the community. These data provide a basis for improving search and rescue efforts, planning emergency health care, developing reliable methodologies for estimating deaths and injuries, and improving design and construction methods to reduce casualties.

Societal Response Studies - These studies use field work and quantitative and qualitative techniques such as interviews to determine how the populace in the stricken area and the region used **earthquake hazards and risk information** and **predictions and warnings**, if any, **before** , **during**, and **after** the earthquake. Databases are also developed to show the distribution of economic losses and the factors that lead communities to make decisions about their earthquake risk management, and the degree to which they took advantage of the **window of opportunity** that follows a major earthquake (i.e., a relatively short period of time during which a stricken community can sometimes act to adopt and enforce new seismic safety policies, often more stringent than those in place before the event).

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Preliminary Agenda

Tuesday, November 10

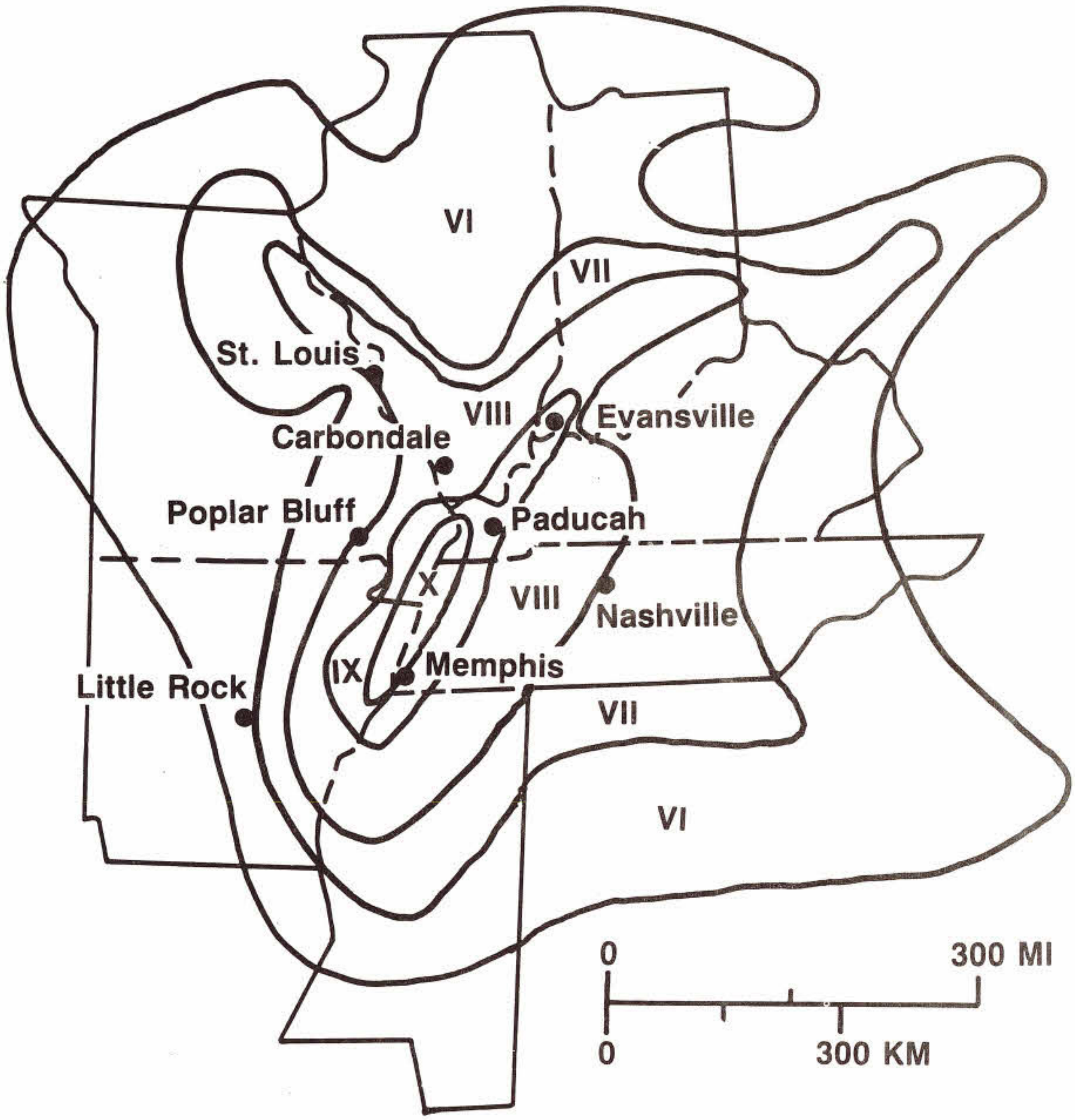
8:30 a.m.	Welcome
	Presentations
8:45 a.m.	Session I: Pilot And Reconnaissance Studies Immediately After The Earthquake To Document And Understand What Happened.
	• Roles and capabilities of the Arkansas Geological Commission and the U.S. Geological Survey
	• Guidelines for conducting postearthquake investigations that contribute to regional geologic, seismological, engineering, seismology, engineering, casualty, and societal response studies after a major earthquake strikes the region.
10:30 a.m.	Break
11:00 a.m.	Session II: Pilot And Reconnaissance Studies Immediately After The After The Earthquake To Document And Understand What Happened (Continued).
12 Noon	Lunch
1:30 p.m.	Working Groups
	Sessions III: Conducting Pilot and Reconnaissance Studies.
	• Continuation of guidelines for conducting postearthquake investigations that contribute to regional geologic, seismological, engineering, seismology, engineering, casualty, and societal response studies after a major earthquake strikes the region.
3:00 p.m.	Break
3:30 p.m.	Session IV: Conducting pilot and reconnaissance studies (continued)

Wednesday, November 11

8:15 a.m.	Working Groups (Continued)
	Session V: A Joint Strategic Plan For Conducting Pilot And Reconnaissance Studies And For Seizing Windows Of Opportunity To Change The Policy Environments.
	• Identification of what should be done and who should do it for geologic, seismological, engineering seismology, engineering, casualty, and societal response studies in Arkansas after a major earthquake in the region.
	• Identification of strategies for cooperative, integrated, intra- and interstate geologic, seismological, engineering seismology, engineering, casualty, and societal response studies that will deepen understanding and contribute to changes in the policy environments for earthquake risk management throughout the region.
10:15 a.m.	Break
10:45 a.m.	Working Groups (Continued)
	Session VI: A Joint Strategic Plan For Conducting Pilot And Reconnaissance Studies And For Seizing Windows Of Opportunity To Change The Policy Environments (continued).
12 Noon	Lunch
1:30 p.m.	Reports and Dialogue
	Session VII: Evaluation of Plans.
	• Proposed Action Plan • Proposed Strategic Plan • Needs • Next Steps
3:00 p.m.	Break
3:30 p.m.	Session VIII: Evaluation of plans (continued).
	Adjourn

II. Technical Information

HYPOTHETICAL INTENSITY MAP--1811-1812 SIZE EARTHQUAKES



Methods of Measurement

The "size" of earthquakes is commonly expressed in two ways—magnitude and intensity.

Magnitude is a measure of the total energy released during an earthquake. It is determined from a seismogram, which plots the ground motion produced by seismic waves. As devised by C.F. Richter in 1935, the magnitude scale allows us to compare earthquakes in relative terms.

Though the term is used somewhat indiscriminately, magnitude is a highly technical calculation. Magnitude is defined as the logarithm (to the base 10) of the maximum wave-trace amplitude expressed in microns (1 micron = .0001 centimeter), as would be recorded by a standard short-period seismograph with specific constants, at an epicentral distance of 100 kilometers (62 miles).

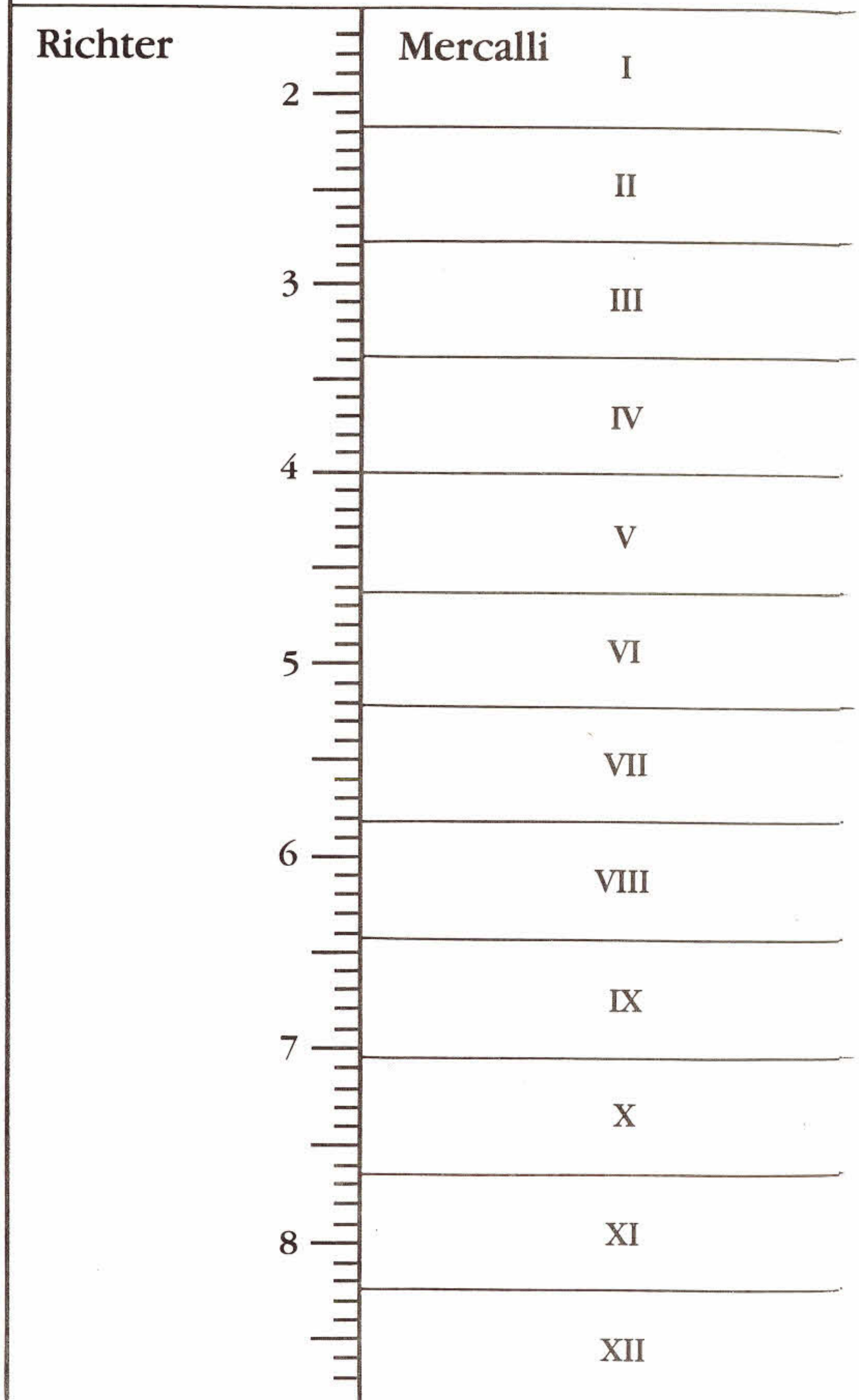
The important thing to remember about magnitude is that the scale is logarithmic, which means that each step in magnitude represents a tenfold increase in amplitude of wave motion. Therefore, an earthquake of magnitude 6.0 has ten times the wave amplitude of an earthquake of magnitude 5.0, a hundred times the wave amplitude of a magnitude 4.0 earthquake, and one thousand times the wave amplitude of a magnitude 3.0 earthquake.

Because magnitude does not describe the extent of the damage, its usefulness is limited to a approximation of whether the earthquake is large, small, or medium-sized. The destructiveness of an earthquake is a complex matter, related to the geology, population density, and cultural features of a specific area at a specific distance from the epicenter.

Seismologists and geologists also describe earthquakes by their intensity. Measured on a numerical scale, intensity is the degree of damage or the observable effects caused by an earthquake at a particular location. An earthquake of a particular magnitude will produce different intensities at different places, according to geology, population density, cultural features, and distance from the epicenter.

The most widely used intensity scale, the Modified Mercalli Scale, is divided into 12 degrees, each identified by a Roman numeral. For example, an earthquake intense enough to be felt by a person standing nearby is said to have an intensity of MM III.

The Relationship Between Richter



Magnitude and Modified Mercalli Intensity

Not felt or rarely felt under favorable circumstances. Sometimes, under certain conditions,

- trees, structures, liquids, and bodies of water sway;
- dizziness or nausea may be experienced;
- doors swing very slowly;
- birds and animals are uneasy or disturbed.

Felt indoors by a few persons, especially on upper floors, or by sensitive or nervous persons. Sometimes

- hanging objects swing;
- trees, structures, liquids and bodies of water sway;
- dizziness or nausea may be experienced;
- doors swing very slowly.

Felt indoors by a number of people. Motion is usually a rapid vibration. and sometimes

- vibrations are not at first recognized as an earthquake;
- movement is significant on upper levels of tall structures;
- standing vehicles rock slightly;
- hanging objects swing.

Felt indoors by many and outdoors by a few.

- A few people awaken, especially light sleepers;
- vibrations feel like those of a heavily loaded truck passing by;
- dishes, windows, and doors rattle;
- walls and frames of structures creak
- liquids in open vessels are slightly disturbed;
- standing vehicles rock noticeably.

Felt indoors and outdoors by many or most people. Outdoors, the direction of the earthquake could be estimated.

- Buildings tremble;
- dishes and glassware break;
- small or unstable objects overturn and may fall;
- doors and shutters open or close abruptly;
- small objects move and furnishings move slightly;
- liquids in well-filled open containers spill slightly;

Felt by all people indoors and outdoors.

- People move unsteadily;
- some plaster cracks, and fine cracks appear in chimneys;
- dishes, glassware, and windows break;
- knick-knacks, books, and pictures fall;
- some furniture overturns;
- moderately heavy furniture moves.

All people are frightened and run outdoors, general alarm.

- Many people find it difficult to stand;
- water is stirred and muddied;
- some sand and gravel stream banks cave in;
- chimneys crack considerably, and walls crack somewhat;
- plaster and stucco fall in considerable to large amounts;
- loosened bricks and tiles fall;

People are generally frightened, with alarm approaching panic.

- Persons driving vehicles are disturbed;
- trees shake strongly and branches break off;
- sand and mud are ejected from earth in small amounts;
- temporary and permanent changes occur in springs and wells;
- ground becomes wet to some extent, even on steep slopes;
- chimneys, columns, monuments, and towers fall;

General panic.

- Ground cracks conspicuously;
- masonry structures are thrown out of plumb;
- large parts of well-built masonry buildings collapse;
- some buildings shift off foundations, and frames crack;
- reservoirs are seriously damaged;
- some underground pipes break.

Ground cracks at widths up to several inches. Parallel to canals and stream banks, fissures form up to a yard wide.

- Numerous landslides occur on river banks and steep coasts;
- dams, dikes, and embankments are seriously damaged;
- most masonry and frame structures are destroyed;
- buried pipelines are torn apart or crushed;
- cracks and broad, wavy folds open in concrete pavements and asphalt road surfaces.

Disturbances in the ground are many and widespread, varying with ground material.

- Broad fissures, landslides, and liquefaction occur;
- water, sand, and mud is ejected from earth in large amounts;
- dams, dikes, and embankments are greatly damaged;
- few masonry structures remain standing;
- large, well-built bridges are destroyed;
- railroad rails are greatly bent and thrust endwise;

Damage is total, and nearly all works of construction are greatly damaged or destroyed.

- Landslides, and numerous shearing cracks appear;
- large rock masses are wrenched loose and torn off;
- lakes are dammed, waterfalls form, and rivers are deflected;
- waves are seen on ground surfaces;
- lines of sight and level are distorted;
- objects are thrown upward into the air.

This Modified Mercalli Scale is an abbreviated version of the 1931 original, as published by the Central United States Earthquake Consortium.

The Knowledge Base for Assessing Earthquake Hazards and Risk in the Mississippi Valley Region

By

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Abstract

The Mississippi Valley Region has the classic problem of earthquake hazard mitigation. The region has a low probability for the occurrence of damaging earthquakes like those that struck the region in the winter of 1811-1812. However, it has a high probability for experiencing damage, economic loss, deaths and injuries, and loss of function from the physical effects that are expected to be generated when earthquakes like these recur. To prepare for their inevitable recurrence as a functi·· of the seismic cycle of the New Madrid Seismic Zone, a..sessments are made to define the potential severity and spatial extent of:

- o ground shaking,
- o ground failure (liquefaction and lanslides),
- o surface fault rupture,
- o regional tectonic deformation,
- o seiches,
- o fire,
- o flooding from dam failure, and
- o aftershocks.

These assessments of the physical effects (hazards) are integrated with the inventory of buildings, facilities, and lifeline systems to determine the risk in terms of potential:

- o damage,
- o deaths,
- o injuries,
- o economic losses, and
- o loss of functions.

Public officials, in cooperation with sientists, engineers, architects, urban planners, and emergency managers use hazard and risk assessments to devise, adopt, and implement seismic safety policies in their communities.

INTRODUCTION

An assessment of the earthquake hazards (physical phenomena accompanying an earthquake) and risk (chance of loss from these phenomena) is a complex task requiring multidisciplinary investigations. These investigations are designed to answer the following questions:

- o Where have earthquakes happened in the past?
- o What happened in past earthquakes?
- o What can happen in future earthquakes?
- o How frequently on the average do earthquakes of magnitude 5.5 and greater occur?
- o How severe are the physical effects of earthquakes of magnitude 5.5 and greater expected to be?
- o What kinds of damage will these physical effects cause to the buildings, facilities, and lifeline systems that are at risk?
- o What have communities done to keep these physical effects from causing damage, deaths, injuries, economic loss, and loss of function?
- o What else can be done to mitigate or reduce potential losses in each community?

By analyzing the geologic, geophysical, seismological, and engineering data, realistic assessments can be made of the potential severity and spatial extent of:

- o ground shaking,
- o ground failure (liquefaction and landslides),
- o surface fault rupture,
- o regional tectonic deformation,
- o seiches,
- o fire,
- o flooding from dam failure, and
- o aftershocks.

This information can be integrated with the inventory of buildings, facilities, and lifeline systems to determine the risk.

The Mississippi Valley Region has the classic problem of earthquake hazard mitigation. The problem has two parts:

- o The region has a low probability for the occurrence of damanging earthquakes like those that struck in 1811-1812.

- o The region has a high probability for experiencing damage, economic loss, and loss of life from thephysical phenomena generated by such earthquakes when they recur.

To accomplish an assessment of earthquake hazards and risk in the Mississippi Valley, the following basic data are required:

- o The earthquake history.
- o Isoseismal maps.

- Information on the New Madrid Seismic Zone and other earthquake sources.
- Earthquake recurrence relations.
- Seismic wave attenuation.
- Soil Response.

These basic data will be discussed in the following sections.

EARTHQUAKE HISTORY OF THE MISSISSIPPI VALLEY REGION

The earthquake history of the Mississippi Valley Region is dominated by the series of great (magnitudes of 8 or greater) earthquakes that ruptured the New Madrid Seismic Zone (Figure 1) in the winter of 1811-1812. On December 16, 1811, three earthquakes ruptured the entire southern segment of the New Madrid Seismic Zone, a length of about 90 miles (150 km) which extends from a point in eastern Arkansas 25 miles (40 km) northwest of Memphis to Reelfoot Lake in northwestern Tennessee. These earthquakes had magnitudes (M_S) of 8.6 (2:30 a.m.), 8.0 (8:15 a.m.), and 8.0 (noon). On January 23, 1812, another great earthquake having a magnitude of 8.4 ruptured the central segment of the fault, a length of about 45 miles (75 km). On February 7, 1812, the last and largest earthquake in the series having a magnitude of 8.8 occurred near the town of New Madrid, rupturing the entire 60-mile-long (100 km) northern branch of the fault zone. Between the occurrence of the first earthquake on December 16, 1811, and March 15, 1812, the aftershock sequence included:

- 5 earthquakes of magnitude (M_S) 7.7
- 10 earthquakes of magnitude 6.7
- 35 earthquakes of magnitude 5.9
- 65 earthquakes of mangitude 5.3
- 89 earthquakes of magnitude 4.3

Since 1812, only two earthquakes of magnitude (M_S) greater than 6 have occurred in the Mississippi Valley Region. Both of them occurred in the New Madrid Seismic Zone. They were:

- <u>A magnitude 6.7 earthquake located near Charleston, Missouri.</u> It occurred on October 31, 1895, near the northern end of the New Madrid Fault Zone and caused chimney, wall, and foundation damage in St. Louis.

- <u>A magnitude 6.3 earthquake located in Arkansas.</u> It occurred on January 4, 1843, at the extreme southern end of the fault about 25 miles (40 km) northest of Memphis. It caused structural damage in Memphis, Southwest Tennessee, Northeast Arkansas, and the northwest corner of Mississippi.

In historic times, 17 moderate-magnitude earthquakes (magnitudes of 4.3 to 5.9) have occurred in the Mississippi Valley Region. Only two of these were in the New Madrid Seismic Zone. Two were in the Wabash Valley, and two were in the Illinois Basin of Southern Illinois. The Wabash Valley is suspected by some experts as the potential loation of a future large earthquake because of the deep (20 km) focal depths.

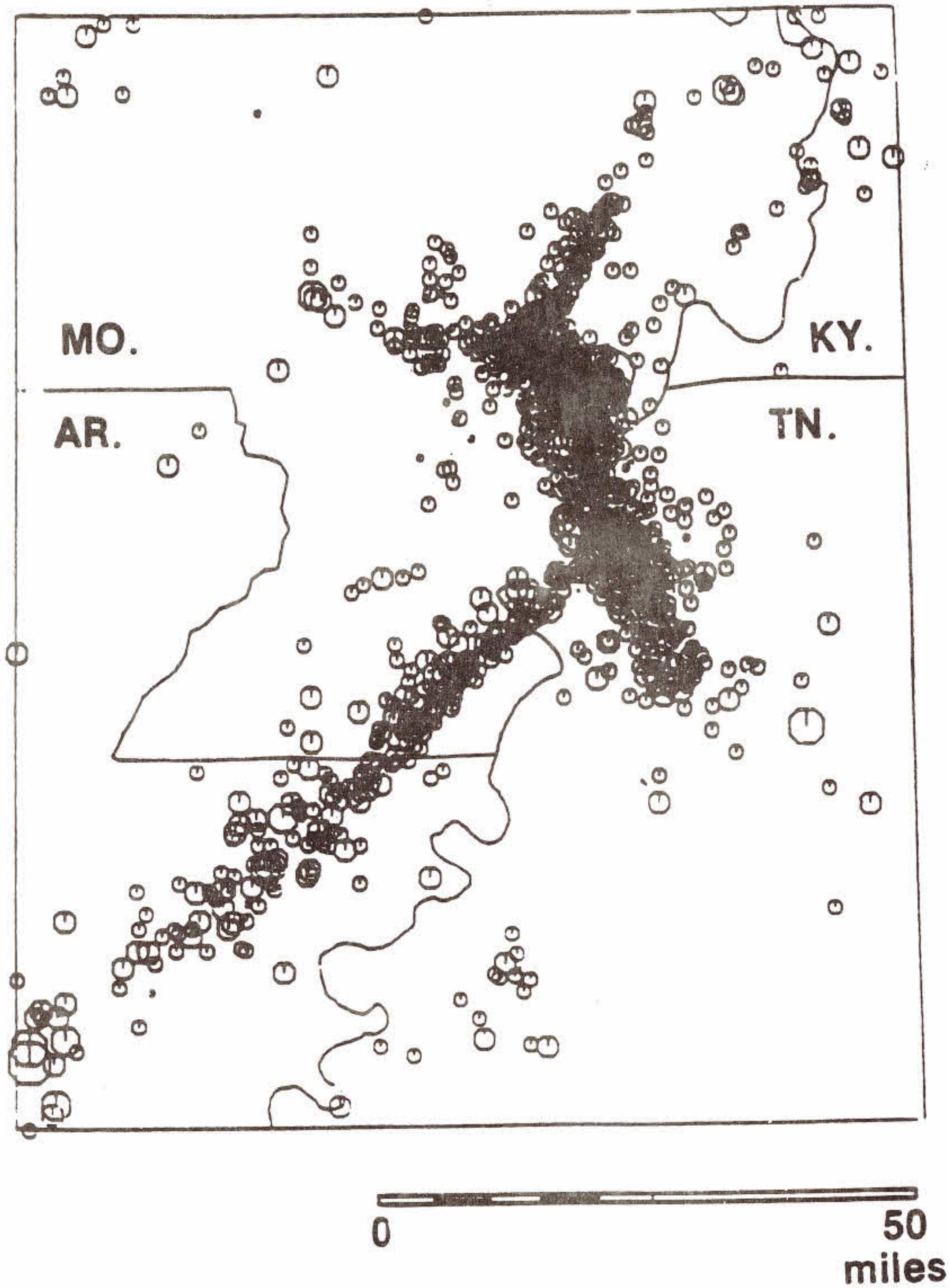

Figure 1: New Madrid Seismic Zone

Isoseismal Maps

In 1973, the late Professor Otto Nuttli of St. Louis University published the results of the reconstruction of the effects of the 1811-1812 earthquakes in terms of Modified Mercalli intensity data (Figure 2). He showed that great earthquakes in the Mississippi Valley can be expected to cause:

- o severe structural damage (intensities of IX-XII) over an area of several thousand square miles,
- o structural damage (intensities of VIII-IX) over an area of several tens of thousands of square miles, and
- o architectural damage and damage to contents (intensities of VI-VII) over an area of several hundred thousand square miles.

The threshold of ground failure occurs at about intensity VI, provided the physical conditions are right.

New Madrid Seismic Zone

The geologic, geophysical, and seismological data show that the New Madrid Seismic Zone is not a fault that breaks the ground surface. Rather, it is a complex zone of buried rifting about 42 miles (70 km) long. It has about 1.2 to 1.8 miles (2 to 3 km) of subsurface structural relief which gravity and magnetic methods have helped to delineate. Numerous microearthquakes located on the seismicity network operated by St. Louis University have helped to outline active segments of the New Madrid Seismic Zone more precisely.

Earthquake Recurrence Relations

The seismicity catalogs have been used to define recurrence relations for the Mississippi Valley Region. The relations are:

- o 655 years for earthquake having magnitudes like those of the 1811-1812 New Madrid events.

- o 158 years for earthquakes having magnitudes like that of the 1886 Charleston, South Carolina earthquake.

- o 38 years for earthquakes having magnitudes like those of the 1843 and 1895 New Madrid events.

- o 12 years for earthquakes having magnitudes like that of the 1968 Illinois event.

- o 3.5 years for earthquakes having magnitudes like that of the 1980 Kentucky event.

Earthquake Sources (Seismogenic Zones)

Although the New Madrid Seismic Zone is the dominant earthquake source, it is not the only seismogenic zone in the Mississippi Valley Region. Other postulated zones include:

- o St. Francois Uplift
- o Wabash Valley Fault
- o Illinois Basin
- o Cincinnati Arch
- o Colorado Lineament
- o Nemaha Uplift
- o Ouachita - Wichita Mountains

These sources are defined on the basis of historical and instrumental seismicity and geologic data.

Seismic Wave Attenuation

The late Professor Otto Nuttli showed that the rate of attenuation of seisic energy in the Mississippi Valley Region is much slower than in the Western United States. This phenomenon creates the possibility for a large area in the Mississippi Valley Region to experience damaging levels of ground shaking. Cities located some distance from the epicentral region of a large- to great-magnitude earthquake could experience damage, especially in cases when the fundamental vibration periods of a building and soil column are closely matched (i.e., a resonant condition).

Soil Response

Soil columns in the Mississippi Valley Region, like many other parts of the world, have physical characteristics that can cause amplification of ground motion in selected period bands. Sites underlain by thin stiff soils can amplify the short-period (high-frequency) components of ground motion; whereas, sites underlain by thick soft sols can amplify the long-period (low-frequency) components of ground motion. Because low-rise buildings are susceptible to short-period ground motion, the damage distribution is controlled to a large extent by the degree to which the response of the building and the soil column are matched. Damage can occur in the upper stores to tall buildings founded on thick soft soils if the building is not designed to accomodate the soil response.

Assessment of the Ground Shaking Hazard

An assessment of the ground shaking hazard must take into account the physical parameters of the:

- o earthquake sources,
- o propagation paths over which the seismic waves propagate, and
- o soil columns underlying the building, facility, or lifeline.

In physical terms, the ground motion generated by the abrupt release of accumulated strain energy in the New Madrid Seismic Zone (or other seismolgenic zones in the Mississippi Valley Region) will consist of:

- o P or compressional waves, which are short-period waves that travel through the earth's crust and mantle at about 18,000 miles/hour (8 km/second).
- o S or shear waves, which arrive after the P-waves, traveling at about 10,800 miles/hour (4.8 km/second).
- o Love waves, which are long-period shear surface waves that arrive after the S-waves, and
- o Rayleigh waves, which are long-period surface waves that arrive last at a site.

These four seismic waves comprise the time history of ground motion that depicts how the ground vibrates elastically over time, with the main movement usually being horizontal. The ground motion causes the mass of a building to vibrate, generating inertial forces that are directly related to the building's configuration (i.e., size and shape). The horizontal or lateral forces use up the strength of the building by bending, shearing, or twisting the columns, floors, beams, and walls elastically and inelastically. Eventually, the force of gravity will act to pull down a weakened and distorted building. Probabilistic and deterministic assessments of the ground shaking hazard are typically made. In a probabilistic assessment, the objective is to calculate the probability (e.g., 10 percent) of exceeding a particular level of ground motion (e.g., a level of peak ground acceleration) at a specific site of interest (e.g., a city) during a specific interval of time (e.g., 50 years, the lifetime of an ordinary building). All of the seismogenic sources and travel paths are considered in the analysis. In a deterministic assessment, the objective is to calculate the ground motion for a specific scenario, usually with a specific earthquake source, a given magnitude, and a specific date.

Figure 3 shows some ground shaking hazard curves published by Dr. S.T. Algermissen of the U.S. Geological Survey. These hazard curves were based on a probabilistic assessment and are part of the 1988 edition of the NEHRP Recommended Provisions for Earthquake Resistent Design produced by the Building Seismic Safety Council.

The Ground Failure Hazard in 1811-1812

The 1811-1812 earthquake produced ground failure over a wide area. Sand craters and sandblows, some of which can still be seen, occurred in the Mississippi, Arkansas, Ohio, and St. Francis river flood plains. Liquefaction and landslides occurred over an area of about 6,000 square miles (15,000 square kilometers) in:

- o Southeast Missouri,
- o western Tennessee, and
- o northeastern Arkansas.

Such failures can be expected to occur again.

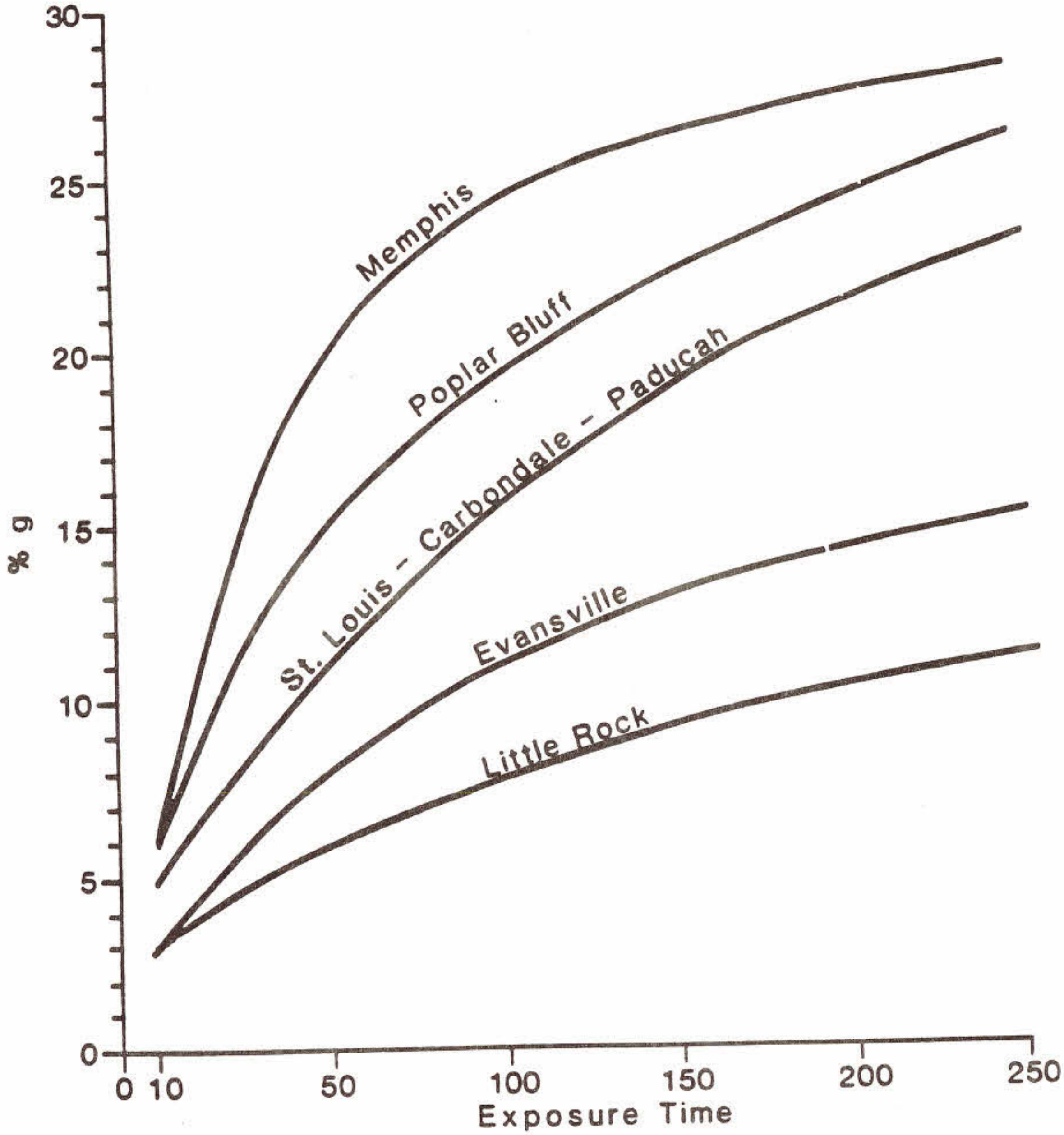

Figure 3: Earthquake Ground Shaking Hazard in Terms of Peak Horizontal Ground Acceleration (Algermissen and others, 1982)

The Surface Fault Ruputure Hazard in 1811-1812

No surface faulting occurred in the 1811-1812 earthquake.

The Regional Tectonic Deformation Hazard in 1811-1812

Vertical uplift and subsidence of 10 to 20 feet occurred in the epicentral region. Also, deep and long rifts formed in the soil. Reelfoot Lake was formed as a consequence of the earthquake.

Assessment of Risk

An assessment of the potential risk (chance of loss) from future earthquakes in the Mississippi Valley Region is a complex task. It requires an integrated evaluation of:

- o the earthquake hazards,
- o the inventory of structures, facilities, and lifelines exposed to the earthquake hazards, and
- o their vulnerability when subjected to the forces and displacements generated by these hazards.

These iterrelations are shown schematically in Figure 4.

A large percentage of the damage and spectacular building collapses in an earthquake are caused by ground shaking, although ground failures also can cause extensive damage. As the ground vibrates, buildings having different frequency-response characteristics begin to vibrate until all are vibrating. Sometimes resonance occurs when the response of the soil column and a building occur at the same period. This physical phenomenon is enhanced when the dominant period of the ground motion occurs at the same period as that of the soil and building response. Such conditions could exist in the Mississippi Valley Region where long-duration surface wave ground motion having dominanat energy in the 1- to 3-second period band propagate great distances because of the low attenuation rates. They are also dispersed in time. These factors increase the likelihood of damage to tall buildings located handreds of miles from the epicenter.

In addition to resonance, adjacent buildings having different heights and different fundamental periods of vibration can vibrate out of phase, pounding one or both of them to pieces. When the elastic strength of the building is exceeded, cracking and various other types of nonlinear behavior occur. These failures can lead to complete collapse of the building.

Some of the buildings, facilities, and lifeline systems are particularly vulnerable to short-period (high-frequency) ground motion; whereas, others are especially vulnerable to long-period (low-frequency) ground motion. Short stifflow-rise buildings and bridges are in the first category; chimenys, water tanks, high-rise buildings, and long-span bridges are in the second category. Buried lifeline systems (e.g., pipelines and tunnels) are more vulnerable to ground failure and fault rupture than to ground motion. Lateral spreads and debris flows can damage highways, railway grades, bridges, docks, ports warehouses, and single family dwellings.

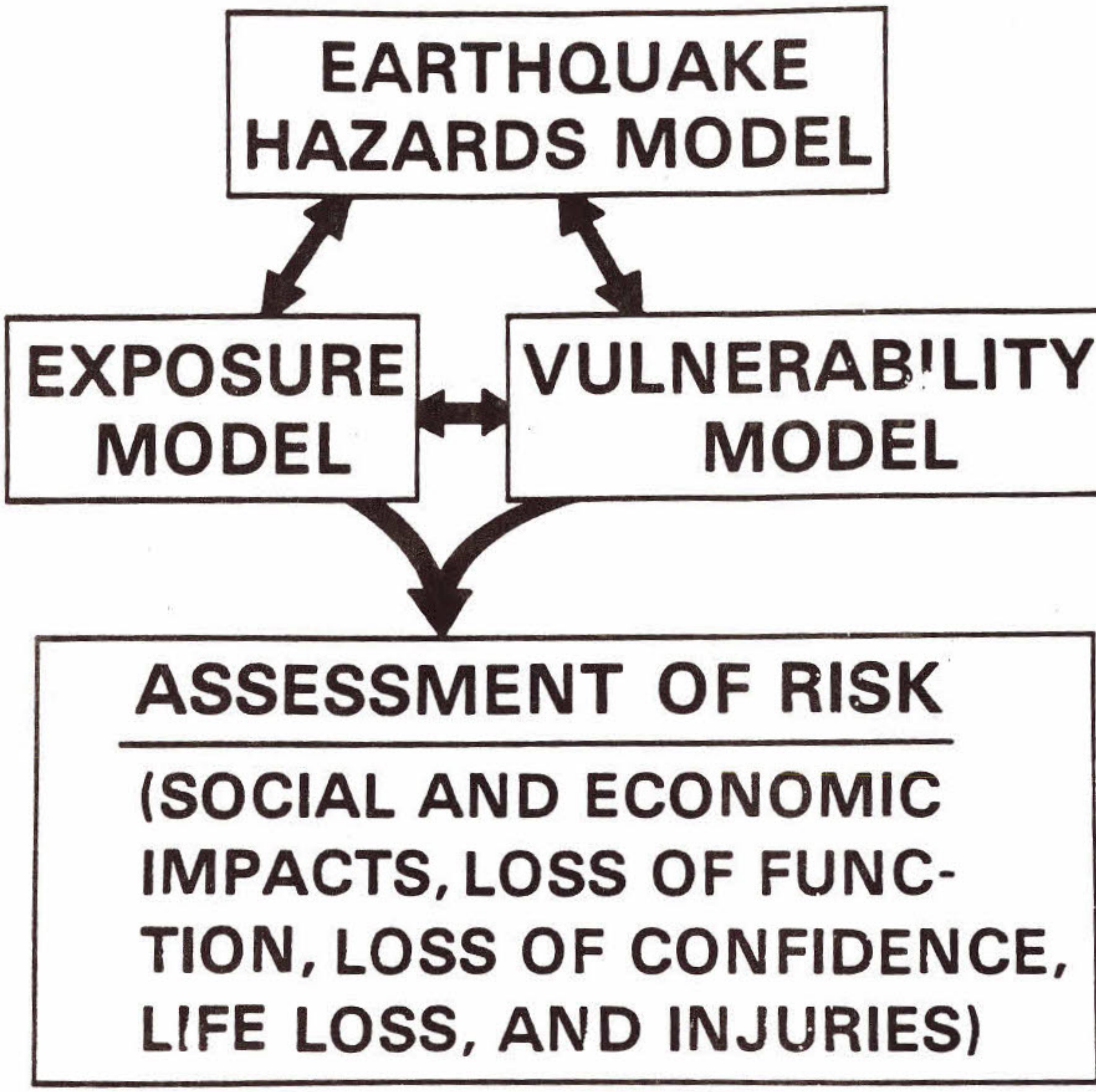

Figure 4: Interrelations of Hazards, Exposure, and Vulnerability.

Background References

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AN ASSESSMENT OF DAMAGE AND CASUALTIES FOR SIX CITIES IN THE CENTRAL UNITED STATES RESULTING FROM EARTHQUAKES IN THE NEW MADRID SEISMIC ZONE

FEDERAL EMERGENCY MANAGEMENT AGENCY

Central United States Earthquake Preparedness Project

October 1985

(prepared under contract # EMK-C-0057)

F O R

E M E R G E N C Y   R E S P O N S E   P L A N N I N G

P U R P O S E S

O N L Y

The primary purpose of this report is to assist emergency managers and planners in the development of response plans to deal with the consequences of major earthquakes in the central United States. This report is not intended for any other use.

In particular, the probabilistic methods which underlie the estimation of damage to structures and the resulting casualties, were developed and applied to yield such estimates only for groupings or aggregations of structures of similar types or purpose. For the level of analysis performed for this report, these techniques were not intended to provide damage descriptions for individual structures. No attempt should be made to use the findings of this report for other than the above stated purpose.

EXECUTIVE SUMMARY

I - General

The Central United States Earthquake Preparedness Project (CUSEPP) is an on-going effort to reduce the hazards associated with earthquakes through determination of the potential consequences of major earthquake events in the New Madrid Seismic Zone, an increase of the awareness of those consequences among public officials and the private sector, the development of response plans for coping with them, and the implementation of actions for reducing them. This report, supported by estimates of ground shaking developed by the U.S. Geological Survey, provides preliminary estimates of the potential consequences of two major sizes of earthquakes in six cities within or near the seismic zone. These cities are: Little Rock, Arkansas; Carbondale, Illinois; Evansville, Indiana; Paducah, Kentucky; Poplar Bluff, Missouri; and Memphis, Tennessee. The cities were chosen on the basis of several factors: 1) population size in relation to the preliminarily identified areas of damage intensities, 2) architectural types and, 3) cooperative environment of the city to be studied. Only those parts of the urbanized area actually within the designated corporate limits of each city were surveyed and studied.

The earthquake effects studied are based upon the ground shaking estimates of two sizes of events, having surface magnitudes (Ms) of 7.6 and 8.6. The reader will note that the effects on the six cities combined are maximized since the estimate of ground shaking assumes that the epicenter of each earthquake scenario is located as close to each city as possible within the entire New Madrid Seismic Zone. The

Ms=8.6 event allows assessment of the upper limits of damage and needs. The 7.6 earthquake represents an event with a greater probability of occurrence, and can be viewed as more appropriate for realistic risk assessment and subsequent emergency management measures.

The selection of these magnitude events for CUSEPP planning is reasonable from at least two points of view. First, such earthquakes have actually occurred in this region; each of the "great" earthquakes of 1811 and 1812, which are widely referenced in earthquake literature, had surface magnitudes above 8.0 on the Richter Scale and approximate the size of the larger (Ms=8.6) earthquake. The 1811-1812 series also included hundreds of aftershocks, many with magnitudes estimated to be between 6.5 and 7.6. Second, recent earthquake research has theorized that current strain in the New Madrid Seismic Zone would create a Ms=7.6 earthquake if it were all released today and, further, that the probability for the occurrence of such an event during the life span of existing and planned structures and the lifetime of persons now living does exist.

The occurrence of either Ms=8.6 or Ms=7.6 earthquakes would result in damages, disruption, casualties, and injuries on a scale never experienced from a natural hazard in the history of this nation; the immediate and long term relief and recovery efforts would place a significant, prolonged burden upon the regional and national economy.

Of equal, if not greater importance is the fact that earthquakes of lesser, yet significant, power are much more likely to occur.

Moderate sized earthquakes are a very real hazard for the CUSEPP planning area. The serious (though localized) damage in Coalinga, California which resulted from the May 2, 1983 event (6.5 on the Richter Scale), demonstrates the damage which can be caused to an area by a moderate earthquake that does not have a high level of seismic design in construction. Due to the different soil conditions and overall lack of adequate seismic design in structures in the Mississippi Valley region, a New Madrid quake could be expected to cause much more extensive and widespread damage than resulted from an event of similar magnitude in California. However, since expected effects of the moderate sized event are encompassed within the effects of the events examined here, a separate scenario for the moderate event is not presented.

To estimate the effects of earthquakes (magnitudes 7.6 and 8.6) in the New Madrid Seismic Zone on the six cities, the following procedures were employed. Structural inventory and critical facilities data were collected and supplemented in some cases by further investigations. Estimated levels of ground shaking in the six cities are expressed in Modified Mercalli Intensities and were provided by the U.S. Geological Survey for both the Ms=7.6 and Ms=8.6 earthquakes. These estimates depict ground shaking intensities which would be expected if each earthquake's epicenter were as close as possible, along the fault zone, to each studied city. On the Modified Mercalli Intensity scale, these estimates ranged between V and X. To assess expected structural damage, a series of fragility curves, (which describe the probability of damage states as a function of the level of ground shaking), were developed for sixteen different types of structures common to the six cities. These structural types included buildings, utility plants and systems, dams, bridges and storage tanks. The fragility curves were applied to the inventoried structures, usually grouped according to a function, to determine the expected damages at the ground shaking intensities estimated for the structure's location. Casualty estimates were based on the expected number of occupants of the buildings and the level of damage estimated to occur to them. Average building occupancies were derived from census data, employment data and inventory data. Restoration and replacement costs were estimated for those structures and systems for which damage estimates were made and were based on average construction costs in the cities studied, and the damage sustained. These determinations of damage, casualties and costs are preliminary estimates derived from implementation of a preliminary vulnerability assessment methodology and should be utilized accordingly.

If exposed to an occurrence of either of the postulated earthquakes, the six project cities would suffer varying effects. The following sections of this summary are a discussion of the overall effects and probable consequences for the six cities.

II - Casualties

The number of casualties (deaths and injuries) resulting from occurrence of either of the postulated events would depend on the time of day at which it occurred. At night, most of the population is found in relatively safe wood frame residential structures, but during a typical working day the majority of the population moves to buildings which are much more vulnerable to severe structural damage or collapse. A substantial proportion of the daytime casualties would occur among school children. Total daytime deaths in the six cities could easily exceed 4,500, as shown in the following summary:

Total Estimated Deaths
Due to Structural Failure

	Ms=7.6 Event			Ms=8.6 Event		
	Night	Day	School Deaths as % of Day Deaths	Night	Day	School Deaths as % of Day Deaths
Memphis	211	2523	26	435	3786	27
Paducah	47	116	18	101	201	19
Carbondale	29	74	30	69	160	25
Evansville	23	227	32	58	492	32
Poplar Bluff	1	17	88	4	52	81
Little Rock	3	64	16	9	216	17
Total	314	3021	26(avg.)	676	4907	27(avg.)

III - Medical Services

Medical services in the six cities would be severely burdened to provide adequate care for all injured persons requiring medical attention, except perhaps in Little Rock. Outside assistance may be a viable consideration for planners to alleviate this situation. Health care professionals would encounter difficulty reaching their places of work, and a few (less than two percent) would be among the dead and injured. The normal availability of beds and medical supplies would be reduced because of severely damaged or collapsed hospital structures. Memphis would be the most severely affected as seen in the following table.

City	Hospital Structures Surveyed	Hospital Beds Estimated to be Available: Ms=7.6 Event Number	% of Total	Ms=8.6 Event Number	% of Total
Memphis	25	3230	52	2290	37
Paducah	7	720	89	600	74
Evansville	20	2020	90	1620	72
Poplar Bluff	7	690	90	590	77
Carbondale	6	190	95	160	79
Little Rock	13	3760	100	3720	99
Total	78	10,610	86 (Avg)	8980	73 (Avg)

Most of the cities would not have sufficient surviving beds to accommodate the number of major injuries estimated in this report in addition to their normal load of patients. Other services would be similarly affected. The number of seriously injured persons requiring prompt medical attention would be about four times the number of deaths in each city. Additional casualties could also result from fires and flooding.

IV - Transportation Systems

Damage to transportation systems would seriously hamper rescue and relief efforts and would have an extensive adverse effect upon regional and national commerce.

Highway access to Memphis as well as major highway availability within the city would be severely limited for both seismic events. With the Ms=7.6 event, the most probable surviving access route would be U.S. 72 from the east; bridge collapses would either cut or block most, but probably not all, of the eight other principal arteries into the city. Poplar Bluff would be vulnerable to loss of highway access from the east. Paducah's highways would suffer some damage, but no serious loss of accessibility would result. Little loss of highway accessibility would occur in Carbondale and Evansville, and almost no serious highway damage would take place in Little Rock.

Damage to railway networks would follow a pattern similar to the highway damages. Little Rock would probably suffer no loss in rail accessibility; Evansville would experience little or none. Carbondale could suffer impaired accessibility from the west, while Paducah is most vulnerable to rail losses to the north (crossing the Ohio River) and from the east. The cities likely to suffer greatest disruption are Poplar Bluff and Memphis. Rail access from all directions into Poplar Bluff would be at risk of serious impairment, though not to the extent expected in Memphis, where over 75% of all system sections have relatively low survival probabilities.

These assessments are based on the likelihood of collapse of highway and railway structures. Some of the rail and highway structures which did not collapse would suffer severe damage that would restrict or prevent their use by heavy vehicles.

For both earthquakes, railway traffic would be stopped for as long as required to inspect all structures in each line segment, possibily 24 to 48 hours. For that reason, the most immediate transportation needs into and out of the six cities would have to be met via highway and air transport, and possibly by river access, although port facilities are likely to be seriously damaged.

River ports are expected to be extensively disrupted, with the minimum disruption occurring in Little Rock. The cities of Carbondale and Poplar Bluff do not possess river port facilities and thus would not be directly affected. Memphis, Evansville and Paducah are expected to sustain substantial damage to their river ports facilities.

Partial or limited availability of major airport facilities is expected following either earthquake. Those facilities at airports which rely on electrical power, e.g., navigation aids and runway lighting, may be out of commission for a period of time, even if emergency power is available. Runways may be available, at least for limited use, even in cities closest to the fault zone. Runways may sustain certain kinds of damage but still have enough useable length to allow landings and takeoffs of aircraft bearing vital supplies. The loss of navigation and landing aids can be significant, especially during winter when weather conditions are frequently marginal or below landing minimums.

V - Utility Systems

The six cities studied, for both earthquake events, are expected to experience serious impairment or loss of their four main utility systems (electric, water, gas, and sewers). Little Rock will lose availability of all systems in an Ms=8.6 event but may not lose availability of all systems for the Ms=7.6 event. Those which are out-of-service after the Ms=7.6 event are likely to be restored relatively quickly. Systems in the other five cities, for both events, will be unavailable for periods of days to months due to likely shortages of supplies, equipment and workers to restore the systems. The most essential and, unfortunately, the most vulnerable of the utility networks, are the electric power systems. So many things depend upon the availability of electric power that even its short term loss, under normal conditions, is a major setback to a community. To superimpose a loss of electric power upon a severe and widespread disaster can mean, for example, no water to fight fires or for drinking and sanitation; no light or heat; no communications; and no sewage pumps. The following summary presents the estimated availability of utility systems for the six project cities for the Ms=7.6 event. All systems are expected to be unavailable for the Ms=8.6 event.

City	Estimated Availability of Utility Systems Ms=7.6 Event			
	Electric	Water	Gas	Sewer
Memphis	U	U	U	M *
Little Rock	U *	A	M *	A
Evansville	U	U	U	U
Paducah	U	U	U	U
Carbondale	U	U	U	U
Poplar Bluff	U	U	U	U

U - System likely to be unavailable.
M - System may be available.
A - System likely to be available.
* - Limited and/or modified use possible.

VI - Critical Facilities

In addition to the examination of critical lifeline systems (utilities, hospitals, communications and transportation), the six cities' vulnerability to earthquakes includes an assessment of facilities that will be crucial to each community's ability to conduct and monitor its immediate response to the estimated losses, particularly those involving life protection. These facilities include police and fire stations, ambulance services, blood banks and clinical laboratories. In general, Little Rock and Evansville were found to be the relatively least vulnerable to damages to these structures while Memphis, Poplar Bluff and Paducah are the most vulnerable.

VII - Flooding

Were the earthquake to occur at a time when high water conditions (i.e. 100 year flood) existed in the area's rivers and streams, flooding of low-lying areas, now protected by levees, is likely to occur. This is because levees are expected to be damaged sufficiently to allow flooding behind them. Earthen dams, however, are not expected to be damaged to the extent that they will lose their reservoirs. This finding, combined with the situation that low or flood-prone areas in the six cities are mostly undeveloped and unoccupied, indicates that relatively few casualties would be expected due to flooding following the postulated seismic events. Flooding would, however, result in displaced persons and would hamper relief efforts.

VII - Fires

Giant fires, or conflagrations, involving major portions of the six cities are unlikely as a direct result of the scenario earthquakes, due to the nature and density of construction. Widespread individual or small-group structural fires are likely, however, due to miscellaneous damage-related factors, (i.e. gas leaks, flammable liquid spills, electric shorts, etc.), and loss of fire suppression capabilities.

VIII - Shelter Requirements

Many individuals will require shelter when their dwellings are rendered uninhabitable by actual earthquake-caused damage, flooding and other causes. These persons may have available alternative shelter in surviving, relatively undamaged structures (following inspections). The following is a listing of the estimated numbers of persons requiring shelter in the six cities:

Persons Likely to Require Shelter
Due to Damage to Residence

City	Due to Flooding	Ms=7.6 Event	Ms=8.6 Event
Memphis	10,100	231,680	353,800
Little Rock	3,500	2,440	21,700
Evansville	24,600	11,095	38,900
Paducah	5,000	13,318	22,600
Carbondale	-	5,728	11,100
Poplar Bluff	-	5,743	10,600
Total	43,200	270,004	458,700

Section IX - Restoration/Replacement Costs

The financial and economic burden placed upon the region and the entire nation by an occurrence of such a disaster would be very great. The following summarizes a part of such costs (restoration and replacement) for the six cities.

Estimated Restoration/Replacement Costs
(Millions of Dollars)

City	Ms=7.6 Event			Ms=8.6 Event		
	Structures	Utilities	Total	Structures	Utilities	Total
Memphis	$22,095	2,908	25,003	27,609	4,071	31,680
Little Rock	1,463	454	1,917	2,886	955	3,841
Evansville	4,781	360	5,141	7,395	595	7,990
Paducah	3,002	1,395	4,397	3,846	1,952	5,798
Carbondale	809	257	1,066	1,185	387	1,572
Poplar Bluff	558	135	693	858	217	1,075
Total (Millons of Dollars)			$38,217			$51,956

X - Summary

In summary, the impact of either the Ms=7.6 or Ms=8.6 earthquake on the six cities would be massive and could cause widespread disruption, damage, and casualties. Remaining resources within the affected region would be unable to adequately provide for the emergency response needs of these communities. This indicates that very large scale outside support and assistance of all kinds may be the primary means to reduce further loss of life, suffering and disruption to regional lifelines. It is hoped that the information contained within this report will be a meaningful step toward the development of appropriate national, regional and local response plans, and longer range strategies.

XI - Organization of this Report

The material contained in this report can be divided into two major areas. The first, Sections 1 and 2, describes the overall project and its methodology. The second, Section 3, is a presentation of the project's findings and consists of an initial general section which contains discussions of each results category, and which also presents findings and conclusions pertaining to all or most project cities collectively. Then follow the six sub-sections presenting and discussing the findings for each project city. An estimation of replacement and restoration costs, glossary, abbreviations list and a bibliography conclude the report.

Hypothetical intensity map for Little Rock:

Intensity VII M.M. is projected at Little Rock on the regional map (Figure 7) for an epicenter near the south end of the New Madrid seismic zone. Little Rock is 170-360 km away from earthquakes in the New Madrid seismic zone, and experienced intensities of IV, V, and I-IV in 1843, 1895, and 1968 (table 4 and Appendix 4).

At Little Rock the hypothetical intensities change from VIII for river and stream alluvium to VI for the neighboring sandstone, shale, and limestone hills of the rest of the city. Landslides are unlikely for most of the city, but a few small landslides might occur along some of the steeper bluffs. There is a moderate potential for liquefaction in the flood plain deposits (area shown as VIII in figure 3), although no geologic evidence of previous liquefaction in the area has been found.

STUDIES OF SIX CITIES

Maps of the six cities studied individually are shown in figures 1-6. The intensity in general in the area of a city can be determined from the map of hypothetical regional intensities, figure 7. But to zone a city in greater detail it is necessary to have some knowledge of the local geologic conitions. For this purpose, field investigations were made for each of the six cities in this study.

The assigned intensities on each city map are intended to be the maximum intensities likely--that is, those that would occur if the assumed 1811-size earthquake occurred on the part of the New Madrid seismic zone nearest that city. All of the cities would not experience these worst-case intensities at the same time. For example, if the assumed earthquake occurred near the south end of the zone, Memphis would in fact experience the IX's and X's shown in figure 7, but Evansville, which is north of the zone, and which is projected in figure 6 and figure 7 to have a maximum intensity of IX, would likely experience only intensity VIII effects. Similarly, if the earthquake were at the north end of the seismic zone, Evansville would have the IX shown, while Memphis would probably experience only intensity VIII-IX effects. However, since in the 1811-1812 series three great shocks all occurred within a short period of time (December 16, 1811 to February 7, 1812), it is possible that the cities might all experience the maximum intensities more or less contemporaneously.

The intensities shown on figures 1-6 take into account both the regional map intensity (figure 7) and the local geologic conditions at each city. The regional map gives the highest common intensity for each city, but it is the local geologic conditions that determine the actual differences in

HYPOTHETICAL INTENSITY MAP, 1811 SIZE EARTHQUAKE

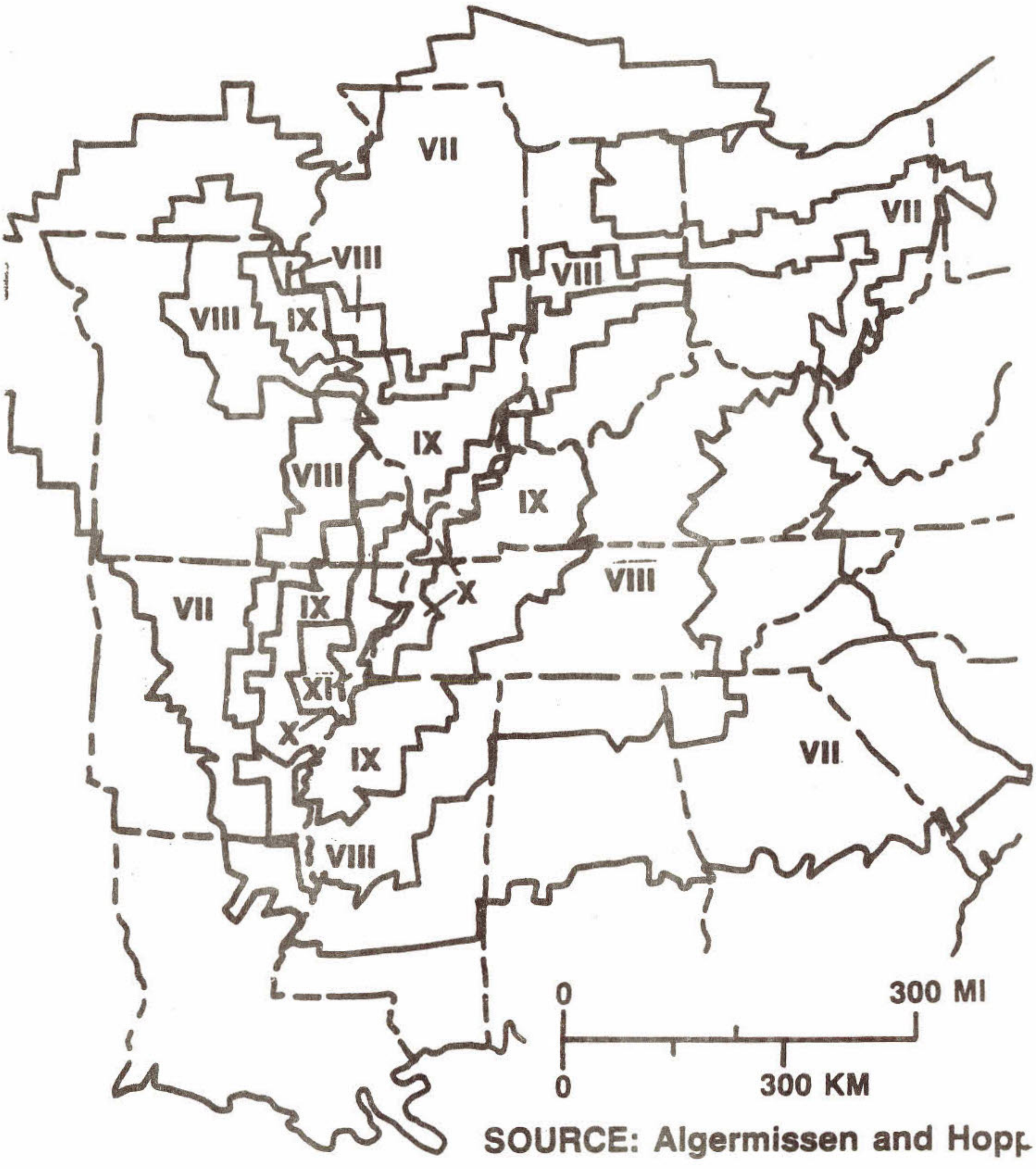

Figure 7. Regional Intensity Map, 1811 Size Earthquake.

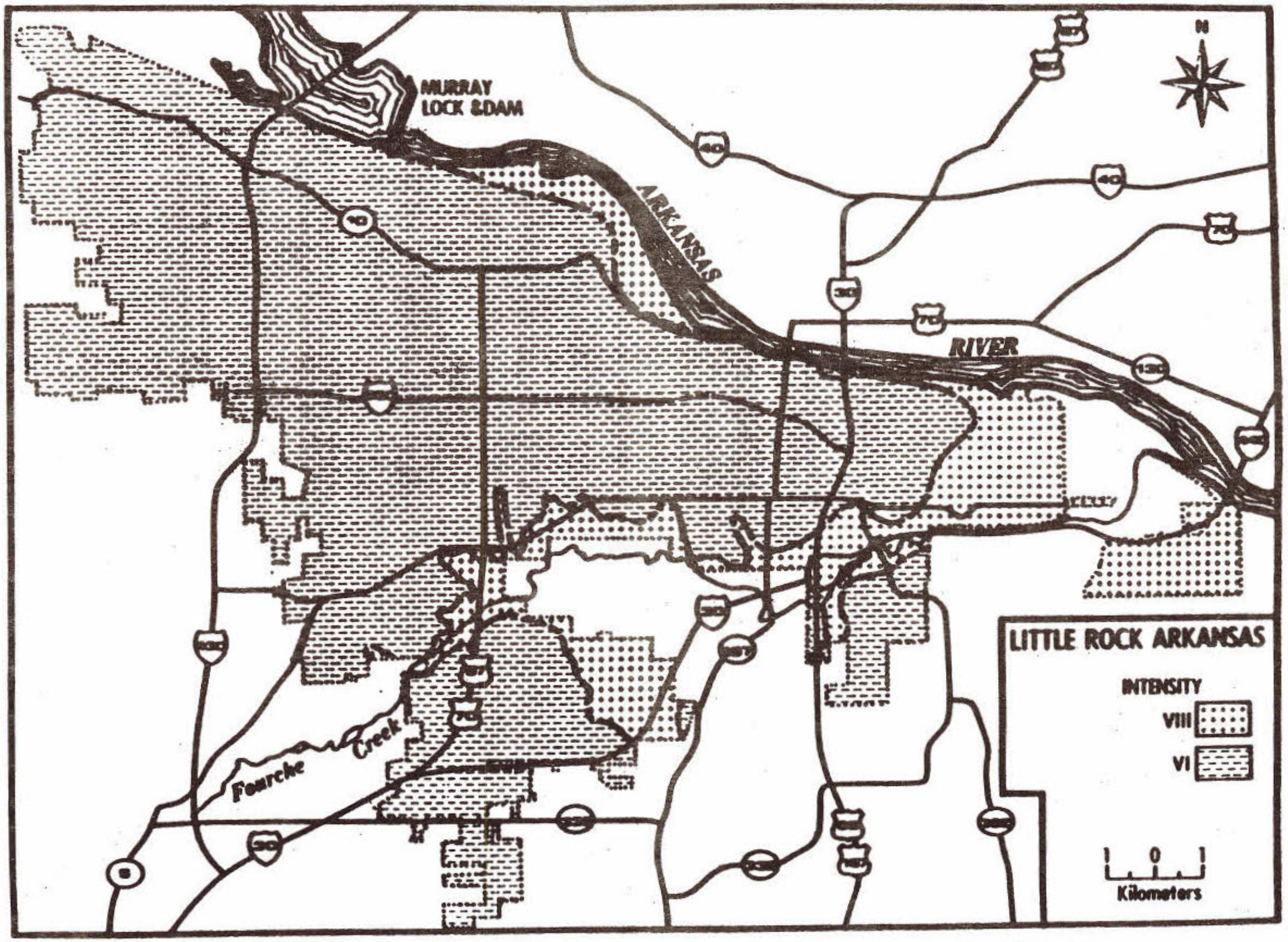

Figure 3 __Hypothetical intensity map for Little Rock, Arkansas. For an earthquake near the south end of the New Madrid seismic zone, intensities projected for Little Rock are: VIII on the river alluvium, but only VI on the sandstones, shales, and limestones of the hills. For an earthquake near the north end of the New Madrid seismic zone, the intensities at Little Rock would be lower.

intensities within each city. For example, one city (Carbondale, figure 5) has so little significant geologic variation as to be assigned only one intensity throughout, IX. Paducah (figure 2), on the other hand, has conditions likely to produce most severe damage along the river and sucessively lower intensities, in areas with different conditions, away from the river; the most stable locations in Paducah are thought to be two intensity levels lower than the area along the river. Thus three intensity levels are shown for Paducah. Poplar Bluff and Little Rock (figures 4 and 3) are also thought to have differences of two intensity levels, but with no intermediate-level intensity. Thus at Poplar Bluff the intensity drops abruptly at the edge of the bluff along the Black River from X in the Mississippi River alluvial plain to VIII on the uplands. Finally, geologic conditions at Evansville and Memphis suggest a difference of one intensity level.

Little Rock, Arkansas

Physiographic description:

Little Rock is situated on the border between the Ouachita province and the Mississippi Alluvial Plain (Fenneman, 1938). Most of the city is located south of the Arkansas River, west of the Mississippi Alluvial Plain, and north of Fourche Creek in the subdued Ouachita Mountains. Within the city area these mountains have a maximum total difference in topographic relief of about 150 feet (46 m) above the Arkansas River. By comparison the Mississippi Alluvial Plain and the Arkansas River flood plain exhibit little topographic relief.

Underlying material:

Most of the city is underlain by the Jackfork Sandstone of Pennsylvanian age (Haley and others, 1976); some shale is interbedded with the sandstone and a fairly thick shale bed is present at the base of the bluff along the Arkansas River near the Murry Lock and Dam. These rocks have been intricately thrust faulted; the faults are inactive; most of them trend east-southeast and the attitudes of the beds vary over short distances.

A part of the city north of Fourche Creek is underlain by Tertiary age interbedded sand, calcareous clay, limestone, silty clay, and silt of the Midway and Wilcox Groups (Haley and others, 1976, and Gordon and others, 1958); these materials are here about 65 feet (20 m) thick.

Along the Arkansas River and where it passes into the Mississippi alluvial plain the underlying material generally consists of dense silty sand, sand, silty clay, and gravel.

Residual soils developed on the Jackfork Sandstone are a gravelly silt loam, shallow to fairly deep, and moderately permeable; soils developed on the Wilcox and Midway Groups are a silty to sandy loam, shallow to fairly deep, and slowly to moderately permeable (Haley, Bickner, and Festervand, 1975, and Soil Conservation Service, 1967).

Physical property tests and other information:

Well logs of three test hole borings were provided by Mr. Jake Clements, Engineer with the Materials and Tests Division, Arkansas Highway Department, Little Rock. Two logs at the Arkansas River crossing of I-440 indicate that the material consists mainly of silty sand in the upper 20 to 30 feet (6 to 9 m) and sand and gravel below that to the depths of the holes, which terminated at 62 feet (18.9 m) and 110 feet (33.5 m); the material is non-plastic, and N values for standard penetration tests range from about 10 in the upper part to 32 and 52 in the lower parts. The log in alluvium along Fourche Creek east of the intersection with U.S. highway 65 consists mainly of silty clay, and sand and gravel near the bottom of the hole at a depth of 55-60 feet (17-18 m); N values are variable; they range from 5 to 10 in the upper part and 41 in the lower 5 feet (1.5 m) of the test section.

According to Mr. William Bush, Geologist, Arkansas Geological Commission, landslides are a minor problem in the vicinity of Little Rock. A landslide occurred at the south end of High Street north of the Chicago, Rock Island and Pacific railroad tracks; it was caused by oversteepening of an artificial cut (Michael Batie, City Engineer, Little Rock, oral communication, 1982). There is also evidence of sloughing and minor landsliding in the bluff along the Arkansas River near the Murry Lock and Dam.

Geologic mapping in the vicinity of Little Rock has not revealed any surficial features that could be attributed to liquefaction (Boyd Haley and William Bush, oral communication, 1982).

Potential for landslides, liquefaction, and other geologic effects:

1) Landslides. Landslides in response to strong earthquake vibrations are unlikely throughout most of the city. However, sloughing and small landslides could occur along some of the steeper bluffs.

2) Liquefaction. The liquefaction potential is very low for the part of the city underlain by the Jackfork Sandstone and by units of the Midway and Wilcox Groups. The liquefaction potential is probably low to moderate for the part of the city underlain by flood plain deposits of the Arkansas River and the Mississippi Alluvial Plain.

III. Exercises

Section 5

Geoscience—Field Investigation

Equipment to Take

1. Hand-held inclinometer.
2. Optical survey equipment.
3. Maps. Every effort should be made to acquire a reasonable topographic map of the affected area prior to departure. A 1:100,000 scale map is good for a regional overview. Maps of 1:25,000 or less are better for more focused and site-specific concentration. Geologic maps and hazard maps (if available) are quite useful. Aerial photos, including stereo pairs, can be especially helpful. If time is available, topographic maps can be obtained from a variety of library services. Aerial photos can be obtained from institutions such as USGS, USGS/EROS (Earth Resources Observation Systems), U.S. Department of Agriculture, and the Department of the Army (see Appendix C).

Type of Data to Be Collected and Recorded

Collect information on the tectonic setting, faulting, ground motion, surface manifestations, seismicity, shock parameters, aftershock sequence, etc.

Checklist

Geoscience

Regional Earth Movements—Tectonic Origin

1. Note location.
2. Describe fault(s).
3. What is relationship of fault(s) to local geologic structure and stratigraphy?
4. What is joint system?
5. Note post-earthquake gravity measurements.
6. Note post-earthquake P- and S-wave velocity measurements (from aftershocks).

7. What were pre-earthquake P- and S-wave velocity measurements?
8. Describe type of earth materials in slope.

Characteristics of Causative Fault

1. Note name of fault and its location (latitude and longitude).
2. Note type of fault. Indicate strike and slip.
3. Describe direction of movement.
4. What is total length of causative fault (m)? What portion ruptured?
5. Draw geologic cross-section of fault to "basement rock" indicating nature of earth materials on each side of fault (use back of field inspection form).
6. Describe expression of fault trace (continuity, straight, curved, sinuous, single or multiple), mole track, scarps, graben, parallel or en echelon fractures, sag pond, other.
7. What is relationship between main fault and subsidiary faulting?
8. Describe compression or tension features.
9. If there is evidence of fault creep, note location, amount, and direction of movement. Was it caused by a foreslip or afterslip? What was its relationship to aftershocks?
10. Note any new faulting in old fault zone.
11. Develop strain maps.
12. Plot damage pattern on geologic map for better correlation between Modified Mercalli Intensity an geology.
13. If underwater, note depth, sea conditions, current velocity (m/sec) and direction, and wave height.

Acceleration

1. Describe peak and general level accelerations as a function of orientation to source magnitude, type of faulting, radiation pattern, travel paths, distance, regional and local geology, and water table depth.
2. Describe nature of ground acceleration (direction of motion, etc.) close to and at a distance from the fault.
3. Collect ground motion data from instrumented buildings.
4. Examine the compatibility of main shock accelerograph records of basement and free-field motions.

5. Aftershock measurements, if adopted, should be quickly implemented in order to catch some of the larger aftershocks. It is very important to coordinate with seismologists regarding the location of seismometers.

Duration of Motion

1. Correlate duration of motion (from strong-motion records) as a function of magnitude, distance, local geology, and depth to water table.
2. Relative importance of duration of motion and ground failures as a function of local geology.
3. Duration of motion, damage to engineered structures, and arrival of P, S, Love, and Rayleigh waves.

Topographic, Focusing, and Resonance Effects

1. Describe apparent focusing of energy due to subsurface geology, wave guides, and wedge or boundary effect.
2. Note existence and importance of shadow zones.
3. What is relative importance of focusing and resonance in alluvial valleys?
4. What is importance of topographic effects on landslides and engineered structures?
5. Document any areas of anomalous high or low damage.
6. Characterize effects of topography, focusing (basement-complex geometry), and resonance as a function of distance, magnitude, and seismic wave type (body and surface waves).
7. Note general travel path effects (regional geology) such as reflection and refraction.

Field Investigation Form—Geoscience

Name of Investigator:________________________ Date:___________

Regional Earth Movements—Tectonic Origin

Uplift:____________________Subsidence:________________________

Location:____

Regional and local tilting and ground warping:__________________

____

Post-earthquake gravity measurements:__________________________

Post-earthquake P- and S-wave velocity measurements (from aftershocks)

____

Pre-earthquake P- and S-wave velocity measurements:________________

____

Characteristics of Causative Fault

Name of fault:____

Location (latitude and longitude):________________________________

Type of fault:_________________Direction of movement:______________

Draw geologic cross-section of fault to "basement rock" indicating nature of earth materials on each side of fault (use back of this sheet).

Total length of causative fault: (m)______________________________

Length of entire fault related to ruptured fault: (m)__________________

Total length of rupture: (m)_______________ Width: (m)______________

Compression or tension features:__________________________________

Describe geologic structure on each side of fault (map units, bedding and/or joint attitudes, other faulting):________________________________

____

____

Expression of fault trace (continuity, straight, curved, sinuous, single or multiple), mole track, scarps, graben, parallel or en echelon fractures, sag pond, other:____

____

____

GEOSCIENCE

Geoscience—
Recommendations for Further Research

Name of Investigator: ______________________ Date: __________

Location: ____

Why needed: ____

Trenching and/or Boreholes

Where, how deep, how many: ____________________________

Why: ____

Instrument Installation

Type and number: ______________________________________

Aftershock Studies

Location: ____

Engineering importance: _________________________________

Type of fault mechanism: ________________________________

Topographic effects: ____________________________________

Geology and soils: ______________________________________

Well water monitoring (elevation and chemical composition): ________

____

Geophysical Surveys

Location: ____

Engineering importance: _________________________________

Recommendations for study: ______________________________

Section 6

Geotechnical—Field Investigation

Equipment to Take

1. Hand-held inclinometer.
2. Optical survey equipment.
3. Maps. Every effort should be made to acquire a reasonable topographic map of the affected area prior to departure. A 1:100,000 scale map is good for a regional overview. Maps of 1:25,000 or less are better for more focused and site-specific concentration. Geologic maps and hazard maps (if available) are quite useful. Aerial photos, including stereo pairs, can be especially helpful. If time is available, topographic maps can be obtained from a variety of library services. Aerial photos can be obtained from institutions such as USGS, USGS/EROS (Earth Resources Observation Systems), USDA, and the Department of the Army (see Appendix C).

Type of Data to Be Collected and Recorded

Determine the effects that earth deformations and strong ground shaking had on structures. Cracks, fault widths, uplift, subsidence, tilting, or warping should be measured and noted. Surface expressions of the causative fault should be examined and documented. Where appropriate, draw geologic cross-sections to indicate the nature of earth materials. Inspect and assess the performance of engineered structures with respect to strong ground motion and earth deformations such as settlement, liquefaction, ground cracking, landslides, and ground offset.

Checklist

Geotechnical

General Site Evaluation

1. What is orientation of the site relative to magnetic north?
2. What is the topography around the site?
3. Note location of sand boils and identify any material ejected.
4. Is there evidence of soil deformation?
5. Are any parts of the site on cut or fill? Can an estimate be made of the depth of the cut or fill just by looking?

6. Obtain as much information as possible on thickness and composition of soils.
7. Estimate slopes with hand-held inclinometer or optical survey equipment.
8. Is the site on alluvium? Inquire as to its depth.
9. Determine type of soil: soft soil, loose sand, unconsolidated silt, loam, mud, dump fill, firm soil, gravel, consolidated sand, consolidated silt.
10. What is drainage of site? Above or below grade?
11. Obtain as much information as possible about depth of water table on both sides of causative fault and throughout affected area.
12. Obtain a Mercalli estimate for the site.
13. Evaluate the overall quality of construction and the use of good seismic practices.
14. Investigate areas where amplification of ground motion may have taken place (topographic ridges, structural basins, soft and sensitive clays, etc.).
15. Contact local geotechnical professionals to obtain information on local subsurface conditions, applicable codes, design and construction procedures, etc. Get name and telephone numbers of those contacted.

Ground Deformation

1. Document length and width of rupture.
2. Describe original displacement or renewed displacement on old fault trace.
3. Did any additional displacements (mainshock or aftershock) occur on nearby or subsidiary faults?
4. What is relative offset? Does offset change (along fault) as distance from epicenter increases?
5. Plot on geologic map: seismic data (instrumental and other) and contours for possible attenuation pattern(s).
6. What was amount of fault separation (slip)? Describe horizontal, oblique, and vertical characteristics. Note location of measurement.
7. Describe uplift, subsidence.
8. Did regional and local tilting and ground warping occur?
9. Identify locations of soil liquefaction.
10. Describe soil liquefaction according to flow failure, lateral spread, subsidence, loss of foundation bearing, and buoyancy effects on buried structures.

11. Describe in-place soil parameters and ground failures such as relative density versus liquefaction.
12. Note slickensides, gouge, fault breccia, other.
13. What is relationship of fault scarp formation and height to local geology, bedrock structure, and geomorphology. Include location.
14. Describe any secondary permanent effects.
15. Document post-earthquake fault creep.
16. Describe geologic structure on each side of fault (map units, bedding and/or joint attitudes, other faulting).
17. If underwater, note depth and sea conditions (velocity, direction, wave height).

Soil-Structure Interaction

1. What is relationship between ground failure displacement and damage to engineered structures?
2. Liquefaction:
   a. What is distribution and severity of liquefaction effects with respect to the source zones of the earthquake?
   b. Assess the consequences of liquefaction (e.g., vertical and lateral displacements).
   c. Assess the performance of structures supported on deep foundations compared to those supported on shallow foundations in liquefied areas.
3. Note cracks in the soil around the base of the structure.
4. Is there foundation or subsoil evidence that the building rocked?
5. Note in particular the performance of stiff, massive structures that rest on flexible soil.
6. Try to correlate superstructure damage with local soil conditions. Geologic maps and soil boring data may be needed.
7. Pay particular attention to damage at locations of soft, sensitive clay. Target the areas for soil borings and in-situ tests.
8. Investigate infilled basins where amplification of ground motions through soft sediments is most likely. Document observations.
9. Was there damage to engineered structures? If so, note type of structure and specify damage and cause. Examine buried as well as surface structures.
10. Comment on any structures not damaged.
11. Examine footings of bridge and pipeline crossings for evidence of lateral spreading. Describe any damage. Observe soil-structure interaction. Observe response of deep foundations and piles to ground movements.

12. Note performance of reinforced earth and other mechanically stabilized walls.
13. Note performance of earth and rock anchor tied-back walls.
14. Note performance of both hazardous and municipal landfills.
15. Note performance of retaining structures, including open fully or partially supported excavations, bridge abutments, etc.
16. Describe any movement of basement contents.

Landslides and Submarine Slope Failure

1. Indicate failures on geologic/topographic map.
2. Note latitude, longitude, area involved (m2), quantity (m3).
3. What was cause of failure?
4. Describe failure, including direction and rate of movement, soil and rock types, and groundwater conditions.
5. What was original slope angle? Ridge orientation?
6. Was this a new slide or a reactivated old slide?
7. Was this a natural or man-made slope?
8. What was time of failure relative to start of ground motion?
9. Was slide composed of artificial fill? If so, note age, type of construction, materials, and degree of compactive effort.
10. Describe any pressure ridge or graben development, including width, length, and depth.
11. Note distribution and frequency of landslides as a function of distance from the epicenter.
12. Document damage to engineered structures.
13. Describe other damage caused by ground failure.

Settlement

1. Describe settlement, including cause (compaction, consolidation, liquefaction).
2. Describe earth materials involved (age, type, sorting, grain size, water content, depth to water table, thickness, artificial fill including age and type of consolidation).
3. What was the amount and extent of settlement? Of differential settlement?
4. Look for settlements at bridge and overpass abutments. Correlate settlement with bridge damage and damage to pipelines that may cross beneath the bridge.
5. Did mud or sand boils occur? If so, note location. Note amount and type of any material ejected.

6. Describe type and extent of damage to engineered structures (surface and buried, artificial fill, other).
7. Describe other damage caused by settlement.

Ground Cracking

1. Take note of geometry, including overall dimensions and slope. Draw geologic cross-section (use back of field inspection form).
2. Describe location, length, width, depth, spacing, and attitude of ground cracking.
3. What type of surface materials (age, thickness, etc.) are involved?
4. Describe any extension or compression features.
5. Describe any relationship of ground cracking to landslides.
6. What were topographic effects? Shattered ridge tops?
7. Describe type and extent of damage to engineered structures (surface and buried, artificial fill, other).

Dams and Reservoirs

Earth and Rock Fill Dams

1. Are there cracks parallel to axis, indicating either sliding of part or all of the upstream or downstream faces?
2. Are there earthquake-induced settlements in rockfill shells?
3. Look for cracks perpendicular to the axis, indicating settlement or distortion of the dam. Are there changes in preexisting cracks?
4. Was there settlement or lateral movements of crest? Resurvey crest lines.
5. Was there increase or decrease in seepage? Is there seepage now occurring where there was none previously?
6. Have there been changes in color of seepage water, indicating solids in water?
7. Did surface slumps or sand boils occur?
8. Did cracking offsets in rock or concrete parapet walls or retaining walls occur?
9. Was there increase or decrease in leakage past gates?
10. Did bulging occur in ground at toe of dam?
11. Where foundation or embankment piezometers are available, have there been any changes in water level or pressure?

Concrete Dams

1. Have any new cracks occurred?
2. Has there been increase or decrease in leakage past gates?
3. Have abutment rockfalls occurred?
4. Have there been any changes in seepage or seepage into galleries and shafts?
5. What is condition of water seals?
6. Where foundation drains or piezometers are available, have there been any changes in water level or pressure?
7. Did settlement or horizontal movement of crest occur? Resurvey crest.

Spillway, Inlet, and Outlet Structures

1. Did damage occur?
2. Was there any damage to auxiliary structures such as gate hoists, gates, or valves?
3. Was operability subsequent to earthquake affected by binding that might indicate distortion?
4. Did joint displacements occur?
5. Did structure maintain ability to function? If not, why?

Waterfront Structures

1. Compare behavior of waterfront dock and pier structures relative to construction type (e.g., pile-supported piers, quay walls, or sheet pile bulkheads).
2. Note types of waterfront retaining walls investigated (gravity, anchored bulkhead, cantilever, reinforced, etc.). Document any damage.
3. Check for ground deformation—liquefaction, sand boils, settlements, or landslides. Note type of soil on which each occurred.
4. Determine influence of batter piles on damage. Compare similar facilities with and without batter piles.
5. Inspect material-handling equipment such as moving cranes and conveyor systems. Did moving equipment jump off rails?

River Crossings

1. Examine footings of bridge or pipeline crossings from evidence of lateral spreading.
2. Document any damage.

Hydrologic Effects

1. Note elevation change(s) in water wells.
2. Note elevation change(s) or pressure changes in artesian wells.
3. Determine whether or not there was any damage to pump stations. Could water elevation change may be due to lack of pumping?
4. Did salt water intrusion occur?
5. Were there changes in stream or spring flow?
6. Did streams exhibit increased sediment transport?
7. Did sag ponds form?
8. Describe any dam failure and inundated areas.
9. Identify benchmarks for changes in water level.

Secondary Impacts

Seiches

1. Describe type of water body affected (lake, bay, harbor, etc.).
2. Describe dimension, depth, location.
3. Determine orientation of major and minor axis of water body.
4. Is a bathymetric map available?
5. What was direction of seiche motion in relationship to shape of water body?
6. Note run-up, location, height, and period (in seconds).
7. Note time (local and UTC) for start and stop of seiche.
8. What is distance (in kilometers) of seiche occurrence from causative fault? From epicenter?
9. Describe geology and geomorphology of area.
10. Describe type and extent of damage to engineered structures (surface and buried, artificial fill, other).

Local Waves

1. Describe damage from local waves due to nearby submarine slope failure or the sliding of surface earth or ice into a body of water.
2. Describe type of water body (lake, bay, harbor, etc.).
3. What was arrival time?
4. Document number of waves, frequency (period in seconds), run-up, and height.
5. Describe geologic setting where slope failure occurred.
6. Describe geologic setting where wave damage occurred.
7. What is distance of wave damage from point of slope failure?

8. What is distance of local wave occurrence from slope failure?
9. Describe type and extent of damage to engineered structures (surface and buried, artificial fill, other).
10. If applicable, note the performance of quay wall and structural retaining walls.

Tsunami

Refer to Section 12, Tsunami–Field Investigation, for checklist.

Field Investigation Form—Geotechnical

Name of Investigator:____________________ Date:__________

Ground Deformation

Amount of fault separation (slip)?____________________

Horizontal: (m)______________ Oblique: (m) __________

Vertical: (m)__________ Location of measurement:__________

Fault: Strike:______________ Dip:______________

Width of fault trace (latest rupture):____________________

Slickensides, gouge, fault breccia, other: ______________

Relationship of fault scarp formation and height to local geology, bedrock structure, and geomorphology (include location):

____

____

Relative offset as a function of depth:________ Location:________

Faulting (original displacement or renewed displacement on old fault trace):____________________

Liquefaction:____________________________________

____

Any additional displacements on nearby or subsidiary faults (mainshock or aftershock)?____________________

____

Evidence of fault creep:

Location:____________________ Amount: (m)______

Sense of movement:____________________

Foreslip or afterslip?____________________

Relation to aftershocks:____________________

Width of old fault zone through which new faulting took place:________

____

Change of offset (along fault) with increase of distance from epicenter:(m)

____

GEOTECHNICAL

Other Effects

Damage to engineered structures (type):______________________________

____

____

Water table depth:

One side of fault: (m)______________ Other side: (m)____________

Secondary Impacts

Secondary effects include landslides, lateral spreading, and submarine slope failures; settlement; ground cracking; hydrologic effects (including dam failure); seiches; and local waves. See checklist for observation details.

____

____

____

Geotechnical—
Recommendations for Further Research

Name of Investigator: ______________________ Date: __________

Location: ______________________________________

Why needed: ____________________________________

Trenching and/or Boreholes

Where, how deep, how many: ______________________

Why: ____

Instrument Installation

Type and number: _______________________________

Geodetic Surveys

Location: ______________________________________

Engineering importance: _________________________

Recommendations for study: ______________________

Strain maps (crustal): _________________________

Measurements of afterslip: ______________________

Local tilting: __________________________________

Submarine Studies

Describe proposed studies: _______________________

____

Recommend SCUBA investigation? __________________

For what purpose? _______________________________

GEOTECHNICAL

Section 7

Engineered Structures—Field Investigation

Type of Data to Be Collected and Recorded

A field investigator looking at engineered buildings is expected to assess the type of damage to buildings. Not all buildings of similar type and size will respond in the same way to the same intensity of ground shaking, even if they all meet the building code. Damage must be documented for enough similar buildings in the same area of seismic intensity—both damaged and undamaged—so that both an average level of damage and the variety of the damage can be determined. It is important to note what did not fail, as well as what did. Whenever possible, get the drawings for the building. This is important for determining how closely design was followed in construction, for performing static and dynamic analyses, and for developing capacity/demand ratios.

In addition to identifying damage to individual structures, field investigators should make an overall building survey on a block-by-block basis. Mark out an area of 9 blocks or so, and make a detailed map of what types of buildings are/were in each block and how much damage each one suffered. Knowing that one unreinforced masonry building was damaged is not nearly as valuable as knowing that there were 50 unreinforced masonry buildings in an X-square-block area and that only one suffered damage. A square block charts is available at the end of this section.

Categories of Damage

The following damage categories can be applied to most buildings (investigation may indicate a need to modify these categories for some applications):

None	No damage.
Slight	Isolated nonstructural damage; repair costs less than 5 percent of market value of the building.
Moderate	Considerable nonstructural and slight structural damage; repair costs less than 25 percent of market value.
Severe	Considerable structural and extensive nonstructural damage; repair costs less than 50 percent of market value.
Total	More economical to demolish than repair.
Collapse	Structural collapse.

Checklist
Engineered Structures

Moment-Resisting Frames

In General

1. Observe behavior of frame as a whole, with particular attention to failure modes, signs of distress, loading variations, types of connections, and inelastic behavior.
2. Observe structural damage caused by deformation affecting adjacent elements.
3. Note damage to nonstructural elements such as infill walls, stairs, and partitions, as well as their influence on structural damage.
4. Note quality of welded, bolted, nailed, and riveted connections.

Reinforced Concrete Moment-Resisting Frames

1. Note general pattern of cracking and any evidence of brittle or ductile behavior. Was there axial load cracking (tensile or compressive)? Shear or diagonal tension cracks?
2. Column performance:
   a. Was tie installation less than current code?
   b. Note mid-height column performance with reduced ties.
   c. What was longitudinal bar splice performance? Offset bar or column performance?
3. Beam performance:
   a. Describe shear performance versus shear capacity.
   b. Was there distress at bar cutoffs or splices?
   c. What was performance of bottom bar anchorage at column?
4. Joint performance:
   a. What was the relative column/beam strength versus performance?
   b. What was joint performance relative to current code?
   c. Describe any joint eccentricity such as beam centerline offset from column centerline.
5. Where possible, determine reinforcing details such as ties, stirrups, and splices of longitudinal steel (if plans are available or bars are visible).

Steel Moment-Resisting Frames

1. Note location of any buckling.
2. Determine relative strength of beams and columns.
3. Note performance of column splices and joints.
4. Did heavy jumbo sections perform differently than the rest of the structure?
5. What was performance at offsets or transfer girders?
6. Was there any tendency to develop a general plastic mode as indicated by permanent story drift?
7. Note any signs of failure in welds, including cracks, lamellar tearing, or laminations.
8. Observe plastic hinge development in columns and/or beams.
9. Examine moment connections. Note type, flexibility, stiffeners, and ductility.
10. How did column bases behave? Describe effects on anchor bolts, local column buckling, connection material, and grout.
11. Note performance of stairs and escalators, including any movement at connections and interaction with frame.

Steel Braced Frames

1. Describe brace performance.
2. What are connection details?
3. What was KL/r?
4. Compare brace pattern versus performance (chevron, k-braced, etc.).
5. Detail signs of distress in eccentric braced frame performance.
6. What was connection performance?
7. Note any effects in offset braces or changes in stiffness.

Masonry Buildings

1. Describe wall performance versus reinforcing details.
2. Note pier/spandrel performance versus detail.
3. What was performance of floor-to-wall and roof-to-wall anchorage?
4. What was quality of workmanship on grout, mortar, etc.?
5. What was placement of reinforcing? Were there any omissions?

Concrete Buildings

Precast Concrete Buildings

1. Describe behavior of the overall structural system.
2. Evaluate joint performance versus detail.
3. Note performance of buildings that have no topping slab.
4. Describe performance of ties/lack of ties.
5. Note connections between elements, between elements and frames, and between element and foundations.
6. Did cracking occur due to vertical motions or reversals?
7. Determine quality of construction materials in concrete as indicated by movements at construction joints, rock pockets, and lack of bond or cover of reinforcing. Describe any obvious omissions. If plans are available, note any deviations from design in placement or reinforcement.

Prestressed/Post-Tensioned Concrete Buildings

1. Describe type of prestress system. Were tendons grouted?
2. What were effects of vertical acceleration (reverse shear cracks, etc.)?
3. How did anchorage perform?
4. Describe the post-tensioned slab-to-wall performance compared to details. Were there any slip planes?
5. Did cracking due to vertical motions or reversals occur?
6. Describe performance of joints between and within horizontal and vertical elements.

Wood Frame Buildings

1. Determine shear wall performance.
   a. Describe nailing patterns.
   b. What was performance of hold-downs?
   c. What was performance of sheathing materials?
2. Note distressed areas and whether or not proper connections existed.
3. Document distress of buildings relying on gypsum board sheathing or other systems, including plywood.
4. Describe effects of spaced sheathing on roof performance.
5. Document the performance of masonry veneer or chimney versus anchorage details.
6. If drawings are available, detail how structure was designed versus how it was constructed. Pay particular attention to any failed connections.

7. Describe construction practices, including bolting, connection eccentricities, edge distances, bearing areas, and split or checked material.
8. Document influence of deterioration.

Shear Walls

In General

1. Look for post-construction modifications (such as holes cut for doorways) that lack adequate strengthening.
2. Note damage to other elements due to shear wall deformation.

Poured-In-Place Concrete Shear Walls

1. Determine layout and vertical continuity of shear walls in each story and the pattern of damage.
2. Note pattern of concrete cracks and crushing in damaged areas.
3. Was there movement at construction joints? Note cracks and implied condition of keys and dowels if they cannot be directly observed.
4. Describe any discontinuity of materials at construction joints.
5. What was performance of joinery between shear walls, diaphragms, framing members, floors, and foundations?
6. Note the presence, continuity, and extent of opening reinforcement. What were types and locations of splicing (if plans are available or bars are visible)?
7. What was quality of concrete?
8. What was the connection of infill shear walls to the frame? How did it perform?

Precast Concrete Shear Walls

In addition to items 1 through 8 above, for poured concrete:

1. Determine type and condition of inserts or other fasteners to the frame, between units, and to the diaphragms.
2. What is the system of load transfer among units? Between units and the structural frame? Between units and the foundation?
3. Determine development of diaphragm chords. Did edge members resist tension and compression?

Masonry Shear Walls

In addition to the items noted for poured concrete:

1. Note the condition of mortar and grout, quality of construction, and type of bond.
2. Were concrete columns poured before or after masonry walls were constructed? Generally, columns poured afterward have exhibited better bond to masonry.
3. Document location of cracking (through mortar or units).
4. What was connection of foundations?

Wood Shear Walls

1. What type of sheathing was used? Blocked or unblocked plywood, straight or diagonal boards, metal straps?
2. Note type, pattern, spacing, and condition of sheathing fasteners.
3. Did buckling, splitting, or delamination of sheathing occur?
4. Describe anchorage and development of ties, struts, chords, or other members transferring concentrated loads among elements of the structure.
5. Describe connections to foundations.

Steel Shear Walls

1. Document type of wall (corrugated or stiffened sheet) and the connections between panels and to supports.
2. Did out-of-plane buckling or tension failures occur?
3. Describe shear transfer elements to frame and foundation.
4. Note shear transfer elements between units.

Fire-Resisting Elements and Damage From Fire

Refer to Section 9, Lifelines—Field Investigation, for checklists.

Diaphragms

1. Describe overall diaphragm system and its performance, including any local buckling.
2. Did diaphragms deflect as anticipated?
3. Determine influence of torsion, discontinuities, reentrant corners, openings, and flexibility on performance of building.
4. Was transfer of forces to walls adequate?
5. Did diaphragm provide lateral support to walls? Check condition of attachments. Did lateral diaphragm deformations contribute to wall damage?

6. What was method of transferring loads between diaphragms and other parts of resisting systems?
7. What was performance of chords? Drag struts? Continuity ties?
8. Note diaphragm webs at points of concentrated loading. How did they perform?
9. Determine relative behavior of plywood diaphragms with and without steel anchors connecting joists to walls.
10. Observe connections and performance of metal deck, fiberboard, pressed paper, cellular concrete, and precast concrete panels.
11. Note concrete topping slab on precast elements, particularly its bond to the elements and any evidence of slab buckling.
12. Observe performance of gypsum deck, its forms, and supporting members.
13. Were horizontal rod bracing systems adequate in terms of connections and rod yielding? Were rod ends upset or straight?
14. Document influence of deterioration.

Foundations

Refer to Section 6, Geotechnical—Field Investigation, for checklists on Soil-Structure Interaction and on Settlement.

1. Document evidence of excessive foundation movement or failure such as:
   a. Vertical movement: Punching or rotation of columns relative to footing or slab on grade, gaps under footings, rocking of footings, damage to grade beams, settlement of foundations, and tension cracks in piles.
   b. Horizontal movement: Open cracks in basement slab, cracks and/or offsets in basement walls, open cracks between backfill and foundation walls, rotation of footings, and cracking or rupture of pile foundations.
2. What is condition of backfilling around structure? Describe soil type, water presence, cracks, subsidence, slumping, movement of attachments (stairs, walks, etc.), and any breakage of utility lines.
3. Note any surface ground ruptures in soils around building, especially those involving vertical or horizontal offset.
4. Did subsoil liquefaction (sand boils) occur?
5. Note basement walls and any horizontal cracks indicating high dynamic soil pressure.
6. Describe influence of batter piles on building behavior.
7. What is depth to water table?
8. Observe influence of deterioration.

Previously Repaired and Strengthened Buildings

1. Note existence and types of repair and/or strengthening details.
2. If the repairs were of mortar and/or plastic adhesive, did failures occur in original materials, in repair materials, or in the bond between the two?
3. Was there evidence of unrepaired or inadequately repaired damage?
4. Is there evidence of parapet removal and/or anchoring?
5. If school building strengthening program was in place, was it effective?

Internal Utilities

Refer to Section 9, Lifelines—Field Investigation, for checklist.

Nonstructural Damage

Note also nonstructural damage to engineered buildings, such as damage to elevators, ceilings, light fixtures, windows, partitions, cabinets, equipment, vibration isolators, file cabinets, shelving, piping, veneer, etc. Refer to Section 8, Industrial Facilities—Field Investigation, for applicable damage checklists.

Field Investigation Form—Engineered Structures

Name of Investigator: ______________________ Date: ___________

Building Information

Building type: ____

Address or location: _________________________ When built: ______

Number of stories: ____________________ Basement(s): ___________

Vertical load system: ____

Lateral load system: ____

Condition of walls: ____

Condition of foundations: _____________________________________

Building configuration: _______________________________________

Evidence of torsional response: ________________________________

Quality of construction: ______________________________________

Strong motion recording instruments present? ____________________

Site Information

Types of soils: ____

Site: Slope: ________% Level: __________________________________

Sand boils present? ____

Ground faulting present? ______________________________________

Earthquake Damage to Structure

____

____

____

____

Total estimated loss:

Less than 10% __________ 10-50% __________ over 50% _________

Is building functional? Yes _____ No _____ If no, why not? ____________

____

Status of utilities: ____

Casualties: Deaths ___________ Injuries ____________ Unknown ______

Estimated Modified Mercalli Intensity: ______________________________

Does building warrant further investigation? Yes________ No________

If yes, why? ____

Nonstructural Damage

Note performance of elevators, ceilings, light fixtures, windows, partitions, cabinets, equipment, vibration isolators, file cabinets, shelving, piping, veneer, etc. Refer to Section 8, Industrial Facilities—Field Investigation, for applicable damage checklists.

Miscellaneous Data

Architect:________________________ Engineer: ____________________

Are plans available? Yes_____No_____ Where?______________________

Photos: Yes______ No______ Roll #:___________ Frame(s) #:________

Use back of sheet for sketches and additional notes

Square Block Damage Assessment Form

Street name

Street name

Street name

Street name | Street name | Street name | Street name

Street name

Structure types:

URM—Unreinforced masonry
WF—Wood frame
C—Concrete
MR—Moment-resisting
S—Steel
C—Collapse

Categories of damage:

N—None
S—Slight
M—Moderate
V—Severe
T—Total

Engineered Structures—
Recommendations for Further Research

Name of Investigator:____________________ Date:__________

ENGINEERED STRUCTURES

Section 8

Industrial Facilities—Field Investigation

Type of Data to Be Collected and Recorded

Warehouses, manufacturing facilities, energy-producing facilities, and factories should be inspected for performance of structure and documentation of any interruption of service or utilities caused by the event. Special attention should be given to nonstructural elements such as anchoring of equipment and computers, performance of sprinkler systems, etc.

Categories of Damage

The damage categories delineated in Section 7, Engineered Structures–Field Investigation, can be used to describe damage to most industrial facilities. However, investigation may indicate a need to modify these categories for some applications.

Checklist

Industrial Facilities

General Observations

1. When equipment or facilities are damaged, in addition to documenting the damage, attempt to determine:
   a. Failure mode(s).
   b. Factors that may have contributed to failure(s).
   c. Implications of the damage on the operation of the facility and system.
   d. Resources required to restore service, including man days, support equipment, spare parts, and total time for restoration of service.
2. Identify and document secondary impacts due to lifeline malfunction/disruption.
   a. Evaluate impact on emergency response—communications, power, and water systems in particular.
   b. Document secondary impacts of a specific lifeline malfunction on other lifelines.
   c. Identify impact of lifeline malfunction on community at large.

3. Attempt to gather sufficient details on the equipment and situation so that recommendations to improve the seismic response of the equipment or post-earthquake operations can be made.
4. Note what performed well in addition to what did not.
5. Pay particular attention to the performance, both good and bad, of new equipment types or designs and new installation practices.
6. If time is available after investigating damage, and if the site has experienced severe ground motions that can be quantified, identify equipment and facilities that performed well that are known to have been damaged in past earthquakes.
7. Note any "tricks" that may be useful for gathering data in future investigations.
8. Did vertical acceleration affect the performance or anchorage of equipment?

Structural Performance

Refer to Section 7, Engineered Structures—Field Investigation, for checklist.

Fire Protection Systems

1. Did fire protection system operate? If so, how well did it perform?
2. Document occurrence and location of any failure in fire protection system.
3. Briefly describe each element of fire protection system and how well it performed. Document lack of damage as well as damage.
4. Was piping properly braced?

Hazardous Materials

If hazardous materials release created a need for emergency response procedures, refer to Section 11, Social Science and Emergency Response—Field Investigation, for applicable checklists.

1. Were hazardous materials stored in the facility? What kind?
2. How were hazardous materials affected by earthquake?
3. Did they create a danger to people? Equipment? The facility? The surrounding community? If so, what action was taken?
4. Were hazardous materials correctly stored?

Storage Tanks

1. Did they slosh? Did sloshing create damage?

2. Compare tanks full and partially full at time of earthquake.
3. Describe type of foundation and soils.
4. Examine tank shell contact with the footing. Was there evidence of vertical or lateral movement?
5. Examine piping connections to tank. Were connections flexible?
6. What is type of roof construction?
7. Were there changes in leakage rates?
8. Examine elevated tanks, including bracing, column and foundations.
9. Did tanks maintain ability to function?

Mechanical, Electrical, and Plumbing

In General

1. Note what performed well and what did not.
2. Document which systems remained operational after the quake and which did not?
3. Conduct a general evaluation of anchorage or bracing of equipment.
4. Collect specific data on principal equipment critical to operational use of building.

Mechanical

1. Equipment in general: was equipment bolted down, anchored, or specially braced? Was it properly designed and installed?
2. Vibration isolators: Did they fail? What part failed? Were snubbers provided? List number and type of isolators used and estimate equipment weight.
3. Was equipment itself damaged, even when adequately anchored and braced?
4. Examine heating and ventilating ducts, including automatic dampers, hangers, straps, and ties.
5. Examine ducts passing through walls at chases or sleeves.
6. Did objects fall on equipment?
7. What was the interaction of the equipment with structural and architectural elements?
8. Did equipment continue to perform, even though damaged?

Electrical

1. Inspect electrical light fixtures, both suspended and flush.
2. Check conduits, transformers, switch gear, panel boards, and nonin terruptible equipment. Document any failures.
3. Determine where or not damage occurred related to overturning,

sliding, or to other objects falling on equipment.

4. Collect information on electrical central control stations in tall buildings. How did they perform?
5. Were auxiliary or alternate power supplies available? Did they function?
6. Was there damage at expansion joints?

Plumbing

1. Was piping braced to resist earthquake forces? Was it effective? Were flexible joints used? If so, how did they perform? Describe.
2. Document locations of breaks and apparent causes. Note materials.
3. Assess condition of pumps, drains, and controls.
4. Did automatic sprinkler system operate?

Damage From Fire

Refer to Section 9, Lifelines—Field Investigation, for checklist.

Equipment

1. Describe type of equipment in facility.
2. Was equipment damaged? Describe type and extent.
3. Did equipment failure affect ability of facility to continue operations? Describe.
4. Were storage racks anchored and/or braced? Was system effective?
5. Are storage racks independent of the building, supported by the building, or do they provide support for the building?
6. Note equipment restraint methods. Were they effective?
7. Were there any secondary effects of equipment damage (e.g., were hazardous chemicals or toxic gasses released)?
8. Were inventories of products or materials damaged or destroyed?
9. Note performance of elevators, counter weights, and controls.

Anchorage Systems

1. Are anchor bolts cast in place or expansion anchors?
2. Can you identify the manufacturer of the anchor?
3. What is their length of embedment?
4. What is their diameter?
5. Were they tested after installation?
6. Did they fail? If so, how?

7. Did they pull out of concrete?
8. Is the concrete cracked?
9. Did fracture cones develop in the concrete?
10. Did the bolts stretch? Break?
11. Is there any indication that they were installed incorrectly?
12. What were the standards, if they existed, when the equipment was installed?
13. How many bolts were there and how were they laid out?
14. Did the bolt pass through a structural member in the equipment framing?
15. Are there signs of distress in the equipment in the region around the anchor bolt? Cracked or chipped paint? Deformation of metal?
16. Did the equipment introduce a prying action in the bolt?
17. Is the bolt hole appropriate to the bolt diameter?
18. Does the load path from the equipment frame to the bolt or weld introduce flexibility in the anchorage system?
19. What are the sources of loading on the anchorage? Note equipment weight, height of center of gravity, dimensions of the base of the equipment?
20. Were there loads applied through interconnections to adjacent equipment?
21. Did the base of the equipment move on its footing?
22. Is there a gap around the footing or equipment pedestal indicating differential movement?
23. Was reinforcing installed around bolt? Note placement, size, hooks, etc.
24. Note bolt spacing and bolt edge distance in concrete.

Power Systems

In General

1. Look for interaction problems between the boiler support structure and the boiler.
2. Look for interaction problems between the turbine pedestal and the powerhouse operating floor.
3. Inquire whether or not the unit went off line. If so, determine why.
4. Are there any indications of turbine bearing damage?
5. Does there appear to be steam coming from the stack, indicating boiler tube damage?
6. In general, how is equipment anchored?

7. Check station batteries. Are they operational?
8. Were sudden pressure relays in transformers activated?
9. Did any protective relays change state? Which ones?
10. Were any relays reset after the earthquake before operations were resumed?
11. Loss of power on any lines into or out of the station?
12. Were there disruptions? What was cause? Duration?
13. Note performance of suspended ceilings.
14. Did anything fall from desks, tables, or shelves in the substation?
15. Was there any disruption in communications? If so, what types of communications are used and which were affected?
16. Have personnel that were on the site at the time of the earthquake describe the earthquake and their actions afterward.
17. Are personnel aware of any other effects that the earthquake had on the power system?
18. Did liquefaction occur nearby? If so, what was its effect on turbine operation?
19. Does the site manager know if there were any special foundation preparations at the site?
20. Estimate the percentage of failures for each type of equipment.
21. Be sure to get a card from the plant manager with his/her name and address.

Fossil Fuel and Hydroelectric Generating Plants

1. Document gas line breaks.
2. Document and analyze damage and lack of damage to transmission and distribution equipment.
3. Document and assess power generation distribution system performance (load flow, demand, etc.) immediately after the earthquake.
4. Evaluate loss of electricity on other lifelines.
5. Note any unnecessary gas shutoff. Did shutoff cause problems?
6. Evaluate performance of seismic gas shutoff valves.
7. Boiler and supporting frame:
   a. Evaluate boiler tubes, lining, equipment, and controls.
   b. Check backstays or lateral force stops.
   c. Check piping and duct work that is connected to the boiler and to the ground or support structure.
   d. Check main support structure for distortion, cracked welds, broken bolts, or rivets.

e. Check footings for new cracks, spalled concrete, or exposed reinforcing.

f. Evaluate auxiliary tanks and chemical feed systems.

g. Document condition of fuel storage and transportation systems.

8. Did earthquake motion agitate sludge in fuel storage tanks? Did it cause generator to stop?

9. Circulating water system:

   a. Check pumps, gates, or other equipment.

   b. Check for cracks, spalled concrete, and exposed reinforcing.

   c. Note change in flow characteristics that might be indicative of damage.

   d. Look for wet spots on ground in vicinity of inlet piping that could indicate leaks.

   e. Look for muddy water that may indicate cracks in discharge lines.

10. Hydroelectric water supply:

    a. Note any change in seepage.

    b. Document distortions or cracks in cradles or footings.

    c. Note any decrease in flow capability of the conduit.

11. Turbines and generators:

    a. Were turbines or auxiliary equipment shut down? If so, ascertain from operating personnel the cause of shutdown and amount of shaft misalignment, if any.

    b. Inspect turbine pedestal for evidence of cracking, spalled concrete, or exposed reinforcing and determine consequences of interaction between pedestal and powerhouse floor.

    c. Check for distortion and possible untracking of main crane beam or trolley.

    d. Note distress of seismic uplift inhibitors, if present.

    e. Was there any damage to turbine thrust bearings?

12. Control room:

    a. Did failure of control room equipment cause plant malfunction? If so, determine nature of the failure and type of mounting used.

    b. Did failure of auxiliary support systems, such as lighting, heating, or ventilation, cause control building to be inoperative?

    c. Evaluate condition and performance of battery and equipment racks.

13. Coal-fired plants: What was interaction between the boiler and

boiler support structure and the coal handling equipment—particularly conveyers that carry coal into the plant?

14. Other structures and appurtenances:
    a. Check fuel oil and gas pipelines and operability of valves.
    b. Check attachments between structures, or between pipelines and tanks and structures.
    c. Evaluate smokestacks, including operability, overall condition, base connection, and conditions at two-thirds height and at breaching. Check for tilting.
    d. Determine operability of doors and windows. Check for cracked windows, buckled siding, and plumbing damage.
    e. Was there ground distortion or subsidence in yard areas?
    f. Note performance of light fixtures, ceilings, overhead vents, and equipment.

Geothermal, Gas Turbine, and Nuclear Power Plants

1. Determine whether or not there may have been changes in geothermal source.
2. Is there danger of incipient landslides adjacent to facilities?
3. Evaluate waste disposal facilities.

Internal Utilities

Refer to Section 9, Lifelines—Field Investigation, for checklist.

Field Investigation Form—Industrial Facilities

Name of Investigator:________________________ Date: __________

Building Information

Building type:____

Address or location:__________________________ When built: _______

Number of stories:________________ Basement(s): ________________

Vertical load system: ____

Lateral load system: ____

Condition of walls: ____

Condition of foundations: ____________________________________

Building configuration: ______________________________________

Evidence of torsional response: _______________________________

Quality of construction: ______________________________________

Strong motion recording instruments present? ____________________

Site Information

Types of soils: ____

Site: Slope ___________% Level_______________________________

Sand boils present? ____

Ground faulting present? _____________________________________

Earthquake Damage to Structure

____

____

____

____

Total estimated loss:

Less than 10%_________ 10-50%_________ over 50%_________

Is building operational? Yes_________ No_________

If no, why not? ____

Were operations disrupted? ___________________________________

If so, for how long?____

INDUSTRIAL FACILITIES

To what degree? ____________________

Current status of utilities: ____________________

Estimated dollar losses: ____________________

Casualties: Deaths__________ Injuries__________ Unknown_____

Estimated Modified Mercalli Intensity: ____________________

Does building warrant further investigation? Yes__________ No______

If yes, why? ____________________

Nonstructural damage: ____________________

Miscellaneous Data

Architect:____________________ Engineer:____________________

Are plans available? Yes____ No____ Where?____________________

Photos: Yes______ No______ Roll #:__________ Frame(s) #:________

Use back of sheet for sketches and additional notes

INDUSTRIAL FACILITIES

Industrial Facilities—
Recommendations for Further Research

Name of Investigator:__________________________ Date: ____________

INDUSTRIAL FACILITIES

Section 9

Lifelines—Field Investigation

Type of Data to Be Collected and Recorded

Attempt to identify primary and secondary impacts of lifeline disruption, e.g., impact on emergency response, effects on other lifelines or on community, etc.

Checklist
Lifelines

In General

If lifeline disruption affected emergency response, refer to Section 11, Social Science and Emergency Response — Field Investigation for applicable checklists.

1. What was the impact of dysfunction on lifeline system? On other lifelines?
2. What was impact of dysfunction of the lifeline on the community?

Communication Systems

In General

1. Evaluate transmission and reception performance with emphasis on facilities, transmission lines, towers, etc.
2. Was communication system disrupted? If so, describe extent.

Telephone and Telegraph

1. Evaluate performance of 911 systems.
2. Evaluate radio communications with emphasis on emergency response and critical facilities.
3. Evaluate overloading of network control on system reliability.
4. Evaluate seismic performance of digital switches, with particular emphasis on loss of function due to circuit packs vibrating out of their racks.
5. Evaluate equipment anchorage and bracing systems used to support communications equipment.

6. Evaluate elevated floors in communications facilities and other computer centers.
7. Evaluate performance of optical fiber transmission lines.
8. Evaluate performance of private branch exchanges with emphasis on critical facilities.
9. Evaluate underground services with emphasis on those systems specifically designed to allow for differential earth movements.
10. Document performance of microwave towers and disks.
11. Determine effectiveness of emergency power supplies.
12. Document any pole or line breakage.

Radio and Television

1. Assess anchorages and bracing with emphasis on ability to remain operational. Did building damage affect operability?
2. Evaluate antenna towers. Note heights, foundations, type (guyed or freestanding), and materials.
3. Were emergency power supplies available? What type? Were they used?

Newspapers and Magazines

1. Did printing equipment remain aligned and operable?
2. Describe any damage to stock of printing materials.
3. Was service interrupted or delayed by damage to the building?
4. Note damage to equipment or storage racks.

Electric Power Delivery Systems

Refer to Section 8, Industrial Facilities—Field Investigation for checklists on fossil fuel and hydroelectric generating plants and on geothermal, gas turbine, and nuclear power plants.

Overhead and Buried Transmission Lines

1. Buried lines:
   a. Collect damage statistics on a unit length basis that de-aggregate data by pipe material, diameter, age, and details of the failure.
   b. Collect detailed information on soil properties at locations where soil failure has caused pipe damage.
2. Overhead lines:
   a. Determine whether or not surface faulting or landslides affected towers, poles, or caused sag in conductors.

b. Were towers or poles damaged? If so, what is condition of tower members and base connections? How far were poles embedded? In what type of soil?

c. Was there any short-circuiting of conductors or damage to insulators?

Substations and Switchyards

1. Check for damaged equipment.
2. Control buildings:
   a. Check electrical equipment, including panelboards.
   b. Did failure of auxiliary support equipment (such as lighting, heating, or ventilation) cause station to be inoperative?
3. Yard equipment:
   a. Was there movement of equipment on rails and base pads? What is condition of anchorages?
   b. Check condition of electrical equipment.
   c. Check condition of ceramic materials. What is impact of flexible and rigid bus on ceramic performance? Evaluate methods to improve earthquake performance of high-voltage ceramic members.
4. Yard structure:
   a. Were there broken connections or distortion in structure? Cracked footings?
   b. Was there any soil movement or cracking between footings?

Transportation Systems

All transportation systems should be assessed with respect to the primary and secondary impacts of loss, if any, of key transportation links.

Highway Bridges and Overpasses

1. Determine extent of damage and whether or not bridge is usable.
2. Compare, if possible, pre- and post-1971 bridges in various intensity zones.
3. Note orientation of longitudinal axis of bridge and compare damage of other structures having similar orientation.
4. Determine relative influences on bridge damage of differential earth movements, foundation failure, and ground shaking.
5. Examine connections or restraints between bridge elements. Note bearing details ("rocker-type" bearings are extremely vulnerable).
6. Determine dynamic action of backfills on retaining wall and bridge abutments.

Highway Roadbeds

1. Determine whether or not any fill settlement was influenced by soil type and depth of underlying soils.
2. Did landslides occur? Were they related to soil types, cuts or fills, moisture content, or slope designs?
3. Was there damage due to surface fault rupture?

Railroads

1. Check for damage in foundations, including piles and spread footings. Check foundation condition at abutments and columns.
2. Determine column type and check column connection detail at foundation and at deck or cap. Check for shear cracking, moment cracking, tilting.
3. Determine orientation of bridge axis.
4. Note deck bearing detail condition.
5. Note abutment condition. Was there deck impacting, dynamic action of backfill, or throwing of stones from deep holes?
6. Did wing wall cracking occur? What was dynamic action of backfill with respect to wing walls?
7. What is condition of apron? Check for slippage.
8. Determine expansion joint condition. Observe both from roadway and from underneath, if possible.
9. Examine approach road to deck and look for compressive failure, buckling, or settlement.
10. What is condition of superstructure? Was there lateral offset at joints, vertical displacement? Check girders, floor beams, stringers, and bracing.

Airports

1. Document condition of control towers, including equipment and its anchorages.
2. Determine condition of runways and taxiways.
3. Note condition of emergency generator and its anchorage.

Public Transit Systems

Inspection items will be similar to Highways, Railroads, and Communications Systems checklists, depending on type of system.

Water Delivery and Treatment/ Wastewater Conveyance and Treatment

1. Document water and sewer line breaks, including details of location.
2. Check mechanical and electrical equipment. Note anchorage and bracing, if any.
3. Describe the facility's ability to continue functioning.
4. Inspect piping and containers that store dangerous liquids or chemicals.
5. Document and assess performance of water treatment facilities with emphasis on tanks, control systems, storage of hazardous materials.
6. Document the design and seismic performance of all facilities that contain hazardous materials.
7. If possible, determine construction practices that affect the performance of large, belowgrade liquid holding tanks.
8. Was there any soil liquefaction at site?

Gas and Liquid Fuels

1. Document types of materials and types of joints in pipelines and conduits that crossed fault displacements, or experienced ground shaking, settlement, landslides, or liquefaction.
2. Check for cracked cradles, footings, or distortion in supply structures.

Damage From Fire

1. What was initial cause of fire and its place of origin?
2. Was the water supply system operational for firefighting? Was there an emergency water supply system? Was it used? Was it adequate?
3. Were there combustible materials in building that fed fire and allowed it to spread? Note conditions of wood paneling, plastic accessories, fabric, furniture, and equipment. Note toxic combustion gases, if existent.
4. In the streets adjacent to the building: Did debris or surface ruptures affect accessibility for fire and rescue team operations?
5. Were elevators, stairways, and corridors operable?
6. Note any weather conditions that intensified or mitigated effects of fire, such as dry or rainy season, high winds and humid or dry conditions.
7. Determine the extent to which firespread affected other floors and areas.
8. What was the availability of firefighting supplies and equipment in the building?

Fire-Resisting Elements

1. Did firewalls and separations between floors maintain their integrity, or did they shatter and permit firespread?
2. Did fire doors work correctly?
3. Was any structural fireproofing present? If so, describe.

Internal Utilities

1. Were emergency electrical power systems or emergency generators available and functional? Were they used? Did they function properly?
2. Was the natural gas supply system equipped with automatic shutoff valve? Did it operate?
3. Describe the effect of utility damage on telephone and communication systems.

Damage From External Water

1. Describe source and cause.
2. What was direction and magnitude of water force?
3. Where appropriate, describe natural environmental conditions and topography in areas adjacent to building.
4. Determine whether water caused damage to foundations, building substructure, or superstructure.
5. Was there any damage from mud and silt?
6. Was there any damage to the building contents, ceilings, carpets, and finishes?

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1. Did firewalls and separations between floors maintain their integrity, or did they shatter and permit firespread?
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5. Was there any damage from mud and silt?
6. Was there any damage to the building contents, ceilings, carpets, and finishes?

Field Investigation Form—Lifelines

Investigator:________________________________ Date:__________

Facility Data

Name of facility:____

Location:____

Lifeline function:____

Owner: ____________________ Contact:____________________

Are drawings available? Yes____ No____ Where? __________________

Date constructed:________________

Strong motion recording instruments present? Yes____ No____

Is lifeline contained in a building? Yes____ No____

(If yes, fill out Engineered Structures form in addition to this form.)

Lifeline description (capacity and features):______________________

____

____

Foundation material: ____

Site: Slope ________% Level______________________

Earthquake Damage

Is lifeline functional? Yes____ No____ If no, why not?________________

____

Estimated time to repair: 1 day____ 1 week____ 1 month____

Complete reconstruction required ____________________________

Describe damage to:

Lifeline:____

____

Building:____

____

Foundation:____

LIFELINES

Principal cause of damage (shaking, differential ground surface movement):

____

____

____

____

Impact of equipment/earthquake damage on facility and system operation:

____

____

What was the extent of disruption at this location?____________________

____

____

____

What was the time to restore service?__________Complete repairs?_____

Total estimated loss:

Less than 10%_________ 10-50%_________ over 50%___________

Performance of anchorages:________________________________

Does lifeline warrant further investigation? Yes________ No___________

If yes, why?______________________________________

Miscellaneous Data

Photos: Yes______ No______ Roll #:________ Frame(s) #:____________

Cross-reference to Engineered Structures form (if applicable):

Name of facility:______________________________ Date:______________

Use back of sheet for sketches and additional notes

Lifelines—
Recommendations For Further Research

Name of Investigator:____________________________ Date:____________

LIFELINES

ARCHITECTURE

Section 10

Architecture and Urban Planning–Field Investigation

Type of Data to Be Collected and Recorded

Research in these fields should be directed at determining the effect that architecture and urban planning have on performance of buildings, blocks of buildings, or systems on a regional basis during earthquakes. Attention should be paid to performance of interior nonstructural elements, entrances, exits, and exterior cladding. Collection of overall urban damage statistics and mapping of geologic hazards should be carried out.

Checklist

Architecture and Urban Planning

Interaction With Structural System

1. Describe building configuration and its role in building performance.
2. How did the architectural elements of the building interact with its structural system? How did they affect building performance? Describe architectural elements used and their connection to structure.
3. Are any changes in architectural design indicated by damage patterns?

Exterior Treatment and Elements

1. Describe glass, glazing details, and mullions, including provisions for distortion of openings.
2. Note condition of cladding and veneer on walls, including attachments.
3. Did canopies or marquees overhang critical exits or pedestrian areas? If so, how did they perform?
4. Describe performance of decorative screens of metal, masonry, wood, or plastic.
5. Were there sunshades over windows and openings? If so, how did they affect damage?
6. Note performance of precast panels, including their attachment to structure.
7. Note any damage caused by large-scale graphics or illuminated signs.

ARCHITECTURE

Interior Treatment and Elements

1. Describe performance of veneers and finish materials on walls, including their attachments to structure.
2. Did building have suspended ceilings? If so, describe materials, grid system, hangers, light fixtures, ceiling grills, and bracing. How did they perform?
3. Describe movable and fixed partitions with respect to provisions for clearances, bracing (in and out of plane), and anchorage.
4. Note performance of furniture and equipment, including wall-hung objects, storage cabinets, displays, shelving systems, and files.
5. Describe performance of office landscaping systems. Was decorative sculpture or ornamentation present? If so, describe anchorage.
6. Note performance of emergency sprinklers.
7. Describe performance of heating, ventilating, and air conditioning systems.

Elevators and Exitways

Elevators

1. Were seismic provisions of the building code applied to the elevator?
2. Describe types of earthquake safety devices used. Did counterweight (CW) derail device and seismic switch work?
3. Did CW derail, and if so, what were the contributing factors: rail weight, retainer plates, added ties or brackets, bracket anchorage failure, location of CW when it failed, deformation of brackets or ties.
4. Did CW hit cab?
5. Describe any other elevator system damage.
6. Was there movement of controllers, motors, traction equipment in the control room?
7. Was there emergency power? Did it work? If not, describe problems.

Exitways

1. Document any debris on stairs, landings, and passageways.
2. Note type of enclosing walls.
3. Note emergency lighting system. How did it perform?
4. Stairways: Note types, locations, widths, and attachments to structure.
5. Note foot traffic circulation patterns and distance to exterior spaces, alleys, streets, or courtyards.
6. Note any debris in streets and exterior spaces that impeded pedestrian circulation, particularly at exits.

7. Were there handrails and other safety devices?
8. Examine exit doors. Were there any operational impairments due to warping, jamming, or other damage?

Occupant Behavior

1. Describe patterns of evacuation.
2. Were there any impediments to evacuation?
3. Was an emergency evacuation plan in place? If so, had occupants been educated to use plan? Had drills been held? Were monitors part of plan? Did plan work?

Damage Assessment

1. Describe residential, commercial, and/or industrial activities that required relocation due to damage to structures or infrastructure.
2. Was temporary or interim housing necessary? Describe.
3. Will reconstruction necessitate changes in population densities, characteristics of building stock, pattern of development, urban form (height, mass, bulk of structures; pattern or amount of open space)?

Damage Patterns

1. Obtain maps of the affected area. Map damage and lack of damage in relation to geologic hazards and land use patterns.
2. With input as necessary from engineers and geoscientists, define zones of high, moderate, and low intensity ground shaking.
3. Develop profile of each zone:
   a. Residential—individual homes, apartments, a mixture of the two?
   b. Commercial—stores, businesses, offices, mixed?
   c. Industrial—light, heavy, primarily warehouses, mixed?
4. Identify location, nature, size, and occupancy of socially significant structures in the area, including high-density apartments, hospitals, clinics, fire and police departments, public utilities, transportation and communication companies, military installations and barracks, government offices, schools, historical structures, jails, etc..
5. Indicate where evacuees gathered (or were gathered by authorities) and note the location of staging areas or coordination points in the operations of emergency and relief organizations.
6. Hospitals and other key health care organizations: Note operational problems from loss of or damage to equipment.

ARCHITECTURE

7. Gather socioeconomic and sociodemographic characteristics of the affected community or region to develop an idea of what the community was like before the earthquake (U.S. Census, City/County Data Book, etc.).

Field Investigation Form— Architecture and Urban Planning

Use this form for all structures examined in depth: office buildings, emergency services facilities, historical monuments and buildings, etc.

Name of Investigator:____________________ Date: __________

Location of structure:____________________

Use of structure at time of earthquake:____________________

Influence of architectural design:____________________

Structural damage:____________________

Nonstructural damage: ____________________

Damage to access/egress: ____________________

Performance of exterior cladding: ____________________

Level of building impairment: ____________________

Original construction drawings available: ____________________

Use back of sheet for sketches and additional notes

Architecture and Urban Planning— Recommendations For Further Research

Name of Investigator:____________________________ Date: ____________

ARCHITECTURE

Section 11

Social Science and Emergency Response—Field Investigation

Type of Data to Be Collected and Recorded

Research in these fields should be directed toward gaining an overview of the impacts of the earthquake on human behavior and community institutions. The impacts of the earthquake on community residents, special "at risk" populations, government operations, and commercial and economic activity are of primary interest.

Reconnaissance activities should provide a general description and preliminary analysis of the emergency response, including:

- Public and organizational response to warnings and predictions.
- Responses of key emergency agencies such as local emergency management agencies, police and fire departments, and emergency medical and health care delivery systems.
- Performance of disaster-related tasks such as search and rescue and provision of emergency shelter.

Study of both the short- and long-term socioeconomic impacts of earthquakes is a complicated and labor-intensive activity. Given the short time typically spent in the field by EERI investigation teams, social scientists cannot expect to obtain enough data to support valid findings and research conclusions. The reconnaissance effort should not attempt to be evaluative, but point out what is known/observed and what topics need further study.

Social scientists participating in EERI field investigations can best contribute to knowledge of the socioeconomic impacts of an earthquake by concentrating on the following field activities:

- Focus as much as possible on obtaining highly perishable data through onsite observation of emergency response activities (where possible) and through in-depth interviews with individuals who were directly involved in the emergency response.
- Draw qualitative observations and tentative conclusions about impacts. Indicate which areas of the community, which institutions, and which economic activities were most disrupted by the earthquake, which were least disrupted. Identify particularly hard-hit groups or organizations in the community.
- Indicate which hospitals or other community facilities experienced the highest demands for service.

- Collect whatever preliminary data on damage and social impacts are available, including: newspaper accounts, FEMA and Red Cross data, information on destroyed and damaged buildings, etc.
- Indicate topics and issues that warrant further, in depth study.

To accomplish the above objectives, it is suggested that the following documents be obtains during field activities.

1. Local newspaper accounts, news video tapes.
2. Records from Red Cross shelters on meals served, housing provided, first aid care given.
3. Hospital emergency department logs.
4. Community disaster plans.
5. Records on disaster assistance applications from FEMA, the Small Business Administration, state disaster assistance agencies, Red Cross, etc.
6. After-actions reports from fire, police, other public safety agencies.
7. Data on business damage and displacement from local merchants associations, chambers of commerce, and other organizations.
8. Statistics from local government agencies and departments, including Building and Safety, that document damage and social impacts.
9. Records from agencies providing crisis intervention and mental health services in the affected area.

The field investigation checklist below contains a listing of the types of data that, ultimately, a good social science investigation of a major earthquake would include. It is highly unlikely that any single reconnaissance effort will provide information on all or most of the topics listed.

Checklist
Social Science and Emergency Response

In General

1. What is distinctive about the earthquake from a social science point of view? For example, were some community activities and functions or some segments of the population more seriously affected than others? Were any distinctive behaviors and response patterns observed?
2. Do generalizations derived from an initial look at the earthquake reinforce or contradict what has been stated in the disaster literature about human and organizational response in disasters?

Casualties and Injuries

1. Where did deaths or injuries occur? Note nature, severity, and cause of injuries. Describe type of structure in which they occurred.
2. Where were casualties and injured taken and how were they transported? By whom?
3. What type of treatment did injuries require? First-aid? If hospitalization was required, what was nature of treatment and duration of stay?
4. Map spatial distribution of injuries and casualties. Note age, race, and ethnicity of victims.
5. Analyze patterns of human response during earthquakes to determine the relationships between behavior and morbidity, and behavior and mortality.
6. Check the coroner's office, public health department, hospitals, clinics, first-aid stations, and local ambulance services to determine causes of death and what kind of injuries were treated.
7. Describe any secondary emergencies such as fires or hazardous materials release.

Search and Rescue

1. Were search and rescue operations carried out? If so, determine where, when, by whom, and under what conditions.
2. How did participants come to take part in search and rescue efforts? Were activities planned or emergent?
3. If those first on the scene were not official emergency personnel:
   a. Determine how many local residents responded and what they did.
   b. When did official search and rescue personnel arrive? What organizations were involved?
   c. Did the citizens first on the scene continue to work with emergency personnel?
   d. What was working relationship? Explore for perceived hostility, competition, cooperation, problems, or special successes.
4. How, when, and by whom were priorities set for performing search and rescue operations?
5. Was there any problem evacuating victims from the area? If so, describe.
6. Was heavy debris removal required? If so, how effective was it? What problems were encountered?
7. If heavy equipment used, from where was it obtained?

8. When and how were search and rescue activities terminated?
9. If participants had to do it over again, what would they change/improve?

Emergency Response

1. Determine baseline organization of response.
   a. Did an emergency plan exist? Was it implemented?
   b. Who was the first responder?
   c. Who was in charge of overall response?
   d. Who was in charge at disaster scene?
   e. How was response coordinated? At local level? At regional level? At national level?
2. Develop chronology of key activities and actions.
   a. Chart activities of key organizations in local, state, other governmental units, and the private sector.
   b. Note key earthquake-related tasks, such as search and rescue, damage assessment, debris clearance, etc.
   c. For each organization or task, indicate when each task began and ended.
   d. Determine what problems each task group encountered and how they were solved.
3. What outside resources were provided? Regional? National? International?
   a. Were outside resources requested?
   b. Who was in charge of coordinating resources and their allocation?
4. Describe phasing of response and chain of responsibility from initiation of response through recovery and reconstruction.

Public Services

1. Describe performance of medical services, including hospitals, public health departments, coroner's office, clinics, ambulance services, blood banks, and medical response by relief agencies.
2. Were there adequate resources available to meet emergency needs?
3. Document the activities of law enforcement agencies and fire departments.
4. If many organizations responded to the earthquake, describe their inter-organizational coordination.

5. What type of response was required from public works departments? Describe street or road repair, refuse collection, sewage system problems, building inspection, and similar activities.
6. Describe the performance of public utilities and any consequences of failure.
7. Describe activities of relief agencies such as the Red Cross, Federal Emergency Management Agency (FEMA), Salvation Army, and local relief groups.
8. Did the military provide any assistance? If so, describe type and extent.
9. Document the degree of effectiveness with which emergency services (fire departments, emergency management organizations, emergency medical service system, hospitals, etc.) responded in the post-earthquake period. Discuss planning, earthquake experience of individuals and organizations, size of event, magnitude of disaster-related demands relative to resources, etc.

Mental Health Services

1. Were emergency mental health and counseling services available? Were they needed?
2. How many people sought assistance?
3. What kind of problems were presented?
4. What was age, race, and ethnicity of those who sought assistance?
5. Were intervention or counseling programs able to reduce victims' stress and prevent future psychological dysfunctions, particularly among emergency workers?

Media Response

1. How did the media respond?
2. Describe post-earthquake dissemination of information. Was it adequate? Responsible? Effective?

Damage From Fire

Refer to Section 9, Lifelines—Field Investigation, for checklist.

Displaced Persons

1. How many people were left homeless?
2. What was done to house them? Describe emergency and temporary shelters. Have any long-term arrangements for housing been made?
3. What was done to feed them?

4. Describe any self-built shelters or housing.
5. Where are displaced persons now? With family members? Friends? In temporary housing? Is temporary housing self-built or officially provided?
6. What was duration of occupancy for both self-built and officially provided housing?
7. How many displaced persons left the area entirely?
8. Were those left homeless disproportionately from one socioeconomic class?

Economic and Social Impacts

1. Develop estimates of the major indicators of social and economic disruption.
   a. Determine number and type of housing units that sustained total or major damage.
   b. Estimate number of displaced households.
   c. Determine number of persons sheltered.
   d. How many businesses were destroyed or otherwise unable to function?
   e. Is there any earthquake-related unemployment?
   f. Describe major businesses and industrial sectors affected.
2. Describe economic impacts on commercial and distribution centers, private offices, public buildings, schools, hospitals, jails, etc.
3. Describe impacts on local businesses, shopping areas, etc.
4. Determine how different segments of the population (the elderly, disabled, non-English speaking, etc.) responded to the earthquake. Were any special problems encountered?
5. Did people have access to their homes or places of business?
6. Describe immediate economic impacts on unskilled, semi-skilled and skilled labor, professionals, shop owners/artisans, and the self-employed.
7. Was there equal access to formal and informal aid programs in the post-earthquake period?
8. Describe problems the community is likely to confront in the post-earthquake recovery period, including land-use changes, replacement of residential housing units, commercial redevelopment and reconstruction, and financial problems.

Mitigation and Preparedness

1. How effective were response planning and operations?
2. To what degree did the community implement building and zoning codes? Did these measures mitigate damage?
3. Analyze benefits attributable to mitigation.
4. Determine whether or not areas or buildings were exempted for some reason. Attempt to determine if factors may have been at work in the community (social, economic, political) that reduced the effectiveness of mitigation measures.
5. Assess "hot lines" and other publicized information sources. Determine usefulness and accessibility.
6. Describe the status of earthquake hazard mitigation and preparedness planning prior to the event.
7. Note any suggestions for new mitigation and/or preparedness measures that would seem warranted in light of the earthquake impacts observed.

Field Investigation Form—
Social Science and Emergency Response

Use this form for site-specific data collection to aid in making subsequent analyses. It is not meant to be substituted for the broader analysis of the earthquake's impacts on the community.

Name of Investigator: ______________________ Date: ________

Site location: ______________________________

Injuries/Deaths

Did injuries or deaths occur? ______________________

Describe nature and causes of injuries/deaths:

____

____

____

Describe type of structure and location in structure where injuries/deaths occurred: ______________________________

____

____

____

____

Emergency Response

Describe effectiveness of emergency services: ______________

____

____

Were search and rescue operations carried out? If so, describe. Note location, nature and extent. ______________________

____

____

____

____

SOCIAL IMPACTS

Did communications problems occur?____________________

If so, describe (e.g., hardware problems, social/cultural problems, interaction between two): ____________________

Was an emergency operations plan in place? Was it followed?

Were temporary measures necessary (e.g., backup generators, rerouting, etc.)?

Use back of sheet for sketches and additional notes

SOCIAL IMPACTS

PROBLEM 2: Simplicity, regularity, and Symmetry in elevations.

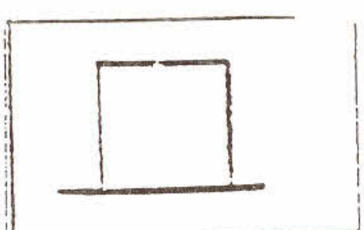
PRINCIPLE: Earthquakes do not respect theories, calculations, division of responsibilities, or geographic boundaries. They respect the simplicity, regularity, and symmetry of the building form which keep the centers of mass and resistance at the same point. They also respect the quality of construction.

INSTRUCTIONS: Opposite each of the 13 sketches of building elevations shown below, enter the following information:

- - The generic building type represented by the sketch.
- - The causes of vulnerability (i.e., in terms of lack of simplicity, irregularity, or asymmetry).
- - Where the damage patterns will occur and why they will occur there.
- - The relative vulnerability where 1 is the lowest (least loss in value) and 10 is highest (greatest loss in value).

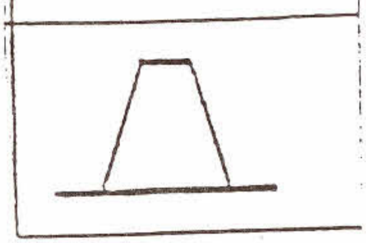
ELEVATIONS

A.



Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

B

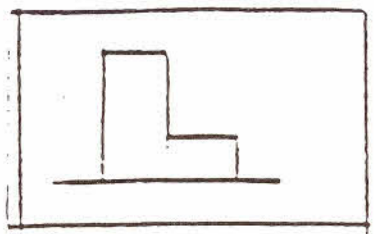


Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

C.

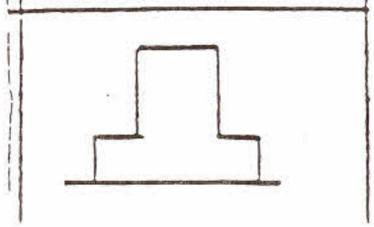
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Relative Vulnerability (1-10): ________

D.



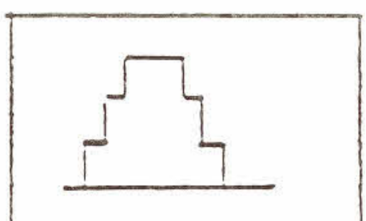
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Relative Vulnerability (1-10): ________

E.



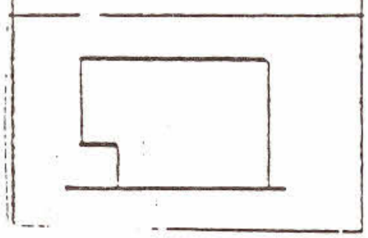
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Relative Vulnerability (1-10): ________

F.



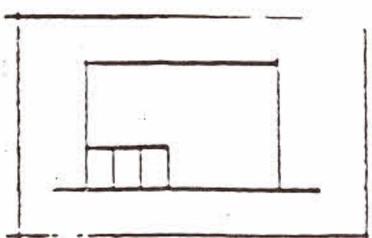
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Relative Vulnerability (1-10): ________

G.



Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Relative Vulnerability (1-10): ________

H.



Generic Name: ____________________

Cause of Vulnerability: ____________________

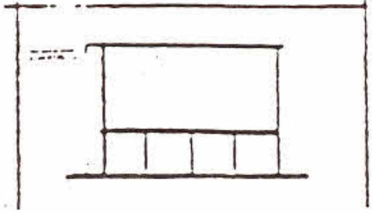
____

Likely Damage Patterns: ____________________

____

Relative Vulnerability (1-10): ________

I.



Generic Name: ____________________

Cause of Vulnerability: ____________________

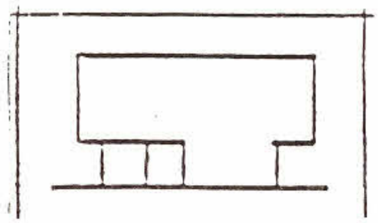
____

Likely Damage Patterns: ____________________

____

Relative Vulnerability (1-10): ________

J.



Generic Name: ____________________

Cause of Vulnerability: ____________________

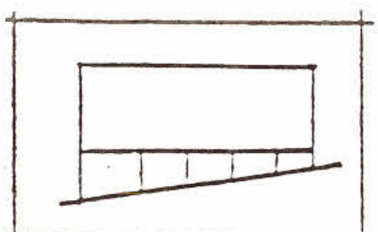
____

Likely Damage Patterns: ____________________

____

Relative Vulnerability (1-10): ________

K.



Generic Name: ____________________

Cause of Vulnerability: ____________________

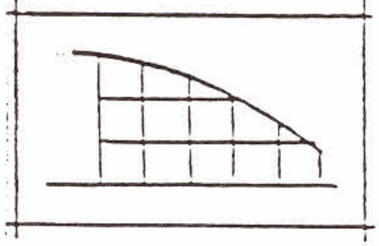
____

Likely Damage Patterns: ____________________

____

Relative Vulnerability (1-10): ________

L.



Generic Name: ____________________

Cause of Vulnerability: ____________________

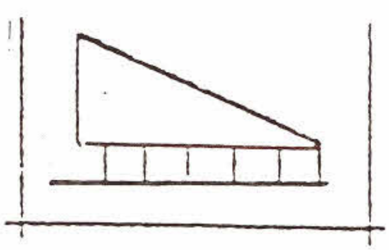
____

Likely Damage Patterns: ____________________

____

Relative Vulnerability (1-10): ________

M.



Generic Name: ____________________

Cause of Vulnerability: ____________________

____

Likely Damage Patterns: ____________________

____

Relative Vulnerability (1-10): ________

C. VULNERABILITY OF BUILDINGS AND BUILDING ELEMENTS

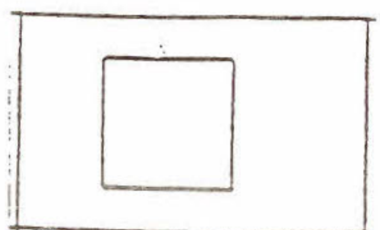
PROBLEM 1: Simplicity, regularity, and symmetry of floor plans.

PRINCIPLE: Earthquake-resistant buildings (i.e., those that are designed to resist major earthquakes without collapse while sustaining structural and non-structural damage) have floor plans which keep the centers of mass and resistance at the same point. The physical properties of each resisting element contribute to the overall integrity of the building's resistance. Sources of brittle failure are minimized through redundancy and adequate margins of safety.

INSTRUCTIONS: Opposite each of the 13 sketches of floor plans below, answer the same questions as in Problem 2 of Exercise B.

FLOOR PLANS

A.

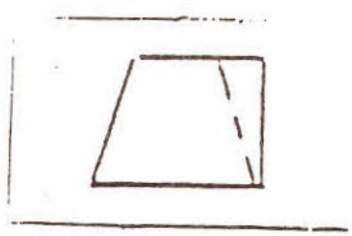


Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Relative Vulnerability (1-10): ________

B.

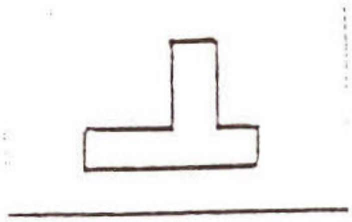
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Relative Vulnerability (1-10): ________

C.



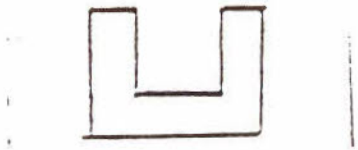
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Relative Vulnerability (1-10): ________

D.



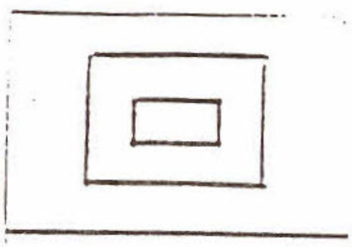
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

E.



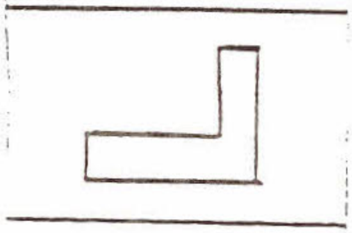
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

F.



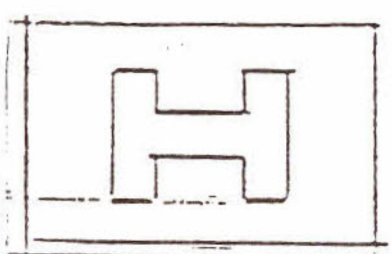
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

G.



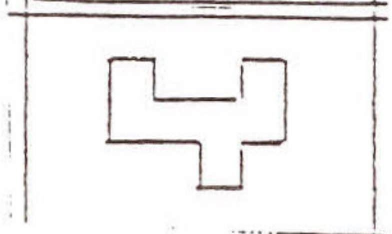
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

H.



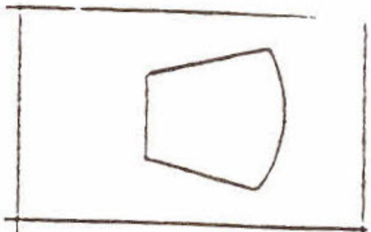
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

I.



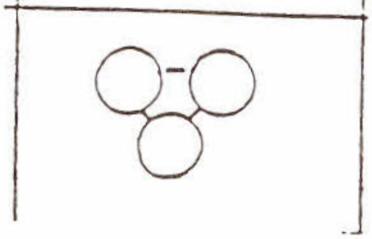
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

J.



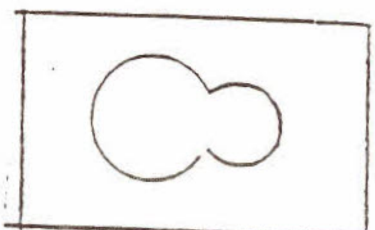
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

K.



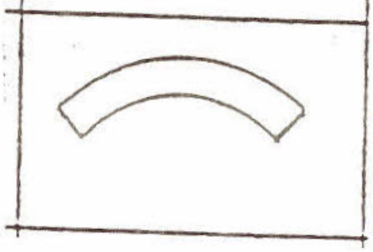
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

L.



Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

M.



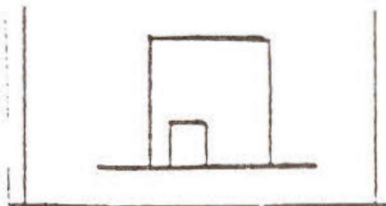
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Relative Vulnerability (1-10): ________

PROBLEM 2: Simplicity, Regularity, and Symmetry of Internal Elements

INSTRUCTIONS: Opposite each of the 11 sketches of internal elements, answer the questions below.

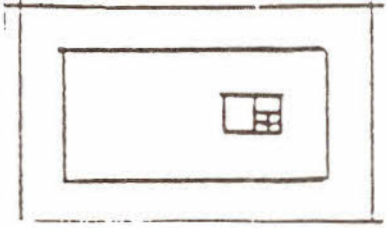
BUILDING INTERNAL PROPERTIES

A.



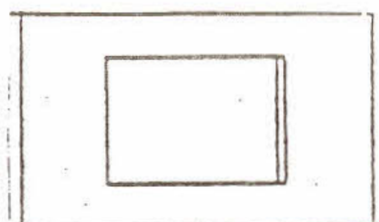
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Why? ____________________
____

B.



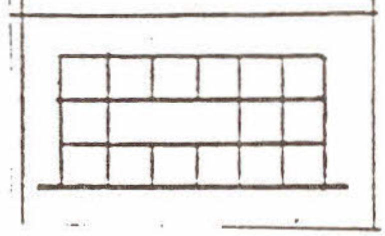
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Why? ____________________
____

C.



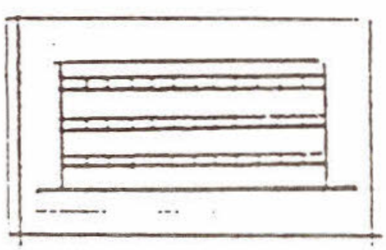
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Why? ____________________
____

D.



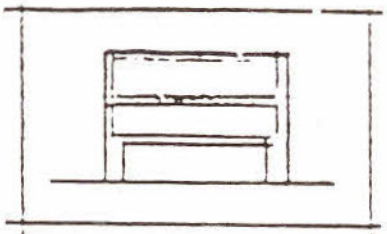
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Why? ____________________
____

E.



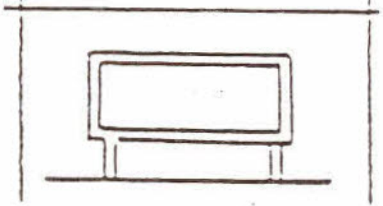
Generic Name: ____________________
Cause of Vulnerability: ____________________
____
Likely Damage Patterns: ____________________
____
Why? ____________________
____

F.



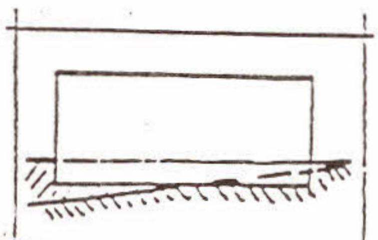
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Why? ______________________
____

G.



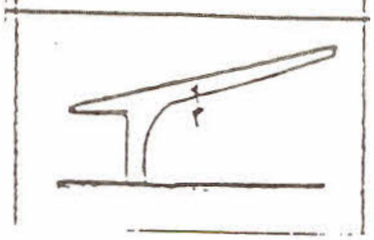
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Why? ______________________
____

H.



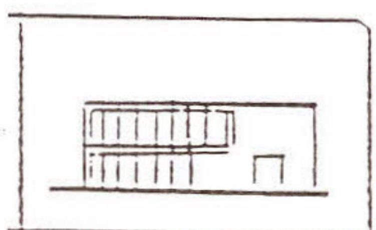
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Why? ______________________
____

I.



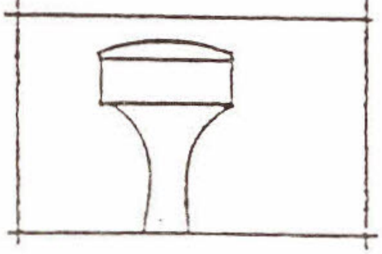
Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Why? ______________________
____

J.



Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
____
Why? ______________________
____

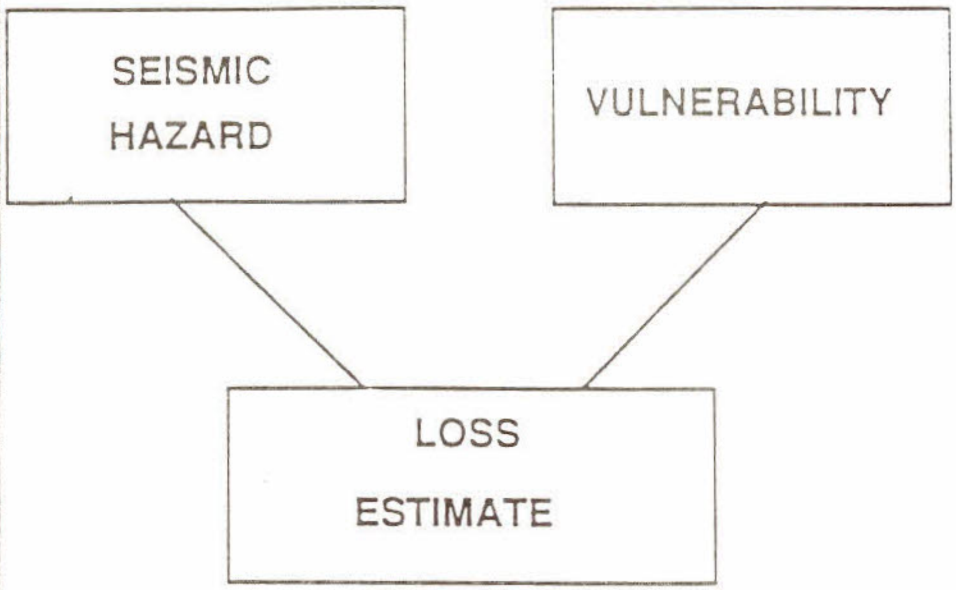
K.



Generic Name: ______________________
Cause of Vulnerability: ______________________
____
Likely Damage Patterns: ______________________
Why? ______________________
____

D. LOSS ESTIMATION

PRINCIPLE: LOSS ESTIMATES



An earthquake loss estimate is a forecast of the effects of a hypothetical earthquake on the inventory of buildings and lifeline systems at risk in a community. Depending on its purpose, a loss study may include estimates of deaths and injuries, property losses, loss of function in industries, lifelines, and emergency facilities, homelessness, and economic impacts. A loss estimate may be used to:

- Identify especially hazardous geographic areas, groups of buildings, or lifelines.
- Aid in the development of emergency response plans.
- Evaluate overall economic impact on the nation.
- Formulate general strategies for earthquake risk reduction such as land use plans or building codes.

PHOTOGRAPHS

INSTRUCTIONS: You are a member of a postearthquake investigations team and encounter the situations portrayed by the following photographs:

For each situation,

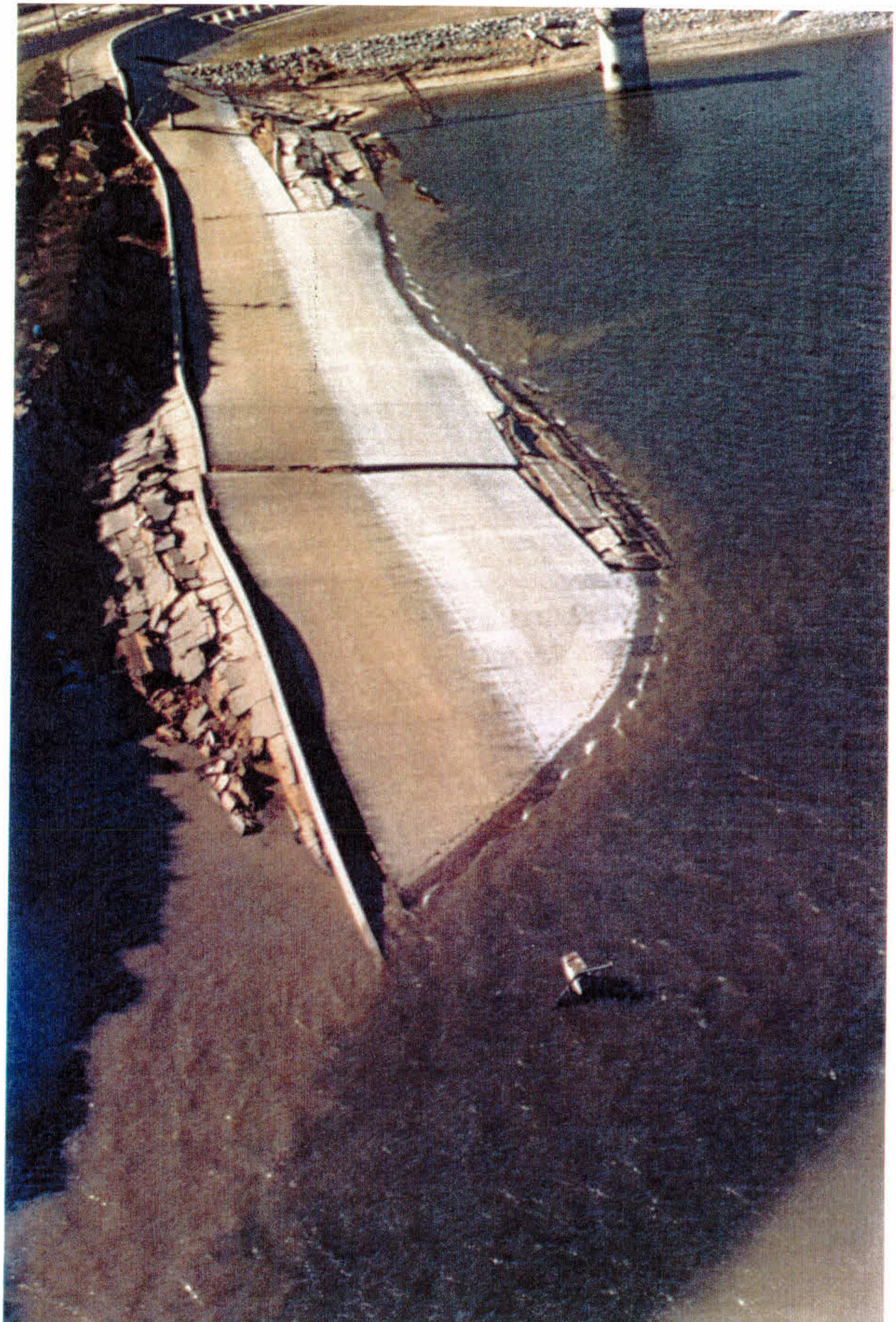
a) Describe what happened and assign an MMI value.
b) Why did this situation occur?
c) What kinds of data should be collected now? later?
d) Where in Arkansas might this situation occur? Why?
e) Where in the Central US might this happen?
f) What types of long-term scientific studies should be undertaken?
g) What pubic policies and professional practices should be adopted to reduce the risk?

Photograph 1

Photograph 2

Photograph 3

Photograph 4

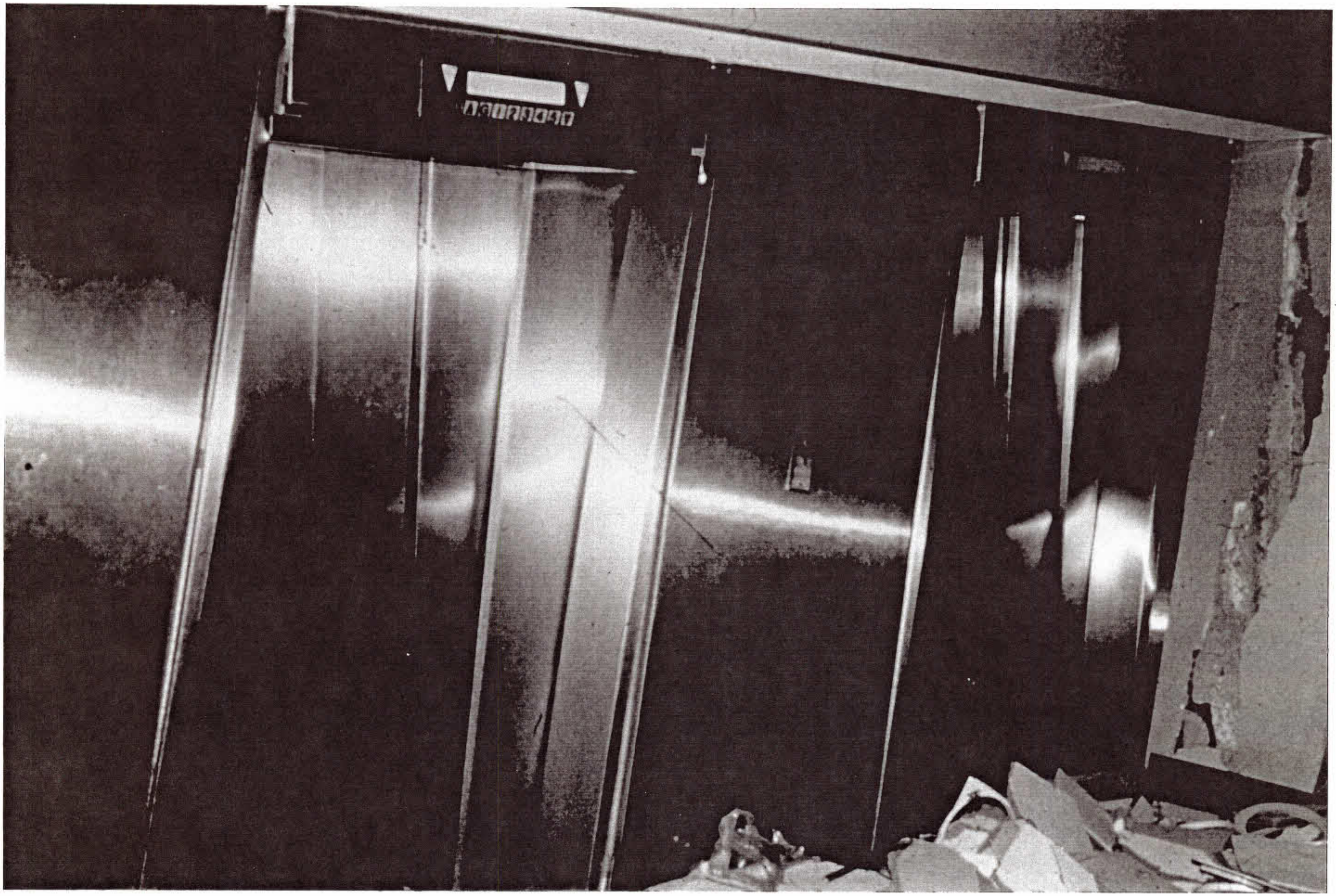


Photograph 5

Photograph 6

Photograph 7

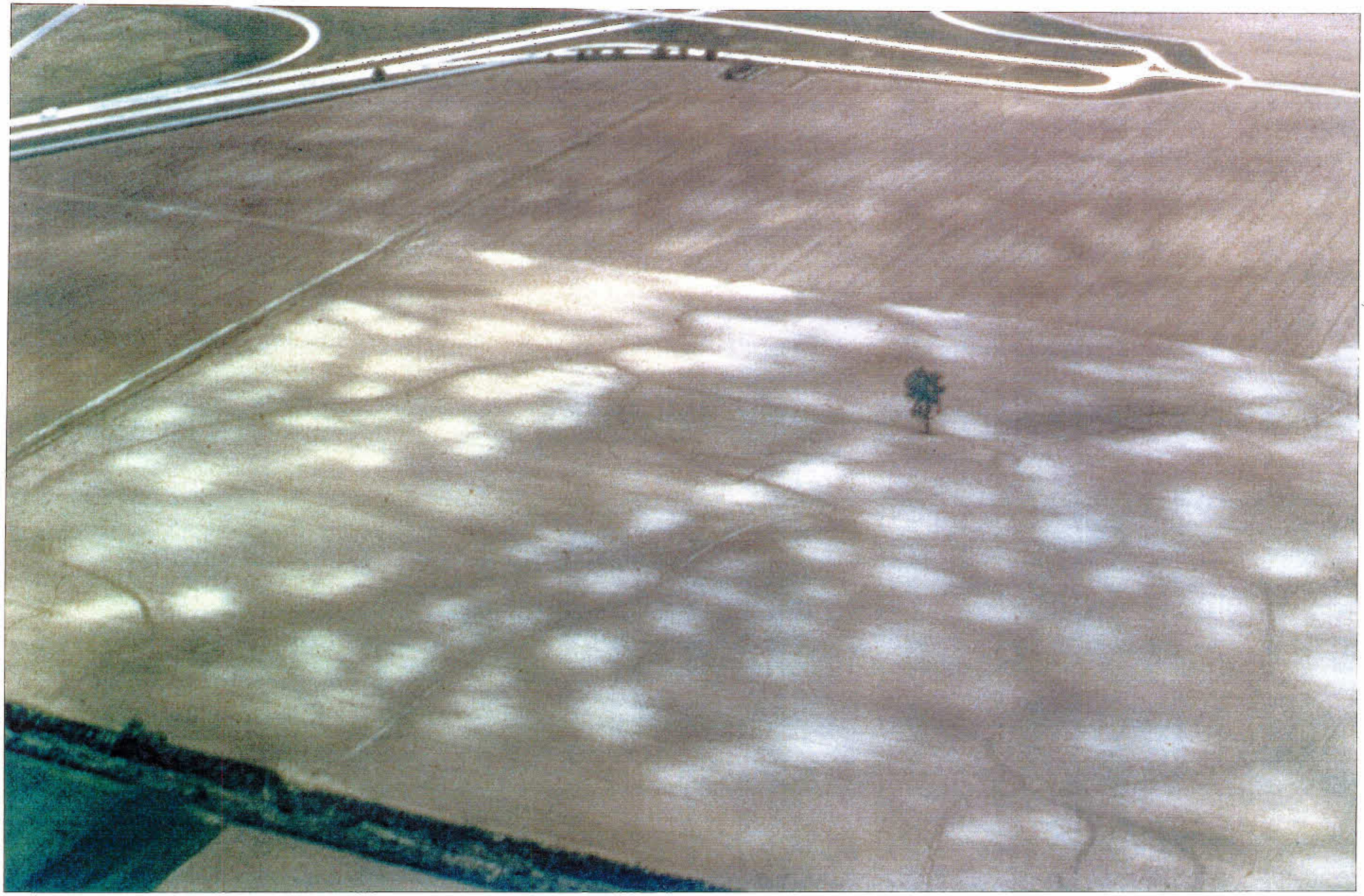
Photograph 8



Photograph 9

Photograph 10

Photograph 11



Photograph 12