SECTION 1

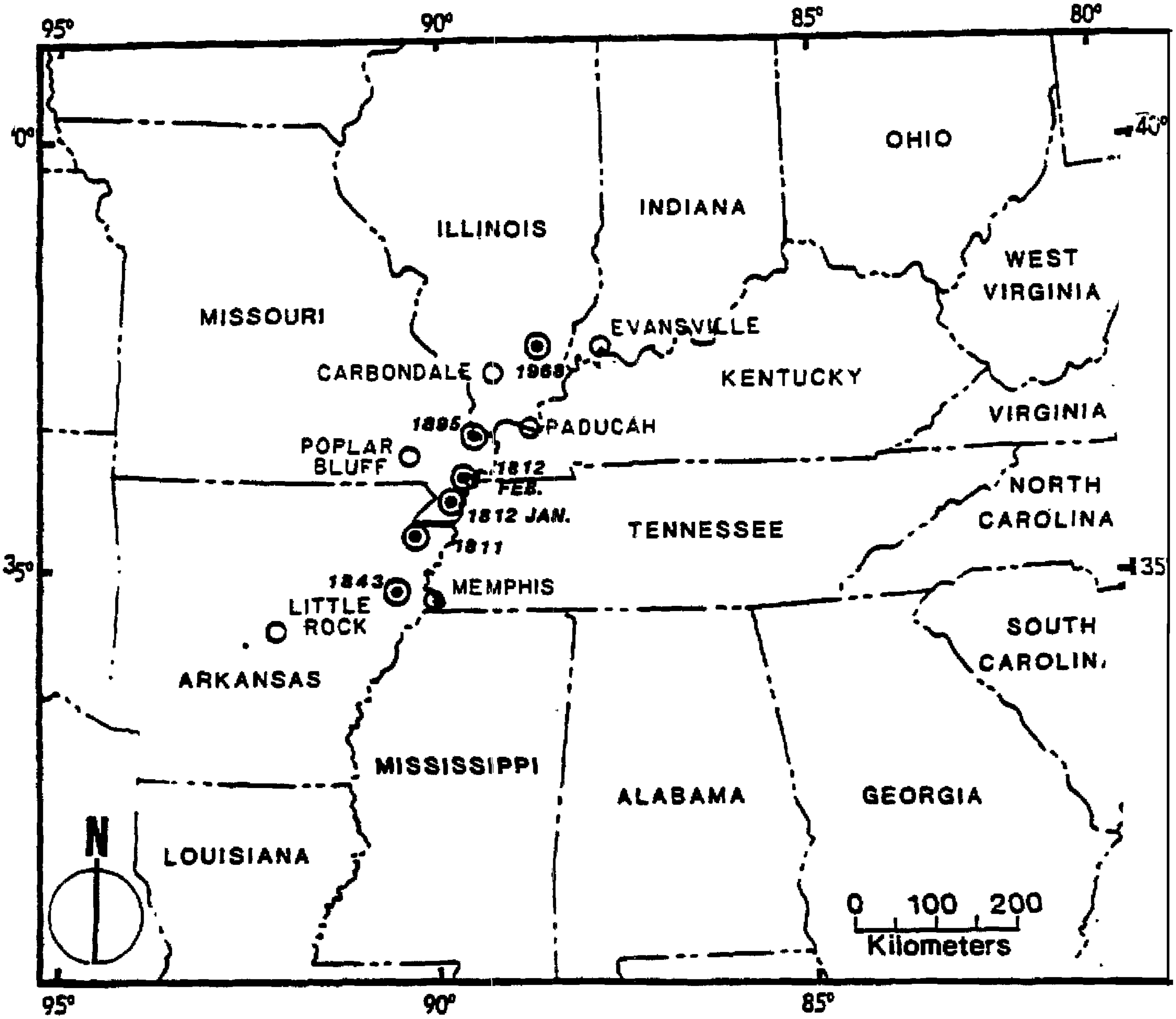
INTRODUCTION

1.1 Purpose and Scope of Project

The purpose of this study is to provide estimates of the effects of a major, (surface magnitude [Ms] = 7.6), and a great, (Ms = 8.6) earthquake upon six cities in the central United States. These are: Carbondale, IL; Evansville, IN; Little Rock, AR; Memphis, TN; Paducah, KY; Poplar Bluff, MO; their locations are shown in Figure 1-1. These cities were selected for their population sizes, proximity to the New Madrid fault zone, ability to assist in the inventorying of structures, and their location in differing States of the CUSEPP.

1.2 Central United States Earthquake Preparedness Project (CUSEPP)

This earthquake vulnerability assessment is part of the ongoing Central United States Earthquake Preparedness Project (CUSEPP). The project's purpose is to reduce the hazards associated with the occurrence of an earthquake event in the the Central United States. Two other report documents of the CUSEPP have preceded this study and contain information which is directly preparatory to it. These reports will be referenced throughout this study and contain considerable relevant background information. The first is titled "Evaluation of Past Studies and Identification of Needed Studies of the Effects of Major Earthquakes Occurring in the New Madrid Fault Zone" (Nuttli, 1981). The second report, (Hopper, etal, 1983) is titled "Estimation of Earthquake Effects Associated with a Great Earthquake in the New Madrid Seismic Zone". This report is supplemented with United States Geological Survey (USGS) Manuscript



Map showing the six cities evaluated in this study. Also shown (circles with dots) are localities of the epicenters of large historical earthquakes

Reference 16

FIGURE 1-1

No. 966 (August 8, 1984).

This study presents the results of the application of estimates of the earthquake-induced ground shaking to an inventory of structures in the six cities to produce an estimation of damage and casualties, and assessments of the disruption of essential services. The earthquakes upon which the ground shaking estimates are based represent large seismic events and are assumed to occur anywhere along the New Madrid Seismic Zone. The selection of an Ms=8.6 event allows assessment of the upper limits of damage and losses. The Ms=7.6 earthquake represents an event with a greater probability of occurrence, and is more appropriate for realistic risk assessment in terms of existing and planned facilities and structures. The assumption that they occur anywhere along the seismic zone also means that they occur at a point closest to each of the six cities studied, thereby maximizing the ground shaking estimates.

This study employs a methodology for vulnerability assessment which has not previously been used for studies of this type. As such, it is a preliminary methodology and has the limitations attendant to being the first application of a methodology. Primarily, the figures cited for earthquake losses should be viewed as preliminary estimates. Nevertheless, this study does serve several purposes. It can assist emergency managers and planners at all levels in the initiation of awareness, preparedness and response plans for the six cities and the region in general and can indicate components of the society's support structure where mitigative measures may be taken. It should also be of great significance and benefit to regional and national planners who seek to define the multiple overall effects of damaging earthquakes in this region.

1.3 Seismicity of the Study Area

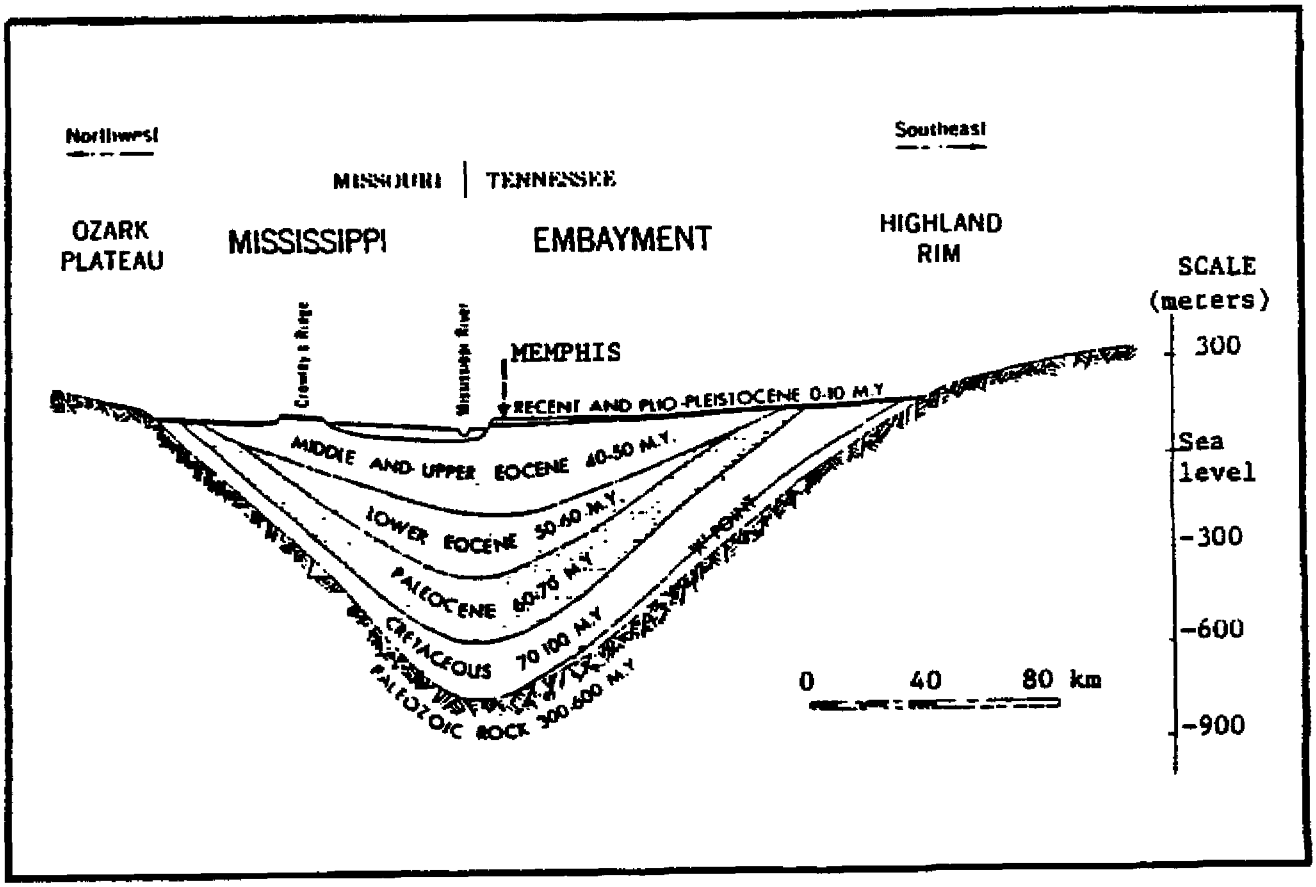
The region of the United States which comprises the CUSEPP area includes that portion of the Central Mississippi Valley which has been determined to be within the area seriously affected by the occurrence of a major earthquake in the New Madrid Seismic Zone. In descriptive terms, this region includes southern Illinois, southwestern Indiana near the Ohio River, western Kentucky, the Missouri Bootheel and the southeastern Missouri Ozark region, central and eastern Arkansas, west Tennessee, and portions of northwest Mississippi. The maximum areas affected by the Ms=7.6 and Ms=8.6 are shown in Figures 2-4 through 2-7 in Section 2.

The seismic activity of the New Madrid Seismic Zone has received increasing interest and attention on the part of seismic experts and emergency planners. The CUSEPP reports of Dr. Nuttli and the USGS (references 16 and 26) provide excellent descriptions of the zone's seismic history and discussions of potential future activity. No attempt will be made in this report to duplicate descriptions contained in them. A brief overview of the seismic situation is presented below to familiarize the reader with overall conditions. The reader is also referred to subsection 1.5 Earthquake Fundamentals found later in this section. This material will aid those not familiar with the basics of earthquakes and the terminology involved and should provide enough descriptive information to allow for useful understanding of the background material and damage and loss estimates of this study.

When referring to earthquakes in the United States, most attention and recognition has been, and continues to be, focused on earthquakes which have occurred in the relatively recent past along the west coast, and the earthquake planning activities regarding earthquakes in that region. However, the New Madrid Seismic Zone produced, in 1811 and 1812, a series of great earthquakes which are among the largest known in the United States and indeed in the world. These events have, until recently, been traditionally viewed by residents of the area and by the nation in general as curiosities or isolated events which had no potential of repetition. This attitude has undoubtedly come to pass due to the timing of the major earthquakes; they occurred early in our nation's history when the region was very sparsely populated, were experienced by relatively few individuals, were reported in sparse and sporadic manner, and were treated in the time span following them in the same manner as Indian legends or other pioneer tales. Since 1811 and 1812, no repetition of such large earthquakes has occurred, although the zone has produced several earthquakes of moderate to strong surface magnitudes. (e.g., 1843 - Ms=6.2; 1895 - Ms=6.2; 1968 - Ms=5.5).

Interest in the events of 1811 and 1812 and in the seismicity involved in the New Madrid Seismic Zone has persisted from one individual researcher to another over the intervening time period, but it has been under relatively recent conditions of improved scientific knowledge and instrumentation that a clearer understanding of this seismic zone has emerged. As referenced in the CUSEPP reports of Dr. Nuttli and the USGS as well as in other references listed in the bibliography, it is now known that this seismic zone is presently active and is the source of hundreds of small (generally too small to be felt) earthquakes each year. The location of the epicenters of these small seismic events have been made possible by networks of modern seismographic equipment, primarily those established by St. Louis University, St. Louis, Missouri and Memphis State University, Memphis, Tennessee. Data from these instruments have enabled scientists to learn a great deal about the nature and behavior of this seismic zone.

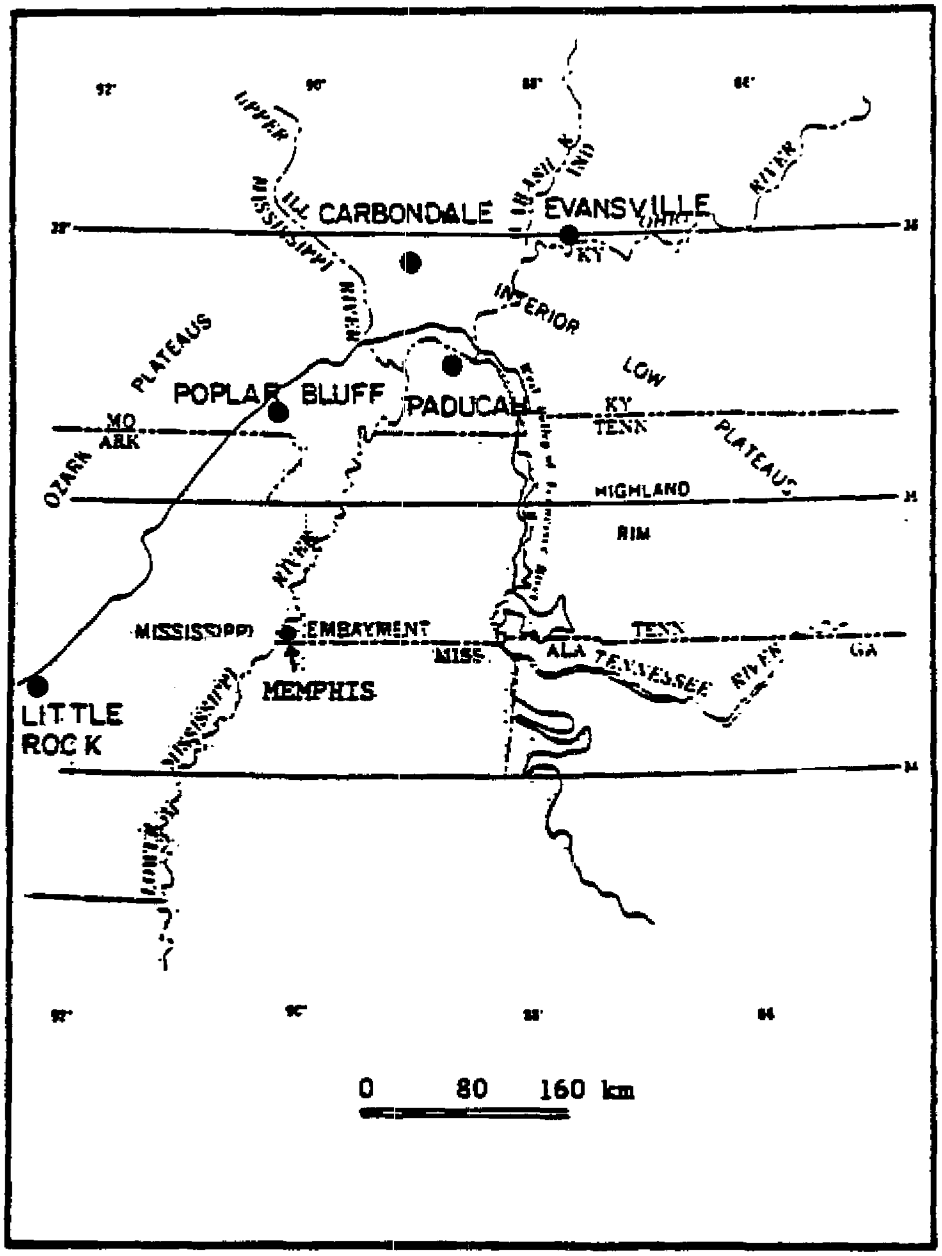
The results of these studies strongly indicate that damaging earthquakes are to be estimated within the lifetimes of people and structures in existence today. They have also shown that there are differing aspects of the earthquake hazard of the central United States as compared to that of the west coast. Among these is the situation that, due to the geologic formations which lie beneath the central portion of the United States, i.e., the Central Mississippi Valley and Mississippi embayment (Figures 1-2 and 1-3), the effects of a significant earthquake will be felt over a much greater area than those which occur in California and ground shaking effects may actually be intensified in the embayment area. Two points of example are presented here as verification of these phenomena. The first is that the events of 1811 and 1812 produced ground shaking that was detectable from the Canadian border of the United States to the Gulf of Mexico and from the Great Plains to the Atlantic Coast and also produced numerous areas of soils failure in the embayment area. Smaller, but nonetheless significantly large, areas of ground shaking have been associated with the lesser earthquakes which have occurred along the New Madrid Fault since 1811 and 1812. These lesser events



Diagrammatic cross-section of the Mississippi Embayment

Reference 31

FIGURE 1-2



Major geologic provinces of the Central Mississippi Valley
Reference 20

FIGURE 1-3

are the basis upon which the isoseismal patterns were estimated for the Ms=8.6 and Ms=7.6 earthquakes which are depicted in Figures 2-4 through 2-7 in Section 2. These depictions of ground shaking intensities, expressed on the Modified Mercalli Intensity Scale (see Table 2.1 in Section 2 for a description of scale), should be studied and reviewed closely. They indicate the great extent of damaged area which can be estimated with the occurrence of an Ms=7.6 or an Ms=8.6 earthquake in this region. Again, it should be noted that these estimates of ground shaking presume the seismic event to occur anywhere along the New Madrid Seismic Zone. Hence it does maximize the depiction of the affected area.

Despite this maximization of ground shaking estimates, when the extent and nature of the estimated damage is reviewed, it becomes apparent that such earthquakes, should they occur, will produce widespread damage and losses and be among the greatest natural disasters ever known or experienced in this nation. Responding to the emergency needs of the impacted area immediately following the disaster and assisting in post-earthquake recovery would tax the resources of the entire country. Although large scale seismic scenarios such as those used for this study have relatively low probabilities of occurring in the near future, it is wise to choose such events for response planning purposes. Doing so allows for appropriate scaling of effort and resources. And it allows the more likely, smaller magnitude events, which also have potential for widespread damage and disruption, to be dealt with in an informed perspective for response and recovery planning. A great many of the estimated effects upon these six cities, which are described in this report, would occur, to a similar but lesser extent, with the occurrence of earthquakes less severe than those selected for this study. This is especially true with respect to damage to certain aspects of electrical utility systems and other utility networks as well.

In summary, an assessment of the seismic status of the central United States, based on current knowledge of the New Madrid Seismic Zone, is that a real potential for serious, damaging earthquakes exists within a time frame which mandates planning activities by all levels of the social structure. This study presents the estimated consequences of two earthquakes in terms of numbers of casualties and disruption to vital urban systems in six selected cities of various populations and various distances from the seismic zone. These estimations will allow planners at all levels to begin to estimate and provide for resources needed to cope with such earthquakes (and with lesser but nonetheless serious ones) and begin strategic planning of the steps needed to effect a recovery, and provide a basis upon which to begin building a strategy to mitigate the effect of such events on the cities studied.

1.4 Methodology Overview

The overall approach or methodology used for this study was to first identify the seismic risk to which this region is exposed. This has been done in the CUSEPP reports of Dr. Nuttli and the USGS and in supplemental information from the USGS. Dr. Nuttli's report, "Evaluation of Past Studies And Identification of Needed Studies of the Effects of Major Earthquakes Occurring in the New Madrid Fault Zone" describes the history of the New Madrid Seismic Zone and the likelihood of this seismic zone producing damaging earthquakes in the future, and makes recommendations as to appropriate planning and investigation activities. Dr. Nuttli concludes that the zone is definitely capable of producing disastrous earthquakes now and in the foreseeable future and therefore urges that appropriate planning start immediately. General estimates are made of the extent and nature of damage which was caused by one of the great earthquakes of 1811 and 1812, and the type of immediate relief required by the various disaster zones which would result from a recurrence of such an event in modern times.

The CUSEPP report of the USGS also begins with an historical review of the events of 1811 and 1812, and gives a more detailed examination of the known effects of these events upon the six cities. It specifically delineates the levels of ground shaking to be estimated in the central United States and the six cities of this study, resulting from a Ms=8.6 and Ms=7.6 event. The ground shaking is expressed in terms of the Modified Mercalli Intensity (MMI) scale; intensities V through X were estimated to occur in the six cities. Soils failure, loss of bearing capacity and liquefaction in the six cities is also addressed. These estimates of ground shaking within the cities are a major and fundamental element required for this vulnerability assessment, and were made assuming the scenario earthquakes occurred as close as possible to each city. They will be discussed further in Section 2, which addresses project methodology in greater detail.

The next major step of the study was to describe the structures and services within the six cities by assembling a body of information of sufficient detail and extent to allow estimation of overall damage to them, presuming exposure to the USGS estimates of ground shaking. To do this required a labor intensive effort on the part of FEMA staff, local government and private volunteers in the six cities. This large body of detailed information was augmented and expanded by the study analysis team. The major feature of this information was that it described, using a variety of methods, the structural systems and construction methods utilized for virtually every structure of interest within the corporate limits of the six cities. This included all buildings, i.e., residential and non-residential, and "critical facilities" (a grouping which encompasses many structures of many kinds and uses, such as bridges and electrical substations, as well as certain special building types, such as hospitals and schools). An equally important data element, assembled from many sources, was the numbers of people occupying buildings within the six cities. Additional information was collected for lifeline and urban services, notably utility, communications and transportation systems. This detailed data compilation, coupled with the ground shaking estimates, were basic inputs to the methodologies used to estimate damage, casualties, disruption to and availability of services and systems. Further discussion of the structural information data base will be presented in Section 2, Methodology.

1.5 Earthquake Fundamentals

The following material has been excerpted from Engineering Aspects of the 1971 San Fernando Earthquake, U. S. Department of Commerce, December, 1971, and is intended to present basic information concerning earthquakes and seismic terminology.

Earthquake Terminology

There are two terms which are commonly used to describe the size of an earthquake. These are "intensity" and "magnitude". These two terms are often confused, and it is important to understand the difference.

INTENSITY is an indication of an earthquake's apparent severity at a specific location, as determined by observers. It is a measure of the effects of an earthquake determined through interviews with persons in the quake-stricken area, damage surveys, and studies of earth movement.

The Modified Mercalli Intensity scale used in the United States grades observed effects into twelve classes ranging from I to XII. Description of this scale is given in Section 2, Table 2.1. The older Rossi-Forel Intensity scale has ten categories of observed effects, and is still used in Europe. Still other intensity scales are in use in Japan and the U.S.S.R.

The potential severity of the earthquake at a particular location can also be determined from the records of a strong motion seismometer (accelerometer) mounted on a rigid foundation. The readings from such instruments indicate the amplitude and frequency of earth accelerations at that specific site and can be integrated to determine both velocities and displacement. Such information can be used by engineers in determining the degree of motion to which structures have been subjected and to make determinations of the forces which are exerted on structures. The measure of potential severity of the earthquake at the recording station is usually expressed as a fraction of the acceleration due to gravity.

MAGNITUDE, on the other hand, expresses the total amount of energy released by an earthquake and is determined by measuring the amplitudes produced on standardized recording instruments. Thus, it is a measure of the absolute size or strength of an earthquake and does not consider the effect at any specific location.

The Richter scale, which gives the numerical value of the magnitude, was defined by Richter in 1935 as logarithms (base 10) of the amplitude in microns of the trace written by a seismograph at a distance of 100 km from the epicenter.

Observations at distances other than 100 km can be corrected to convert them to the standard distance. Because the Richter Scale is expressed in logarithms of base 10, a unit increase in the scale is equivalent to a ten fold increase in the real trace magnitude. For example, an earthquake of magnitude 8 represents a seismograph amplitude 10 times greater than that of a magnitude 7 earthquake, 100 times greater than that of a magnitude 6 earthquake, and so on. There is no upper limit to the Richter scale. The largest magnitude ever recorded is 8.9.

Magnitude-Intensity Relations

Magnitude and maximum intensity of an earthquake are interdependent to some degree, but there is no close correlation between them. For example, an earthquake might have a low magnitude but because of shallow focus, poor soil conditions, or poor building construction practices, it might cause a great deal of damage; thus, it would have a very high intensity. On the other hand, an earthquake of very large magnitude might have a great focal depth, or might occur in an area where there is very little man-made structure to damage. It would not, therefore, have a high apparent intensity.

For the purpose of illustration, a released energy (from a high explosive - TNT) and its corresponding Richter scale magnitude are plotted in Figure 1-4, with several earthquakes indicated for comparison.

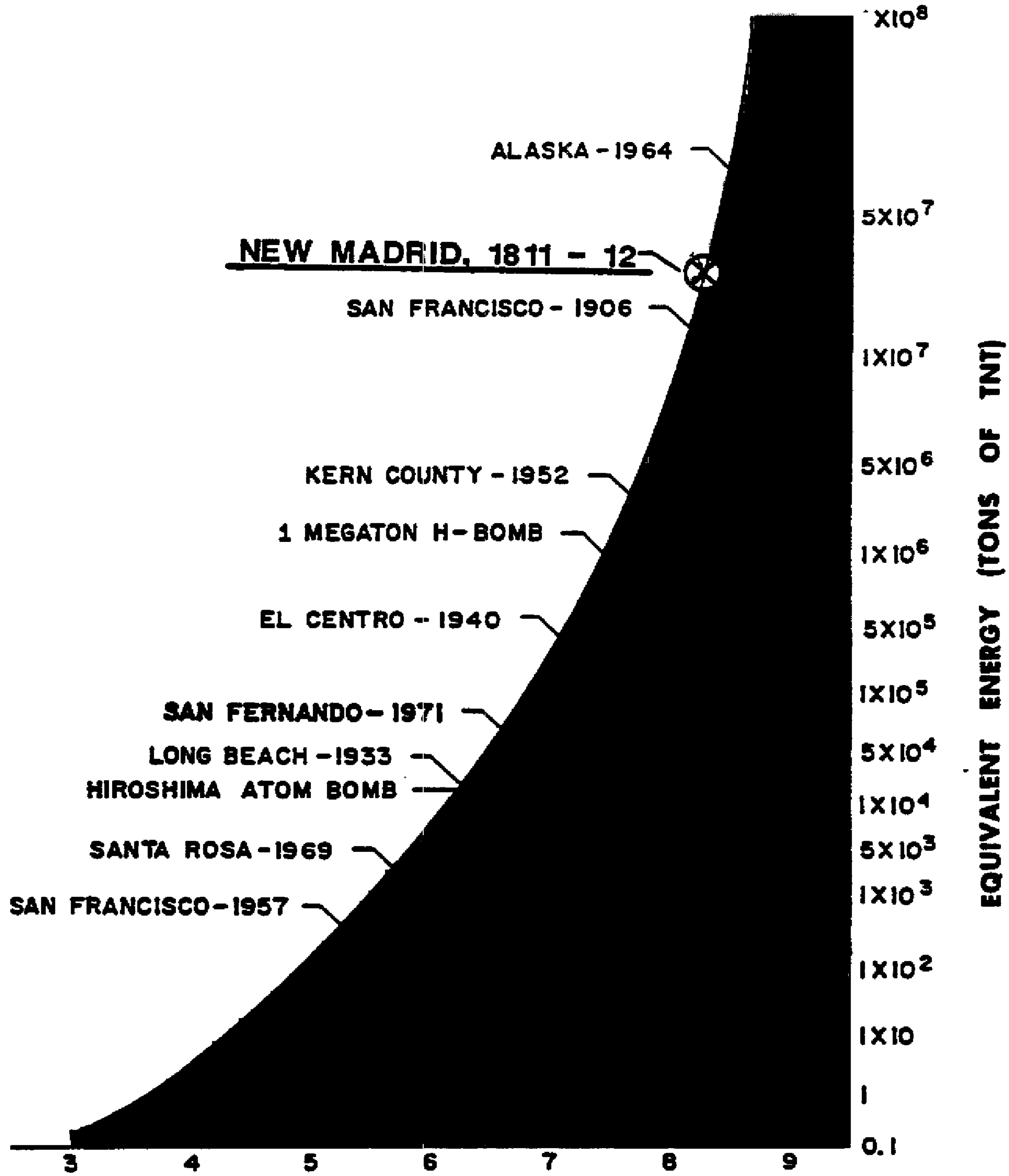
Seismic Waves

Ground motion is excited by the propagation of waves which emanate from the hypocenter (source) of an earthquake. There are four basic seismic waves: two preliminary "body" waves which travel through the earth and two which travel only at the surface. The total wave propagation pattern is shown schematically in Figure 1-5. Combinations, reflection, and diffractions produce countless numbers of waves of other types. In addition, a large earthquake generates inelastic waves.

The two body waves are the primary (P) wave and the secondary (S) wave. The P wave travels about twice as fast as the S wave, and is the first instrumental indication that an earthquake has occurred.

The P wave is longitudinal, like a sound wave, and propagates through both liquids and solids. It travels about 4 miles per second or nearly 15,000 miles per hour. As the compressional P wave passes through the earth's crust, an object embedded in the ground or on the surface is subjected to a series of sharp pushes and pulls parallel to the wave path-motion similar to that which the passengers feel when a long train gets under way.

The S wave is transverse, like a light or radio wave, and travels barely more than half as fast as the P wave. As this wave

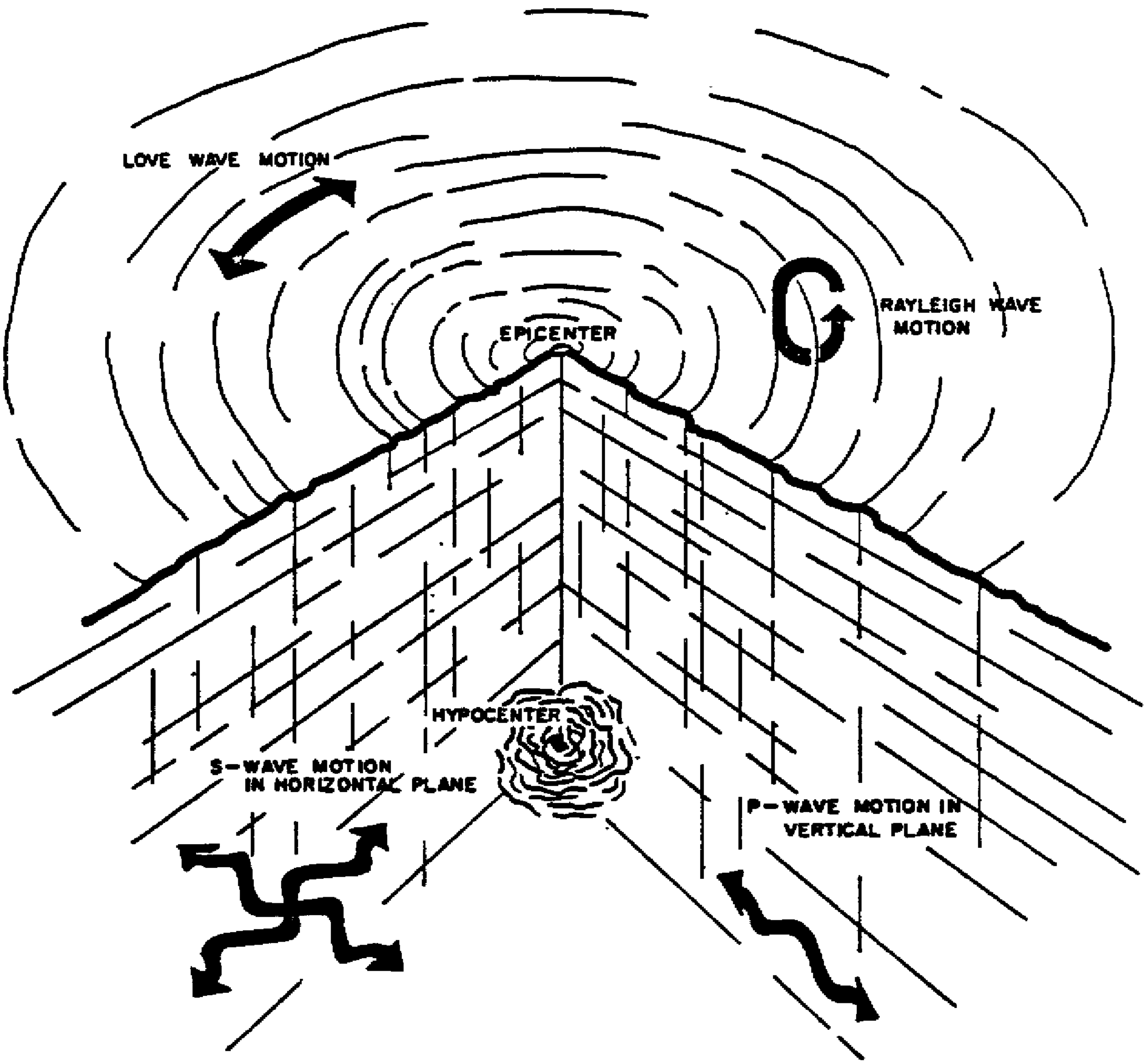


RICHTER SCALE OF MAGNITUDE

Comparison of Richter Scale Magnitude versus Equivalent Energy of TNT

Reference 20

FIGURE 1-



Elastic earthquake generated waves.

Reference 20

FIGURE 1-5

travels, it displaces objects at right angles to the direction of wave travel.

The Love wave produces lateral shear in the horizontal plane, and Rayleigh wave induces a retrograde, elliptical motion, similar to wind-driven ocean waves. The speed of the Love wave is about 2.5 miles per second and the Rayleigh wave is about 10 percent slower (3.1).

Because of the waves generated by an earthquake travel at different speeds, the seismic waves arrive at a given point at different times. A recording station located at a great distance could record a single event for days as reflected, combined, and resonated waves propagate through the earth's mantle and core.

The first indication of an earthquake is signaled by the arrival of the compressional (P) waves. This will be followed by the shear (S) waves and then the "ground roll" caused by the surface waves. When compared with the body waves (P and S), the surface waves usually have the stronger vibrations and probably cause most earthquake damage.

The vibrations induced by earthquakes are detected, recorded, and measured by seismographs. In the region of strong ground motions near a high-energy source, "strong motion" seismographs are used. These seismographs are usually installed in tall and large buildings, in some dams and bridges, and at nuclear reactor sites. They are triggered by the earthquake-generated vibration above a given threshold amplitude, so that the onset of the earthquake motion is usually lost. However, the lost portion of the record has little value to earthquake engineering which is primarily concerned with the earthquake-resistance design of structures.