AN INTRODUCTION TO EARTHQUAKES

By Tom Irvine
Email: tomirvine@aol.com

July 20, 2000

TECTONIC PLATES

The Earth is composed of a number of layers.

The center of the Earth is the solid core, made of solid nickel and iron. A liquid core, consisting of molten nickel and iron, envelops the solid core.

The next layer is the mantle, composed of melted rock in a viscous but dense form. The mantle itself is subdivided into several layers.

The asthenosphere is a somewhat plastic layer of the mantle. It is soft and partially molten.

The next layer outward is the lithosphere, which is hard and rigid.

The Earth's crust is the outermost part of this lithosphere. The crust is a rocky shell.

Some five billion years ago, the Earth consisted of hot gases. These gases cooled into the dense liquid and solid layers mentioned above. The lithosphere itself cracked like an eggshell. Its crustal surface split into seven large and twelve small plates, each with ragged edges. These tectonic plates "float" on the underlying mantle layers, which are soft and molten.

The plates gradually move relative to one another. This motion is driven by lava flows which are continually upwelling at submerged midoceanic ridges. These ridges are called "spreading zones." New sea floor is created as this lava cools. Older portions of the sea floor are pushed outward in a sort of conveyor belt effect.

Neighboring plates accumulate strain energy at the their boundaries due to frictional effects. The sudden release of this energy results in an earthquake.

Most earthquakes occur at or near plate boundaries.

Most of the North American continent is on the North American Plate. Part of the California coast, however, is on the Pacific Plate. The boundary between these two plates is called the San Andreas Fault. The 1994 Northridge and 1989 Loma Prieta earthquakes occurred near this fault.

SEISMIC WAVES

Waveforms

There are four types of seismic waves: primary, secondary, Rayleigh, and Love. A diagram of the waveforms is shown in Figure 1, as taken from Reference 1.

The primary and secondary waves are both body waves which travel through the body of the Earth. The Rayleigh and Love waves are both surface waves which can travel along the Earth's surface.

Body Waves

Primary Wave

The primary wave, or P-wave, is a sound wave. It thus has longitudinal motion. Note that the primary wave is the fastest of the four waveforms.

The wave speed c for P-waves is given by

$$c = \sqrt{\frac{B + \left(\frac{4}{3}\right)G}{\rho}} \tag{1}$$

where B is the bulk modulus,
G is the shear modulus,
ρ is the mass per unit volume.

Secondary Wave

The secondary wave, or S-wave, is a shear wave. This wave produces an amplitude disturbance which is at right angles to the direction of propagation. Note that water cannot withstand a shear force. S-waves thus do not propagate in water.

The wave speed c for S-waves is given by

$$c = \sqrt{\frac{G}{\rho}} \tag{2}$$

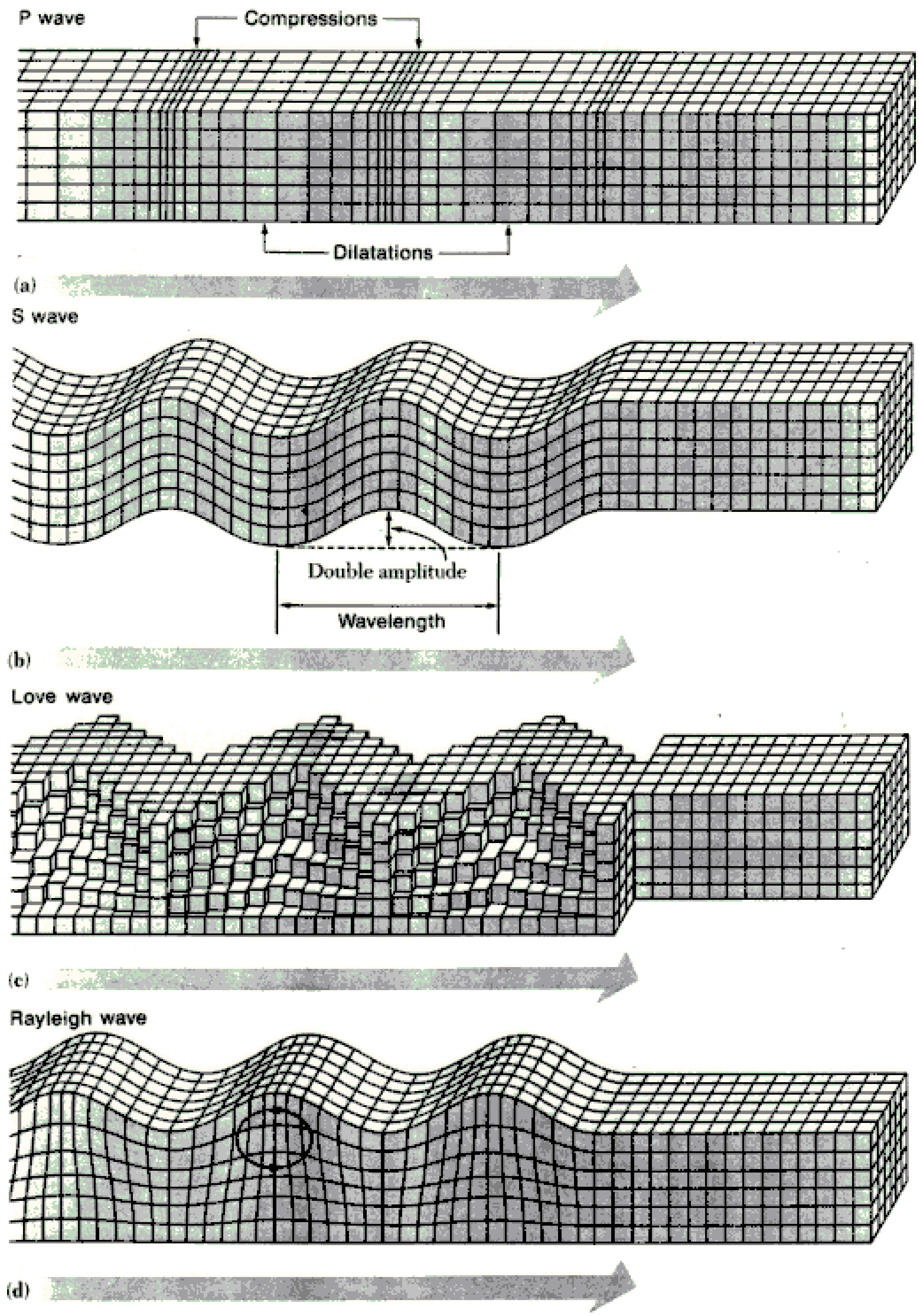

P wave
Compressions
Dilatations
(a)
S wave
Double amplitude
Wavelength
(b)
Love wave
(c)
Rayleigh wave
(d)

Figure 1.

Surface Waves

Common Characteristics

Surface waves are dispersive. The velocity varies with frequency.

Specifically, low-frequency surface waves propagate faster than high-frequency surface waves. This is also true of ocean waves.

Love Waves

Love waves are shearing horizontal waves. The motion of a Love wave is similar to the motion of a secondary wave, except that Love waves only travel along the surface of the Earth.

Love waves do not propagate in water.

Rayleigh Waves

Rayleigh waves produce retrograde elliptical motion. The ground motion is thus both horizontal and vertical. The motion of Rayleigh waves is similar to the motion of ocean waves except that ocean waves are prograde.

X-RAY OF THE EARTH

Seismologists use their knowledge of these waveforms to X-ray the Earth. R. D. Oldham in 1906 was one of the first scientists to propose this technique. In 1887, scientist in Germany had detected an earthquake which had occurred in Japan. This led Oldham to conclude that a large, central core was best way to explain the travel times of P and S wave from one side of the Earth to the other.

Note that when an earthquake wave reaches a boundary between layers a reflected wave and a refracted wave are formed. Oldham, Beno Gutenberg, Dr. Inge Lehmann and other seismologists studied these reflected and refracted waveforms in great detail, using seismograph made at stations through the world. Their collective work has revealed that the Earth consists of the layers described at the beginning of this report.

The outer core appears to be liquid, consisting mainly of iron, oxygen, and silicon. No S waves have ever been detected propagating through the outer core. Recall that S waves cannot travel through liquids. This is indirect evidence that the outer core is in some liquid form.

Seismologists' Perspective

Seismologists are largely content to analyze their data in the time domain since seismic waves are transient. They convert the displacement value into a single logarithmic magnitude value so that the energy released can be compared to that of other seismic events.

On the other hand, Seismologists must determine whether a given event is natural or man-made. A particular concern is clandestine underground nuclear explosions.

Explosions have a different spectral content than natural earthquakes as shown in Figure 2.

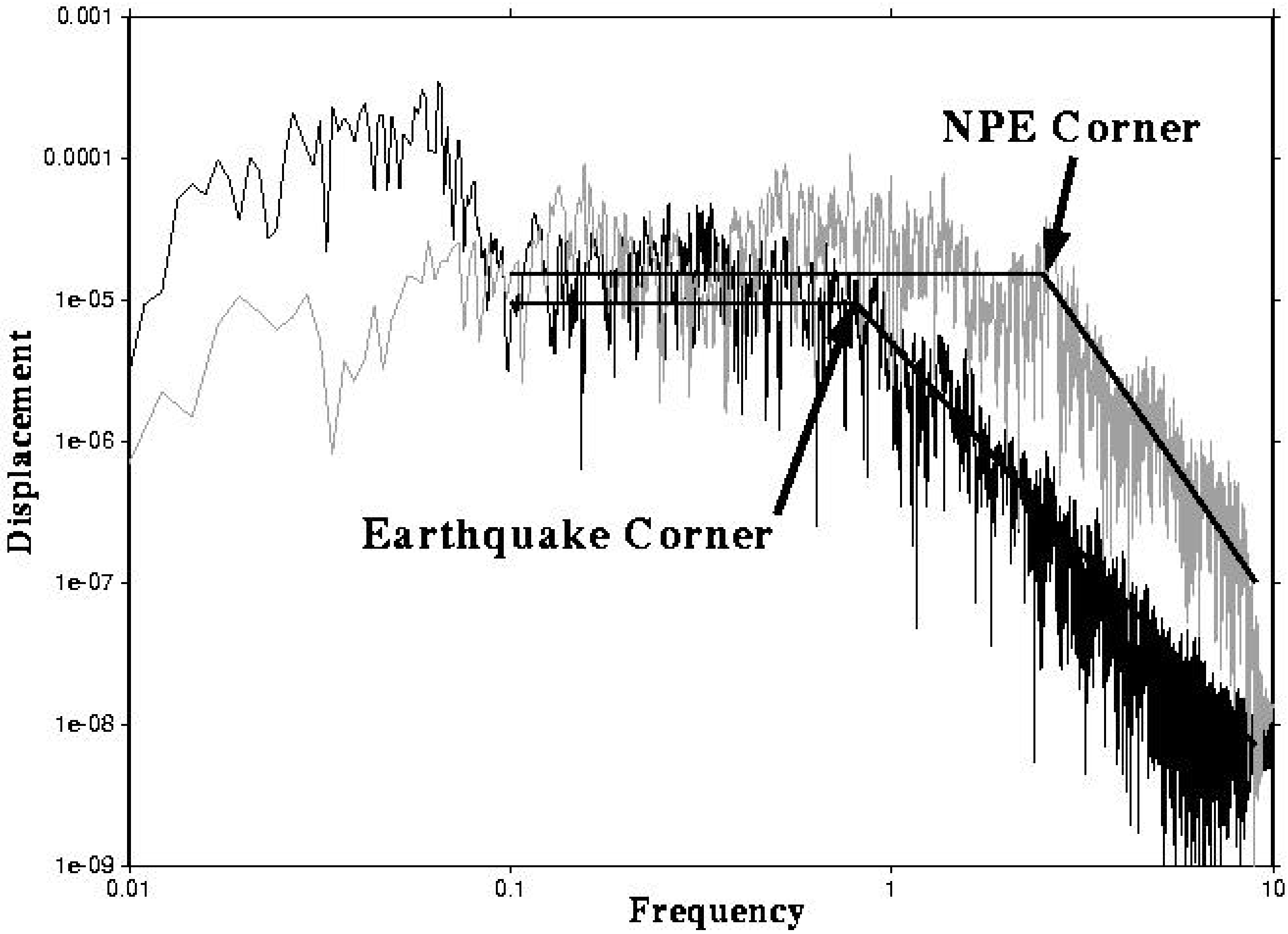


Figure 2.

This plot is courtesy of Mark Tinker of the University of Arizona. The NDE curve is the result of an explosion.

Civil Engineering Perspective

Surface waves cause more property damage because they cause larger ground displacements, velocities, and accelerations. They also travel more slowly, and may collect waveforms from the entire fault rupture; thus the duration of strong shaking may last for several minutes.

Civil engineers are interested in frequency content since they must design buildings to withstand ground-shaking. A particular concern is equipment which must withstand ground or floor shaking.

EARTH'S NATURAL FREQUENCY

According to Reference 2, The fundamental natural frequency of the Earth is 309.286 micro Hertz. This is equivalent to a period of 3233.25 seconds, or approximately 54 minutes.

In addition, the Earth has higher natural frequencies.

SEISMOGRAPHS

A Chinese scientist named Chang Heng invented a seismoscope about 132 A.D. This instrument did not make a time recording of the earthquake oscillation. Rather it indicated the direction of the principal impulse of the earthquake.

The modern seismograph was invented in the late 1800s. There are two basic types. One type uses a mass suspended by a pendulum. The other is based on a device which responds to strain. J.A. Ewing invented a pendulum seismograph in 1880. Lucien LaCoste improved this design. A Ewing three-component seismograph at Mt. Hamilton made a partial recording of the 1906 San Francisco earthquake.

Many other scientists added further improvements.

H.O. Wood and J. Anderson developed a seismograph with a mass suspended by torsion. This seismograph became the standard for magnitude determination of local shocks. This magnitude is the Richter scale. Charles Richter developed this scale in 1935.
Hugo Benioff developed the strain seismograph in 1935.

MODERN SEISMOGRAPH TYPES

Relative Displacement

The first type is a device which relies on the measurement of relative displacement. The ground moves underneath some pendulum-type device. The pendulum itself remains unmoved due to its own inertia. Note that inertia is resistance to acceleration. The pendulum thus serves as a reference point. The relative displacement is measured between the ground and this reference point.

Absolute Velocity

The second type is a sensor which measures absolute velocity. A geophone is an example.

Absolute Acceleration

The third type is an accelerometer, which measures absolute acceleration. The accelerometer is easier to use, but it is only useful for measuring "strong motions" nearby the earthquake epicenter. Note that displacement can be calculated from acceleration.

The following comments apply to all seismograph types:

1. The output signal of the measuring device may require some form of mechanical or electrical amplification.

2. Some type of recording method is required, such as a strip chart recorder or a computer. The computer is called a "data acquisition system."

Note that references 3 through 5 give designs for building seismographs for science projects.

EARTHQUAKE MAGNITUDE SCALES

Richter Magnitude

Charles F. Richter introduced the Richter scale in 1935.

The Richter magnitude is denoted as ML. It is also called the "local magnitude." It is based on the maximum excursion of the needle on the "Wood-Anderson seismograph." The Richter scale was intended for southern California earthquakes only.

The Richter scale is a logarithmic scale. The earthquake wave displacement amplitude increases by a factor of 10 for every 1 unit increase of the Richter magnitude.

The same 1 unit increase in magnitude, however, corresponds to an increase of approximately 32 times the earthquake energy.

The magnitude calculation depends on two parameters:

1. The maximum displacement indicated on the Wood-Anderson seismograph
2. The distance from the focus to the seismograph

For example, a 23 millimeter displacement measured at a station 210 kilometers from the focus would have a value of ML = 5.0.

A maximum displacement of 2.3 millimeters at this same station and distance would correspond to ML = 4.0.

Finally, note that the displacement indicated on the Wood-Anderson seismograph is proportional to, but not equal to, the ground displacement. The sensitivity of the Wood-Anderson instrument must be known in order to calculate the true ground displacement. A typical amplification factor is 2080. The ground displacement is thus much smaller than the displacement indicated on the seismograph.

<u>Other Magnitude Scales</u>

There are several other scales for measuring earthquakes.

The moment magnitude is denoted by Mw. It takes into account both the energy released and the amplitude of a distant earthquake. This scale is intended for severe earthquakes.

The body-wave scale is mb. It is based on the P-wave, which is the primary wave. This scale is intended for deep focus earthquakes.

The surface-wave scale is Ms.

<u>Mercalli Intensity</u>

The Mercalli intensity scale is yet another system for characterizing earthquakes. This scale is based on qualitative observations, such as building damage. The Modified Mercalli Intensity (MMI) scale is given in the Table 1.

Table 1. The Mercalli Intensity Scale	
Scale	Effects
I	Not felt, except by a few under very favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but not recognized as an earthquake by many people. Standing motorcars may rock slightly. Vibration is like a passing truck.
IV	During the day felt indoors by many, outdoors by a few. At night some awakened. Dishes, windows and doors disturbed; walls make creaking sound. Sensations like heavy truck striking building. Standing motorcars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and constructions; slight to moderate in well built ordinary structures; considerable in poorly built or badly designed structures. Some chimneys broken. Noticed by persons driving motorcars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys. Factory stacks, columns, monument walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures remain standing; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks.
XI	Few, if any masonry structures remain standing. Bridges destroyed. Broad fissures in the ground. Underground pipelines total out of service. Earth slumps and land slips in soft ground. Rails bent slightly.
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown up and into the air.

HISTORICAL EARTHQUAKES: NEW MADRID 1811-1812

The town of New Madrid is located in the southeast corner of Missouri, near the Mississippi River. The New Madrid seismic zone extends along the Mississippi River from the northeast corner of Arkansas up to Cairo, Illinois.

A series of powerful earthquakes occurred in the New Madrid fault zone during the winter of 1811 - 1812. The first earthquake occurred about 2 AM on December 16, 1811.

According to Reference 1, the three worst earthquakes were estimated to have Richter magnitudes of 7.5, 7.3, and 7.8. Note that some sources give estimates as high as 8.7, however.

The New Madrid earthquakes were an anomaly because they occurred in the middle of the North American Tectonic Plate. Note that most major U.S. earthquakes occur along the edge of this plate. The Northridge and Loma Prieta earthquakes are examples of two recent earthquakes which occurred near the western edge of this plate.

The cause of the New Madrid earthquakes remained a topic of speculation for many years. Finally, geologists in the 1970s discovered a shallow fault in the New Madrid area. They used sound waves to make this discovery. They also found a rift valley underneath the fault and 25 miles below the surface. Rifts occur where the tectonic plate has been weakened by volcanic activity.

Furthermore, east-to-west compression of the North American plate may have been a related factor in the New Madrid earthquakes. Strain energy may have accumulated as a result of this compression.

Small earthquakes occur frequently in the New Madrid seismic zone. The last earthquake of serious consequence occurred on November 9, 1968. This earthquake was centered in southern Illinois. It was strongest in the central United States since 1895. The magnitude 5.5 shock caused moderate damage to chimneys and walls at Hermann, St. Charles, St. Louis, and Sikeston, Missouri. The earthquake was felt in portions of 23 states.

SAN FRANCISCO 1906

Damage at Union Square. Photo courtesy of the Museum of the City of San Francisco.

INTRODUCTION

The San Francisco earthquake occurred at 5:12 A.M. on April 18, 1906. The source was a rupture of the San Andreas Fault. The duration of severe shaking was about 40 seconds, according to Professor Alexander McAdie who experienced the earthquake firsthand.

Reference sources give magnitude estimates ranging from 7.7 to 8.25. Note that there are actually several different magnitude scales.

A "Ewing" three-component seismograph at Lick Observatory on Mt. Hamilton made a partial recording of the 1906 San Francisco earthquake. The earthquake amplitude was so severe that it exceeded the range capability of this seismograph. The Ewing seismograph was based on pendulum motion.

BUILDING DAMAGE FROM EARTHQUAKE

The earthquake damaged many buildings. The Valencia Hotel was a four-story wooden building which collapsed into its own basement.

The luxurious Palace Hotel shed its rear wall but was otherwise undamaged. It had been built in 1875 to withstand earthquakes.

DEATH TOLL

Many people died in the earthquake and in the fires which followed. Death toll estimates range from 700 to 3000. For example, Bruce Bolt gives a number of 700 in Reference 1.

Fire Chief Engineer Dennis T. Sullivan was mortally wounded when a chimney of the California Theater and hotel crashed through the fire station in which he was living at 410-412 Bush St.

FIRE DAMAGE

The fires resulted from ruptured gas lines. Water mains also ruptured, sending geysers shooting up through broken pavement. As a result, firemen had no water to fight the fires. The fires raged for three days.

Fire destroyed many buildings, including the Windsor Hotel at Fifth and Market Streets.

Fireman used dynamite to destroy some buildings in an effort to stop the fires from spreading. The fires continued to spread despite this action.

REFUGEE CAMPS

San Francisco was known as the "Paris of the West" in 1906. The earthquake, however, reduced it to a "tent city." Golden Gate Park became a refugee camp.

The area around the U.S. Mint building became a refugee village because Superintendent Frank Leach installed two pipes from the Mint's artesian well after the fire to provide fresh water to the homeless.

COST

Damage cost estimates range from $400 million to $524 million.

CONCLUSION

The 1906 San Francisco earthquake was by far the worst U.S. earthquake in terms of death toll, even using the lower estimate of 700. The worst U.S. earthquake in terms of magnitude, however, was the 1964 Alaskan earthquake.

The San Francisco earthquake has become a benchmark by which other earthquakes are judged. For example, scientists discovered sunquakes using data from the SOHO spacecraft. Specifically, the spacecraft recorded a solar flare on July 9, 1996. This flare generated a quake that contained about 40,000 times the energy released in the 1906 San Francisco earthquake.

ALASKA

Prince William Sound, Alaska, earthquake of March 27, 1964.

PHOTOGRAPHS

The Alaskan earthquake generated a tsunami which destroyed this waterfront in Kodiak.

In addition, the earthquake caused a city street in Anchorage to collapse.
Photos courtesy of USGS.

INTRODUCTION

The Alaskan earthquake occurred on Good Friday, March 27, 1964, at 5:36 PM local time. It was the largest earthquake ever recorded in North America.

Duration estimates range from 3 to 5 minutes.

Sources vary as to the magnitude of this earthquake, in part because a variety of scales are used to measure earthquakes. Bruce Bolt lists it as 8.6 Ms, where Ms is the surface-wave magnitude. The USGS gives its a 9.2 Mw, where Mw is the moment magnitude.

EPICENTER

The epicenter was located between Valdez and Anchorage, near Prince William Sound.

The earthquake occurred on a thrust fault. This fault was a subduction zone, where the Pacific plate plunges underneath the North American plate.

The first slip occurred at a depth of 30 km, which is a shallow depth.

TSUNAMI

The sudden uplift of the Alaskan seafloor caused a tsunami, which was responsible for 122 of the 131 deaths.

The tsunami reached the Hawaiian Islands. The tsunami also struck Crescent City, California, killing five people.

A total of 16 people died in Oregon and California.

LANDSLIDES

The earthquake also caused ground liquefaction, whereby the soil and sand temporarily turned from a solid to a liquid state.

Rockslides and avalanches occurred as a result of the liquefaction. Some of the landslides occurred in Anchorage, particularly at Turnagain Heights. Soft clay bluffs at this location collapsed during the strong ground motion. About 75 homes were thus destroyed.

The property damage cost was about $311 million. Much of the property damage occurred in Anchorage. For example, the J.C. Penny Company building and the Four Seasons apartment building were damaged beyond repair.

Several schools in Anchorage were also destroyed. Fortunately, the schools were closed due to the Good Friday holiday.

In addition, water, sewer, and gas lines ruptured. Telephone and electrical service was also disrupted.

CONCLUSION

The 1964 Alaskan earthquake was the largest earthquake ever recorded in North America in terms of magnitude.

The 1906 San Francisco earthquake was the worst U.S. earthquake in terms of death toll, however, resulting in at least 700 deaths.

HAICHENG, CHINA 1975

Instruments

Seismologists use a variety of instruments to monitor earthquake prone areas. Seismometers measure the abrupt oscillations of the earth.

Creepmeters measure the relative displacement between two points on opposite sides of a fault line. The distance between the two reference points is typically 3 meters. Creep is a slow movement. For example, the relative displacement across the San Andreas Fault is 1.5 centimeters per year, as measured near Hollister, California; according to Reference 1.

Geodimeters are laser-based instruments which measure the relative displacement between mountaintops on opposite sides of a fault line.

Seismologist can sometimes predict the time and location of earthquakes based on measurements from these instruments.

Haicheng Earthquake

For example, seismologists noted increasing seismic activity in Liaoning Province, China in 1975. The activity occurred near the cities of Haicheng and Yingkow.

The seismologists sent out warnings days before the February 4, 1975, earthquake of magnitude 7.3. The people in nearby cities remained outdoors, despite the cold weather. As a result, many lives were saved. Reference: M. Levy and M. Salvadori, Why the Earth Quakes, Norton, London, 1995.

Nevertheless, there have been some "false alarms" over the years. Furthermore, many earthquakes occur without any notable precursor signs.

LOMA PRIETA 1989

Collapse of Cypress Viaduct. Photo courtesy of U.S. Geological Survey.

MAGNITUDE AND EPICENTER

The Loma Prieta earthquake occurred on October 17, 1989 at 5:04 p.m. Pacific Daylight Time. It had a moment magnitude of 7.0. The duration was 15 to 20 seconds.

The earthquake occurred due to slip in the San Andreas Fault. The epicenter was near Loma Prieta, which is a peak in the Santa Cruz Mountains. This location is 10 miles northeast of the city of Santa Cruz.

A strong-motion seismograph gave an acceleration reading of 0.6 G near the source.

The fault rupture did not break the ground surface. The focal depth was 11 miles, which is unusually deep. Typical California earthquake focal depths are 4 to 6 miles.

This earthquake was the largest earthquake to occur in the San Francisco Bay area since 1906.

The earthquake interrupted the baseball world series between the San Francisco Giants and the Oakland Athletics.

DEATH TOLL AND PROPERTY DAMAGE

The earthquake caused damage throughout the San Francisco Bay area. Sources place the death toll between 63 to 68 people. The cost was 6 to 8 billion dollars. San Francisco had 22 structural fires during the seven hours from the time the earthquake struck until midnight.

Some homes and buildings San Francisco's Marina district suffered severe damage. These structures were built on loose, sandy soil, permeated with water. As a result, liquefaction occurred. Liquefaction is a process whereby the shaking motion and the weight of the buildings causes water to be squeezed out from the soil. The soil thus temporarily develops a liquid consistency, similar to quicksand. Buildings may topple over or collapse when liquefaction occurs.

In addition, more than 1,000 landslides and rockfalls occurred in the epicentral zone in the Santa Cruz Mountains. One slide, on State Highway 17, disrupted traffic for about 1 month. Areas outside of Santa Cruz, including the towns of Watsonville, Hollister, and Los Gatos, also suffered heavy damage.

CYPRESS VIADUCT

The earthquake caused the Cypress Viaduct to collapse, resulting in 42 deaths. The Viaduct was a raised freeway which was part of the Nimitz freeway in Oakland, which is Interstate 880. The Viaduct had two traffic decks.

Resonant vibration caused 50 of the 124 spans of the Viaduct to collapse. The reinforced concrete frames of those spans were mounted on weak soil. As a result, the natural frequency of those spans coincided with the forcing frequency of the earthquake ground motion. The Viaduct structure thus amplified the ground motion. The spans suffered increasing vertical motion. Cracks formed in the support frames. Finally, the upper roadway collapsed, slamming down on the lower road.

The remaining spans which were mounted on firm soil withstood the earthquake.

In addition, a span of the San Francisco Bay Bridge collapsed.

NORTHRIDGE 1994

Collapsed Parking Structure, California State University at Northridge.
Photo Courtesy of U.S. Geological Survey.

MAGNITUDE AND EPICENTER

The Northridge earthquake occurred at 4:30 a.m. local time on January 17, 1994. Northridge is located about 30 km northwest of Los Angeles. This earthquake had a 6.9 moment magnitude. The hypocentral depth was 19 km. The duration was about 10 seconds to 20 seconds. The earthquake occurred along a "blind" thrust fault, close to the San Andreas fault. Note that a blind fault is a fault which does not extend to the surface. In other words, it is buried.

The Northridge earthquake was the worst earthquake in the Los Angeles basin since the San Fernando earthquake in 1971, which had a 6.7 magnitude.

DEATH TOLL

The number of fatalities in the Northridge earthquake was 57. About 9000 people were injured. The fact that the earthquake occurred at 4:30 a.m. minimized the death toll.

STRUCTURAL DAMAGE

The Northridge earthquake caused extensive damage to parking structures and freeway overpasses.

For example, a section of the Antelope Valley Freeway collapsed onto the Golden State Freeway south of Newhall. Also, a section of the Santa Monica Freeway in West Los Angeles collapsed.

In addition, a 2500-car parking garage at the California State University at Northridge collapsed. This structure was about 3 km away from the epicenter.

Furthermore, the Northridge earthquake triggered landslides in the Santa Susana Mountains, Santa Monica Mountains, and western San Gabriel Mountains. These landslides blocked roads and damaged water lines. The landslides also damaged homes, particularly in the Pacific Palisades area.

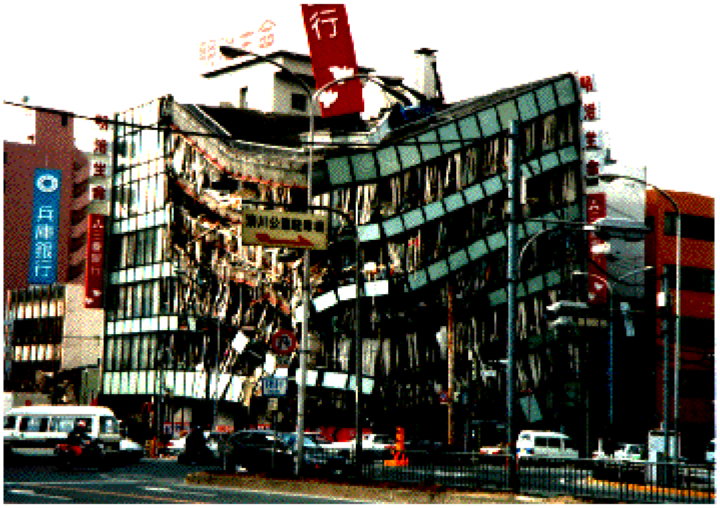
One positive note was that the Olive View Hospital in Sylmar withstood the Northridge earthquake. This hospital had been destroyed by the 1971 San Fernando earthquake. After its collapse, the hospital was rebuilt to a more exacting seismic code.

Fortunately, the Northridge area has arid, dry soil. Thus, there were few significant liquefaction and ground failure effects. In contrast, soil liquefaction caused massive damage in the 1964 Alaskan and the 1989 Loma Prieta earthquakes.

AFTERSHOCKS

Thousands of aftershocks occurred after the main earthquake. For example, a magnitude 5.9 aftershock occurred about 1 minute after the mainshock. A magnitude 5.6 earthquake occurred 11 hours later. Aftershocks are a concern because they can trigger the collapse of structures weakened by the mainshock.

KOBE 1995



Collapse of Bank Building. Photo courtesy of Tokyo University.

MAGNITUDE AND EPICENTER

The Great Hanshin earthquake occurred at 5:46 a.m. on Tuesday, January 17, 1995. This earthquake is also called by the following names: Kobe, South Hyogo, Hyogo-ken Nanbu.

The earthquake had a local magnitude of 7.2. The duration was about 20 seconds. The focus of the earthquake was less than 20 km below Awaji-shima, an island in the Japan Inland Sea. This island is near the city of Kobe, which is a port city.

The earthquake was particularly devastating because it had a shallow focus. The earthquake had a "strike-slip mechanism." The resulting surface rupture had an average horizontal displacement of about 1.5 meters on the Nojima fault. This fault which runs along the northwest shore of Awaji Island.

DEATH TOLL

The earthquake caused 5100 deaths, mainly in Kobe.

The Hanshin earthquake was the worst earthquake in Japan since the 1923 Tokyo earthquake, which is also called the Great Kanto earthquake. The Great Kanto earthquake claimed 140,000 lives.

On the other hand, the Kobe region was thought to be fairly safe in terms of seismic activity.

STRUCTURAL DAMAGE

An elevated highway connects the cities of Kobe and Osaka. The earthquake caused several portions of this highway to collapse.

Most of the deaths and injuries occurred when older wood-frame houses with heavy clay tile roofs collapsed. Note that homes and buildings are designed to be very strong in the vertical direction because they must support their own static weight. On the other hand, buildings can be very susceptible to horizontal ground motion.

Furthermore, many of the structures in Kobe built since 1981 had been designed to strict seismic codes. Most of these buildings withstood the earthquake. In particular, newly built ductile-frame high rise buildings were generally undamaged.

Unfortunately, many of the buildings in Kobe had been built before the development of strict seismic codes.

The collapse of buildings was followed by the ignition of over 300 fires within minutes of the earthquake. Ruptured gas lines caused the fires. Response to the fires was hindered by the failure of the water supply system and the disruption of the traffic system.

PROFESSOR KATAYAMA

Japanese seismology professor Tsuneo Katayama wrote that he "had opportunities to observe the damages caused by the 1989 Loma Prieta and the 1994 Northridge earthquakes." However, he thought that Japanese structures would not collapse as U.S. structures had in those earthquakes.

Professor Katayama also wrote, "While our country was having a bubbling economy, we Japanese forgot to pay due attention to mother nature."

SUNQUAKES, MARSQUAKES, MOONQUAKES

Sun

The Sun experiences "Sunquakes."

A solar flare is an enormous explosion of hydrogen and helium above the sun's surface. A solar flare can cause a huge ripple to spread across the surface of the Sun.

Scientists discovered sunquakes using data from the SOHO spacecraft. Specifically, the spacecraft recorded a solar flare on July 9, 1996. This flare generated a quake that contained about 40,000 times the energy released in the 1906 San Francisco earthquake.

Moon

The Moon experiences "moonquakes."

During several of the Apollo missions, astronauts set up seismic instruments on the lunar surface to measure moonquake activity. The data from these instruments revealed that the Moon is very reverberant, with oscillations continuing for one hour or longer.

The astronauts themselves intentionally generated moonquakes by a variety of means.

For example, the Apollo 12 astronauts crashed their lunar module into lunar surface after the astronauts had reunited in the command module.

The Apollo 14 astronauts, Shepard and Mitchell, performed a seismic experiment in which they detonated 13 small charges on the lunar surface. They used geophones to measure the resulting reverberation.

Mars

Viking 2 was launched on September 9, 1975. It reached Martian orbit on August 7, 1976. Its lander touched down on the Martian surface on September 3, 1976. The landing site was called Utopia Planitia.

Viking 2 had a seismometer which was able to measure a "Marsquake."

REFERENCES

1. Bruce Bolt, Earthquakes, Freeman, New York, 1999.

2. Reference: T. Lay and T. Wallace, Modern Global Seismology, Academic Press, New York, 1995.

3. "The Amateur Scientist," Scientific American, pp 152-162, January 1963.

4. Walker, J., "How to build a simple seismograph to record earthquake waves at home," Scientific American, vol 241, #1, pp. 152-161, 1979.

5. Averill, G.E., "Build your own seismograph: An earth-shaking, in-class project," The Science Teacher, vol 62, #3, pp. 48-52, March 1995.

6. M. Levy and M. Salvadori, Why the Earth Quakes, Norton, London, 1995.

7. M. Levy and M. Salvadori, Why Buildings Fall Down, Norton, London, 1992.
.