# Chapter 2 – Measuring and Recording Intensity, Magnitude, Energy and Acceleration

Measuring Earthquakes – Intensity, Magnitude and Energy

Differentiate between intensity and magnitude

- **The intensity of an earthquake is based on the damage and other observed effects on people, buildings, and other features. Intensity varies from place to place within the disturbed region.** An earthquake in a densely populated area that results in many deaths and considerable damage may have the same magnitude as a shock in a remote area that does nothing more than frightens the wildlife.

- The scale most often used in the United States to measure intensity is the **"Modified Mercalli Intensity Scale"**. It was developed in 1931 by American seismologists Harry Wood and Frank Newmann).

- The Modified Mercalli Scale consists of twelve (12) increasing levels of intensity (expressed as Roman Numerals following the initials MM) that range from imperceptible shaking to catastrophic destruction.

- The lower numerals generally are based on the manner in which the earthquake is felt by people. The higher numerals are based on observed structural damage.

- The numerals do not have a mathematical basis and therefore are more meaningful for non-technical people.

## Modified Mercalli Intensity Scale

| Intensity | Observed effects of earthquake |
|---|---|
| I | Not felt except by very few under especially favorable conditions. |
| II | Felt only by a few persons at rest, especially by those on the upper floors of buildings. Delicately suspended objects may swing. |
| III | Felt quite noticeably by persons indoors, especially in upper floors of buildings. Many people do not recognize it as an earthquake. Standing vehicles may rock slightly. Vibrations similar to the passing of a truck. Duration estimated. |

| | |
|---|---|
| IV | During the day, felt indoors by many, outdoors by a few. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing vehicles rock noticeably. |
| V | Felt by nearly everyone; most awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop. |
| VI | Felt by all, many frightened. Some heavy furniture moved. A few instances of fallen plaster. Damage slight. |
| VII | Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built structures. Some chimneys broken. |
| VIII | Damage slight in specially designed structures; considerable damage in ordinary substantial buildings, with partial collapse. Damage great in poorly built structures. Fallen chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. |
| IX | Damage considerable in specially designed structures; well designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. |
| X | Some will-built wooden structures destroyed; most masonry and frame structures with foundations destroyed. Rails bent. |
| XI | Few, if any, masonry structures remain standing. Bridges destroyed. Rails bent greatly. |
| XII | Damage total. Lines of sight and level are distorted. Objects thrown into air. |

- **<u>Magnitude</u> is a measure of the earthquake strength**. The magnitude, M, of an earthquake is determined from the logarithm to base 10 of the amplitude recorded by a seismometer. The magnitude is typically measured on the Richter Magnitude Scale. This scale was developed by Charles F. Richter in 1935.

- Because the Richter Magnitude is a logarithmic scale, each whole number increase in magnitude represents a ten-fold increase in measured amplitude.

- The magnitude of an earthquake depends on the length and breath of the fault slip (i.e. how much strain energy is stored and released).

- The Richter scale has no lower or upper limit. The largest known shock-waves have had magnitudes in the 8.7 to 8.9 range. The actual factor limiting energy release (and hence the Richter Magnitude) is the strength of the rocks in the Earth's crust.

### Estimated Number of Earthquakes per year with respect to magnitude

| Magnitude | Earthquake Effects | Estimated Number Each Year |
|---|---|---|
| 2.5 or less | Usually not felt, but can be recorded by seismograph. | 900,000 |
| 2.5 to 5.4 | Often felt, but only causes minor damage. | 30,000 |
| 5.5 to 6.0 | Slight damage to buildings and other structures. | 500 |
| 6.1 to 6.9 | May cause a lot of damage in very populated areas. | 100 |
| 7.0 to 7.9 | Major earthquake. Serious damage. | 20 |
| 8.0 or greater | Great earthquake. Can totally destroy communities near the epicenter. | One every 5 to 10 years |

### Earthquake Magnitude Classes

Earthquakes are also classified in categories ranging from minor to great, depending on their magnitude.

| Class | Magnitude |
|---|---|
| Great | 8 or more |
| Major | 7 - 7.9 |
| Strong | 6 - 6.9 |
| Moderate | 5 - 5.9 |
| Light | 4 - 4.9 |
| Minor | 3 -3.9 |
| Micro | 2.0 or less |

## Magnitude / Intensity Comparison

**Magnitude / Intensity Comparison**

| Magnitude | Intensity | Description |
|---|---|---|
| **1.0 - 3.0** | **I** | **I**. Not felt except by a very few under especially favorable conditions. |
| **3.0 - 3.9** | **II - III** | **II**. Felt only by a few persons at rest, especially on upper floors of buildings.<br><br>**III**. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated. |
| **4.0 - 4.9** | **IV - V** | **IV**. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.<br><br>**V**. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop. |
| **5.0 - 5.9** | **VI - VII** | **VI**. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.<br><br>**VII**. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. |
| **6.0 - 6.9** | **VII - IX** | **VIII**. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.<br><br>**IX**. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. |
| **7.0** and higher | **VIII** or higher | **X**. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.<br><br>**XI**. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.<br><br>**XII**. Damage total. Lines of sight and level are distorted. Objects thrown into the air. |

**Peak Ground Acceleration**

Acceleration is the rate of change in velocity of the ground shaking (how much the velocity changes in a unit time), just as it is the rate of change in the velocity of your car when you step on the accelerator or put on the brakes. Velocity is the measurement of the speed of the ground motion. Displacement is the measurement of the actual changing location of the ground due to shaking. All three of the values can be measured continuously during an earthquake.

Peak ground acceleration (PGA) is what is experienced by a particle on the ground.

Spectral acceleration, Sa, is approximately what is experienced by a building, as modeled by a particle on a massless vertical rod having the same natural period of vibration as the building. This will be addressed in future discussions.

PGA can be given in various units, including ft/sec$^2$, in/sec$^2$, m/sec$^2$. However it is most common to specify the PGA in "g's" (i.e. a fraction or percent of gravitational acceleration).

$$PGA = (a_{ft/sec^2}/32.2) \times 100\%$$

$$PGA = (a_{in/sec^2}/386) \times 100\%$$

Of course, the ground acceleration will decrease as the distance from the epicenter increases. This decrease in acceleration with distance is called attenuation.

**Although there are some empirical relationships, no exact correlations of intensity, magnitude and acceleration with damage are possible since many factors contribute to seismic behavior and structural performance.**

Approximate Relationship between Mercalli Intensity and PGA

| MMI | PGA (g) |
|---|---|
| IV | 0.03 and below |
| V | 0.03 – 0.08 |
| VI | 0.08 – 0.15 |
| VII | 0.15 – 0.25 |
| VIII | 0.25 – 0.45 |
| IX | 0.45 – 0.60 |
| X | 0.60 – 0.80 |
| XI | 0.80 – 0.90 |
| XII | 0.90 and above |

Other characteristics of seismic events that contribute to the effects of earthquakes on structures are:

- Duration of strong shaking. The longer the duration of strong shaking, the greater the energy can be imparted to a structure. Since various parts of a structure can absorb only a limited amount of elastic energy, a longer earthquake has a greater chance of driving structural performance into inelastic behavior.

- Frequency of Earthquake. If the frequency of the seismic wave (the frequency of the soil must also be considered) is applied at the same frequency as the natural period of vibration, the oscillation of the structure can be greatly magnified.

**Instruments used to measure seismic events**

- Seismometer – A seismometer is the detecting and recording part of a seismograph. Seismometers are pendulum type devices that are mounted on the ground and measure the displacement of the ground with respect to a stationary reference point.

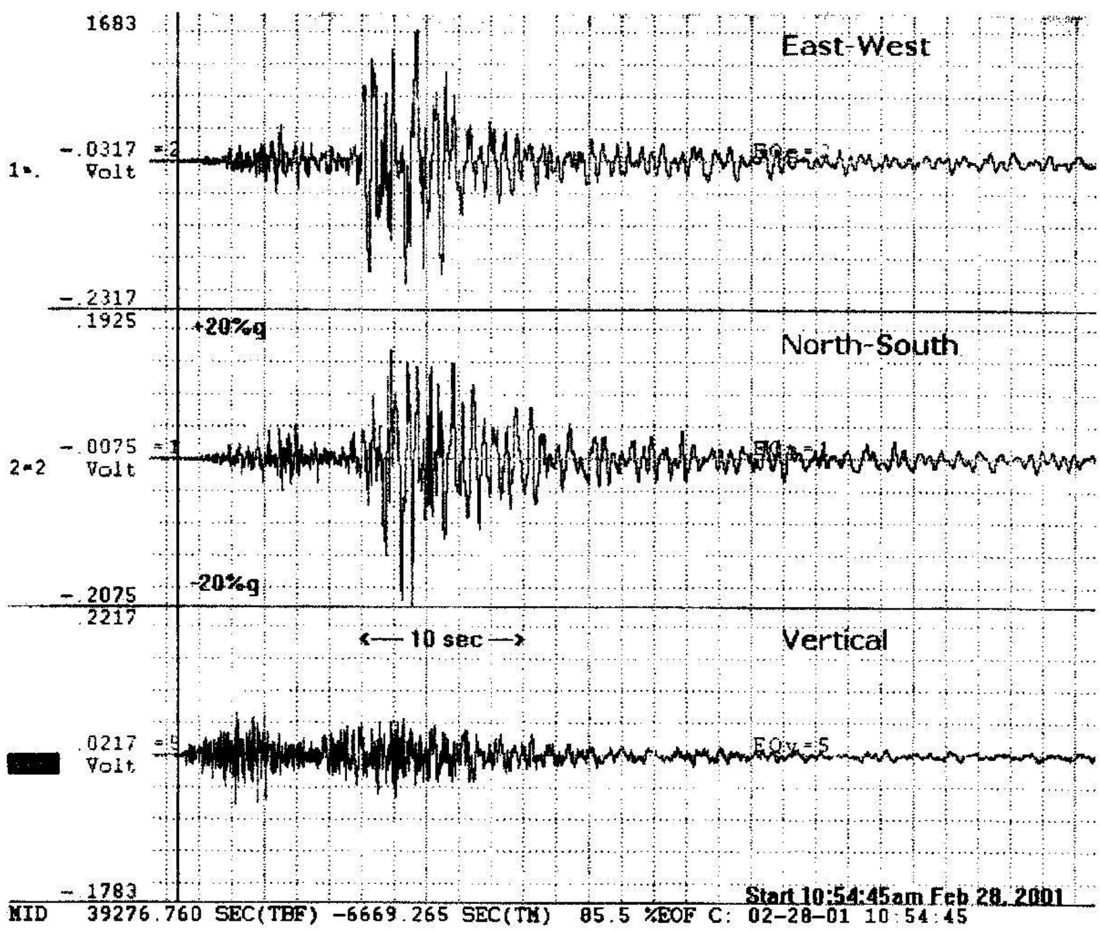
  Since a seismometer usually records ground motion in only one direction, three seismometers are needed to record all components of ground motion (horizontal (E-W), horizontal (N-S) and vertical).

- Accelerometer: An accelerometer is a seismometer mounted in buildings for the purpose of recording large accelerations. An accelerometer located in a building does not run continually, it is triggered by a P-Wave and runs for a fixed period of time.

- Tiltmeter – A tiltmeter works on the same principal as a carpenter's level. The slightest movement of a bubble floating in a spherical dome is electronically detected to reveal the tilt or displacement.

# Mw6.8 Earthquake in WASHINGTON
# 28 February 2001
# The Nisqually Earthquake

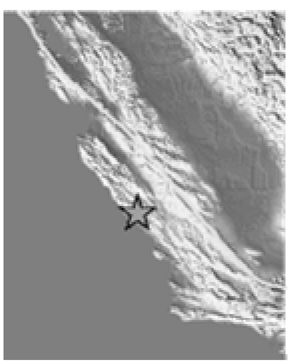
| | |
|---|---|
| Date & Time: | February 28, 2001 10:55am PST |
| Magnitude: | 6.8 |
| Location: | 20km NE of Olympia, Washington |
| | 47.2 N 122.7 W |
| Depth: | 52 km |




**Nisqually Earthquake Measured at Safeco Field in Seattle, WA – 2/28/01**

# Magnitude 6.5 - CENTRAL CALIFORNIA
# 2003 December 22 19:15:56 UTC

**Preliminary Earthquake Report**
U.S. Geological Survey, Menlo Park, California
U.C. Berkeley Seismological Laboratory, Berkeley, California

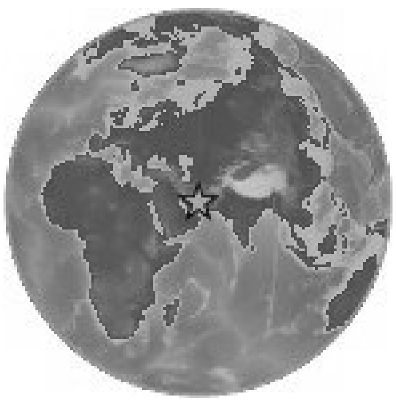


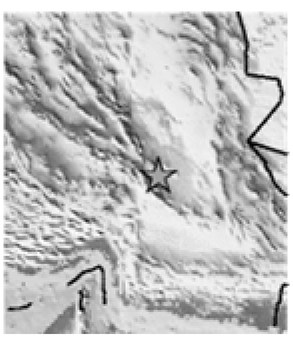
| | |
|---|---|
| **Magnitude** | **6.5** |
| **Date-Time** | **Monday, December 22, 2003 at 19:15:56 (UTC)**<br>= Coordinated Universal Time<br>**Monday, December 22, 2003 at 11:15:56 AM**<br>= local time at epicenter |
| **Location** | 35.706°N, 121.102°W |
| **Depth** | 7.6 km (4.7 miles) |
| **Region** | **CENTRAL CALIFORNIA** |
| **Distances** | 11 km (6 miles) NE (49°) from **San Simeon, CA**<br>17 km (10 miles) N (356°) from **Cambria, CA**<br>20 km (13 miles) W (260°) from **Lake Nacimiento, CA**<br>39 km (24 miles) WNW (283°) from **Paso Robles, CA**<br>195 km (121 miles) SSE (158°) from **San Jose City Hall, CA** |
| **Location Uncertainty** | horizontal +/- 0.2 km (0.1 miles); depth +/- 0.8 km (0.5 miles) |
| **Parameters** | Nst= 46, Nph= 46, Dmin=5.4 km, Rmss=0.05 sec, Gp= 83°,<br>M-type=regional moment magnitude (Mw), Version=3 |
| **Source** | U.S. Geological Survey, Menlo Park, California<br>U.C. Berkeley Seismological Laboratory, Berkeley, California |
| **Event ID** | nc40148755 |
| **Felt Reports** | Two people killed and about 40 buildings collapsed or severely damaged at Paso Robles.At least 40 people injured in the Paso Robles-Templeton area. Buildings damaged and small firesoccurred at Cambria and Morro Bay. The airport at Oceano was closed due to cracks in the runway.More than 10,000 homes and businesses were without power in the Paso Robles area. Felt (VII) atAtascadero, Bradley, Cambria, Cayucos, Creston, Lockwood, Los Osos, Morro Bay, Nipomo, Oceano, PasoRobles, San Miguel, San Simeon, Shandon and Templeton; (VI) at Arroyo Grande, Beverly Hills, GroverBeach, Guadalupe, Pismo Beach, San Luis Obispo, Santa Margarita and Santa Maria; (V) at Avenal,Danville, Filmore, Inglewood, King City, Lompoc, Santa Inez, Santa Monica, Solvang, Taft and Wasco;(IV) throughout west-central California; (III) from San Francisco and Santa Rosa to Los Angeles andOceanside. Felt in much of central California and at Bullhead City, Arizona. |

# Magnitude 6.6 - SOUTHEASTERN IRAN
# 2003 December 26 01:56:52 UTC

**Preliminary Earthquake Report**

U.S. Geological Survey, National Earthquake Information Center
World Data Center for Seismology, Denver

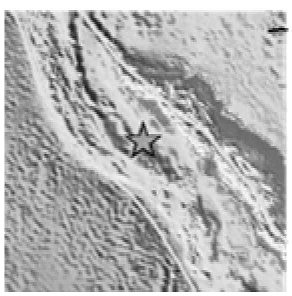




| | |
|---|---|
| **Magnitude** | **6.6** |
| **Date-Time** | **Friday, December 26, 2003 at 01:56:52 (UTC)**<br>= Coordinated Universal Time<br>**Friday, December 26, 2003 at 5:26:52 AM**<br>= local time at epicenter<br>Time of Earthquake in other Time Zones |
| **Location** | 29.004°N, 58.337°E |
| **Depth** | 10 km (6 miles) set by location program |
| **Region** | **SOUTHEASTERN IRAN** |
| **Distances** | 185 km (115 miles) SE of **Kerman, Iran**<br>255 km (160 miles) WSW of **Zahedan, Iran**<br>265 km (165 miles) E of **Sirjan, Iran**<br>990 km (610 miles) SE of **TEHRAN, Iran** |
| **Location Uncertainty** | horizontal +/- 5.3 km (3.3 miles); depth fixed by location program |
| **Parameters** | Nst=343, Nph=343, Dmin=991.8 km, Rmss=1.1 sec, Gp= 43°,<br>M-type=teleseismic moment magnitude (Mw), Version=U |
| **Source** | USGS NEIC (WDCS-D) |
| **Event ID** | uscvad |
| **Felt Reports** | At least 30,000 people killed, 30,000 injured, 85 percent of buildings damaged or destroyed and infrastructure damaged in the Bam area. Maximum intensities IX at Bam and VIII at Baravat. Felt (V) at Kerman. Surface faulting observed on the Bam Fault between Bam and Baravat. Maximum acceleration of 0.98g recorded at Bam. A detailed report on this earthquake can be obtained from the International Institute of Earthquake Engineering and Seismology (IIEES), online at http://www.iiees.ac.ir/English/Bam_report_english.html. |

# Magnitude 9.0 - SUMATRA-ANDAMAN ISLANDS EARTHQUAKE OFF THE WEST COAST OF NORTHERN SUMATRA

**2004 December 26 00:58:53 UTC**



| | |
|---|---|
| Magnitude | 9.0 |
| Date-Time | Sunday, December 26, 2004 at 00:58:53 (UTC)<br>= Coordinated Universal Time<br>Sunday, December 26, 2004 at 7:58:53 AM<br>= local time at epicenter<br>Time of Earthquake in other Time Zones |
| Location | 3.307° N 95.947° E |
| Depth | 30 km (18.6 miles) set by location program |
| Region | OFF THE WEST COAST OF NORTHERN SUMATRA |
| Distances | 250 km (155 miles) SSE of Banda Aceh, Sumatra, Indonesia<br>310 km (195 miles) W of Medan, Sumatra, Indonesia<br>1260 km (780 miles) SSW of BANGKOK, Thailand<br>1605 km (990 miles) NW of JAKARTA, Java, Indonesia |
| Location Uncertainty | horizontal +/- 5.6 km (3.5 miles); depth fixed by location program |
| Parameters | Nst=370, Nph=370, Dmin=644.5 km, Rmss=1.17 sec, Gp= 29°,<br>M-type=teleseismic moment magnitude (Mw), Version=U |
| Source | USGS NEIC (WDCS-D) |
| Event ID | usslav |

Felt Reports: This is the fourth largest earthquake in the world since 1900 and is the largest since the 1964 Prince William Sound, Alaska earthquake. The tsunami caused more casualties than any other in recorded history. In total, more than 153,200 people were killed, 27,000 are still listed as missing and 1,236,000 were displaced in South Asia and East Africa. At least 106,500 people were killed by the earthquake and tsunami in Indonesia. Tsunamis killed at least 30,800 people in Sri Lanka, 10,300 in India, 5,300 in Thailand, 150 in Somalia, 82 in Maldives, 68 in Malaysia, 59 in Myanmar, 10 in Tanzania, 3 in Seychelles, 2 in Bangladesh and 1 in Kenya. Tsunamis caused damage in Madagascar and Mauritius and also occurred in Mozambique, South Africa, Australia and Antarctica. The tsunami crossed into the Pacific and Atlantic Oceans and was recorded in New Zealand and along the west and east coasts of South and North America. The earthquake was felt (VIII) at Banda Aceh and (V) at Medan, Sumatra and (II-IV) in parts of Bangladesh, India, Malaysia, Maldives, Myanmar, Singapore, Sri Lanka and Thailand. Subsidence and landslides were observed in Sumatra.