Session No. 5

Course Title: Earthquake Hazard and Emergency Management

Session Title: Characteristics of Earthquakes: Magnitude, Intensity, and Energy

Author: James R. Martin, II

Time: 120 minutes

Objectives:

5.1. Describe how the sizes of earthquakes are measured.

5.2. Explain how earthquake intensity is determined.

5.3. Explain how earthquake magnitude is determined.

5.4. Describe the energy associated with earthquakes and compare magnitude and intensity.

5.5. Explain the type of waves generated by earthquakes.

5.6. Describe other important earthquake terms.

Scope:

In this session, the instructor will discuss important characteristics of earthquakes, including earthquake sizes and how they are measured/determined, types of earthquake waves, and the significance of these characteristics in terms of the hazard posed. Terms such as “magnitude” and “intensity” are commonly used by the seismological community and popular media to express earthquake hazard and damage potential and they should be understood by emergency managers from more than just a cursory standpoint. The lecture format will be mostly conventional lecture with the use of visual aids in the form of electronic visuals. A homework assignment is included in the attached handouts. This assignment should be distributed at the end of the session. Electronic versions of the visuals presented in these notes are included in the accompanying file: “Session 5 Electronic Visuals.ppt”

Readings:

Required student reading:

http://earthquake.usgs.gov/bytopic/mag_int.html

http://neic.usgs.gov/neis/phase_data/mag_formulas.html

Reading Assignment: all of the highlighted sections on these web pages related to magnitude and intensity.

Required instructor reading and resources:

http://earthquake.usgs.gov/bytopic/mag_int.html

http://neic.usgs.gov/neis/phase_data/mag_formulas.html

Reading Assignment: all of the highlighted sections on these web pages related to magnitude and intensity.

Visual aids provided in the accompanying file: "Session 5 - Electronic Visuals.ppt"

Other useful references;

http://earthquake.usgs.gov/image_glossary/

Electronic visuals included: [*see Session 5 – Electronic Visuals.ppt*]

5.1 Measuring Earthquakes
5.2 Modified Mercalli Intensity I, II, III
5.3 Modified Mercalli Intensity IV, V
5.4 Modified Mercalli Intensity VI, VII
5.5 Modified Mercalli Intensity VIII, IX, X
5.6 Modified Mercalli Intensity XI, XII
5.7 MMI Contours from 1811 New Madrid Earthquake
5.8 Seismographs Record Earthquake Motions Common Types of Magnitude
5.9 Common Types of Magnitude
5.10 Moment Magnitude vs. Other Magnitude Scales
5.11 Magnitude vs. Fault Length for California Earthquakes
5.12 Average Number of Annual Earthquakes Worldwide
5.13 Seismic Energy Release
5.14 Magnitude, Intensity, and Earthquake Energy
5.15 Seismic Wave Forms (body waves)
5.16 Typical P- and S-Wave Travel Speeds

5.17 Seismic Wave Forms (surface waves)
5.18 Arrival of Seismic Waves at Seismograph
5.19 Epicenter and Hypocenter

Handouts Included:

Handout 5.1: Homework Assignment 5.1

General Requirements:

Special Note: *The information presented in this session is technical in nature and additional background study will be required by instructors with non-scientific backgrounds. Accordingly, the instructor should thoroughly review the recommended reading material for this session. In some cases, the instructor may wish to enlist the aid of an outside expert, such as faculty from a geological sciences or engineering department, to teach this material,. While some instructors alternatively may elect to reduce the technical content presented, the concepts are important for a complete understanding of earthquakes and the nature of the hazard they pose. Therefor, the instructor should cover as much of this material as feasible, and make adaptations where appropriate as the makeup of the class and availability of outside resources dictates.*

Strongly emphasize the important differences between the characterization of the sizes of earthquakes. It is important for students in this class to understand basic issues associated with earthquakes and to understand the way in which this hazard is characterized by the earthquake community. For instance, students should understand that a magnitude 7 earthquake releases roughly 30 times more energy than a magnitude 6 event. A cue to remember to ask the students a question on this issue is provided in Objective 5.4. It is less important that the students understand the nuances of all the various type of magnitudes, but it is key for them to understand the basic idea of magnitude and what various units of magnitude means in terms of hazard. This information will not only foster a better understanding of earthquake hazards, but foster improve communication with scientists, engineers, policy makers, and the public.

Additional Requirements:

Computer and projector for electronic visuals.

Objective 5.1 Describe how the sizes of earthquakes are measured.

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 5.1 Measuring Earthquakes

Remarks:

I. Earthquake Size

A. The "size" of earthquakes generally refers to the amount of energy released by the event.

B. Two approaches by which earthquake size is categorized are: **intensity** and **magnitude**. *[Electronic visual 5.1 (summarized in text below)]*

1. ***Intensity*** is a crude measure of earthquake size based on indirect, ***subjective*** descriptions, such as how strongly people reacted and the type and extent of building damage. This method was used primarily before the advent of modern seismic instruments.

2. ***Magnitude*** is a ***quantitativ****e* measure of earthquake size and is based on the response of seismic **instruments.**

C. Both measurements attempt to characterize the size of the earthquake (essentially correlated to the amount of energy releases) on the basis of one number. But, as will be shown later, magnitude is the more reliable parameter to use in this effort.

Objective 5.2 Explain how earthquake intensity is determined.

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 5.2 Measuring Earthquakes - Modified Mercalli Intensity I, II, III
Electronic Visual 5.3 Measuring Earthquakes - Modified Mercalli Intensity IV, V, VI
Electronic Visual 5.4 Measuring Earthquakes - Modified Mercalli Intensity VII, VIII
Electronic Visual 5.5 Measuring Earthquakes - Modified Mercalli Intensity IX, X

Electronic Visual 5.6 Measuring Earthquakes - Modified Mercalli Intensity XI, XII
Electronic Visual 5.7 MMI Contours from 1811 New Madrid Earthquake

Remarks:

I. Intensity:

A. ***Earthquake intensity*** is the oldest measure of earthquake size, based on subjective interpretations of observed damage and human reactions.

B. A number of different intensity scales (i.e., standard descriptions of earthquake effects), have been developed in different parts of the world beginning in the late 1800s. (Modified Mercalli, Rossi-Forel, Japanese Meteorological Agency, etc.).

C. The Modified Mercalli Intensity Scale (MMI), developed in 1931, is the most commonly-used scale worldwide. MMI scale ranges from Intensity I to Intensity XII, with I being barely felt to XII being near total destruction of constructed facilities. See table below that describes the Modified Mercalli Intensity scale. *[Electronic visuals 5.2, 5.3, 5.4, 5.5, 5.6 in succession]*

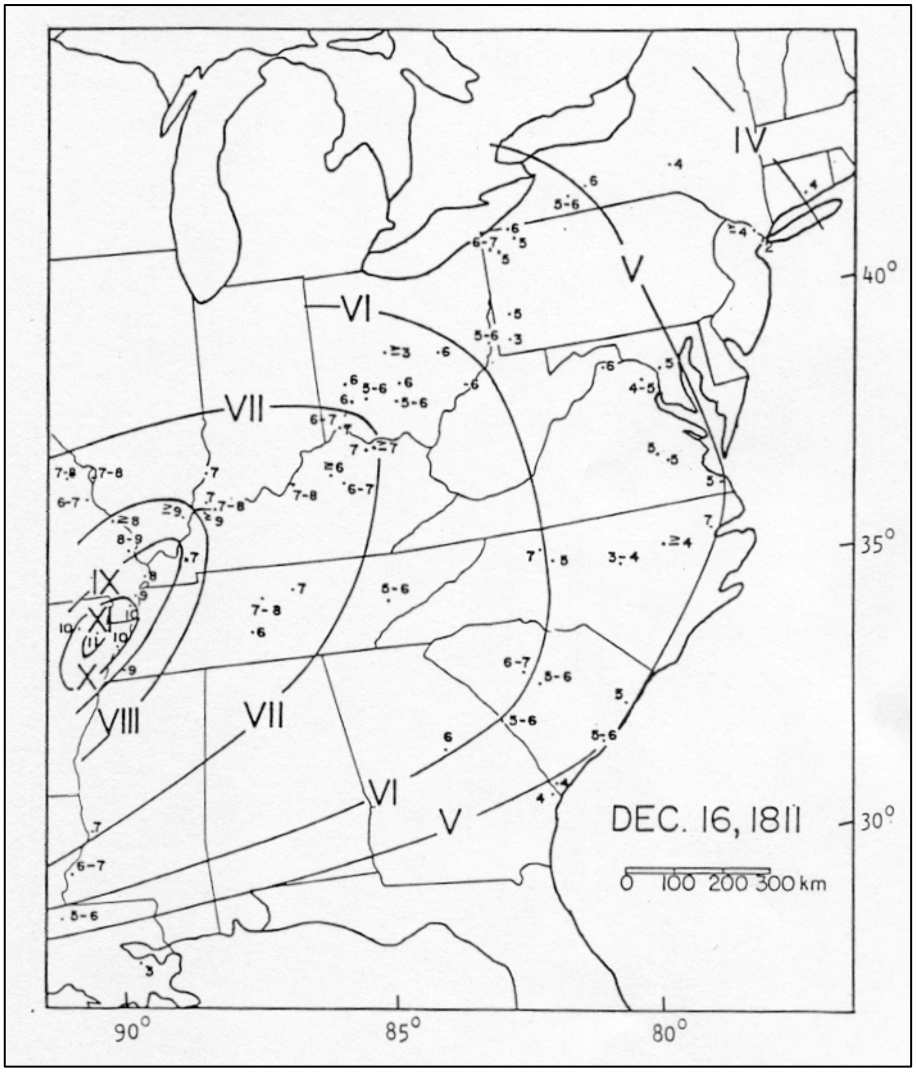
D. **Intensities vary across the affected region**. Maximum intensity normally occurs near the earthquake epicenter, with intensity values then decreasing with distance. (**However, many factors, such as varying geological conditions and quality of building construction, also can cause erratic variations in intensity**).

E. The highest intensity value in the affected region is reported as the earthquake's intensity. For instance, the 1811-12 New Madrid Earthquakes were MMI=XI, as shown in the visual on the following page: [*Electronic Visual 5.7*]

Table 5.1 - MODIFIED MERCALLI INTENSITY (MMI) SCALE OF 1931

MMI	Description of Observed Earthquake Effects
I	Not felt except by a very few under especially favorable circumstances.
II	Felt by only a few persons at rest, especially on upper floors of buildings.
III	Felt quite noticeably indoors, especially on upper floors of buildings.
IV	During the day, felt indoors by many, and outdoors by few.
V	Felt nearly by everyone, many awakened; some windows, dishes broken.
VI	Felt by all; many frightened and run outdoors; some heavy furniture moved. Few instances of cracked plaster; unstable objects overturned.
VII	Everybody runs outdoors; damage negligible in buildings of good design; slight-to-moderate in well-built ordinary structures; chimneys broken.
VIII	Damage slight in specially-designed structures, considerable in ordinary substantial buildings with partial collapse; fall of chimneys; sand boils.
IX	Damage considerable in specially-designed structure; well-designed frame structures thrown out-of-plumb; damage great in substantial buildings with partial collapse; underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked, rails bent; landslides from river banks and steep slopes; water splashed on banks.
XI	Few, if any, (masonry) structures remain standing; bridges destroyed; broad fissures in ground; underground pipelines completely out of service; earth slumps and land slips in soft ground; rails bent greatly.
XII	Damage total; practically all works of construction are damaged greatly or destroyed; waves seen on ground surface; lines of sight and level are distorted; objects thrown into the air.

Visuals 5.2-5.6 - Modified Mercalli Intensity (MMI) description.



Visual 5.7 - Intensity contours for the 1811 New Madrid, MO earthquake. The highest value of intensity is reported for a given earthquake. Thus, this large earthquake is reported as MMI = XI. Credit: USGS

II. Intensity has many shortcomings in terms of indicating the energy released by an earthquake.

A. A major drawback is that intensity is a function of many factors other than earthquake energy, including near-surface site conditions (especially soft sediments), topography, quality of building construction, people, etc., all of which vary from region to region.

B. For instance, an earthquake in a region where buildings are well-built would have lower intensity values than the same event in a country where building practices are not as advanced.

C. Also, there are problems in remote areas because there may be too few people to establish reliable values. For instance, intensity values could not be established in a remote area such as middle of a desert or beneath and ocean.

D. Intensity was used primarily before seismometers were developed and before Richter developed the concept of magnitude; most populated seismically active area have modern seismic instruments to determine magnitude.

E. Intensity is still important in areas where seismic instruments are not available, and intensity values are all that is available for determining the sizes of earthquakes that occurred before the advent of seismic instruments (i.e., the 1886 Charleston, SC earthquake).

F. Rough correlations are available to relate intensity values to magnitude (see table at end of following section).

Objective 5. 3 Explain how earthquake magnitude is determined.

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 5.8 Seismographs Record Earthquake Motions
Electronic Visual 5.9 Common Types of Magnitude
Electronic Visual 5.10 Moment Magnitude vs. Other Magnitude Scales
Electronic Visual 5.11 Magnitude vs. Fault Length for California Earthquakes
Electronic Visual 5.12 Average Number of Annual Earthquakes Worldwide

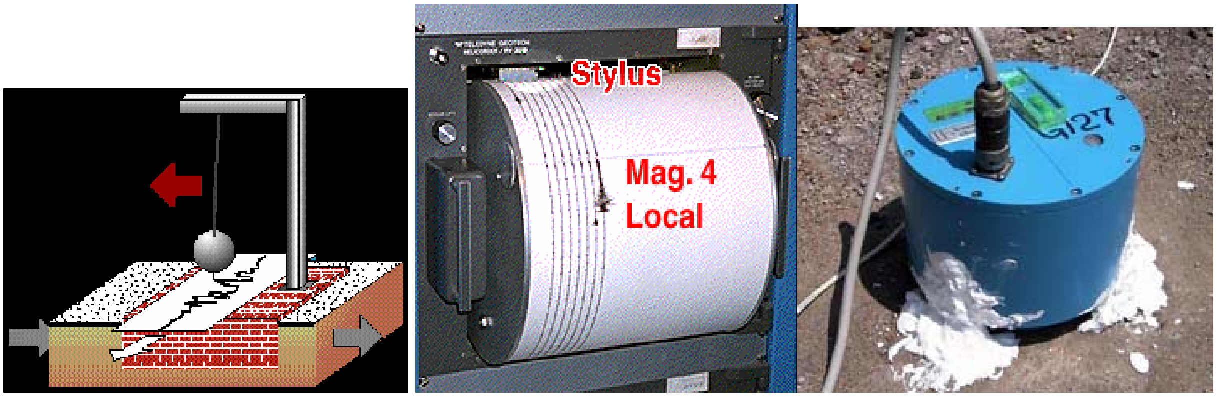
Remarks:

I. Magnitude:

A. ***Earthquake magnitude*** is a quantitative measure of energy release typically based on the response of an instrument designed to detect waves generated by an earthquake (seismograph).

B. Magnitude is calculated from a measurement of either the amplitude or the duration of specific types of recorded seismic waves.

C. A seismograph is used to measure the waves generated by an earthquake.



Visual 5.8 - From the left, a schematic depiction of a seismograph; a drum-type seismograph, popular until the early 1990s, and an actual seismometer (right) being installed at a site in Japan. Photo credits: Seismograph drum: USGS; seismometer: http://hakusan.s.kanazawa-u.ac.jp/~yoshizo/elephants/hakusanseis2001.html

D. A ***seismograph***, or ***seismometer***, is an instrument used to detect and record earthquakes. Generally, it consists of a mass attached to a fixed base. During an earthquake, the base moves as the ground shakes and the mass does not. The motion of the base with respect to the mass is commonly transformed into an electrical voltage. The electrical voltage is recorded on paper, magnetic tape, or another recording medium. This record is proportional to the motion of the seismometer mass relative to the earth, but it can be mathematically converted to a record of the absolute motion of the ground. **Seismograph** generally refers to the seismometer and its recording device as a single unit. [*Electronic Visual 5.8*]

E. The concept of magnitude was first proposed by Richter in the 1930s due to a need for an instrumental standard for rating sizes of earthquakes.

II. Richter devised way of rating earthquakes in California according to the response of a standard seismometer. H. Wood suggested the term "magnitude" for this new measure. Richter published his magnitude scale in 1935; eventually became known as the *Richter scale*. His original definition of magnitude is as follows:

> "The logarithm (base 10) of the maximum trace amplitude, expressed in microns, measured by a standard (Woods-Anderson) short-period seismometer (0.8 seconds) on 'firm' ground at a distance of 100 km from the epicenter (local)." A set of correction factors is used for distances ≠100 km, varying geologic conditions, etc.

A. Note that Richter scale refers to a standard quantitative rating system of an earthquake, and is not a physical instrument (a scale of sorts) as many believe.

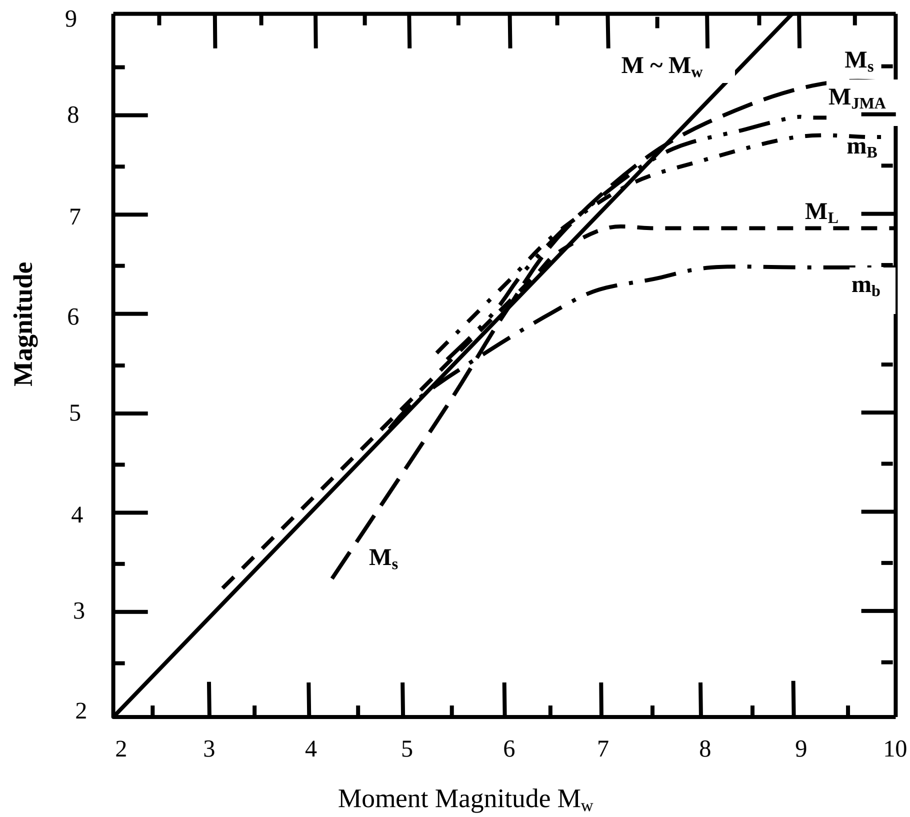
B. Because a wide range of earthquakes, ranging from very small earthquakes that release little energy to large earthquakes that release tremendous energies, must be measured, Richter proposed a logarithmic scale for the measurement of magnitude. That means each unit increase in magnitude represents a 10-fold increase in the size of the recorded signal. Therefore, a magnitude 7 earthquake would have a maximum signal amplitude 10 times greater than that of a magnitude 6 earthquake, and 100 times greater than a magnitude 5 earthquake. The peak motion of the seismograph trace in the example above is about 20 mm, corresponding to a magnitude 5 earthquake; therefore, the peak seismograph trace for a magnitude 6 earthquake would be roughly 200 mm. (Note carefully that this refers to the **amplitude of the response of the seismograph needle**. This is different from the energy released by the earthquake. The **amount of energy released increases by a factor of about 30 for each unit increase in magnitude, as discussed later).**

C. As seismograph stations became more common following Richter's development, it became apparent that the method developed by Richter only worked well for measuring the energy of certain earthquakes in certain regions at certain distances. It was learned the response of the instrument he used did not provide a true measure of the energy of large earthquakes and for deep-focus earthquakes.

D. New magnitude scales that were an extension of Richter's original idea were developed to measure earthquakes that were large (>M6.5), deep, and located far away. These include body-wave magnitude, m_b, and surface-wave magnitude, M_S. ***Body wave magnitude*** is based on the measure of body waves and ***surface wave magnitude*** is based on the measurement of surface waves. Each uses a slightly different type of seismograph than originally used by Richter, and each is valid for a particular frequency range and type of seismic signal. [*Electronic Visual 5.9*]

E. Because of the limitations of all three magnitude scales that depend upon the response of instruments (M_L, m_b, and M_S), a new, more uniformly applicable extension of the magnitude scale, known as moment magnitude, or M_W, was developed.

F. ***Moment magnitude*** is based on the actual mechanics of the fault rupture and is a more fundamental measurement of earthquake energy. Moment magnitude is more difficult to determine, but it is the current standard. The chart below shows the various magnitude scales relative to the standard (45° line). [*Electronic Visual 5.10*]



Visual 5.10 - Chart showing the various magnitude scales relative to the moment magnitude scale that is the current standard. It can be seen the other scales are deficient in certain areas (namely small and large events) in characterizing the true energy released from an earthquake; Visual adapted from Kramer (1996).

G. All of the various magnitude scales are roughly equal in moderate magnitude ranges [except for big (>7.5) and small (<5.5) events], as shown in the visual above.

H. The news media usually states "Richter Magnitude," or simply "magnitude" but actually the magnitudes are either M_L, m_b, M_S, or M_W.

I. Magnitude is related to fault length; a longer fault produces a bigger earthquake that lasts a longer time: [*Electronic Visual 5.11*]

Table 5.2 – Magnitude Versus Fault Length and Duration of Strong Ground Shaking for California Earthquakes				
Magnitude	**Date**	**Location**	**Length (kilometers)**	**Duration* (seconds)**
7.8	January 9, 1857	Fort Tejon	360	130
7.7	April 18, 1906	San Francisco	400	110
7.5	July 21, 1952	Kern County	75	27
7.3	June 28, 1992	Landers	70	24
7.0	October 17, 1989	Loma Prieta	40	7
6.9	May 18, 1940	Imperial Valley	50	15
6.7	February 9, 1971	San Fernanado	16	8
6.7	January 17, 1994	Northridge	14	7
6.6	November 24, 1987	Superstition Hills	23	15
6.5	April 9, 1968	Borrego Mountain	25	6
6.4	October 15, 1979	Imperial Valley	30	13
6.4	March 10, 1933	Long Beach	15	5
6.1	April 22, 1992	Joshua Tree	15	5
5.9	July 8, 1986	North Palm Springs	20	4
5.9	October 1, 1987	Whittier Narrows	6	3
5.8	June 28, 1991	Sierra Madre	5	2
*Duration here refers to the duration of the strong shaking portion of the earthquake. Data from: http://www.data.scec.org/eqcountry/measureeq2.html				

Visual 5.11 – Table showing relationship between fault length and magnitude. Data from USGS, SCEC.

J. Informally, earthquakes are classified according to their magnitude size:

Magnitude	Classification
< 5	small
5 - 6	moderate
6 - 7	large
7 - 7.8	major
> 7.8	great

III. Key points to remember about magnitude:

A. Magnitude is based on responses of instruments, not subjective assessments from people.

B. There are several types of magnitude scales; all indicate nearly the same thing, but have special cases where one system is preferred over another (i.e., if your station is located far from the event, say 100s of miles, perhaps Ms, the surface wave magnitude, is the scale you would need to determine the size of the event from your location).

C. These include Richter magnitude, body wave magnitude, local magnitude, moment magnitude, and surface wave magnitude. Moment magnitude is now the accepted “standard” magnitude used by seismologists.

D. The bottom line is that the type of specific magnitude used typically is not important for non-engineers and scientists to understand the threat and perform their jobs (i.e., emergency managers). In general, all of the magnitudes roughly agree except for smaller events and large events. The main keys to remember are that:

1. People begin to feel earthquakes at about magnitude 2.
2. **Damage to buildings typcially begins at about M5 to 5.5.**
3. The severity of ground shaking (measured in terms of peak ground acceleration) increases as magnitude increases **up to a point**, but the duration of the earthquake and the potential for damage increase steadily with magnitude. For instance, a magnitude 7 earthquake might have peak ground accelerations just as high as a magnitude 8 event; however, the magntidue 8 event would definitely affect a much wider area and the duration of maximum ground shaking levels would be much longer – both factors that produce a higher damage potential (see Table 5.2 for duration effects). **Thus, the damage potential to buildings and lifelines increases steadily with increasing magnitude.** And this damage potential is due only partly to stronger ground shaking, as the **increased duration of strong ground shaking and larger affected regions** are important causes as well.

E. Earthquakes with magnitudes of about 4.5 or greater occur several thousands of times annually (USGS).

F. Great earthquakes, such as the 1964 Good Friday earthquake in Alaska, have magnitudes of 8.0 or higher. On the average, one earthquake of such size occurs somewhere in the world each year (USGS). [*Electronic Visual 5.12*]

Table 5.3 – Average Number of Annual Earthquakes Worldwide

Descriptor	Magnitude	Average Annually
Great	8 and higher	1
Major	7 - 7.9	17
Strong	6 - 6.9	134
Moderate	5 - 5.9	1319
Light	4 - 4.9	13,000 (estimated)
Minor	3 - 3.9	130,000 (estimated)
Very Minor	2 - 2.9	1,300,000 (estimated)
Based on observations since 1900. Data source: USGS		

Visual 5.12 – Descriptors for earthquakes of various magnitudes and frequency of occurrence. Credit: data from USGS.

Objective 5.4 Describe the energy associated with earthquakes and compare magnitude and intensity.

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the electronic visual files should be presented. The instructor should query the students at beginning of the objective: "*What do you think the difference is in total energy released between magnitude 5 and magnitude 6 earthquakes*?" This sets the stage for the main lesson to be learned in this objective. Most students are surprised to find out that each unit of magnitude represents approximately a 30-fold increase in energy output.

Electronic Visuals Included:

Electronic Visual 5.13 Seismic Energy Release
Electronic Visual 5.14 Magnitude, Intensity, and Earthquake Energy

Remarks:

[Instructor asks students here: "*What do you think the difference is in total energy released between magnitude 5 and magnitude 6 earthquakes*?"]

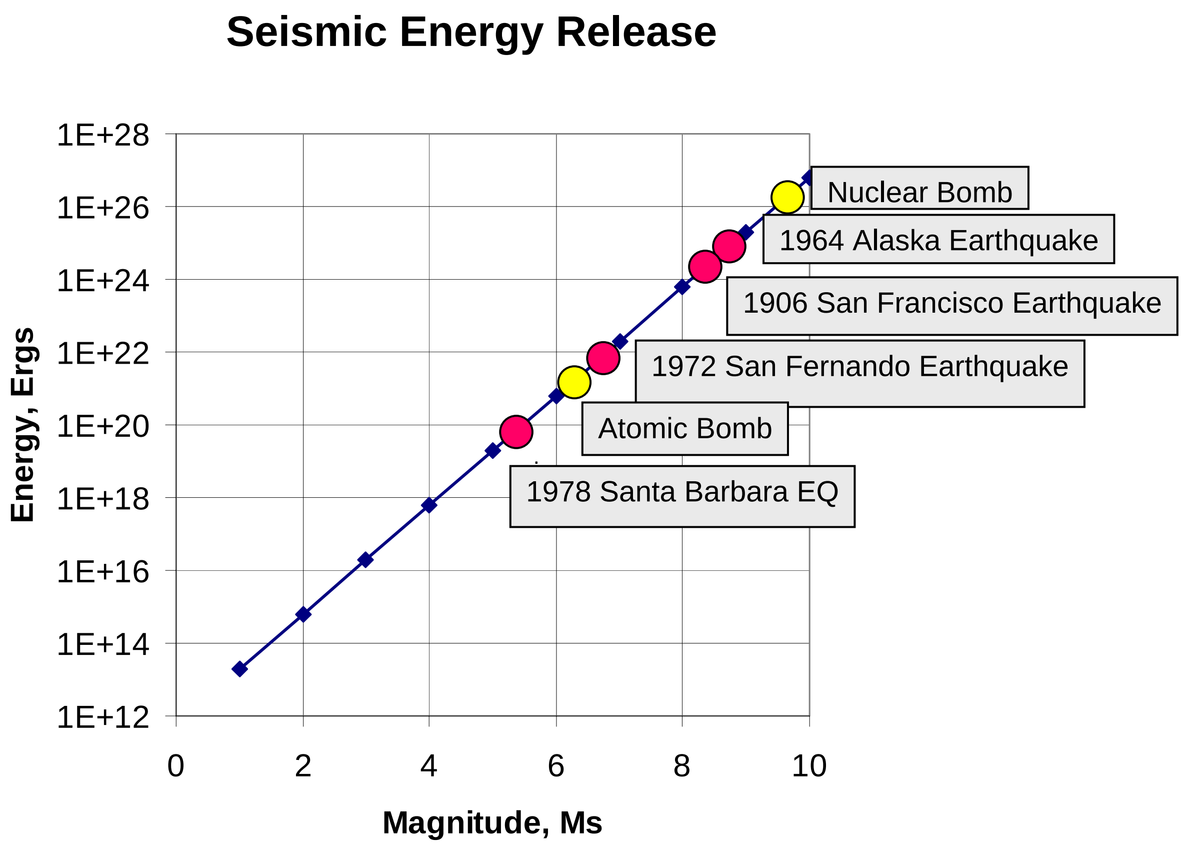
I. Earthquake Energy

A. Seismic energy is the energy contained in waves radiated from an earthquake. Only a small fraction (about 1%) of the total energy of an earthquake is radiated in seismic waves. Most of the energy released in an earthquake is expended in friction on the fault surface, lifting parts of the earth's surface, or breaking rock.

B. Radiated seismic energy is estimated by log (E) = 4.4 + 1.5 • M where E is energy in joules, and M is surface wave magnitude. (1 Erg = 10^{-7} joules).

II. For an M8 earthquake this works out to about 7 billion kilowatt-hours. This is equal to total electric consumption of the US in one day. Unfortunately, the energy is released in a few seconds, not hours, so the power of a 30 second M8 earthquake is more than a thousand billion horsepower. A kilowatt is 1.34 horsepower. If the area of strong shaking measures 200 km by 100 km, about 25 horsepower are applied to every square meter during that 30 seconds, with more near the center, and less near the edge.

III. Energy rises quickly with magnitude. A unit increase in magnitude corresponds to a $10^{1.5}$ (or 32-fold increase) in released energy. For instance, *an M7 earthquake releases roughly 1,000 times more energy than an M5 event*. The world's largest nuclear explosion released about 0.5 X 10^{25} ergs of energy, which corresponds to an earthquake moment magnitude of about 8.5. [*Electronic Visuals 5.13, 5.14*]



Visual 5.13 - Seismic Energy Release. Credit: adapted from USGS.

Table 5.4 – Comparison of Magnitude, Intensity, and Earthquake Energy				
Magnitude	**Equivalent energy in weight of TNT***	**Equivalent energy in Hiroshima-size atomic bombs**	**Mercalli intensity near epicenter**	**Witnessed observations:**
3-4	**15 tons**	**1/100**	**II-III**	**Feels like vibration of nearby truck**
4-5	**480 tons**	**3/100**	**IV-V**	**Small objects upset, sleepers awaken**
5-6	**15,000 tons**	**1**	**VI-VII**	**Difficult to stand, damage to masonry**
6-7	**475,000 tons**	**37**	**VII-VIII**	**General panic, some walls fall**
7-8	**15,000,000 tons**	**1,160**	**IX-XI**	**Wholesale destruction, large landslides**
8-9	**475,000,000 tons**	**36,700**	**XI-XII**	**Total damage, waves seen on ground surface**

Visual 5.14 - Correlation between earthquake energy, magnitude, and tons of TNT for bombs.

**This is the amount of TNT that would be required to generate ground shaking similar to an earthquake of each magnitude. This is based on the observation that a 1,000-ton explosion is approximately equivalent to a magnitude 4 earthquake. Data source: USGS from http://neic.usgs.gov/neis/general/mag_vs_int.html*

Objective 5.5 Explain the type of waves generated by earthquakes.

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the electronic visual files should be presented.

Electronic Visuals Included:

Electronic Visual 5.15 Seismic Wave Forms (body waves)
Electronic Visual 5.16 Typical P- and S-Wave Travel Speeds
Electronic Visual 5.17 Seismic Wave Forms (surface waves)
Electronic Visual 5.18 Arrival of Seismic Waves at Seismograph

Remarks:

I. Types of Seismic Waves:

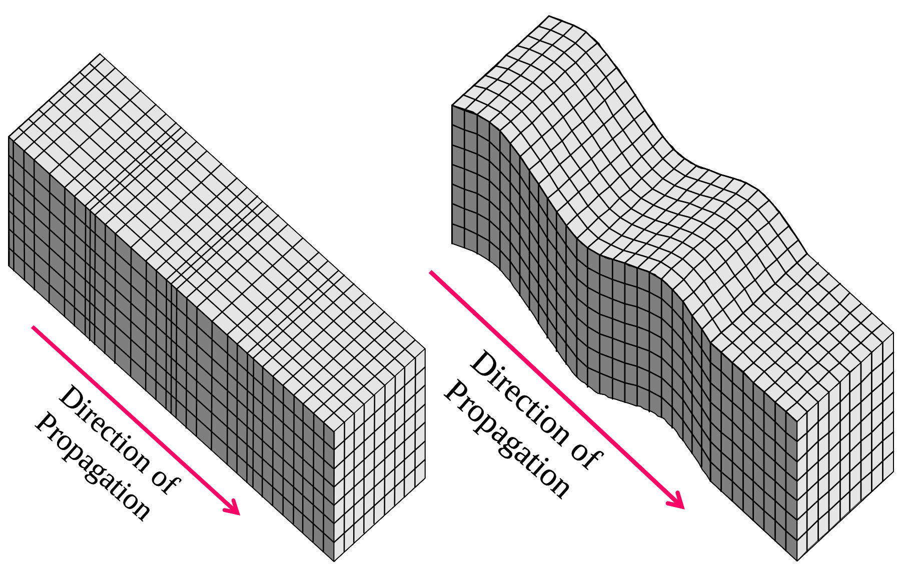
A. When a fault ruptures, waves are generated and radiate throughout the earth, similar to ripples in a pond when a stone is thrown in.

B. There are two types of seismic waves associated with earthquakes-- **body waves** and **surface waves**.

II. Body Waves – Two types ⇒ P-waves and S-waves.

A. ***P-waves*** are Primary or compression (longitudinal) waves. These waves are analogous to sound waves and are the first to arrive at a particular location.

B. ***S-waves*** are Secondary or shear (transverse) waves. These waves cause shear deformation of the ground**. S-waves are typically associated with about <u>85% of the damage</u> caused by earthquakes**. [*Electronic Visuals 5.15, 5.16*]



Visual 5.15 - Schematic illustrating primary (or compression) wave motion (left) and secondary (or shear) wave motion (right).

Table 5.5 - Typical Speed of P-Wave and S-Wave Travel		
Medium	**P-Wave Velocity, Vp (ft./sec.)**	**S-Wave Velocity, Vs (ft./sec.)**
Water	5,000	0
Soft Clay	1,600 - 2,400	250 - 500
Medium Sand	3,000 - 4,500	800 - 1,200
Dense Sand	4,500 - 6,000	1,200 - 1,800
Soft Rock	8,000+	2,500+
Hard Rock	18,000+	12,000+

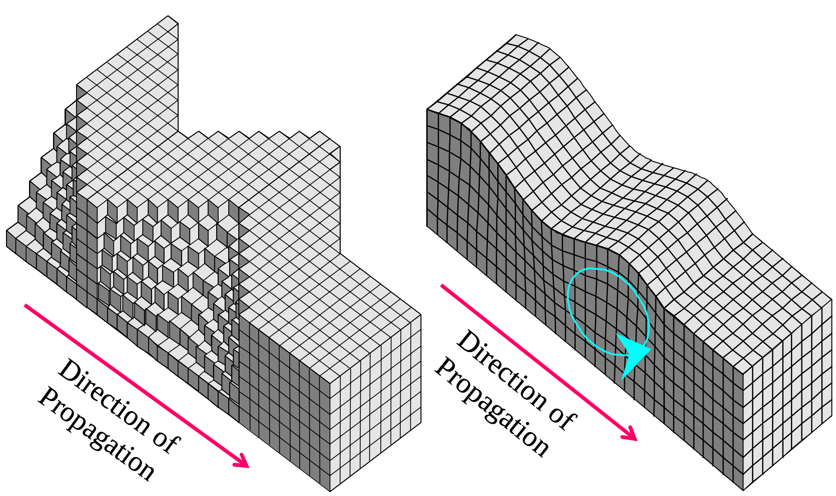
Visual 5.16 - Table showing relationship between fault length and magnitude. Data from USGS.

III. *Surface Waves* – Two types: Love and Rayleigh waves. [*Electronic Visual 5.17*]

A. ***Surface waves*** are caused by an interaction of body waves with the ground surface. These waves become the more dominant at great distances from the earthquake. At these distances, surface waves can be responsible for peak ground accelerations. These waves typically cause less than 15% of the total damage to structures, but can be more damaging to pipelines and long-span structures by producing relative motions between supports.

B. ***Rayleigh waves*** are rolling waves that induce motion similar to ocean waves.

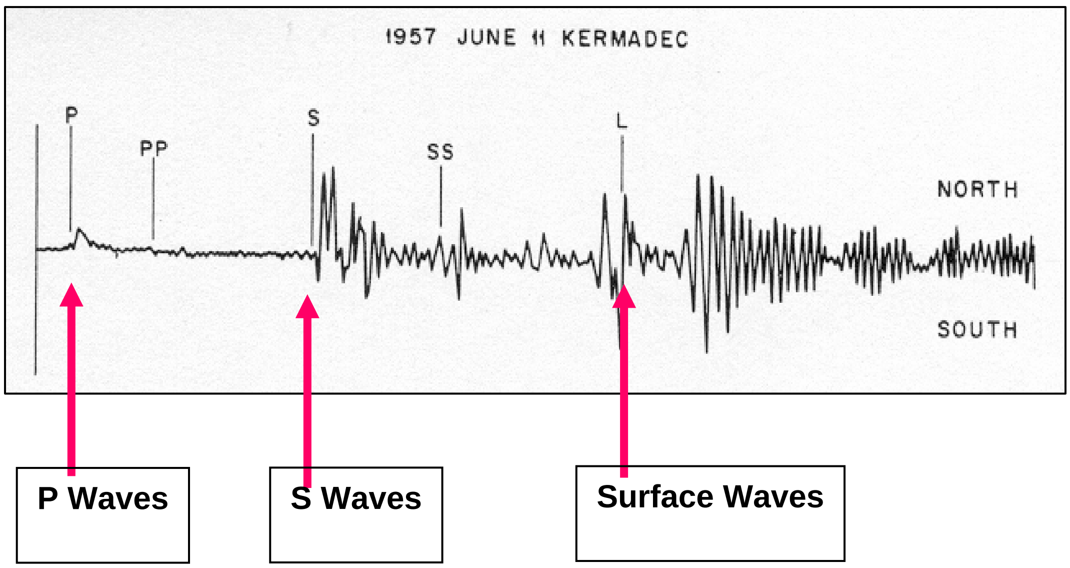
C. ***Love waves*** are basically sideways shear waves.



Visual 5.17 - Schematic illustrating Love wave (left) and Rayleigh wave motion (right).

D. Due to their different amplitude and speed of travel (arrival times), the different types of waves can be distinguished at a seismograph recording station, as shown in Visual 5.18.

[*Electronic Visual 5.18*]



Visual 5.18 - Visual showing arrival of body waves and surface waves at a seismograph station. Visual adapted from USGS.

Objective 5.6 Describe other important earthquake terms.

Requirements:

The content should be presented as lecture, supplemented with electronic visuals. The instructor is cued as to when the graphics from the electronic visual files should be presented.

Electronic Visuals Included:

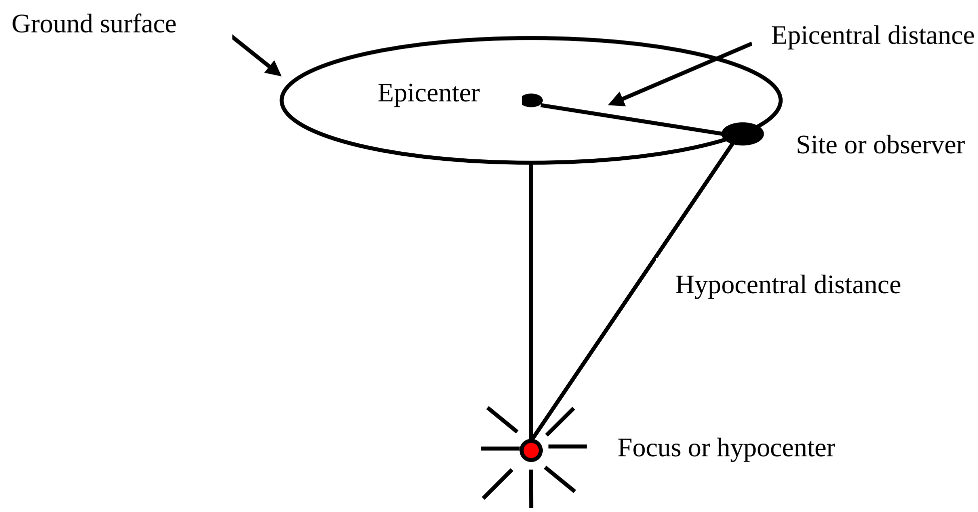
Electronic Visual 5.19 Epicenter and Hypocenter

Remarks:

I. ***Attenuation* – Decay or reduction of earthquake energy with distance from the zone of energy release.**

II. ***Epicenter* – Point on earth's surface above hypocenter.** [*Electronic Visual 5.19 Epicenter and Hypocenter]*

III. ***Hypocenter* – Point in earth where fault rupture actually initiates.**



Visual 5.19 - Visual illustrating hypocenter and epicenter.

IV. ***Maximum Credible Earthquake or Maximum Considered Earthquake (MCE)* – Largest earthquake that, based on all known geologic and seismological data, can be reasonably expected to occur in a region. The design standard in building codes in most states in the U.S. are based on the MCE. The MCE for building design is typically considered to be the earthquake shaking level with a 2% chance of being exceeded in 50 years (2,500-yr. motion).**

V. ***Soil amplification* – Process by which the intensity of ground shaking is amplified in certain earth materials. Soil amplification is often a big problem in soft soils such as clays. In the 1985 Mexico City and 1989 Loma Prieta, CA earthquakes, soil amplification was responsible for much of the damage. This concept will be discussed further in Session 7**.

References Utilized:

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