Introduction to Earthquakes and Seismology

I. Importance of Earthquakes

A. Death and Destruction
1. Examples
a. Turkey, Auguest, 1999
(1) Mag. 7.4 quake
(2) 15,000 dead, 600,000 Homeless
(a) 15,000 more missing
b. 16th Century China
(1) 850,000 dead
c. 1923 Tokyo
(1) 143,000 dead
d. 1995 Kobe Japan
(1) 5000 dead
(2) 100 billion $ in damage
e. San Francisco 1906
(1) 700 dead
(2) 25 million $ damage
f. 1989 Loma Prieta, CA
(1) 62 dead
(2) 5 billion$ in damage
g. Northridge, CA 1994
(1) 61 dead
(2) 30 billion$ in damage

II. BASIC DEFINITIONS

A. Earthquake - vibration of earth produced by rapid release of energy

B. Focus of Earthquake- point source of earthquake on or within earth's interior

C. Epicenter of Earthquake- map position vertically above focus, at earth's surface

D. Seismic waves- energy in wave form which radiates in all directions from the focus, vibrational waves in the earth. Wave energy dissipates with distance away from focus

E. Source of Earthquakes
1. Volcanic eruptions
2. Fault movement
3. Explosions

F. Faults-fractures within the earth along which movement occurs on either side, i.e. a fault is a plane of discontinuous movement. Earthquakes are often associated with sudden movement and release of stress along a fault.

1. Movement along fault may be horizontal, vertical, or oblique (combo of two). Vertical component of movement along a fault may be expressed at earth's surface via a fault scarp.

2. Fault Types
   a. Normal
   b. Reverse
   c. Strike-Slip
      (1) left-lateral (sinstral)
      (2) right lateral (dextral)
3. Surface Fault Traces vs. Buried or "Blind" Faults
   a. Surface Traces = fault intersects earth surface
   b. Blind Fault = fault at depth, no surface expression
4. Other Fault Terms
   a. Fault Strand = individual fault
   b. Fault Zone = zones of multiple faults
   c. Fault Segment
      (1) Individual lengths of fault zones that act as coherent units
   d. Inactive vs. Active Faults
      (1) active - displacement in last 10,000 yrs

G. Nature of Seismic Events or Earthquakes

1. Rock Deformation Styles in Response to Stress

(Stress = Force / unit area)

   a. Ductile
      (1) plastic, permanent deformation
   b. Elastic
      (1) defomation recovers once stress is removed
   c. Brittle
      (1) permanent rupture / deformation of rocks
   d. Elastic Rebound
      (1) Follows brittle rupture, rocks elastically re-adjust shape

2. Process: crustal rocks are placed under force or stress, the rocks undergo elastic deformation until frictional/atomic forces within the rock are exceeded, and slippage or rupture along a fault occurs.

   a. Slippage and release of stress allows rocks to "snab back" or rebound after the release of stress ("elastic rebound"), the elastic rebound is the cause of earth quake or vibrations.

   b. Aftershocks- periodic mechanical adjustments that occur in rocks following an initial rupture along a fault. Aftershocks are generally weaker than primary seismic event, but may cause damage to already weakened structures.
      (1) Aftershocks result from elastic rebound

c. Foreshocks- seismic activity that precedes a major earthquake on order of days to years.

3. Stick-slip motion along a fault- process of discontinuous movement along a fault: build up of stress-elastic deformation (stick)-sudden release along fault (slip)-earthquake-build up of stress-elastic deformation (stick)

4. Creep- continuous movement along a fault, very little build-up of strain, lower earthquake potential

III. Earthquakes Sources vs. Plate Tectonics
   A. Intraplate Earthquakes
      1. Epicenter/focus located within interior of tectonic plates
         a. e.g. New Madrid, MO seismic zone
      2. Focus within the center, vertically, of tectonic plates
      3. Crustal Earthquakes
         a. focus within earth's crust
   B. Plate Boundary Earthquakes
      1. Interface quakes - focus at plate boundaries / shear zones

IV. EARTHQUAKE WAVES (SEISMOLOGY)

   A. Seismology-study of earthquake waves, dates back 2000 years to ancient Chinese and primitive seismographs used to detect earth vibration.

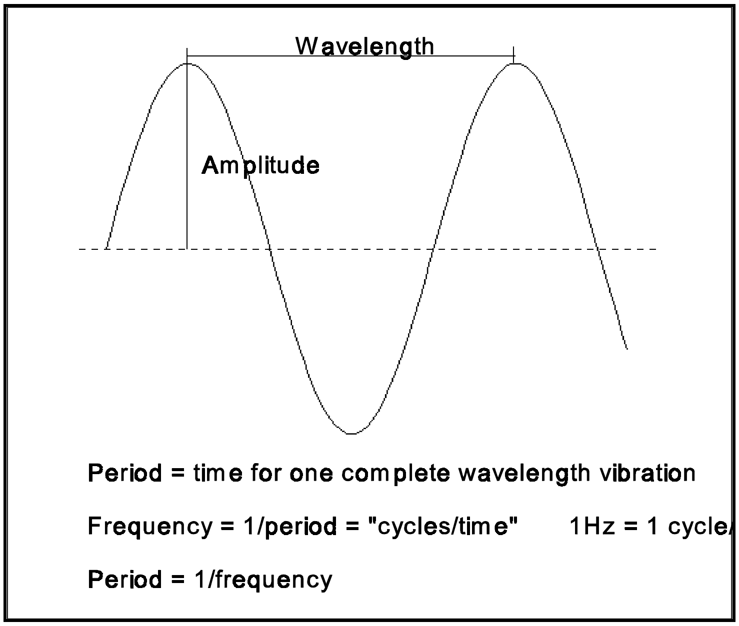
      1. Seismograph-instrument to detect seismic waves or earthquake activity.

         a. mechanism- weight is freely suspended from a support imbedded in bedrock, weight is attached to a pen and when an earth quake hits, the weight will remain stationary while the frame/support shakes with the earth, the support is connected to a rotating drum with paper on it, and the relative intensity of quake waves is recorded by the pen.

         b. seismograms-records from the seismographs

   B. Wave Form
      1. Waves = Vibrational Energy

      2. Basic Form = "Sine Curve"



Remember to Show:
Node Points - points of mimimum energy on the wave form (points at equilibrium)

C. Seismic waves- elastic energy traveling through earth's crust that is propagated or transmitted outward radially from the focus of the earthquake. Wave types....(direction of movement)

1. Surface Waves - seismic vibrations that move along the outer layer of the earth's surface. Have both a vertical and horizontal components of motion, horizontal components cause the most damage.
    a. Love Waves
        (1) horizontal vibration, perpendicular to travel
    b. Rayleigh Waves
        (1) rolling / orbital ground vibration
            (a) like ocean waves

2. Body waves- seismic vibrations that move through earth's interior

    a. Primary waves or P waves- push-pull waves, waves move back and forth in the direction in which the wave is travelling. Change both volume and shape of material in which they pass. Affect and can pass through solids, liquids, and gasses (as they all exhibit resistance to change in volume)

        (1) Longitudinal Waves
            (a) wave motion is parallel to direction of travel
                i) e.g. accordian motion, to and fro
                ii) e.g. spring bobbing up and down

    b. Secondary waves or S waves-vibrations occurring at right angles to direction of wave propagation, shaking motion. Result in changing only shape of material they travel through. Affect and can pass through only solid materials (only solids offer resistance to change in shape).

(1) Transverse Waves
  (a) wave motion is perpendicular to direction of travel
    i) e.g. amplitude is perpendicular to direction of travel

3. Seismograms : plot of time vs. intensity of motion, First waves to arrive at seismograph are P waves, 2nd are S waves, and 3 rd are Surface waves. Arrival of waves relates to velocity with which they are transmitted through the earth's crust. Vel. P wave = 1.7(vel S wave), Vel Surface = .90 (vel S waves). Surface waves ride immediately behind S waves which are moving in layer directly beneath them.

V. LOCATION OF EARTHQUAKES

A. Earthquakes can be located by use of several seismic stations at diff. locations on the earth's surface, and by use of arrival times of seismic waves at each station

B. Epicenter of Earthquake- location on earth's surface directly above the focus of the earthquake.

C. Focus: actual point of origination of seismic event, may be at depth below earth's surface

D. Location method: difference in velocity of P and S waves provides method of determining epicenter. Based on Vel P > Vel S waves, the greater the distance of travel, the greater the time lag between first arrivals of P and S waves: i.e. the > diff. in arrival times, the > the distance to epicenter. (based on known times and distances from earthquakes, and atomic bomb testing in 50's and 60's). Determine the distance to 3 or more seismic stations and draw circles about the station locations, the common intersection of 3 or more circles = epicenter of quake.

VI. EARTHQUAKE INTENSITY AND MAGNITUDE

A. A method of determining earthquake intensity was needed for relative comparison of quakes and for assessing damage expected from a given earthquake.

1. Early attempts at earthquake measuring were based on description of extent of damage generated by a quake, but this was variable due to modes of construction and types of surface materials constructed upon

2. Mercalli scale: method of ranking earthquake intensity on basis of destruction and influence of quake on cultural features

3. Magnitude of Earthquake: the total amount of energy released during an earthquake

a. Richter Scale: measurement of quake magnitude, determined by measuring the amplitude of the largest wave recorded on the seismogram. The larger the amplitude, the more displacement of the recording pen, the greater the earthquake. (sensitivity of seismograph and distance of station from quake must be adjusted for in the calculation).

b. Each increase of magnitude on the Richter scale = a 10 fold increase in amplitude of wave recorded on seismogram, and corresponds to 30 times more energy released by a quake.

(1) e.g. M6 vs. M7 earthquake = 30 times energy released
(2) e.g. M5 vs. M7 earthquake = 30 x 30 energy released (900 times)

B. Classification
1. Magnitude 8.0 or higher = great earthquake
a. highly destructive
b. highest magnitude recorded = 8.7
2. Magnitude 7.0-7.9 = major earthquake

VII. Quantitative Approaches to Earthquake Activity
A. Fault Slip Rate
1. Time-average rate of offset along a fault zone (e.g. mm/yr)
B. Fault Displacement
1. distance of offset / motion along a fault during a given time interval (km)
C. Earthquake Recurrence Interval
1. Methods of Calculation
a. Paleoseismic Record
(1) Identify seismic events recorded in geologic record
(a) quake-induced landslide deposits
(b) tsunami deposits
(c) land motion / subsidence / buried vegetation
(d) liquefaction / sand boils
(e) fault scarp degradation
i) diffusion equation
(2) Date seismic events
(a) Numerical Age Dating
i) Radiocarbon dating
ii) cosmogenic isotopes
(b) Soils Chronosequences
(3) Determine time between seismic events
(4) Calculate time-averaged recurrence interval
b. Slip Rate Calculations
(1) Determine total offset along a fault (distance - km)
(2) Date total offset along a fault (time -years)
(3) Determine offset associated with 1 earthquake event (distance /quake)
(4) Calculation time-averaged recurrence interval (yrs / quake)

c. Seismicity
   (1) Examine historical seismic record for an area
   (2) time-average between seismic events
   (3) project recurrence interval over longer time period

VIII. NATURE OF QUAKE DESTRUCTION

A. Seismic vibrations: cause the ground to move both up and down and sideways at the same time.

B. Quake destructions function of :

1. intensity and duration of the vibrations

   a. avg quake on order of 15-40 secs, longer ones up to 3-4 mins. The longer the shaking the greater the chance for structural damage.
   b. earthquake frequency

2. nature of material upon which the structure is built
   a. generally soft, water laden sediments amplify the effect of a quake more than solid bedrock
   b. Material Amplification
      (1) unconsolidated sediments amplify shaking
         (a) silt and clay greatly amplify shaking
         (b) shaking jell-o model
      (2) Bedrock - mitigates shaking intensity

3. the design of the structure
   a. engineering / design
   b. re-inforced Buildings

C. Related Effects

1. Tsunami- seismic sea waves.
   a. Seismic waves transmitted through water, as in a nearby ocean.
   b. Often results from sub-sea faulting of ocean floor sending seismic shocks through the water, creating large waves, low amplitude but of long period moving at 500-700 mph.
   c. Upon approaching shore, the water piles up into 100 feet waves.

2. Fires: associated with broken electrical and gas lines, compounded by broken water lines.

3. Landslides and Ground Subsidence- shaking of ground often triggers landslides, slumps, and liquefaction of water-laden sediments...causing ground failure.

4. Shaking and Ground Rupture

5. Liquefaction
    a. transformation of water saturated sediment from solid to liquid
    b. shaking + saturated sediments = reduced strength / failure
        (1) high pore pressures

IX. Man-Induced Earthquakes
  A. Nuclear Explosions
  B. Deep Waste Disposal
    1. e.g. Denver, early 1960's
  C. Reservoir-Induced Seismicity
    1. Loading of Crust by Dams / Reservoir water
        a. e.g. Hoover Dam in Vegas

X. Earthquake Prediction

  A. uplift or subsidence of land along fault prior to quake
  B. seismic quiescence followed by periods of renewed activity
  C. >in radon gas liberated from rock fractures prior to quake (radon gas generated from radium in minerals)