MAGNITUDE AND INTENSITY (10)

I Main Topics

A Seismic waves

B Magnitude

C Intensity

D Evernden's equation for intensity decay

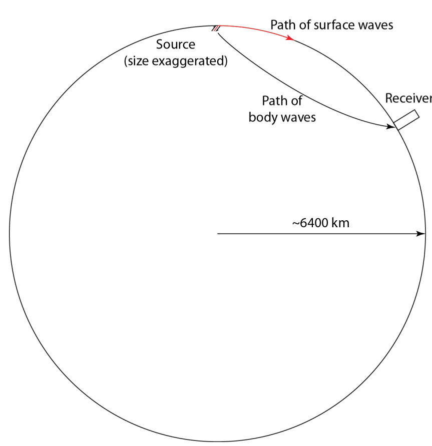
II Seismic waves: Nearly-pure elastic waves

A Seismic waves

1 Cause damage

2 Provide quantitative information on source, path(s) of waves

3 Record of waves depends on receiver

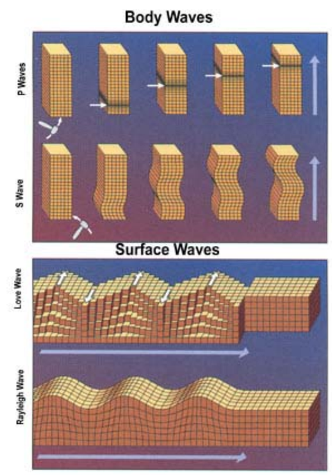


II Seismic waves: Nearly-pure elastic waves

B Body waves: travel inside the earth.

1 <u>P-waves</u>: <u>P</u>rimary (compressional) waves. First arrival.

2 <u>S-waves</u>: <u>S</u>econdary (shear) waves. Second arrival



http://earthquake.usgs.gov/learn/glossary/?term=P%20wave

II Seismic waves: Nearly-pure elastic waves

C Surface waves: travel at the earth's surface

1 <u>Cause strong ground motion near the epicenter</u>

2 Polarization

a Horizontally polarized waves

i Love waves

ii especially destructive

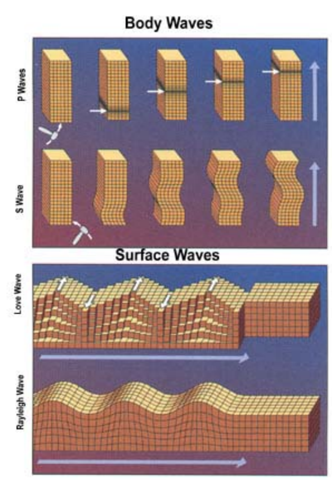
b Vertically polarized waves

i Rayleigh waves

5 Amplitudes

a Tend to saturate (have a ceiling)

b Scale with shear stress drop ("strength") of fault



http://earthquake.usgs.gov/learn/glossary/?term=P%20wave

II Seismic waves: Nearly-pure elastic waves

C Speed of body waves: c = L/T

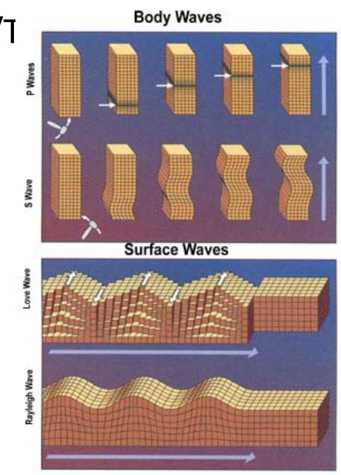
1. L = wavelength
2. T= period
3. P-wave speed

$$V_p = \sqrt{\left(K + \frac{4}{3}\mu\right) / \rho}$$

4. S-wave speed

$$V_s = \sqrt{\mu / \rho}$$

K = bulk modulus
μ = shear modulus
ρ = density

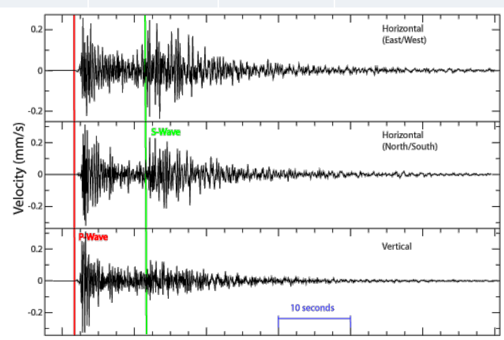


http://earthquake.usgs.gov/learn/glossary/?term=P%20wave

II Seismic waves: Nearly-pure elastic waves

Material	K (N/m²)	μ (N/m²)	ρ (kg/m³)	V_p (m/sec)	V_s (m/sec)	V_p - V_s (m/sec)
Granite	48×10^9	32×10^9	2720	5800	3400	2400
Water	22×10^8	0	1000	1500	0	1500

Key point: $V_p > V_s$
($V_p \approx 1.7\ V_s$ for rock)

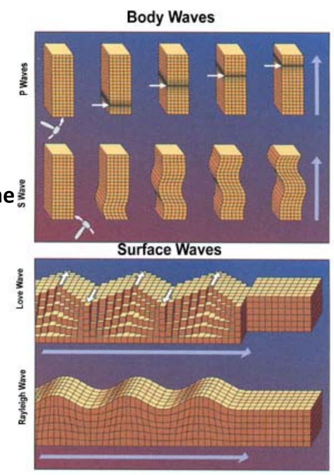


http://en.wikipedia.org/wiki/Seismology

II Seismic waves: Nearly-pure elastic waves

D Speed of surface waves
- a Horizontally polarized waves
  - i Love waves
  - ii $V_{Love} \approx V_s$
- b Vertically polarized waves
  - I Rayleigh waves
  - ii $V_{Rayleigh} \approx 0.92\ V_s$
- c "Feel" deeper as wavelength increases (akin to water waves)
- d Velocity increases with wavelength

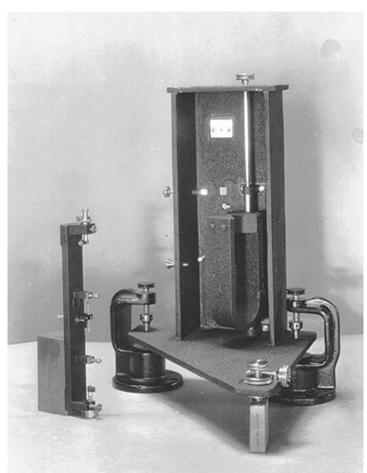
XII. Extreme



http://earthquake.usgs.gov/learn/glossary/?term=P%20wave

III Magnitude

- A Magnitude ideally measures only the source strength
- B Local (Richter) magnitude (M_L)
  1. $M_L = \log (A/A_0)$
  2. A_0 = amplitude A (in microns) of a Wood-Anderson seismograph 100 km from epicenter
  3. Devised for southern California; reflects wave attenuation there
  4. Does not discriminate between types of waves
  5. Sensitive to surface waves with periods of 0.8 sec
  6. Originally gave M_L to nearest 1/4
  7. Because surface waves saturate, intensity tends to saturate too at $M_L \approx 6.5$



http://www.eas.slu.edu/eqc/eqc_instruments/wood_and.jpg

III Magnitude

C Surface wave magnitude (M_s)
  1 Based on surface waves with 20-second periods.
  2 Saturates at $M_s \approx 6.8$-7.5.
  3 Has been set to match Richter magnitude for $M_L < 7.5$.
D Body wave magnitude (M_b)
  1 Based on P-waves with periods of about 1 second
  2 Primarily for deep focus events and for small shallow events
  3 Saturates at $M_b \approx 6.8$.
E Coda Magnitude: Based on decay of seismic wave amplitude.
F Moment magnitude (M_w): based on seismic moment M_o
  1 $M_w = (2/3) \log M_o - 10.7$ (M_o in dyne-cm)
  2 Designed to dovetail with M_s for $M_w < 7.5$

IV Intensity: a measure of the local shaking

A Modified Mercalli Scale (MMI = I to XII) *See next page*

I. Not felt Not felt except by a very few under especially favorable conditions	**II. Weak** Felt only by a few persons at rest, especially on upper floors of buildings	**III. Weak** 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.
IV. Light 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.	**V. Moderate** 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.	**VI. Strong** Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

http://en.wikipedia.org/wiki/Mercalli_intensity_scale

IV Intensity: a measure of the local shaking

A Modified Mercalli Scale (MMI = I to XII)

VII. Very Strong 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.	**VIII. Severe** 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.	**IX. Violent** 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. Extreme Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	**XI. Extreme** Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.	**XII. Extreme** Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

http://en.wikipedia.org/wiki/Mercalli_intensity_scale

IV Intensity: a measure of the local shaking

B Rossi-Forel Scale (I to X) *Predates Modified Mercalli*

I. Microseismic tremor. Recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds. The shock felt by an experienced observer	**VI. Strong tremor.** General awakening of those asleep. General ringing of bells. Oscillation of chandeliers, stopping of clocks, visible agitation of trees and shrubs. Some startled persons leaving their dwellings.
II. Extremely feeble tremor. Recorded by several seismographs of different kinds. Felt by a small number of persons at rest.	**VII. Very strong tremor.** Overthrow of movable objects, fall of plaster, ringing of church bells. General panic. Moderate to heavy damage buildings.
III. Feeble tremor. Felt by several persons at rest. Strong enough for the direction or duration to be appreciable.	**VIII. Damaging tremor.** Fall of chimneys. Cracks in the walls of buildings.
IV. Slight tremor. Felt by persons in motion. Disturbance of movable objects, doors, windows, cracking of ceilings.	**IX. Devastating tremor.** Partial or total destruction of buildings.
V. Moderate tremor. Felt generally by everyone. Disturbance of furniture, ringing of some bells. http://en.wikipedia.org/wiki/Rossi–Forel_scale	**X. Extremely high intensity tremor.** Great disaster, ruins, disturbance of the strata, fissures in the ground, rock falls from mountains.

IV Intensity: a measure of the local shaking

C Why use intensity?

"All too often, peak acceleration is misguidedly used as a direct measure of earthquake damage potential. It is convenient to discuss an earthquake that has just occurred in terms of its location, magnitude, and peak acceleration. But, as time goes on, magnitude and acceleration may no longer be so relevant. There is a vast gap between peak instrumental acceleration and the base shear coefficients used to design buildings....They can be reconciled only if all the many factors related to the earthquake are considered....it follows that the spikes observed on records have little or no structural design significance....We need to continue to record acceleration and to treat it as a valuable tool but to recognize that it is not a reliable index of damage potential."

J. Blume (1981)

IV Intensity: a measure of the local shaking

C Why use intensity?

"Although intensity is subjective by nature and is by definition linked to the loss extent, it is the only measure available which takes into account such important damage factors as the spectral characteristics and the duration of ground motion in addition to its severity. Therefore, Mercalli intensity is still superior to all known instrumental quantities such as, e.g., instrumental intensity (Housner intensity, Arias intensity) or spectral acceleration, which have failed up to now in reflecting the whole of important damage factors."

(Smolka and Berz, 1981)

V Evernden's Rossi-Forel Intensity Formula (From USGS Prof. Paper 1360)

A Relates attenuation of "radiated seismic energy" (a function of source strength), the distance from the source and the regional attenuation characteristics of the basement rocks (the "path"), and the near surface geology (part of the "path", part of the receiver").

B Uses Rossi-Forel intensity instead of Modified Mercalli because Rossi-Forel intensity apparently scales better with the RMS (root mean square or "average") acceleration over the frequencies of greatest interest. For example, accelerations increase by a factor of 2 for each half unit of increase in the Rossi-Forel scale, but this doesn't hold for the Modified Mercalli scale.

C Focusing (e.g. due to surface topographic effects or the shape of the bedrock surface at the bottom of an alluvial basin) are ignored.

D Empirical

V Evernden's Rossi-Forel Intensity Formula

$$(1)\quad I = 3(0.5 + \log\left\{ A\left(\frac{10^{11.8+1.5M}}{n}\right)^{1/\gamma}\left(\sum_{i=1}^{n}\left(R_i + C\right)^{-k\gamma}\right)^{1/\gamma}\right\})$$

- The term *n* is the number of segments the fault will be broken into. For simplicity, we will not subdivide the fault, so n = 1.

$$(2)\quad I = 3\left\{0.5 + \log\left[A\left(10^{11.8+1.5M}\right)^{1/\gamma}\left(\left(R + C\right)^{-k\gamma}\right)^{1/\gamma}\right]\right\}$$

- The first term in parentheses is the energy (in ergs) as calculated from the magnitude M. This will be a constant and defines the contribution from the source.
- The second term in parentheses is an attenuation term. It decreases with distance from the epicenter and defines part of the contribution from the seismic wave path. This part of the expression simplifies for *n* = 1:

$$(3)\quad I = 3\left\{0.5 + \log\left[A\left(10^{11.8+1.5M}\right)^{1/\gamma}\left(R + C\right)^{-k}\right]\right\}$$

V Evernden's Rossi-Forel Intensity Formula

- The log term in equation (3) can be broken down into simpler form:

$$(3)\ \ I = 3\left\{0.5+\log\left[A\left(10^{11.8+1.5M}\right)^{1/\gamma}(R+C)^{-k}\right]\right\}$$

$$(4)\ \ I=3\left\{0.5+\left[\log A+ \tfrac{1}{\gamma}\log\left(10^{11.8+1.5M}\right)+\log(R+C)^{-k}\right]\right\}$$

$$(5)\ \ I=3\left\{\underbrace{0.5+\left[\log A\right.}_{\text{Calibration term}}+\underbrace{\tfrac{1}{\gamma}(11.8+1.5M)}_{\text{Source energy term}}-\underbrace{\left.k\ \log(R+C)\right]}_{\text{Decay term}}\right\}$$

V Evernden's Rossi-Forel Intensity Formula

- Now let's pick a spot on a fault (R=0) in coastal California and assume a magnitude 6.5 earthquake occurs. This is the magnitude that the intensity scale should saturate at, so the expression should yield a Rossi-Forel intensity of X (10). Evernden gives the following parameters: A = 0.779; γ = 4, k = 1.75, C (a pseudo-depth) of 25 km.

$$(5)\ \ I=3\left\{0.5+\left[\log A+\tfrac{1}{\gamma}(11.8+1.5M)-k\ \log(R+C)\right]\right\}$$

Now substitute for the parameters

$$(6)\ \ I=3\left(0.5+\left\{\log(0.779)+\tfrac{1}{4}(11.8+1.5[6.5])-1.75\ \log(25)\right\}\right)$$

Now carry out the arithmetic

$$(7)\ \ I=3(0.5+\{-0.108+5.388-2.446\})=10.002$$

- This is the <u>maximum</u> intensity and can be corrected for the local geology (See p. 161 of PP 1360).