

## MAGNITUDE AND INTENSITY (10)

## I Main Topics

A Types of seismic waves

B Magnitude

C Intensity

## II Seismic waves: Nearly-pure elastic waves

A Seismic waves a) cause damage and b) provide quantitative information on source strength and effect of "path" on wave energy

B Speed of seismic waves:  $c = L/T$  ( $L =$  wavelength;  $T =$  period)

C Body waves: Seismic waves that travel inside the earth.

1 **P-waves**: **P**rimary (compressional) waves. First arrival.2 **S-waves**: **S**econdary (shear) waves. Second arrival

3 Speeds of body waves

a  $V_p = \{(k + 4\mu/3)/\rho\}^{1/2}$  ( $\rho =$  density;  $\mu =$  shear modulus;

b  $V_s = \{\mu/\rho\}^{1/2}$  ( $k =$  bulk modulus)

$k = 1/\text{compressibility}$

Material	$k$ (N/m <sup>2</sup> )	$\mu$ (N/m <sup>2</sup> )	$\rho$ (kg/m <sup>3</sup> )	$V_p$ (m/sec)	$V_s$ (m/sec)
Granite	$48 \times 10^9$	$32 \times 10^9$	2720	5800	3400
Water	$22 \times 10^8$	0	1000	1500	0

c Key point:  $V_p > V_s$  ( $V_p \approx 1.7 V_s$  for rock)D **Surface waves**: waves that travel at the earth's surface1 These cause strong ground motion near the epicenter

2 Surface waves "feel" deeper as their wavelength increases (Analog to water waves and wave base).

3 Surface wave velocity increases as wavelength increases.

4 Surface waves are polarized.

a Horiz. polarized waves: especially destructive;  $V \approx V_s$ .b Vertically polarized waves:  $V \approx 0.92 V_s$ .

5 Amplitudes of surface waves tend to saturate (have a ceiling). The amplitudes scale with stress drop ("strength") of fault.

### III Magnitude

<http://www.scecdc.scec.org/measureeq2.html>

A Magnitude ideally measures only the source strength

B Local (Richter) magnitude ( $M_L$ ):  $M_L = \log A - \log A_0$

- 1  $A_0$  = Base-ten log of the amplitude (in microns) of a Wood-Anderson seismograph located 100 km from the epicenter.
- 2 Devised for southern California; reflects wave attenuation there
- 3 Does not discriminate between types of waves.
- 4 Sensitive to periods of 0.8 seconds.
- 5 Originally set up to give magnitude to nearest 1/4.
- 6 Because surface waves saturate, intensity tends to saturate too
- 7 Saturates at  $M_L \approx 6.5$

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  $M_0$

- 1  $M_W = (2/3) \log M_0 - 10.7$  ( $M_0$  in dyne-cm)
- 2 Designed to dovetail with  $M_S$  for  $M_W < 7.5$ .

IV Intensity: A "semi-quantitative" measure of the local degree of shaking

A Function of source strength (and duration) and wave path

Intensity = f(magnitude, distance from source, local geology)

B An alternative to quantitative acceleration or velocity spectra

1 Modified Mercalli Scale (MMI = I  $\Rightarrow$  XII) Note Roman numerals

<http://wwwneic.cr.usgs.gov/neis/general/handouts/mercalli.html>

2 Rossi-Forel Scale (R-FI = I  $\Rightarrow$  X)

[http://www.seismo.nrcan.gc.ca/magnitudes/rossi\\_e.html](http://www.seismo.nrcan.gc.ca/magnitudes/rossi_e.html)

C Because magnitude saturates, intensity tends to also

D Evernden's equation for intensity decay

## Evernden's Rossi-Forel Intensity Formula

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

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

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

The term in the first set of 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 energy term is multiplied by the attenuation term in the second set of parentheses. This will vary with distance from the epicenter and defines part of the contribution from the seismic wave path. This part of the expression simplifies for  $n = 1$ :

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

The log term can be broken down into simpler form:

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

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

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 values:  $A = 0.779$ ;  $\gamma = 4$ ,  $k = 1.75$ ,  $C$  (a pseudo-depth) of 25 km. So (5) reduces (7) in two steps:

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

$$(7) \quad I = 3(0.5 + \{-.108 + 5.388 - 2.446\}) = 10.002$$

This is the maximum intensity and can be corrected for the local geology as shown on p. 161 of PP 1360.

### Evernden's Method for Calculating Seismic Intensity

- 1 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").
- 2 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.
- 3 Focusing (e.g. due to surface topographic effects or the shape of the bedrock surface at the bottom of an alluvial basin) are ignored.

### 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)

"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)