NPTEL ONLINE CERTIFICATION COURSES

EARTHQUAKE SEISMOLOGY

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Module 11: Source parameters, Earthquake statistics.
Lecture 01: Magnitudes and moments

CONCEPTS COVERED

- Magnitude and moments
  - Richter Scale
  - Body wave and Surface wave magnitude
  - Advantages and Limitations
  - Uncertainties in magnitude estimation
  - Moment Magnitude
- Summary

Magnitudes and moments

- **Magnitude is used to quantify earthquake's size, both for scientific purposes and to discuss their effects on society.**

- **The first measure introduced was the magnitude, which is based on the amplitude of the resulting waves recorded on a seismogram.**

- **The concept is that the wave amplitude reflects the earthquake size once the amplitudes are corrected for the decrease with distance due to geometric spreading and attenuation.**

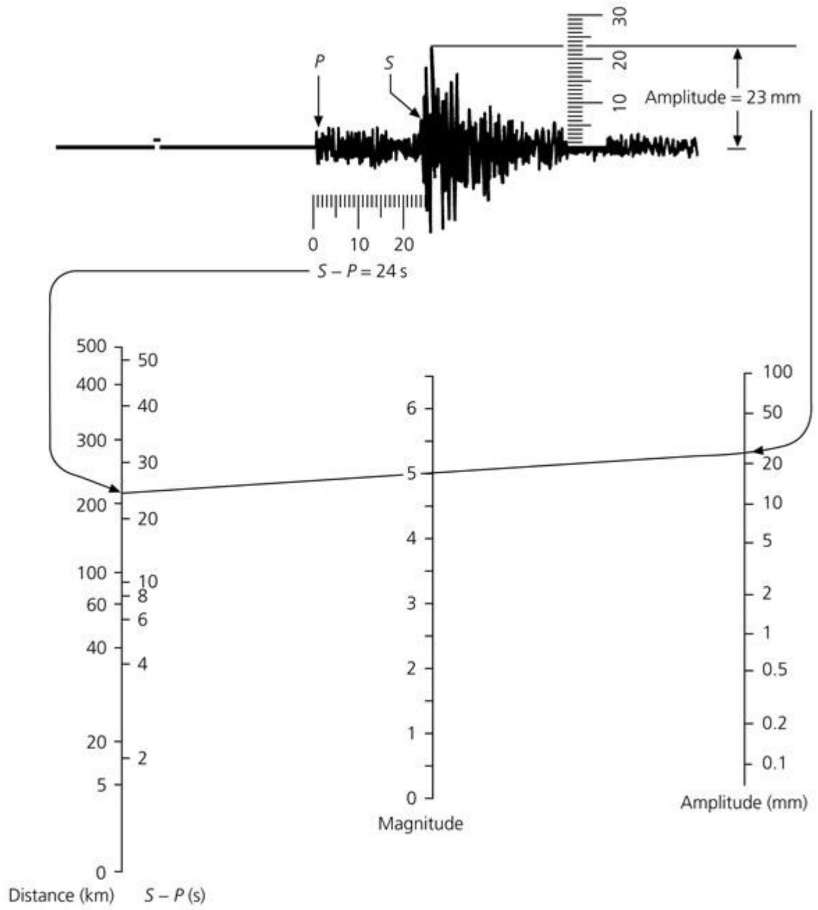
$$M = \log_{10}(A/T) + F(h, \Delta) + C$$

A is the amplitude of the signal,
T is its dominant period,
F is a correction for the variation of amplitude with the earthquake's depth h
Δ is epicentral distance,
C is a regional scale factor.

Magnitudes and moments: Richter Scale

Measured magnitudes range more than 10 units because the displacements measured by seismometers span more than a factor of 10^{10}

Figure 4.6-1: Example of the determination of the Richter scale.



Also referred as local magnitude M_L.

It is defined for southern California earthquakes and determined from the amplitude measured on a specific seismograph, known as the Wood–Anderson seismograph.

Magnitudes and moments: Richter Scale

The magnitude of the largest arrival (often the S wave) is measured and corrected for the distance between the source and the receiver, given by the difference in the arrival times of the P and S waves.

$$M_L = \log A + 2.76 \log \Delta - 2.48$$

- Richter magnitudes in their original form are no longer used because most earthquakes do not occur in California and Wood–Anderson seismographs (period 0.8 s) are rare.

- However, local magnitudes are sometimes still reported because many buildings have resonant frequencies near 1 Hz, close to that of a Wood–Anderson seismograph, so M_L is often a good indication of the structural damage an earthquake can cause.

Magnitudes and moments: Body wave and Surface wave magnitude

- For global studies, the primary two were the body wave magnitude, m_b, and surface wave magnitude, M_s.
- Body wave magnitude m_b is measured from the early portion of the body wave train, usually the P wave, using

$$m_b = \log_{10}(A/T) + Q(h, \Delta)$$

- ➔ A is the ground motion amplitude in microns after the effects of the seismometer are removed.
- ➔ Generally first 5s of the record are used and period less than 3s, usually about 1s.
- ➔ T is the wave period in seconds, and Q is an empirical term depending on the distance and focal depth.
- ➔ m_b is measured out to 100° distance, beyond which diffraction around the core has a complicated effect on the amplitude.

Magnitudes and moments: Body wave and Surface wave magnitude

The surface wave magnitude, M_s, is measured using the largest amplitude (zero to peak) of the surface waves.

The general form of M_s

$$M_s = \log_{10}(A/T) + 1.66\log_{10}\Delta + 3.3$$

- A is the ground motion amplitude in microns after the effects of the seismometer are removed
- T is the wave period in seconds, and the distance Δ is in degrees.

Most often Rayleigh wave of period 20s have largest period, so above form changed to,

$$M_s = \log_{10} A_{20} + 1.66\log_{10}\Delta + 2.0$$

Magnitudes and moments

Advantages

- They are directly measured from seismograms without sophisticated signal processing.

- They yield units of order 1 which are intuitively attractive: magnitude 5 earthquakes are moderate, magnitude 6 are strong, 7 are major, and 8 are great.

Limitations

- They are totally empirical and thus have no direct connection to the physics of earthquakes. Magnitude equations are dimensionally incorrect—logarithm can be taken for dimensionless quantities.

- A second difficulty is with the numbers that emerge. Magnitude estimates vary noticeably with azimuth, due to the amplitude radiation patterns, although this difficulty can be reduced by averaging results.

Magnitudes and moments

- The different magnitude scales yield different values.
- Body and surface wave magnitudes do not correctly reflect the size of large earthquakes.
- Magnitude saturation is a general phenomenon for m_b above about 6.2 and M_s above about 8.3.
- Larger fault dimensions give rise to greater slip, so the combined effects of larger fault area and more slip cause the largest earthquakes to occur at subduction zones rather than on transforms.

Magnitudes and moments

Table 4.6-1 Source parameters for selected earthquakes.

Earthquake	Body wave magnitude, m_b	Surface wave magnitude, M_s	Fault area (km^2) (length × width)	Average dislocation (m)	Moment (dyn-cm), M_0	Moment magnitude, M_w
Truckee, 1966	5.4	5.9	10 × 10	0.3	8.3×10^{24}	5.9
San Fernando, 1971	6.2	6.6	20 × 14	1.4	1.2×10^{26}	6.7
Loma Prieta, 1989	6.2	7.1	40 × 15	1.7	3.0×10^{26}	6.9
San Francisco, 1906		7.8	450 × 10	4	5.4×10^{27}	7.8
Alaska, 1964	6.2	8.4	500 × 300	7	5.2×10^{29}	9.1
Chile, 1960		8.3	800 × 200	21	2.4×10^{30}	9.5

Sources: Values from Geller (1976), Wallace *et al.* (1991), and Wald *et al.* (1993).

- **As shown, m_b and M_s differ significantly. The earthquakes with moments greater than that of the San Fernando earthquake all have m_b 6.2, even as the moment increases by a factor of 20,000.**

- **Similarly, the earthquakes larger than the San Francisco earthquake have M_s about 8.3, even as the moment increases by a factor of 400.**

Magnitudes and moments

Uncertainties in magnitude calculation

- There are considerable uncertainties due to various causes.

- There are uncertainties due to the earth’s variability and deviations from the mathematical simplifications used. For example, even with high-quality modern data, seismic moment estimates for the Loma Prieta earthquake vary by about 25%, and M_s values vary by about 0.2 units.

- The estimation techniques vary. The actual approaches used to compute magnitudes have changed with time (note that the pre-1964 earthquakes do not have m_b values) in various ways. Uncertainties for historic earthquakes are especially large.

Magnitudes and moments

Uncertainties in magnitude calculation

- **Different techniques (body waves, surface waves, geodesy, geology) can yield different estimates.**

- **The fault dimensions and dislocations shown are average values for quantities that can vary significantly along the fault**

- **We have seen that the amplitudes depend on the scalar moment, the azimuth of a seismometer relative to the fault geometry, the distance from the source, and the source depth.**

Magnitudes and moments

Moment Magnitude

- A magnitude based on the seismic moment is referred as moment magnitude,

$$M_w = \frac{\log M_o}{1.5} - 10.73$$

M_0 in dyn-cm

- It gives a magnitude directly tied to earthquake source processes that does not saturate.

- Moreover, it preserves the simplicity of the magnitude scale by giving values of order 1 compatible with other magnitude scales.

- M_w is comparable to M_s until M_s saturates at about 8.2, but then increases.

- Estimation of M_0 (and therefore M_w) requires more analysis of seismograms than for m_b or M_s .

Summary

- The general form of earthquake magnitude is $M = \log_{10}(A/T) + F(h, \Delta) + C$

  A is the amplitude of the signal,
  T is its dominant period,
  F is a correction for the variation of amplitude with the earthquake's depth h
  Δ is epicentral distance,
  C is a regional scale factor.

- Richter Scale magnitude is: $M_L = \log A + 2.76 \log \Delta - 2.48$

- Body wave magnitude m_b is $m_b = \log_{10}(A/T) + Q(h, \Delta)$

- Surface wave magnitude M_s is: $M_s = \log_{10}(A/T) + 1.66 \log_{10} \Delta + 3.3$

- Body and surface wave magnitudes do not correctly reflect the size of large earthquakes and saturate about 6.2 and 8.3 respectively.

Summary

- There are uncertainties in magnitude estimation due to the earth’s variability and deviations from the mathematical simplifications used.

- Different techniques (body waves, surface waves, geodesy, geology) can yield different estimates.

- Moment magnitude is given as:

$$M_w = \frac{\log M_o}{1.5} - 10.73$$

- It gives a magnitude directly tied to earthquake source processes that does not saturate.

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THANK YOU !