Moment magnitude scale

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The **moment magnitude scale** (abbreviated as **MMS**; denoted as M_W or **M**) is used by seismologists to measure the size of earthquakes in terms of the energy released.[1]

The scale was developed in the 1970s to succeed the 1930s-era Richter magnitude scale (M_L). Even though the formulas are different, the new scale retains a similar continuum of magnitude values to that defined by the older one. As with the Richter magnitude scale, an increase of one step on this logarithmic scale corresponds to a $10^{1.5}$ (about 32) times increase in the amount of energy released, and an increase of two steps corresponds to a 10^3 (1,000) times increase in energy. Thus, an earthquake of M_W of 7.0 releases about 32 times as much energy as one of 6.0 and 1,000 times that of 5.0.

The magnitude is based on the seismic moment of the earthquake, which is equal to the rigidity of the Earth multiplied by the average amount of slip on the fault and the size of the area that slipped.[2]

Since January 2002, the MMS has been the scale used by the United States Geological Survey to calculate and report magnitudes for all modern large earthquakes.[3]

Popular press reports of earthquake magnitude usually fail to distinguish between magnitude scales, and are often reported as "Richter magnitudes" when the reported magnitude is a moment magnitude (or a surface-wave or body-wave magnitude). Because the scales are intended to report the same results within their applicable conditions, the confusion is minor.

Contents

Historical context

The Richter scale: a former measure of earthquake magnitude

In 1935, Charles Richter and Beno Gutenberg developed the local magnitude (M_L) scale (popularly known as the Richter scale) with the goal of quantifying medium-sized earthquakes (between magnitude 3.0 and 7.0) in Southern California. This scale was based on the ground motion measured by a particular type of seismometer (a Wood-Anderson seismograph) at a distance of 100 kilometres (62 mi) from the earthquake's epicenter.[3] Because of this, there is an upper limit on the highest measurable magnitude, and all large earthquakes will tend to have a local magnitude of around 7.[4] Further, the magnitude becomes unreliable for measurements taken at a distance of more than about 600 kilometres (370 mi) from the epicenter. Since this M_L scale was simple to use and corresponded well with the damage which was observed, it was extremely useful for engineering earthquake-resistant structures, and gained common acceptance.[5]

The modified Richter scale

The Richter scale was not effective for characterizing some classes of quakes. As a result, Beno Gutenberg expanded Richter's work to consider earthquakes detected at distant locations. For such large distances the higher frequency vibrations are attenuated and seismic surface waves (Rayleigh and Love waves) are dominated by waves with a period of 20 seconds (which corresponds to a wavelength of about 60 km). Their magnitude was assigned a surface wave magnitude scale (M_S). Gutenberg also combined compressional P-waves and the transverse S-waves (which he termed "body waves") to create a body-wave magnitude scale (M_b), measured for periods between 1 and 10 seconds. Ultimately Gutenberg and Richter collaborated to produce a combined scale which was able to estimate the energy released by an earthquake in terms of Gutenberg's surface wave magnitude scale (M_S).[5]

Correcting weaknesses of the modified Richter scale

The Richter Scale, as modified, was successfully applied to characterize localities. This enabled local building codes to establish standards for buildings which were earthquake resistant. However a series of quakes were poorly handled by the modified Richter scale. This series of "great earthquakes", included faults that broke along a line of up to 1000 km. Examples include the 1957 Andreanof Islands earthquake and the 1960 Chilean quake, both of which broke faults approaching 1000 km. The M_S scale was unable to characterize these "great earthquakes" accurately.[5]

The difficulties with use of M_S in characterizing the quake resulted from the size of these earthquakes. Great quakes produced 20 s waves such that M_S was comparable to normal quakes, but also produced very long period waves (more than 200 s) which carried large amounts of energy. As a result, use of the modified Richter scale methodology to estimate earthquake energy was deficient at high energies.[5]

In 1972, Keiiti Aki, a professor of Geophysics at the Massachusetts Institute of Technology, introduced elastic dislocation theory to improve understanding of the earthquake mechanism. This theory proposed that the energy release from a quake is proportional to the surface area that breaks free, the average

distance that the fault is displaced, and the rigidity of the material adjacent to the fault. This is found to correlate well with the seismologic readings from long-period seismographs. Hence the moment magnitude scale (M_W) represented a major step forward in characterizing earthquakes.[6]

Recent research

Recent research related to the moment magnitude scale has included:

- Timely earthquake magnitude estimates to improve early warnings of earthquakes and tsunami. Earthquake early warning systems are operating in Japan, Mexico, Romania, Taiwan, and Turkey and are being tested in the United States, Europe, and Asia. These systems rely on a variety of analytic methods to attain an early estimate of the moment magnitude of a quake.[7]
- Efforts to extend the moment magnitude scale accuracy for high frequencies, which are important in localizing small quakes. Earthquakes below magnitude 3 scale poorly because the earth attenuates high frequency waves near the surface, making it difficult to resolve quakes smaller than 100 meters. By use of seismographs in deep wells this attenuation can be overcome.[8]

Definition

The symbol for the moment magnitude scale is M_w, with the subscript w meaning mechanical work accomplished. The moment magnitude [9]M_w is a dimensionless number defined by Hiroo Kanamori as

$$M_w = \frac{2}{3} \log_{10}(M_0) - 10.7,$$

where M_0 is the seismic moment in dyne·cm (10^{-7} N·m).[1] The constant values in the equation are chosen to achieve consistency with the magnitude values produced by earlier scales, such as the Local Magnitude and the Surface Wave magnitude.

Comparative energy released by two earthquakes

As with the Richter scale, an increase of one step on this logarithmic scale corresponds to a $10^{1.5} \approx 32$ times increase in the amount of energy released, and an increase of two steps corresponds to a $10^3 = 1000$ times increase in energy. Thus, an earthquake of M_W of 7.0 contains 1000 times as much energy as one of 5.0 and about 32 times that of 6.0.

The following formula, obtained by solving the previous equation for M_0, allows one to assess the proportional difference $f_{\Delta E}$ in energy release between earthquakes of two different moment magnitudes, say m_1 and m_2:

$$f_{\Delta E} = 10^{\frac{3}{2}(m_1 - m_2)}.$$

For example, an earthquake with a moment magnitude of 7.0 is 5.62 times greater than a quake with moment magnitude 6.5.

Radiated seismic energy

Potential energy is stored in the crust in the form of built-up stress. During an earthquake, this stored energy is transformed and results in

- cracks and deformation in rocks
- heat
- radiated seismic energy E_s.

The seismic moment M_0 is a measure of the total amount of energy that is transformed during an earthquake. Only a small fraction of the seismic moment M_0 is converted into radiated seismic energy E_s, which is what seismographs register. Using the estimate

$$E_s = M_0 \cdot 10^{-4.8} = M_0 \cdot 1.6 \times 10^{-5},$$

Choy and Boatwright defined in 1995 the *energy magnitude* [10]

$$M_e = \tfrac{2}{3} \log_{10} E_s - 2.9$$

where E_s is in N.m.

Nuclear explosions

The energy released by nuclear weapons is traditionally expressed in terms of the energy stored in a kiloton or megaton of the conventional explosive trinitrotoluene (TNT).

A rule of thumb equivalence from seismology used in the study of nuclear proliferation asserts that a one kiloton nuclear explosion creates a seismic signal with a magnitude of approximately 4.0.[11] This in turn leads to the equation[12]

$$M_n = \tfrac{2}{3} \log_{10} \frac{m_{TNT}}{Mt} + 6,$$

where m_{TNT} is the mass of the explosive TNT that is quoted for comparison (relative to megatons Mt).

Such comparison figures are not very meaningful. As with earthquakes, during an underground explosion of a nuclear weapon, only a small fraction of the total amount of energy released ends up being radiated as seismic waves. Therefore, a seismic efficiency needs to be chosen for the bomb that is being quoted in this comparison. Using the conventional specific energy of TNT (4.184 MJ/kg), the above formula implies that about 0.5% of the bomb's energy is converted into radiated seismic energy E_s.[13] For real underground nuclear tests, the actual seismic efficiency achieved varies significantly and depends on the site and design parameters of the test.

Comparison with Richter scale

The moment magnitude (M_w) scale was introduced in 1979 by Caltech seismologists Thomas C. Hanks and Hiroo Kanamori to address the shortcomings of the Richter scale (detailed above) while maintaining consistency. Thus, for medium-sized earthquakes, the moment magnitude values should be similar to Richter values. That is, a magnitude 5.0 earthquake will be about a 5.0 on both scales. This scale was based on the physical properties of the earthquake, specifically the seismic moment (M_0). Unlike other scales, the moment magnitude scale does not saturate at the upper end; there is no upper limit to the possible measurable magnitudes. However, this has the side-effect that the scales diverge for smaller earthquakes.[1]

The concept of seismic moment was introduced in 1966,[14] but it took 13 years before the M_w scale was designed. The reason for the delay was that the necessary spectra of seismic signals had to be derived by hand at first, which required personal attention to every event. Faster computers than those available in the 1960s were necessary and seismologists had to develop methods to process earthquake signals automatically. In the mid-1970s Dziewonski[15] started the Harvard Global Centroid Moment Tensor Catalog.[16] After this advance, it was possible to introduce M_w and estimate it for large numbers of earthquakes.

Moment magnitude is now the most common measure for medium to large earthquake magnitudes,[17] but breaks down for smaller quakes. For example, the United States Geological Survey does not use this scale for earthquakes with a magnitude of less than 3.5, which is the great majority of quakes.

Magnitude scales differ from earthquake intensity, which is the perceptible shaking, and local damage experienced during a quake. The shaking intensity at a given spot depends on many factors, such as soil types, soil sublayers, depth, type of displacement, and range from the epicenter (not counting the complications of building engineering and architectural factors). Rather, magnitude scales are used to estimate with one number the size of the quake.

The following table compares magnitudes towards the upper end of the Richter Scale for major Californian earthquakes.[1][18]

Date	Seismic moment $M_0 \times 10^{25}$ (dyne-cm)	Richter scale M_L	Moment magnitude M_w
1933-03-11	2	6.3	6.2
1940-05-19	30	6.4	7.0
1941-07-01	0.9	5.9	6.0
1942-10-21	9	6.5	6.6
1946-03-15	1	6.3	6.0
1947-04-10	7	6.2	6.5
1948-12-04	1	6.5	6.0
1952-07-21	200	7.2	7.5
1954-03-19	4	6.2	6.4

See also

- Earthquake engineering
- Geophysics
- List of earthquakes
- Other seismic scales
- Surface wave magnitude

Notes

1. Hanks, Thomas C.; Kanamori, Hiroo (May 1979). "Moment magnitude scale" (PDF). *Journal of Geophysical Research*. **84** (B5): 2348–50. Bibcode:1979JGR....84.2348H. doi:10.1029/JB084iB05p02348. Archived from the original on August 21, 2010.
2. "Glossary of Terms on Earthquake Maps". USGS. Retrieved 2009-03-21.
3. "USGS Earthquake Magnitude Policy (implemented on January 18, 2002)".
4. "On Earthquake Magnitudes".
5. Hiroo Kanamori, 1978, Quantification of Earthquakes, Nature 271, 411-414 doi:10.1038/271411a0
6. K. Aki; Earthquake Mechanism; Tectonophysics; Elsevier B.V.; Vol 13, pages 423-446
7. Caprio, M., M. Lancieri, G. B. Cua, A. Zollo, and S. Wiemer (2011), *An evolutionary approach to real-time moment magnitude estimation via inversion of displacement spectra*, Geophys. Res. Lett., 38, L02301, doi:10.1029/2010GL045403.
8. Abercrombie, R. E.; Earthquake source scaling relationships from -1 to 5 using seismograms recorded at a 2.5 km depth; Journal of Geophysical Research, Vol. 100, No. B12, p. 24, 015-24, 036, 1995

9. Hiroo Kanamori, 1977, The energy release in great earthquakes. Journal of geophysical research, 82(20), 2981-2987.
10. Choy, George L.; Boatwright, John L. (1995), "Global patterns of radiated seismic energy and apparent stress", *Journal of Geophysical Research*, **100** (B9): 18205–28, Bibcode:1995JGR...10018205C, doi:10.1029/95JB01969
11. "Nuclear Testing and Nonproliferation" (http://www.iris.iris.edu/HQ/Bluebook/chapter5.magnitude.html), "Chapter 5: Assessing Monitoring Requirements"
12. "Nevada Seismological Lab".
13. Q: How much energy is released in an earthquake? (http://earthquake.usgs.gov/learn/faq/?categoryID=2&faqID=33)
14. Aki, Keiiti (1966). "4. Generation and propagation of G waves from the Niigata earthquake of June 14, 1964. Part 2. Estimation of earthquake moment, released energy and stress-strain drop from G wave spectrum" (PDF). *Bulletin of the Earthquake Research Institute*. **44**: 73–88.
15. Dziewonski, A. M.; Gilbert, F. (1976). "The effect of small aspherical perturbations on travel times and a re-examination of the corrections for ellipticity". *Geophys. J. R. Astron. Soc*. **44** (1): 7–17. Bibcode:1976GeoJI..44....7D. doi:10.1111/j.1365-246X.1976.tb00271.x.
16. "Global Centroid Moment Tensor Catalog". Globalcmt.org. Retrieved 2011-11-30.
17. Boyle, Alan (May 12, 2008). "Quakes by the numbers". MSNBC. Retrieved 2008-05-12. "That original scale has been tweaked through the decades, and nowadays calling it the "Richter scale" is an anachronism. The most common measure is known simply as the moment magnitude scale."
18. "Upper end magnitudes comparison" (http://www.fxsolver.com/solve/share/1rirAppy6UtEnjWGtMiYgg==/) Fxsolver

References

- Utsu, T (2002). Lee, W.H.K.; Kanamori, H.; Jennings, P.C.; Kisslinger, C., eds. "Relationships between magnitude scales". *International Handbook of Earthquake and Engineering Seismology*. International Geophysics. Academic Press, a division of Elsevier. **A** (81): 733–46.

External links

- USGS: Measuring earthquakes (http://earthquake.usgs.gov/learning/faq.php?categoryID=2)
- Earthquake Energy Calculator (http://www.alabamaquake.com/energy.html) with seismic energy approximated in everyday equivalent measures.

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