OPINION

On Quantification of the Earthquake Source

The opinion article by Jones (*Seism. Res. Lett.* **71**, 395–396, 2000) and follow-up communications in *Seismological Research Letters* (**71**, 670–672, 2000) discuss pros and cons of seismic moment vs. magnitude as scaling sizes for the earthquake source and possible related units. While the moment clearly provides a better physical quantification of the earthquake source than magnitude, it has a simple and easily fixable shortcoming that stems from the inclusion of rigidity in the definition of the moment. The basic problem is that linear elastic waves generated by a slip source have no information on material properties *at the source region itself*. This is because elastic properties at the source produce two opposite effects on (a) the amount of slip generated by a given force (or stress drop) and (b) the propagation of disturbances away from the source. As shown analytically in my 1989 paper (*Geophys. J. Int.* **98**, 213–222), these two opposite effects cancel out internally in the seismic representation theorem that formalizes the calculations of seismic radiation from a slip source. Heaton and Heaton (*Bull. Seism. Soc. Am.* **79**, 813–841, 1989) give related static results.

While the moment clearly provides a better physical quantification of the earthquake source than magnitude, it has a simple and easily fixable shortcoming that stems from the inclusion of rigidity in the definition of the moment.

The internal cancellation of the source material properties in the seismic representation theorem may be viewed as fortunate since the definition of material properties becomes pathological as we get close in space and time to the earthquake source. This is because fault zone structures contain abrupt spatial material heterogeneities, and brittle instabilities are associated with rapid temporal evolution of rock properties. The remaining scaling parameter in the seismic representation theorem for the size of a slip source is just the integral of slip over the rupture area, or moment divided by rigidity. This has been labeled "geometric moment" by King (*Phil. Trans. Roy. Soc. Lond. A* **288**, 197–212, 1978) and "potency" by Ben-Menahem and Singh (Springer-Verlag, New-York, 1981). The potency (or geometric moment) is the actual *observable* parameter away from the source, and it thus provides a proper physical measure for the overall size of an earthquake. The potency has volumetric units (a convenient choice may be km^2-cm) representing the volume of material associated with permanent inelastic deformation at the earthquake source. Additional "single" observable parameters on the earthquake source that augment the information contained in the potency, but are more difficult to measure, are the seismic energy and stress drop.

Calculations of seismic moment from observed data always involve first finding the potency, *e.g.*, by taking the zero spectral asymptote of the source term in a seismogram and then multiplying the observed result by an *assumed* rigidity. If everyone were using consistently the same assumed rigidity, this extra factor in the definition of the earthquake size would have produced only an intellectual noise. However, different people generally employ different assumed rigidity values, so the use of moment instead of the directly observable potency produces an artificial scatter in reported values of the earthquake size. This scatter propagates into all other studies based on compilations of moment values. For example, estimates of seismic moment and moment magnitude for the same earthquake by different groups may differ solely because of different assumed rigidities. Similarly, estimates of seismic moment and moment magnitude for deep, shallow, continental, and oceanic earthquakes with the same potencies and stress drops will in general differ because of different assumed rigidities.

Given that magnitudes have been (and will continue to be) widely reported, but are narrow-band quantities rather than giving a faithful physical representation of the entire source, it is important to establish empirical scaling relations between magnitudes, seismic energy, and moments or potencies. Potency-magnitude relations are superior to moment-magnitude relations since they are not masked by the mixture of rigidities that are assumed and included in various subsets of the moments. However, seismologists have been tabulating moments, so at present it is necessary first to convert the reported moments to potencies by removing the assumed rigidities as was done, *e.g.*, by Ben-Zion and Rice (*J. Geophys. Res.* **98**, 14,109–14,131, 1993) and Amelung and King (*Nature* **386**, 702–705, 1997). While the removal of the rigidity from the moment is in principle simple, practical problems may arise since a formal record of the assumed rigidities does not always exist.

The development and early use of the seismic moment were associated with pioneering theoretical and observational works based on the long-standing tradition of using Green functions and representing complex sources by superpositions of point forces. The establishment of the equivalence between double-couples and slip sources (Maruyama, *Bull. Earthq. Res. Inst., Tokyo U.* **41**, 467–486, 1963; Burridge and Knopoff, *Bull. Seism. Soc. Am.* **54**, 1,875–1,888, 1964) and initial determinations of seismic moment from observed seismograms (Aki, *Bull. Earthq. Res. Inst., Tokyo U.* **44**, 23–88, 1966; Kanamori, *Nature* **271**, 411–414, 1978) are fundamental landmarks in the history of quantitative seismology. However, since it is now clear that the actual scaling factor for the size of a slip event in the seismic representation theorem is not the moment but the potency, it is time to replace the use of seismic moment with the directly observable potency (or geometric moment). Until this is done, reports of moment values should always include a clear specification of the rigidity that is assumed in each case.

... since it is now clear that the actual scaling factor for the size of a slip event in the seismic representation theorem is not the moment but the potency, it is time to replace the use of seismic moment with the directly observable potency (or geometric moment).

Yehuda Ben-Zion
Department of Earth Sciences
University of Southern California
Los Angeles, CA 90089-0740