4.4 EARTHQUAKE MAGNITUDE AS CHARACTERISTIC OF SPECTRAL FEATURES OF THE SEISMIC SOURCE

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Synopsis: The conventional definitions of earthquake magnitudes are reviewd. Shortcomings of the magnitude concept are indicated. The results of new observations of seismic phenomena lead to the conclusion that earthquakes have individual character as to the spectral content of the radiated energy. The magnitude is re-interpreted as measure of the radiation intensity at particular periods of the investigated range. Advantages of an improved definition of the earthquake magnitude are shown.

The earthquake magnitude is a concept introduced into seismology some 40 years ago. In the time since, the magnitude became one of the basic characteristics of the earthquake. The success of the magnitude scale can be seen from its wide utilization in seismological research and from its wide applications in earthquake engineering. The interest of the general public in magnitudes of particular earthquakes can be considered as ultimate prove for the success of the concept.

However, difficulties in the concept have led to some critism of it, and even to propositions to replace the magnitude by another measure of the size of an earthquake. It appears that the difficulties originate from the lack of an exact definition of the magnitude and from misunderstandings as to the physical significance of the earthquake magnitude. It appears that a clarification of the open questions is likely to further increase the potential of the concept. As is known, the magnitude was originally defined for local earthquakes in California (C.F.Richter, 1935). The definition was based on the maximum trace amplitude recorded on a particular horizontal-component instrument, the Wood-Anderson seismograph. Since California-earthquakes are shallow, the focal depth did not enter the definition. Also, the period of the seismic wave was without significance in the definition for two reasons:

1. usually, the high-frequent waves predominate at short epicentral distances and are virtually the only ones applicable for the determination of the local magnitude, and

2. the amplitude-response of the Wood-Anderson seismograph warrant that only a small range of periods is recorded and subsequently used for the determination.

The magnitude scale was extended to teleseismic distances (B.Gutenberg, C.F.Richter, 1936). The surface-wave magnitude was

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based on the 20 sec-surface-wave train. The surface-wave magnitude is applicable to earthquakes with "normal" focal depths. Its relation to the local magnitude was never satisfactorily established, in spite of respective attempts. Today, with improved insight into the earthquake process, it appears that a generally valid relation between the local magnitude based on waves with periods of about 1 sec and the surface-wave magnitude based on 20-sec-waves, cannot be expected.

A further development took place when the body-wave magnitude was introduced, applicable to all focal depths (B.Gutenberg, C.F.Richter, 1945a, b, 1956). Here, however, the question arose when to consider two earthquakes with different focal depths as having the same magnitude. Equality of the seismic energies released in the two earthquakes was accepted as criterion for the equality of the magnitudes. In line with the criterion the notion was established that the earthquake magnitude is a measure of the seismic energy released in an earthquake. Apart from the practical difficulties in determining the seismic energy of an earthquake, and thus making it the basis of a new concept, it appears today that the magnitude cannot be considered as just another expression of the mechanical energy liberated in course of the earthquake process. Numerous relations between the magnitude and seismic energy have been proposed, the formulae usually being valid only for narrow magnitude ranges, but giving energies differing by orders of magnitude. The uncertainty of the magnitude-energy relation is thereby attributed to scatter in the observational data. The coupling between the magnitude and the seismic energy appears to be an essential difficulty in the full development of the potential of the earthquake magnitude concept.

With increase of the standard of seismological observatories it became possible to recognize differences in the spectral features of individual earthquakes. Here, of basic importance was the observation that explosions, notably nuclear explosions, are characterized by body waves (P-waves) with amplitudes much larger than would be observed for earthquakes with comparable surface waves (Rayleigh waves). The observation led to one of the methods of discrimination between earthquakes and explosions (m_b - m_s-method). The radiation intensity of explosive sources is apparently higher for short-period body waves than for long-period surface waves, if related to the radiation intensity of earthquakes.

However, it also became possible to recognize an apparently anomalous behavior of earthquakes such, that the radiation intensity of long-period waves is proportionally larger than that of short-period waves, if related to the respective radiation intensities of "normal" earthquakes. We make here a reference to the "low-magnitude, low-stress-drop earthquake" of 4 March 1966, which was characterized by an unusually low local magnitude, if compared to the extent of the zone faulted during the earthquake (J.N.Brune, C.Allen, 1967). We further refer to the observation of earthquakes near the Wilmington Oil Field in California. The sequence of earthquakes produced only negligible short-period body waves, featured however clear long-period surface waves (R.Kovach, 1974).

In a sequence of earthquakes with epicenters in the Gala-pagos Islands it became possible to recognize a systematic change of the predominant period of S-waves produced (S.J.Duda, 1975).

A number of well-recorded earthquakes, for which magnitude determinations were made with high reliability, deviations of the short- and long-period radiation intensities from normal were established.

It appears then that for a given, say, short-period radiation intensity (as expressed e.g. through the body-wave magnitude) variable long-period radiation intensities are being found, and vice versa. Subsequently, the same seismic energy, being an integral effect of radiation intensities at frequencies in the range investigated, can correspond to various body-wave, or surface-wave magnitudes depending on the particular earthquake. And opposite, earthquakes with a particular body-wave, or surface-wave magnitude can have released variable amounts of seismic energies. Thus, a unique relation between the magnitude and the energy cannot be expected for all earthquakes. The same seismic energy can be released in earthquakes having spectral peaks in different parts of the frequency range. With some simplification, and in analogy to optics, it can be said that earthquakes differ as to the color, ranging from "blue" for explosive-type events to "red" for earthquakes producing low-frequent waves (S.J.Duda, O.W.Nuttli, 1974). The spectral character of earthquakes with reference to the geographic distribution, timal variability, and others, has yet to be investigated. Also, at variance with optics, the radiation characteristic of seismic sources has to be treated a priori independently for longitudinal and for transverse waves.

It appears then that a single magnitude figure cannot suffice to characterize fully the size of an earthquake. Rather, the body-wave magnitude is to be considered as a measure of the radiation intensity in the short-period frequency range; the surface-wave magnitude is to be considered correspondingly as a measure of the radiation intensity at the period of about 20 sec. No unique relation between both magnitudes can be obtained for all earthquakes, and deviations from an average relation are likely to be indications of the tectonic state in the region under consideration.

It finally can be asked, whether the body-wave magnitude and the 20-sec surface wave magnitude suffice for the characterization of the size of an earthquake. Both magnitudes developed somewhat incidentally, due to the then recording capabilities of observatories and to transmission effects in the earth crust. A more complete characterization of the size of an earthquake would be obtained from radiation intensities at a sequence of several fixed periods. Eg. a 5-second, 10-second, 20-second and 40-second P-wave magnitude would sample the spectral features of the earthquake at the respective periods. The recording capabilities of modern observatories, in particular magnetic tape recording and filtering, can make the determination to largely a computer routine.

Consequently, it appears that a continuous transition exists between earthquakes and so called aseismic tectonic motions, recognizable from precise magnitude determinations.

Bibliography

C.F.Richter, 1935: An instrumental earthquake scale, Bull.Seism. Soc.Am., 25, 1-32

B.Gutenberg, C.F.Richter, 1936: On seismic waves, 3rd paper, Gerlands Beitr.z.Geophysik, 47, 73-131

B.Gutenberg, C.F.Richter, 1945a: Amplitudes of surface waves and magnitudes of shallow earthquakes, Bull.Seism.Soc. Am., 35, 3-12

B.Gutenberg, C.F.Richter, 1945b: Magnitude determination for deep-focus earthquakes, Bull.Seism.Soc.Am., 35, 117-130

B.Gutenberg, C.F.Richter, 1956: Magnitude and energy of earthquakes, Ann. di Geofisica, 9, 1-15

J.N.Brune, C.Allen, 1967: A low-stress-drop, low-magnitude earthquake with surface faulting: The Imperial California Earthquake of March 4, 1966, Bull.Seism.Soc.Am., 57, 501-542

R.Kovach, 1974: Source Mechanisms for Wilmington Oil Field, California, Subsidence Earthquakes, Bull.Seism.Soc.Am., 64, 699-712

S.J.Duda, 1975: Seismizität und Tektonik der Vulkan-Eruption in den Galâpagos-Inseln von Juni 1968, Abstracts, Jahrestagung der Deutschen Geophys.Gesellschaft, Stuttgart

S.J.Duda, O.W.Nuttli, 1974: Earthquake Magnitude Scales, Geophysical Surveys, 1, 429-458

DISCUSSION

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It seems to me that the figure presented correlating M_s vs M_b may have a very large impact on Design Considerations. We saw that for the many earthquakes plotted M_b never exceeds 7.0 while M_s reaches values greater than 8. Considering that M_b is measured with 1 second seismographs and M_s is measured with 20 seconds seismographs and that most of the structures that we design have periods around 1 second or less, the use of M_s may be inappropriate in many cases. This is because in many cases extrapolation of attenuation relationships to 8 + magnitudes are made to determine design criteria for short period structures for which M_b would be more significant. It seems that the whole use of the concept of magnitude should be evaluated for its use in design of structures.

Author's Closure

I agree with the comment of Dr. Guzman.

It must be remembered that the Mb-magnitude as published currently is based on P-waves of unspecified period. Though some of the seismographs employed have a narrow-band amplitude characteristic, the prevailing period of P-waves is found to vary on the records of different earthquakes, which fact indicates individualistic spectral characters of the sources of seismic waves.

It seems that the full potential of the magnitude concept for earthquake engineering purposes has not been exploited yet. It becomes apparent that the physical significance of the earthquake magnitude lies in sampling various parts of the spectrum of the signal radiated from the focus, not in being just another expression for the amount of seismic energy radiated from the focus.

Attempts are being undertaken to arrive at a definition of the earthquake magnitude which will account for the higher accuracy of magnitude determinations, in principle possible with instruments in present-day use, and to implement the definition in seismological practice.