RELEVANCE OF THE EARTHQUAKE MAGNITUDE IN ENGINEERING SEISMOLOGY

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SUMMARY

Conventional earthquake magnitudes are of limited significance in engineering seismology. The primary draw-back of present-day magnitude determinations is that the period of the seismic wave is disregarded.

Recordings of broad-band observatories allow the routine determination of spectral magnitudes in the period range 0.1 to 100 s. A clear period-dependence of the magnitudes is seen. Averaging of magnitude figures obtained at different periods is not permissible. Instead it is proposed to publish a set of spectral magnitudes as function of period.

Spectral magnitudes are a measure of the energy spectral density of the motion at the focus. They are readily usable for the determination of the velocity and acceleration spectral density.

INTRODUCTION

The earthquake magnitude is a quantity of basic interest in numerous branches of pure and applied seismology. As example, we refer to studies on the distribution of damaging earthqaukes, and, generally, to the various aspects of seismic risk analysis.

In most cases instrumental recordings of the earthquake motion is limited to teleseismic distances. Though the number of strong motion seismographs in seismically endangered regions is encreasing, usually only the far field observation is available as a means for estimating the strength of the surface motion in the near field. Thus, the quantification of the near field motion from observations at arbitrary distances continues to be of great significance, in particular for earthquake engineering problems.

Conventionally, the earthquake magnitude, together with the focal depth of the earthquake, the local ground conditions etc. is thought to adequately describe the ground motion near the epicenter. Thereby the magnitude is considered to strongly correlate with the seismic energy released in the focus. The magnitude is thus supposed to be the same for a given earthquake, irrespective of the type and period of the seismic wave utilized for its determination. This appears questionable.

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On the other hand, it is known that the load which a mechanical structure can withstand is dependent on the period of the loading. It must then be asked whether the conventional earthquake magnitude is an appropriate quantity for the investigation of the related earthquake engineering problems.

In the following the definition of the magnitude is refined, and the so called spectral magnitude introduced. The spectral magnitude is obtained from broad-band observations of the ground motion. Finally, the relevance of the spectral magnitudes in engineering applications is shown.

MAGNITUDE AND EARTHQUAKE MODELS

In present seismological practice several magnitude scales are in use, and correlated with each other. As has been pointed out in Ref. 1, the differences between the magnitude scales in use lie primarily in the period ranges utilized, even though the periods usually are not published with the magnitudes. While the 'body-wave magnitude' m_B is being determined from P-waves ranging in period from about 0.1 to 10 s, is the 'body-wave magnitude' m_b from the World Wide Standardized Seismograph Network (WWSSN) stations based on P-waves with a period of about 1 s (short period Benioff seismometer). The local magnitude M_L emphasizes periods around 0.8 s, and the surface-wave magnitude M_S for shallow earthquakes is based on waves in the period range 17 to 23 s.

The situation is aggravated, however, by the fact that no consistency exists as to the wave type underlying the scales. While for the determination of the local magnitude usually the S_g- or L_g-phase is being employed, the 'body-wave magnitude' is restricted to P-waves, and for the surface-wave magnitudes an unspecified mixture of Love- and Rayleigh-waves is used. It is eventually clear that to reconcile the magnitudes with each other is a formidable task. The large variety of magnitude scales indicates that the strength of an earthquake needs to be determined in various parts of the radiated spectrum.

It is obvious that P- and S-waves are the only waves radiated from the focus, and, in principle, it suffices to base the magnitude scale on the two kinds of body-waves.

In the past, the problem of radiation intensity as function of wave period was investigated theoreticaly (cp. Ref. 1). The investigations aim at finding the relation between the physical parameters of the focal process on one side, and the radiated signal in the time or frequency domain on the other. The physical parameters of special importance are thereby the fault length and width, the dislocation, the fracture velocity, the rise time, the stress drop and the seismic moment. Based on the similarity principle, the authors postulate relations between two or more of the parameters. The spectra of the signals radiated though prove to be dependent on the model, and no unanimous opinion exists as to the optimum model, applicable to all earthquakes. For a given model, however, the shape of the spectrum radiated is fixed, as is the relation between the magnitudes obtained as result af sampling the spectrum in the respective period ranges.

It has been proposed in Ref. 2 to sample the seismic energy radiated in specific period bands, and to express the strength of radiation by way of so called spectral magnitudes. Evidently, a set of spectral magnitudes will correspond to a given earthquake, the spectral magnitudes being determined independently for P- and S-waves. In practice it is recommendable to utilize for this purpose digital broad-band recordings of the seismic waves.

THE SPECTRAL MAGNITUDE

In Fig. 1 a set of 10 box-car octave filters is defined. The mid-band and band-edge periods comply thereby with the recommendation in Ref. 3.

From the original broad-band seismograms a set of 10 band-pass seismograms ia obtained, in accordance with the octave filters. From each of the 10 band-pass seismograms of the P-wave and of the S-wave motions, a corresponding number of magnitudes can be calculated. For the calculation of the magnitudes new magnitude calibration functions are utilized, which depend on epicentral distance, focal depth, and the period of the given type of body-wave. Also, the bandwidth effect is compensated for. Magnitudes obtained in this way are called spectral magnitudes. Details of the algorithm are given in Ref. 2.

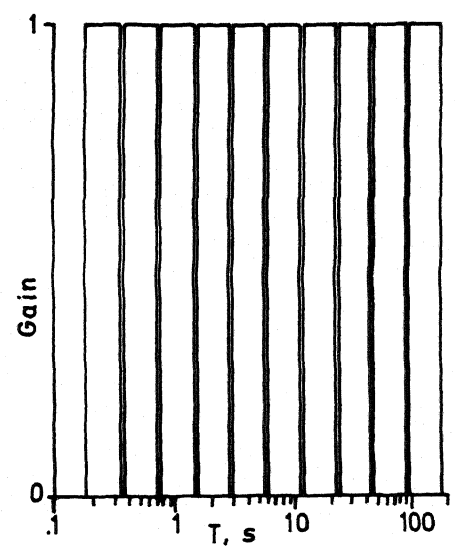

Fig.1. Octave band-pass filters employed for the computation of band-pass seismograms. From the seismograms so-called spectral magnitudes are determined for P- and S-waves.

TWO EXAMPLES

The spectrum of the ground motion at teleseismic distances is biased relatively to the spectrum of the waves radiated from the focus. The bias is caused by the different attenuation for P- and S-waves, due to the different perviousness of the intervening medium for both types of body-waves. As a rule, the attenuation is higher for S-waves. For a given wave type, the perviousness increases with the period of the wave. The period-dependent calibration function from Ref. 2 compensates the bias, and yields magnitude figures believed to reflect the stength of the radiation of P- and S-waves from the focus.

The spectral magnitudes m(T) are related to the energy spectral density of either one of the two wave types. Thereby the relation holds:

$$E(T) = 10^{2m(T)+k} \text{ in joules / hertz.}$$

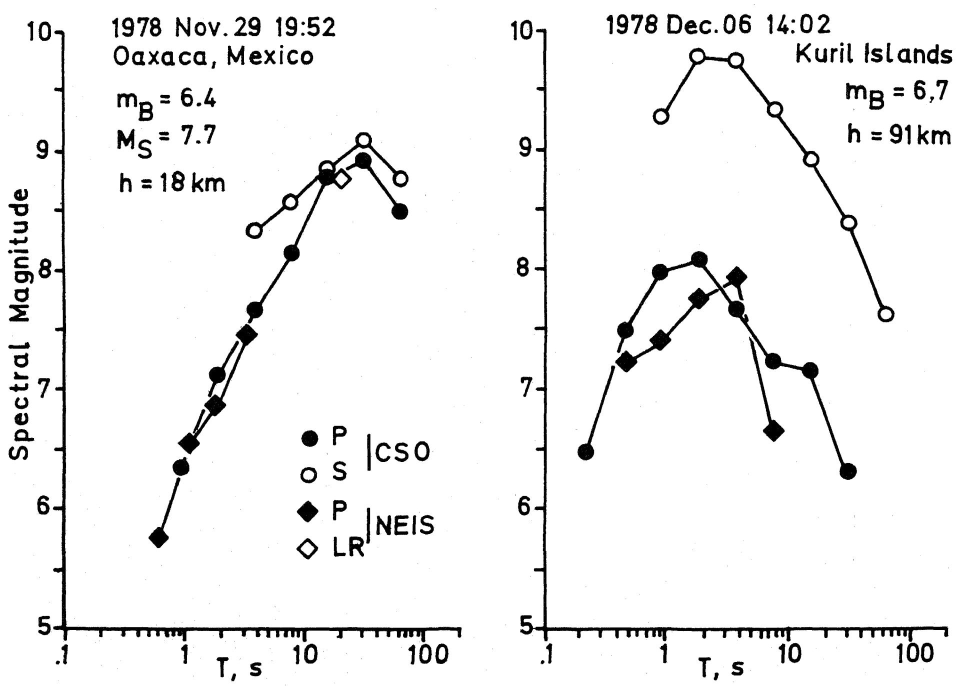

Fig. 2a,b. Spectral magnitudes of two earthquakes. The corresponding band-pass seismograms have been obtained from the broad-band recording at the Central Seismological Observatory of the Federal Republic of Germany at Erlangen. Included are spectral (P-wave) magnitudes obtained from amplitudes and periods as reported by NEIS, as well as the surface-wave magnitude compensated for bandwidth of the seismograph system. Note that the maxima of the spectral magnitudes of the two earthquakes occur at widely differing periods.

The constant k was chosen as -1.4, in order to assure maximum consistency with magnitude figures obtained earlier on the basis of the calibration functions from Ref. 4.

From the energy spectral density the ground velocity v(T) and the ground acceleration a(T) near the focus and in the respective period range can readily be estimated, on the basis of the relations:

$$v(T) \sim E(T)^{1/2} \text{ and}$$
$$a(T) \sim E(T)^{1/2}/T.$$

Fig. 2a,b gives the spectral magnitudes from P- and S-waves for two earthquakes, as indicated in the figures. As can be seen, the spectral magnitudes vary with period for both types of waves. In both cases a maximum spectral magnitude does occur in the period range investigated. Some of the band-pass seismograms yielded amplitudes to small to be applicable for a magnitude determination. This is the case especially for S-waves, which generally suffer a stronger attenuation than P-waves (see above). Nonetheless, in general, the spectral magnitudes for S-waves exceed numerically those for P-waves. Fig. 2a signifies that the total seismic energy radiated from the focus in the form of S-waves is 3.2 orders of magnitude larger than that of P-waves, i. e. that the P-wave radiation is neglible energywise with respect to that of the S-wave.

Added in the figures are spectral magnitudes for P-waves calculated from amplitudes and periods, as published in the National Earthquake Information Service (NEIS, Boulder, Colorado) Earthquake Data Report for the two earthquakes. The spectral magnitudes from the NEIS data agree well with the respective spectral magnitudes from the broad-band recordings.

Above all, however, it can be seen from the two examples that the maxima of the two earthquakes do occur at periods differing by a factor of 10, namely at 4 s (Kuril Islands) and 40 s (Oaxaca), respectively. This substantial difference between the two earthquakes is completely lost in the conventional magnitude of the two earthquakes. Consequently, the spectral magnitudes offer a means to determine the spectral characteristics of the radiation from earthquake focus, as applicable to problems in earthquake engineering.

CONCLUSIONS

In a recent research project the spectral magnitudes for several hundred earthquakes have been determined. From the investigation it appears that significant deviations from some average spectral characteristic are given. Regions can be indicated with earthquakes differing towards a preponderance of either short-period or long-period radiation. Conventional observational facilities do not favour the recognition of particularities of the energy density spectra. Broad-band seismological observatories in sufficient number would probably yield an answer to the question whether a significant portion of the seismicity of the earth is occuring in modes deviating from some normal one.

The concept of spectral magnitudes offers a new means of quantifying the energy density spectrum of the waves radiated from the earthquake focus, as well as a means of classifying earthquakes in accordance with their spectral characteristics.

REFERENCES

1. Duda, S. J. and Nortmann, R., 1983.
   Normal, blue and red earthquakes - a new way of earthquake classification on the basis of body-wave magnitudes. In: S. J. Duda and K. Aki (Editors), Quantification of Earthquakes. Tectonophysics, 93: 295-306.

2. Nortmann, R., and Duda, S. J., 1983.
   Determination of spectral properties of earthquakes from their magnitudes. In: S. J. Duda and K. Aki (Editors), Quantification of Earthquakes. Tectonophysics, 93: 251-275.

3. I.E.C. 255, 1966.
   Octave, half-octave and third-octave band filters intended for the analysis of sound and vibration. Int. Electrotech. Comm., Publ. 255, Geneva.

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