EXTRAIT DES

PUBLICATIONS

DU

BUREAU CENTRAL SÉISMOLOGIQUE INTERNATIONAL

Série A, Travaux Scientifiques

Fascicule 17

(Mémoires présentés à l'Assemblée d'Oslo 1948.)

Publications of the Division
of the Geological Sciences
California Institute of Technology
Pasadena, California
Contribution No. 46 3

HISTORY AND APPLICATIONS OF THE MAGNITUDE SCALE

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Magnitude in seismology is a concept complementary to intensity. The latter is a measure of effects at a particular point of observation; whereas magnitude is a measure of a given shock as a whole.

At the conference at Strasbourg in July, 1947, M. E. Peterschmitt presented an excellent report on the magnitude scale and its implications. Only a very few details in his discussion call for qualification.

Especially for theoretical purposes it is desirable to use the instrumentally determined magnitudes as indicators of the energy radiated in the form of elastic waves. However, the relation between energy and magnitude is not yet satisfactorily determined and is possibly not invariable. Hence the magnitude will be discussed as an empirical quantity, in which form it is already capable of furnishing valuable statistical information.

The magnitude scale was devised in southern California in response to a purely local and practical problem. Before beginning to circulate lists of earthquakes in that area, it was thought desirable to attach some notation to each, in order to distinguish the larger shocks from the numerous small ones. Since many of the epicenters are in nearly unpopulated mountain or desert areas, while still others are submarine, it was apparent that any such notation must be based on the instrumentally recorded amplitudes. Because all the stations used were equipped with similar instruments, it was possible to work with the seismographic trace amplitudes, and thus eliminate the additional errors and loss of time involved in reducing the recorded amplitudes to ground motion.

The instruments which furnished the standard for the original magnitude scale are Wood-Anderson torsion seismometers, designed to have the constants $T_0 = 0{,}8$ sec., bined vectorially (instead of taking the mean as for local shocks). The amplitude curve thus set up (Table 2) applied only to shallow earthquakes at the « normal » depth of about 25 km.

The principal difficulty is in fixing the zero of the extended magnitude scale to correspond with that of the local California scale. This was done partly by using the data of the few California shocks (magnitude 6 or over) which recorded with measurable maxima at distant stations. Since the California shocks are shallower than 25 km., it must be expected that their surface waves will be somewhat larger than those of the « normal » shocks. A second method involved extending the California scale by extrapolation. Table 1 extends only to 600 km.; but from 200 to 600 km. it is represented very closely by an inverse cube law : $\log A = 3.37 - 3 \log \Delta$. This is probably fortuitous, being determined by an accidental combination of the constants of the torsion instruments with the decrease in amplitude and increase in period of the ground motion with increasing distance. This inverse cube law was at first used to extrapolate Table 1 to a distance of about 25°. This is undesirable; the fortuitous inverse cube law is not involved in subsequent investigations and adjustments, which have reduced the uncertainty in the relation between the California scale and the empirical curve extended to the antipodes. The largest magnitude now assigned is 8.6, and there is probably no serious error in referring this to the same zero as the small California shocks.

Dr. Gutenberg has carried out the large task of developing the magnitude scale to the point of application to shocks at any focal depth. This involved studying the amplitudes of body waves for shocks whose magnitudes had already been determined from the surface waves. The first result was the construction of tables which allow of the determination of magnitude from the amplitudes and periods of P, PP and S, at least as accurately as from the surface waves. However, it is necessary to consider the period explicitly by subtracting its logarithm from that of the amplitude. In effect, this amounts to determining magnitude from the velocity of the earth particle rather than from its displacement.

The magnitude of a deep shock is defined as equal to that of a normal shallow shock which radiates the same energy in the form of body waves. Applying the definition involves the theory of seismic waves in the interior of the earth. This has been carried out by Gutenberg, and the necessary tables and charts have been set up for the assignment of magnitudes. The only possible type of systematic error which might be introduced here would depend on the admittedly imperfect applicability of the customary theory of elastic waves to the conditions in mantle of the earth.

Thus it is now possible to assign definite magnitude numbers whenever a few good stations have reported the maximum amplitude and corresponding period found in the wave groups P, PP and S, and the maximum amplitude of surface waves with periods of 20 seconds. It will be of interest to have the various stations make independent determinations of magnitude from their own data; but this should not be done without giving the readings of amplitude and period on which these are based. During the past two years magnitudes for many shocks have been determined independently at Pasadena and Strasbourg from the readings at those stations; the agreement of the results on later comparison has been most gratifying.

Quite apart from the question of the relation of magnitude to energy, the assignment of magnitude is proving useful in introducing a greater measure of order into earthquake statistics. It is now possible to set up critical lists of the larger shocks of a given period or in a given region which are far more suitable for correlation studies than any previous data of the kind, and which give a far clearer picture of the geography of earthquakes.

Studies based on the magnitude scale show that the number of earthquakes is larger than earlier methods of estimation indicated. Statistics of the small earthquakes and of the large shocks for the world agree in yielding an approximately eightfold increase in frequency for a decrease of one unit in magnitude. This must reach a limit, but apparently that is not attained at the zero of the magnitude scale. One million is a very conservative figure for the total number of earthquakes during a year.

Earthquake magnitude should ultimately be interpreted in terms of radiated elastic energy. In current publication Gutenberg and Richter are using the partly empirical relation

$$\log E = 12 + 1.8 M$$

where E is the elastic energy and M is the magnitude. The constant term 12 here replaces 11.3 as given in an earlier publication. Its authors are by no means satisfied with this formula, which occasionally appears to yield values of log E too large by one unit or even more. The constant term is more likely to be in error than the coefficient of M, but even this is not too well determined. It does not appear likely, however, that further revision will alter the conclusion that in any given period most of the seismic energy is radiated in the larger earthquakes. This introduces peculiar difficulties into statistics of seismicity; it also suggests modification of the notion, prevalent in seismic regions, according to which smaller earthquakes may operate as a « safety valve » to prevent the occurrence of larger ones.

TABLE 1

Logarithm of the amplitudes A (in millimeters) with which the standard torsion seismometer

$$(T_0 = 0.8,\ V = 2800,\ h = 0.8)$$

should register a shock of magnitude zero :

Δ (km.)	— log A	Δ (km.)	— log A
0	1.4	210	3.6
5	1.4	220	3.65
10	1.5	230	3.7
15	1.6	240	3.7
20	1.7	250	3.8
25	1.9	260	3.8
30	2.1	270	3.9
35	2.3	280	3.9
40	2.4	290	4.0
45	2.5	300	4.0
50	2.6	310	4.1
55	2.7	320	4.1
60	2.8	330	4.2
65	2.8	340	4.2
70	2.8	350	4.3
75	2.9	360	4.3
80	2.9	370	4.3
85	2.9	380	4.4
90	3.0	390	4.4
95	3.0	400	4.5
100	3.0	410	4.5
110	3.1	420	4.5
120	3.1	430	4.6
130	3.2	440	4.6
140	3.2	450	4.6
150	3.3	460	4.6
160	3.3	470	4.7
170	3.4	480	4.7
180	3.4	490	4.7
190	3.5	500	4.7
200	3.5	510	4.8
		520	4.8
		530	4.8
		540	4.8
		550	4.8
		560	4.9
		570	4.9
		580	4.9
		590	4.9
		600	4.9

TABLE II

Magnitudes of shallow earthquakes recording at the given distances with maximum combined horizontal ground amplitude of 1 micron with period of 20 seconds.

20°	4.0	100°	5.1
25	4.1	110	5.2
30	4 3	120	5.3
40	4.5	140	5 3
45	4.6	160	5 35
50	4.6	170	5 3
60	4 8	180	5 0
70	4.9		
80	5.0		
90	5.05		

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