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THE MAGNITUDE SCALE - ITS USE AND MISUSE

There is often wide discrepancy between the public attention an earthquake receives (which generally depends on the toll it takes of lives and property) and its importance as indicated by seismograms. A working seismologist may find that a distant event, for which his instruments have recorded only a small trace, has been very destructive in a limited area; while a major earthquake, writing spectacularly large records, may have centered in some remote part of the world and be of scientific interest only.

Before the invention of effective seismographs (about 1880), the known history of earthquakes covered almost exclusively those which affected populated regions. When seismographic recording made it possible to survey the large earthquakes of the whole world, it was learned with some surprise that about 80% of them originate under the oceans. Many of them have their centers close enough to nearby coasts to be destructive on land; but there is a large fraction of them whose occurrence would not even be suspected if it were not for the many seismograph stations of the world.

Detection of earthquakes is more complete in areas where there are numerous recording stations; for years this led to an overestimate of the number and size of earthquakes in Europe as compared with the rest of the world, simply because there was a denser concentration of recording stations there than elsewhere (except Japan, where the level of earthquake activity really is high).

Comparisons of earthquakes are often important in relation to public policy and discussions of public safety. In California confusion has sometimes arisen by failing to distinguish clearly between the effects of a great earthquake (like that of 1906, destructive at San Francisco), a moderately strong destructive earthquake (like that of 1933 in the area of Long Beach and Los Angeles), and a minor but locally damaging earthquake (like that at San Francisco in 1957).

For proper comparisons, most seismologists now apply an instrumentally based magnitude scale, to supplement - not to replace - the older intensity scales.

The term intensity has long been used in seismology to rate the shaking produced by an earthquake at a particular point; it is usually highest not far from the epicenter (which is the point under which the earthquake is considered to have originated), and falls off more or less irregularly with increasing distance, out to the margin of perceptibility to persons, which in a great earthquake may be some hundreds of miles away. Beyond that margin, seismographs continue to record the shock, but the grades of the intensity scale are not applied. These grades are purely descriptive, and are assigned by experienced investigators working in the field, or using reports from observers on the spot. They are usually denoted by Roman numerals to emphasize that they do not represent measurements. The Rossi-Forel (R.F.) intensity scale, formerly much in use, has arbitrary grades from I to X; the Modified Mercalli Scale (M.M.) has grades from I to XII. On the M.M. scale, I indicates (in brief) that the earthquake was not felt by persons at the reported place; II that it was barely felt; IV that it was locally strong enough to rattle windows; VII that it caused some damage to weak structures - and so on. The highest intensity, XII, reports a level of shaking only rarely observed - sufficient to cause almost total destruction to buildings, and even to throw stones into the air.

The magnitude scale, on the other hand, represents measurement, and magnitudes are expressed by ordinary numbers and decimals. The intention is to rate an earthquake as a whole, independent of effects at any particular point. This is done by following the common-sense line of noting how large the seismogram at some station is, and then taking account of the great or small distance of that station from the epicenter. For rough purposes magnitudes can be estimated from the records at a single station; but magnitudes determined at different stations usually vary by a few tenths of a unit (sometimes more); so that final assignments of magnitude are based, like other measurements, on the average of all the independent determinations.

Magnitude was originally defined as the common logarithm of the largest deflection during an earthquake recording, as measured directly on the seismogram written by an instrument of a specified standard type, when at a distance of 100 kilometers (about 62 miles) from the epicenter. We have tables for finding from the seismogram written at any actual distance what the corresponding reading at 100 km. should be; and methods are available for calculation when seismographs of non-standard type are used. The measurement is made in thousandths of a millimeter; so that if at 100 km. the deflection is one millimeter, the magnitude is the logarithm of 1000, or 3. This choice of unit for measurement sets the level of the scale, which was purposely chosen so that the smallest earthquakes being recorded (in 1932) received magnitudes between 0 and 1. For every upward step by one unit of the scale, recordings increase tenfold. The following table illustrates this, giving the deflection on the seismogram for various magnitudes, as a multiple of that for magnitude 3.

Magnitude	Deflection, in terms of that for magnitude 3.
1	0.01
2	0.1
3	1
4	10
5	100
6	1000
7	10000
8	100000

The magnitude scale has no arbitrary ceiling, like the XII of the intensity scale; as is sometimes said, it is an open-end scale. There is no reason in the scale itself why magnitudes should not go up to 10, 12, or 100 for that matter; but as a matter of observation the largest known earthquakes are of magnitude 8.8 or slightly over. If the largest and smallest earthquakes could be recorded by a single instrument at the same distance from both, the deflections would be in the ratio of over a hundred million to one - which suggests why we need to work with instruments having several different ranges of magnification.

The notion often arises, quite naturally, that the magnitude scale itself is some kind of measuring instrument. It merely consists of a set of tables and charts, used for reducing measurements on seismograms, written by different instruments and at different distances, to those expected for a standard instrument at a distance of 100 km. from the epicenter.

Representative Magnitudes.

The following list gives magnitudes for a number of earthquakes, including those most frequently inquired for. Some slightly different figures for a few of these have been published by investigators. Especially for the largest earthquakes, discrepancies of one or two tenths are common and should not be taken very seriously; the scale is not that good.

Dates are according to local time in the country of occurrence; they may differ by one day from dates according to world standard time used in scientific reports.

March 22, 1957	Near San Francisco. Much minor damage	5.2
June 27, 1966	Parkfield-Cholame, central California. Minor damage; minor faulting (San Andreas fault)................	5.6
Aug. 22, 1952	Damage at Bakersfield, Calif.; one killed............	5.8
Feb. 29, 1960	Agadir, Morocco. Destructive; 12000 killed..........	5.8
July 26, 1963	Skopje, Jugoslavia. Heavy damage....................	5.9
Jan. 15, 1968	Western Sicily. Disastrous..........................	6.0
March 19, 1954	Borrego Valley, California. No damage..............	6.2
June 29, 1925	Santa Barbara, California; destructive..............	6.3
March 10, 1933	Long Beach area, California; disastrous.............	6.3
Sept. 12, 1966	West of Reno, Nevada. Minor damage.................	6.3
April 8, 1968	Borrego Mountain, California. Minor damage; minor faulting..................................	6.5
Dec. 16, 1954	East of Fallon, Nevada. Major faulting; minor damage.	7.1
Aug. 17, 1959	Montana. Lives lost in landslide...................	7.1
Aug. 2, 1968	Philippines; damage and lives lost at Manila.........	7.2
June 16, 1964	Niigata, Japan. Destructive........................	7.4
July 21, 1952	Kern County, California. Destructive at Arvin and Tehachapi. 12 killed. Major faulting.............	7.7
March 9, 1957	Aleutian Islands....................................	8.2
Apr. 18, 1906	California; destructive at San Francisco. Major faulting, along the San Andreas fault..............	8.3
Sept. 1, 1923	Japan; very destructive at Tokyo, etc................	8.3
May 22, 1960	Chile; destructive...................................	8.4
March 27, 1964	Alaska; heavy damage at Anchorage. Large sea wave...	8.5
Sept. 10, 1899	Yakutat Bay, Alaska. Major faulting................	8.6
Aug. 16, 1906	Chile; destructive at Valparaiso.....................	8.6
Dec. 16, 1920	Kansu, China. Many lives lost........................	8.6
Aug. 15, 1950	Tibet...	8.7
March 3, 1933	Off the coast of Japan. Destructive sea wave.........	8.8
Jan. 31, 1906	Colombia and Ecuador.................................	8.9

More extensive lists, and discussion of the magnitude scale, may be consulted in: C. F. Richter, "Elementary Seismology" (W. H. Freeman and Company, San Francisco, 1958). Still more inclusive cataloguing will be found in: B. Gutenberg and C. F. Richter, "Seismicity of the Earth" (1954; now reprinted, Stechert-Hafner).

Many persons who were exposed to the strong shaking of the Long Beach earthquake in 1933 find it difficult to understand that, although it was a major disaster (it cost 120 lives, and at least 50 million dollars in damage) - yet it was not a major event like the earthquake of 1906, which was not only destructive at San Francisco, but reached damaging violence over a large part of California. The difference of magnitude, 2.0, between these events, expressed an observed fact - namely, that the actual ground oscillations as recorded at distant stations (in Europe, for example) were about 100 times greater in 1906 than in 1933. The minor damaging earthquake of March 22, 1957, which caused a great sensation in the press, appeared at the distance of Europe only as a very small trace on the seismograms of the most sensitive instruments in use there.

The earthquake of August 22, 1952, was more damaging at Bakersfield than the major earthquake on July 21 preceding, chiefly because it centered much closer to that city; indeed, it had almost no damaging effects outside the city limits. Yet in the recollections of local residents it still looms larger than the earlier event, of which it was merely one of several considerable aftershocks.

The thoughtful reader may well compare this Bakersfield shock with the earthquake of the same magnitude in Morocco in 1960, which proved enormously more disastrous because of the weakness of the prevailing type of construction in that area.

As this is written (1968), we have lately before us an example of great loss of life due to moderately strong shaking, in the collapse at Manila of an unsafe structure when damage to other buildings, though sometimes serious, was generally much less.

Any sane statistics of earthquakes must necessarily be based on a magnitude scale or some equivalent. Early writers on earthquake occurrence allowed their results to be distorted by large numbers of earthquakes which happened to be felt in populated areas, while unfelt but great earthquakes under the sea or in remote parts of the continents were unnoticed or underestimated. By 1922 every earthquake of magnitude 7 or over was recorded at seismological stations all over the world; now no shock of magnitude 6 or over, and probably very few of magnitude 5 or over, escape being reported in the international catalogues and lists. In the southern California area we are at present maintaining complete statistics down to magnitude 3.0; this can be continued indefinitely if there is no reduction of our present installations and personnel. Since the occurrence of small earthquakes anywhere is an almost sure guarantee of larger ones sooner or later in the same area, the value of such cataloguing for estimating long-term risk is evident.

The following table, from observations over 50 years, gives the approximate annual frequency of earthquakes of various magnitudes, counted or estimated for the whole world.

Magnitude	Annual number
9.0 or over	0
8.0 - 8.9	2+
7.0 - 7.9	18
6.0 - 6.9	150
5.0 - 5.9	800
4.0 - 4.9	6200
3.0 - 3.9	49000

Especially for large shocks, the frequency varies considerably. From 1965 through 1967 the annual totals for magnitude 7 or over were much less than average.

There is absolutely nothing to the assertion, lately repeated by certain prejudiced persons and organizations, that earthquakes are now generally increasing.

It is intensity, rather than magnitude, which is most often of direct concern to the engineer, since he is primarily interested in the effects which actually have occurred, and in general less in the destructive potentialities of an earthquake in an unpopulated area; though in looking forward we have to plan for the expansion of population and development into new districts, and consequently to the setting up of new risks. However, the type of ground motion associated with intensity IX, for example, may be notably different for an earthquake of magnitude 6, with epicenter near by, than for one of magnitude 8 with epicenter 50 miles away; this accordingly affects designing to resist earthquakes.

In giving out estimated magnitudes to the press and public, we believe we are answering the ordinary question of "how big it is" more directly than by naming an intensity, or guessing what an intensity ought to be. To be sure, the ordinary man, not knowing about the logarithmic nature of the scale, may think that an earthquake of magnitude 4 is "half as big" as one of magnitude 8; but the same mistake can be made with intensity, and it has been seriously maintained that the Long Beach earthquake was "three quarters" as intense as the shaking at San Francisco, on the basis of intensity ratings of VIII and X.

The relation between magnitude and intensity is one familiar in the physical sciences; it is like that between the power of a radio station and the strength of the signal received at a distant point. Many persons do not realize how rapidly shaking falls off with distance, and how localized strong earthquake effects usually are. Work with the magnitude scale shows, that if there is no distorting effect like that of very unstable ground, the actual oscillation near the earthquake center is roughly ten times as great as it is 25 miles away.

Magnitude rating can be used for deliberate misrepresentation. Thus, the fact that a structure has stood through a large earthquake may be brought forward as evidence for its soundness, without admitting that the intensity was relatively low in its vicinity. Misuse of intensities has been more common; low intensity, in some cities, of a large earthquake has been used to cry down the general risk - or a moderately strong shock, like that of Long Beach, which was locally destructive, has been represented as typical of the probable effects of a great earthquake. We cannot discontinue using correct terms, like magnitude and intensity, because they are sometimes misapplied; otherwise we would soon be reduced to silence.

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