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INTENSITY

The Mercalli Scale

(modified from Richter, 1958 – Elementary Seismology)

The scale was put forward by Mercalli in 1902 at first with ten grades of intensity, later with twelve following a suggestion by Cancani who attempted to express these grades in terms of acceleration. An elaboration of the Mercalli scale, that includes earthquake effects of many kinds and ostensibly correlated with Cancani's scheme, was published by Sieberg in 1923. This form was in turn used as the basis for the Modified Mercalli Scale of 1931 (commonly abbreviated M.M.) by Wood and Neumann.

Modified Mercalli Scale Restated

The original publication gives the M.M. scale in two forms: one a lengthy statement modelled on that of Sieberg, with additions and modifications suggested by later experience; the other an abridgement meant for rough-and-ready use. The abridged form was prepared chiefly by one author, and at a few points is in conflict with the main scale. Richter (1958) presents an expansion of the shorter form, including most of the items in the complete form.

Masonry A, B, C, D. To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following lettering.

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Modified Mercalli Intensity Scale of 1931 (Abridged and rewritten)

I. Not felt. Marginal and long-period effects of large earthquakes (for details see below).

II. Felt by persons at rest, on upper floors, or favourably placed.

III. Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.

V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle-CFR).

VII. Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments-CFR). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations-CFR.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake fountains, sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

From the definition of the intensity scale, it is evident that, for a given earthquake, the intensity I can be different in different places.

Long-Period Effects.

The most important general consideration in applying such a scale is that it brings together long-period and short-period effects. The latter are in the majority and may be roughly correlated with acceleration. The long-period effects represent large displacement, which often goes with comparatively moderate acceleration. With increasing magnitude the proportion of long-period to short-period phenomena tends to increase at all distances from the epicenter. Since the scale in general places the long-period effects where they appear during earthquakes of moderate magnitude, serious confusion has sometimes arisen in dealing with large shocks.

Large landslides, particularly those of the earth-slump type, are typical long-period effects; they are triggered more readily by large slow motion than by rapid shaking. This is the effect referred to in assigning large slides to X. Smaller slides, many of them of the earth-avalanche type, are common, as indicated, at intensity VII. However, great earthquakes sometimes precipitate large slumps in distant areas where the intensity is otherwise indicated as low as VI. Cracks and fissures, especially those due to earth lurches, behave similarly, so that intensity from such evidence has to be assigned with some reference to magnitude. The same applies to effects on works of construction where a long-period resonance is involved, as in the swaying and distortion of tall buildings or towers and in the overturning of elevated tanks.

A special group of long-period effects is that referred to under I. The complete scale lists them as: dizziness or nausea; birds or animals uneasy or disturbed; swaying of trees, structures, liquids, bodies of water; doors swing slowly. The swinging of chandeliers may be added. All these may be observed when no actual shaking is perceptible. Many of them are pendulum effects; chandeliers and large branches of trees may act as long-period seismoscopes. The oscillation of bodies of water is analogous; these effects are seiches. The increased number of such observations with higher magnitude depends in part on the greater proportion of long-period motion. There is another factor of importance: intensity measured by any reasonable criterion falls off with increasing distance at first rapidly and then more and more slowly. For relatively small magnitude, the limiting distance for perceptibility is short, and the range of distance over which intensity is close to the limiting level is narrow. For large magnitude, intensity decreases gradually near the limiting distance, and the critical zone of marginal effects expands into a broad band surrounding the area of intensity II. Long period motion is particularly relevant for seismic isolation.

Subsequently other intensity scales have been introduced by Mercalli, Cancani and Sieberg (MCS) and by Medvedev, Sponeuer and Karnik (MSK) and their comparison is given in table IX. From table IX one may conclude I_{MM}~(5/6) I_{MCS} (Decanini et al., 1995) and I_{MM}~I_{MSK} (Reiter, 1990).

More recently the EMS-1992 macroseismic scale has been proposed (see http://www.es.mq.edu.au/NHRC/web/scales/scalespage3&4.htm). The existence of many different scales is a demonstration of the complexity of the problem of describing earthquake effects. The multiplicity of scales generates some problems in practical applications, that must therefore rely upon very conservative assumptions.

Intensity and Acceleration

Richter participated in an attempt to correlate the degrees of the M.M. scale with peak ground acceleration in the manner attempted by Cancani (1904). Many excellent seismograms written by the U.

S. Coast and Geodetic Survey instruments in California and elsewhere are available for such study. A passable empirical relation is

$$\text{Log a} = 0.33\ I - 0.50 \qquad (1)$$

where a is the acceleration in cm/sec^2 and I is the M.M. intensity. This is similar to Cancani's (1904) result

$$\text{Log a} = 0.33\ I - 1.17 \qquad (2)$$

although it differs somewhat numerically.

Here, of course, the intensity grades must be treated as true numerical quantities, which they are not. If one lets I = 1.5 represent the limit of perceptibility between intensities I and II, log a = 0 or a = 1 cm/sec^2. Various lines of evidence point to this as the level of shaking ordinarily perceptible to persons. If one lets I = 7.5, log a = 2 or a = 100 cm/sec^2 = 0.1 g approximately. This is the acceleration commonly accepted by engineers as that which damages ordinary structures not designed to be resistant. One gets acceleration equal to g for I = 10.5, which is rather low.

Peak values of ground motion and intensity are poorly correlated and their scatter is considerable (Ambraseys, 1974, Decanini et al., 1995). In fact, if we apply the correlation hypothesis:

$$\text{Log}\ (y) = b_0 + b_1\ I \qquad (3)$$

(where y is a peak value and I is the intensity) to the whole available set of data, we must reject (3), because the hypothesis is statistically significant. Equation (3) is acceptable if average data, determined for every value of intensity, are used.

Quite recently, Panza et al. (1997; 1999) have produced new relations between Intensity, I, and the peak values of acceleration, velocity and displacement, valid for the Italian territory. They used two different versions of the GNDT earthquake catalogue (NT3.1 and NT4.1.1) and two sets of observed intensity maps for the Italian territory (ING and ISG data) and exploited advanced modeling methods for seismic waves propagation (Panza, 1993; Panza et al., 2001). The results obtained for accelerations do not differ significantly from the earlier results of Cancani (1904).

The application of (3) to ING and ISG intensity data using NT3.1 earthquake catalogue gives the results reported in Tables I and II, where the χ^2 is determined assigning to the value obtained from the regression coefficients an error of 2σ. For each Intensity data set (ING and ISG) the slopes of (1) are comparable between themselves, but the slopes obtained with ING data are smaller than the slopes obtained with ISG data

The results obtained with NT4.1.1 are reported in Tables III and IV, and tabulated for different intensities in Table V and VI.

The main conclusion are: (1) the slope is quite independent from the data set used, while the intercept is quite different, when changing catalogue, (2) an increment of one intensity degree corresponds to the doubling of peak values.

Other empirical relations have been proposed by Medvedev (1977) and Lliboutry (2000) and are given in Tables VII and VIII. A comparison of numerical values for some suggested relationships between PGA and MM intensity is given in table X, while in Table XI the mean values and standard deviation of PGA, PGV, PGD for different values of intensity MM, in the Western USA, from 187 strong ground motion records are shown.

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TABLES

(horizontal components)

Table I. ING – NT3.1 (MCS)

Displacement (cm)	Velocity (cm/s)	Acceleration (cm/sec^2)	DGA (g)
b_0 = -2.3 ± 0.3	b_0 = -1.9 ± 0.2	b_o =- 4.3 ± 0.2	b_0 = -3.6 ± 0.2
b_1 = 0.30 ± 0.03	b_1 = 0.29 ± 0.02	b_1 = 0.28 ± 0.02	b_1 = 0.26 ± 0.02
c_5^2 = 3.7	c_5^2 = 4.1	c_5^2 = 4.6	c_5^2 = 4.5

Table II. ISG – NT3.1 (MCS)

Displacement (cm)	Velocity (cm/s)	Acceleration (cm/sec^2)	DGA (g)
b_0 = -2.7 ± 0.1	b_0 = -2.4 ± 0.2	b_o = - 4.9 ± 0.2	b_0 = -4.1 ± 0.2
b_1 = 0.35 ± 0.01	b_1 = 0.35 ± 0.02	b_1 = 0.35 ± 0.02	b_1 = 0.32 ± 0.02
c_3^2 = 1.8	c_3^2 = 2.2	c_3^2 = 2.2	c_3^2 = 2.0

Table III. ING – NT4.1.1 (MCS)

Displacement (cm)	Velocity (cm/s)	Acceleration (cm/sec^2)	DGA (g)
b_0 = -2.0 ± 0.5	b_0 = -1.85 ± 0.35	b_o =- 4.25 ± 0.35	b_0 = -3.5 ± 0.3
b_1 = 0.31 ± 0.06	b_1 = 0.32 ± 0.05	b_1 = 0.32 ± 0.04	b_1 = 0.28 ± 0.04
c_5^2 = 4.1	c_5^2 = 4.2	c_5^2 = 4.3	c_5^2 = 4.1

Table IV. ISG – NT4.1.1 (MCS)

Displacement (cm)	Velocity (cm/s)	Acceleration (cm/sec^2)	DGA (g)
b_0 = -2.0 ± 0.2	b_0 = -2.1 ± 0.1	b_o =- 4.6 ± 0.1	b_0 = -3.7 ± 0.1
b_1 = 0.31 ± 0.03	b_1 = 0.35 ± 0.01	b_1 = 0.35 ± 0.01	b_1 = 0.30 ± 0.01
c_3^2 = 1.9	c_3^2 = 2.0	c_3^2 = 2.2	c_3^2 = 2.1

Table V. ING – NT4.1.1 (MCS)
(horizontal components)

Intensity	Displacement (cm)	Velocity (cm/s)	DGA (g)
V	0.1 – 0.5	0.5 – 1.0	0.005 – 0.01
VI	0.5 - 1.0	1.0 –2.0	0.01 – 0.02
VII	1.0 – 2.0	2.0 – 4.0	0.02 – 0.04
VIII	2.0 – 3.5	4.0 – 8.0	0.04 – 0.08
IX	3.5 – 7.0	8.0 – 15.0	0.08 – 0.15
X	7.0 – 15.0	15.0 – 30.0	0.15 – 0.30
XI	15.0 – 30.0	30.0 – 60.0	0.30 – 0.60

Table VI. ISG – NT4.1.1 (MCS)
(horizontal components)

Intensity	Displacement (cm)	Velocity (cm/s)	DGA (g)
VI	1.0 – 1.5	1.0 – 2.0	0.01 – 0.025
VII	1.5 – 3.0	2.0 – 5.0	0.025 – 0.05
VIII	3.0 – 6.0	5.0 – 11.0	0.05 – 0.1
IX	6.0 - 13.0	11.0 – 25.0	0.1 – 0.2
X	13.0 – 26.0	25.0 – 56.0	0.2 – 0.4

Table VII
The Intensity scale MSK-76 and associated average peak values of ground motion (Medvedev, 1977).

Intensity (degree)	Acceleration (g)	Velocity (cm/s)	Displacement (cm)
V	0.025	2	1
VI	0.05	4	2
VII	0.1	8	4
VIII	0.2	16	8
IX	0.4	32	16
X	0.8	64	32

Table VIII
The Intensity scale EMS-1992 and associated average peak values of ground motion (Lliboutry, 2000).

Intensity (degree)	Acceleration (cm/s^2)
V	0.012-0.025
VI	0.025-0.05
VII	0.05-0.1
VIII	0.1-0.2
IX	0.2-0.4
X	0.4-0.8
XI	0.8-1.6
XII	>1.6

Table IX

Comparison of seismic intensity scales (Reiter, 1999; Murphy and O'Brien, 1977; Richter, 1958); MM – Modified Mercalli; RF – Rossi-Forel; JMA – Japanese Meteorological Agency; MCS – Mercalli-Cancani-Sieberg; MSK – Medvedev-Sponheuer-Karnik

<table>
<tr><th>MM</th><th>RF</th><th>JMA</th><th>MCS</th><th>MSK</th></tr>
<tr><td rowspan="2">I</td><td rowspan="3">I</td><td></td><td rowspan="2">II</td><td rowspan="2">I</td></tr>
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<tr><td rowspan="2">IX</td><td rowspan="4">VI</td><td rowspan="2">IX</td></tr>
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<tr><td>XI</td><td rowspan="2">VII</td><td rowspan="2"></td><td>XI</td></tr>
<tr><td>XII</td><td>XII</td></tr>
</table>

Decanini et al. (1995) propose the following relation I_{MM}~(5/6) I_{MCS}

Reiter (1990) propose the following relation I_{MM}~I_{MSK}

Table X

Comparison of numerical values for some suggested relationships between PGA* and MM intensity, from Trifunac and Brady (1975).

Modified Mercalli Intensity	Ishimoto (1932) Ave. Accel.	Kawasumi (1951) Ave. Accel.	Hershberger (1956) Ave. Accel.	Richter (1958) Ave. Accel.	Neumann (1954)	Medvedev and Sponheuer (1969)	Japan Meterological Agency (Okamoto, 1973)	Savarensky and Kirnos (1955).	This Study Horiz Ave. Accel.	This Study Vert. Ave. Accel.
I	0.1	0.5	0.3	0.7	2.0		<1.0	>0.5		
II	0.3	1.4	0.9	1.4	4.0		1-2			
III	0.7	2.5	2.5	3.1	8.0		2.1-5			
IV	1.5	4.5	6.6	6.6	16.0		5.0-10.0		16.6	11.0
V	3.6	14.0	17.8	14.0	32.0	12-25	10.0-21.0		34.0	17.0
VI	12.0	44.0	47.9	30.0	64.0	25-50	21-44	>10.0	66.0	45.0
VII	50.0	89.0	128.8	64.0	130.0	50-100	44-94		126.0	83.0
VIII	144.0	190.0	346.7	138.0	265.0	100-200	94-202		251.0	166.0
IX	302.0	331.0	933.3	295.0	538.0	200-400	202-432	>100.0	501.0	331.0
X	616.0	616.0	2512.0	631.0	1094.0	400-800			1000.0	676.0
XI	1122.0	1000.0								
XII								>500.0		

measured in centimeters per second per second.

Table XI. Mean values and standard deviations of PGA, PGV, PGD for different MMI in the Western USA from 187 accelerograms are used (from Trifunac and Brady, 1975).

M.M. Intensity	Component	Acceleration *cm/sec²*		Velocity *cm/sec*		Displacement *cm*		
		Mean PGA	s	Mean PGV	s	Mean PGD	s	No. of data points used
I								
II								
III	Vert.	12.50	-	1.25	-	1.00	0.50	2
	Horiz.	12.50	-	1.25	-	1.25	0.83	4
IV	Vert.	12.50	-	1.25	-	1.83	0.47	3
	Horiz.	16.67	9.32	2.50	1.25	1.83	0.75	6
V	Vert.	18.56	10.71	1.63	1.09	1.29	0.77	33
	Horiz.	37.12	29.35	3.48	2.89	1.92	2.18	66
VI	Vert.	38.99	34.25	3.23	2.46	1.92	1.27	67
	Horiz.	82.46	77.67	7.57	5.98	3.69	3.08	134
VII	Vert.	68.17	34.78	7.15	4.24	3.54	2.00	75
	Horiz.	131.29	61.30	16.48	8.46	8.41	4.48	150
VIII	Vert.	116.67	99.39	9.17	10.45	7.17	8.75	6
	Horiz.	166.67	84.06	18.95	9.65	8.58	6.46	12
IX								
X	Vert.	687.50	-	58.75	-	19.50	-	1
	Horiz.	1087.50	50.0	86.25	27.50	24.00	13.50	2
XI								
XII								

Table XII

<table>
<tr><th>MM</th><th>RF</th><th>JMA</th><th>MCS</th><th>MSK</th><th>PGA (g)</th></tr>
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<tr><td rowspan="2">V</td></tr>
<tr><td rowspan="2">V</td><td rowspan="2">III</td><td rowspan="2">VI</td><td rowspan="2">V</td><td rowspan="2">0.01-0.025</td></tr>
<tr><td rowspan="2">VI</td></tr>
<tr><td rowspan="2">VI</td><td rowspan="2">IV</td><td rowspan="2">VII</td><td rowspan="2">VI</td><td rowspan="2">0.025-0.05</td></tr>
<tr><td>VII</td></tr>
<tr><td rowspan="2">VII</td><td rowspan="3">VIII</td><td rowspan="5">V</td><td>VIII</td><td rowspan="2">VII</td><td>0.05-0.1</td></tr>
<tr><td rowspan="3">IX</td><td rowspan="3">0.1-0.2</td></tr>
<tr><td rowspan="3">VIII</td><td rowspan="3">VIII</td></tr>
<tr><td rowspan="4">IX</td></tr>
<tr><td rowspan="2">X</td><td rowspan="3">0.2-0.4</td></tr>
<tr><td rowspan="2">IX</td><td rowspan="4">VI</td><td rowspan="2">IX</td></tr>
<tr><td rowspan="2">XI</td></tr>
<tr><td rowspan="2">X</td><td rowspan="4">X</td><td rowspan="2">X</td><td rowspan="2">0.4-0.8</td></tr>
<tr><td>XII</td></tr>
<tr><td>XI</td><td rowspan="2">VII</td><td rowspan="2"></td><td>XI</td><td>0.8-1.6</td></tr>
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</table>

Comparison of seismic intensity scales (Reiter, 1999; Murphy and O'Brien, 1977; Richter, 1958); MM – Modified Mercalli; RF – Rossi-Forel; JMA – Japanese Meteorological Agency; MCS – Mercalli-Cancani-Sieberg; MSK – Medvedev-Sponheuer-Karnik and ranges of PGA (Lliboutry, 2000; Panza et al., 2001).

EMS-1992 is very close to MSK; I_{MM}~(5/6) I_{MCS} (Decanini et al., 1995); I_{MM}~I_{MSK} (Reiter, 1990).

Roughly: PGV(cm/s)=100PGA(g); PGD(cm)=1/2PGV(cm/s)

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Japanese scientists use the following relations

JMA scale	Level of intensity	Ground surface acceleration
0	No feeling	Below 0.8 gal
I	Slight	0.8 ~ 2.5 gal
II	Weak	2.5 ~ 8.0 gal
III	Rather strong	8.0 ~ 25.0 gal
IV	Strong	25.0 ~ 80.0 gal
V	Very strong	80.0 ~ 250.0 gal
VI	Disastrous	250.0 ~ 400.0 gal
VII	Very disastrous	Over 400 gal

Therefore Table XII could be modified as follows:

Table XIII

<table>
<tr><th>MM</th><th>RF</th><th>JMA</th><th>MCS</th><th>MSK</th><th>PGA (g)</th></tr>
<tr><td rowspan="2">I</td><td rowspan="3">I</td><td></td><td rowspan="2">II</td><td rowspan="2">I</td><td rowspan="2"></td></tr>
<tr><td rowspan="4">I</td></tr>
<tr><td rowspan="2">II</td><td rowspan="2">III</td><td rowspan="2">II</td><td rowspan="2"></td></tr>
<tr><td>II</td></tr>
<tr><td>III</td><td>III</td><td>IV</td><td>III</td><td></td></tr>
<tr><td rowspan="2">IV</td><td>IV</td><td rowspan="2">II</td><td rowspan="2">V</td><td rowspan="2">IV</td><td rowspan="2"></td></tr>
<tr><td rowspan="2">V</td></tr>
<tr><td rowspan="2">V</td><td rowspan="2">III</td><td rowspan="2">VI</td><td rowspan="2">V</td><td rowspan="2">0.01-0.025</td></tr>
<tr><td rowspan="2">VI</td></tr>
<tr><td rowspan="2">VI</td><td rowspan="2">IV</td><td rowspan="2">VII</td><td rowspan="2">VI</td><td rowspan="2">0.025-0.05</td></tr>
<tr><td>VII</td></tr>
<tr><td rowspan="2">VII</td><td rowspan="3">VIII</td><td rowspan="5">V</td><td>VIII</td><td rowspan="2">VII</td><td>0.05-0.1</td></tr>
<tr><td rowspan="3">IX</td><td rowspan="3">0.1-0.2</td></tr>
<tr><td rowspan="3">VIII</td><td rowspan="3">VIII</td></tr>
<tr><td rowspan="4">IX</td></tr>
<tr><td rowspan="2">X</td><td rowspan="3">0.2-0.4</td></tr>
<tr><td rowspan="2">IX</td><td rowspan="2">VI</td><td rowspan="2">IX</td></tr>
<tr><td rowspan="2">XI</td></tr>
<tr><td rowspan="2">X</td><td rowspan="4">X</td><td rowspan="4">VII</td><td rowspan="2">X</td><td rowspan="2">0.4-0.8</td></tr>
<tr><td>XII</td></tr>
<tr><td>XI</td><td rowspan="2"></td><td>XI</td><td>0.8-1.6</td></tr>
<tr><td>XII</td><td>XII</td><td>>1.6</td></tr>
</table>