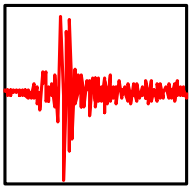
DIPARTIMENTO DI INGEGNERIA DELL'UNIVERSITA' DEGLI STUDI ROMA III

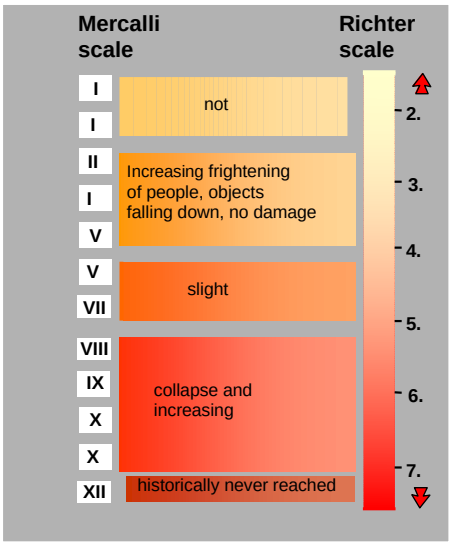
Laurea magistrale in Ingegneria Civile per la Protezione dai Rischi Naturali (Dm 270)

Corso di costruzioni in zona simica
Modulo di Determinazione della pericolosità sismica



MAGNITUDE (Richter scale)
Instrumental scale measuring the amplitude of the ground motion recorded by a seismograph. It's proportional to the energy released

INTENSITY (Mercalli scale)
Empirical scale measuring the effects of an earthquake on the environment, people, and buildings



F.Sabetta

4. Magnitudo e intensità
Scale macrosismiche
Terremoti in Italia e nel mondo

Anno accademico 2022/23

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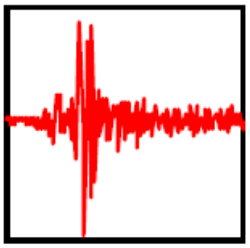
Magnitude scales

Measuring the size of an earthquake



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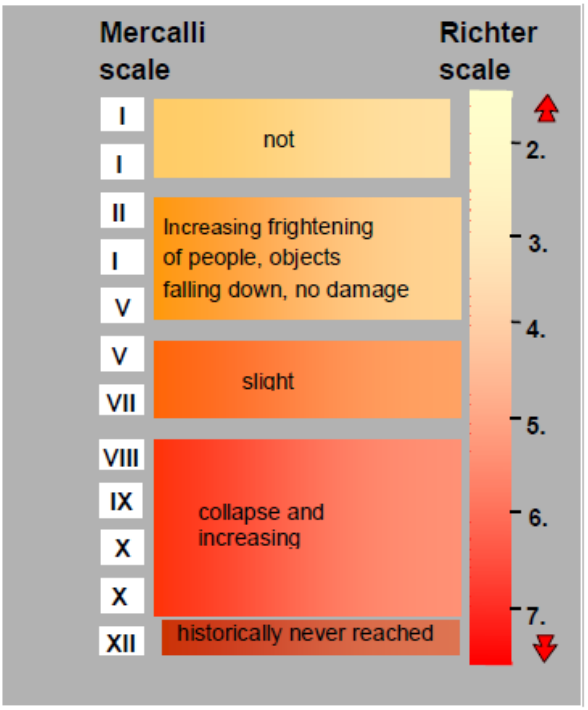


An approximate correlation can be established between epicentral intensity (Io-MCS) and Richter magnitude

Richter (Local) magnitude ML

Richter, 1935

The concept of Earthquake magnitude (which was based on the concept of absolute stellar magnitude in astronomy) was first introduced by C. Richter in 1935 to quantify the size of earthquakes in southern California.

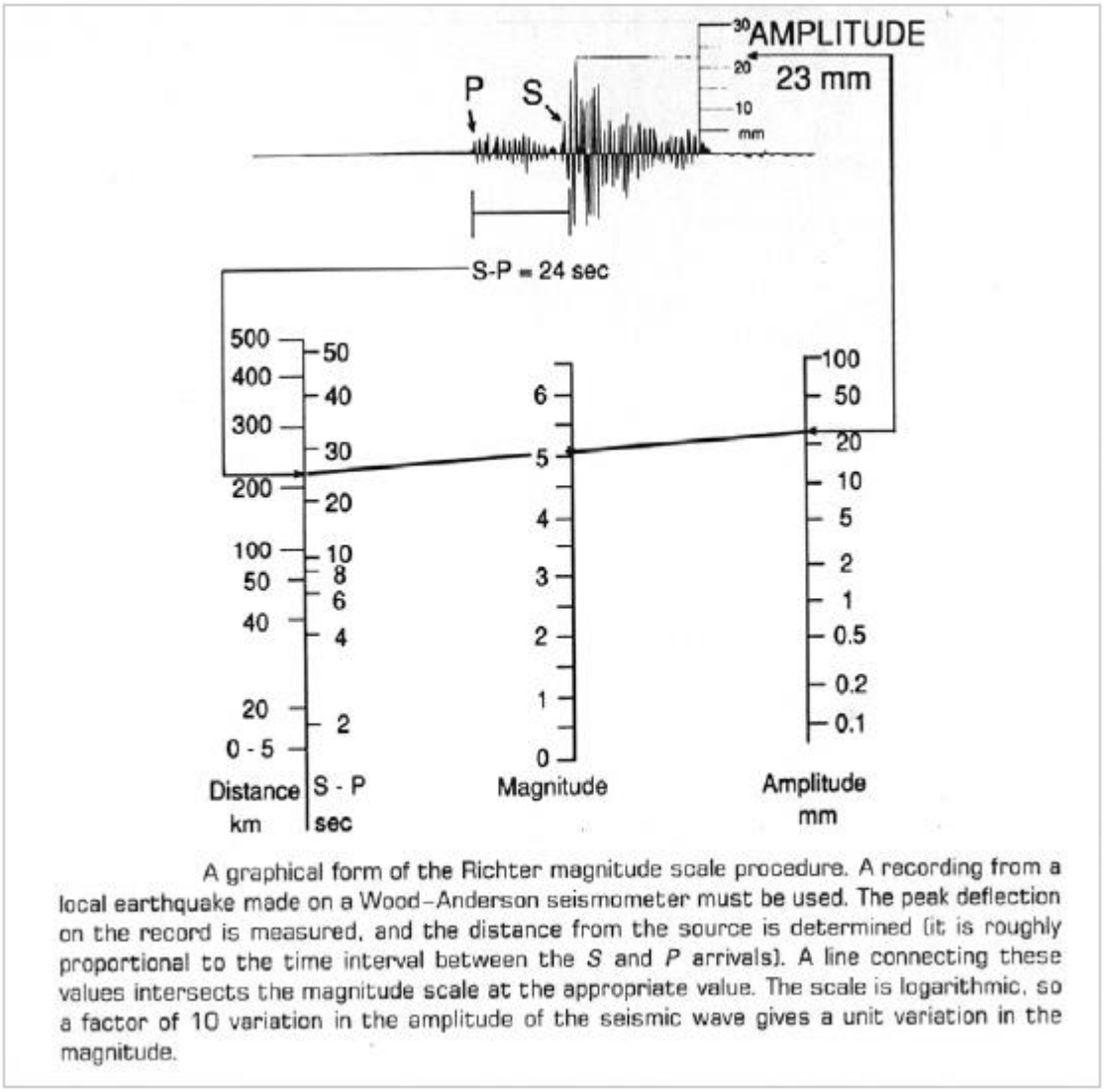
Richter measured the maximum amplitude A (mm) of recordings on Wood-Anderson seismographs and defined the magnitude of the earthquake as

$$M_L = \log(A) - \log(A_0)$$

where A0 is the amplitude that an earthquake of magnitude zero (1mm amplitude at a distance of 100 km) would produce at the same epicentral distance.

Richter presented tables of log(A0) as a function of epicentral distances up to 1,000 km.

Magnitudes calculated in this way are referred to as local magnitudes and represented by the symbol **ML.** The logarithmic scale is used because the seismic waves amplitudes vary enormously.



A graphical form of the Richter magnitude scale procedure. A recording from a local earthquake made on a Wood–Anderson seismometer must be used. The peak deflection on the record is measured, and the distance from the source is determined (it is roughly proportional to the time interval between the *S* and *P* arrivals). A line connecting these values intersects the magnitude scale at the appropriate value. The scale is logarithmic, so a factor of 10 variation in the amplitude of the seismic wave gives a unit variation in the magnitude.

In case of strong and close earthquakes the high sensitivity of the seismometers will often cause the record traces to go off scale (***saturation or clipping***). In such cases, the magnitude is often derived from the length of the wave train and such measures are called ***duration magnitudes, MD***

ML is limited in its application because it's calibrated **specifically for southern California**, is **based on the Wood-Anderson** seismograph and is **limited to distances less than 1,000 km**.

However ML is a very useful scale, particularly for the Engineers, because it's correlated to short period waves (Wood-Anderson T0 = 0.8 sec) and the extent of earthquake damage is closely related to ML.

Body and surface waves magnitude

The disadvantages of ML are overcome by the use of ***teleseismic magnitude scales*** which are based on the maximum ratio of the amplitude ***A*** of the recorded trace to the period ***T*** of the ground motion and are independent of the type of seismograph employed. There are two main teleseismic magnitude scales.

The first is based on the first few cycles of the P-wave arrival and is called ***body waves magnitude***:

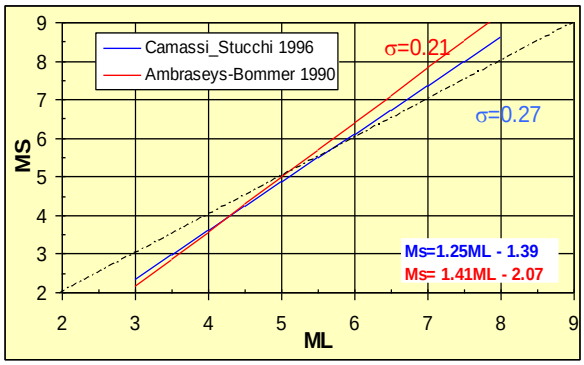
$$m_b = \log(A/T) + Q(\Delta°,h)$$

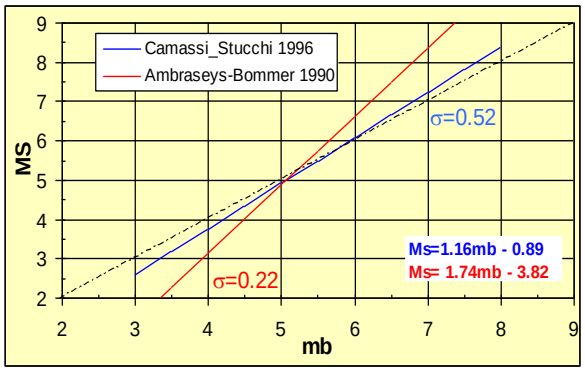
The second, ***surfaces waves magnitude***, is based on surfaces waves (dominating, with a period of about 20 sec., seismograms of shallow earthquakes at distances beyond 600 km):

$$M_S = \log(A/T) + 1.66 \log(\Delta°) + 3.3 + C_i \qquad \textit{(Prague formula)}$$

The correction for distance and depth **Q(Δ°, h)** and the station calibration coefficient C_i are determined empirically.

Empirical relationships exist between different scales. Caution should be used in the application because standard deviations are significant. Unless correction is made for depth, M_s values for deep earthquakes (which produce weak surface waves) will be much lower than m_b





Moment magnitude

All of the magnitude scales described so far have a fundamental shortcoming: they are unable to distinguish the relative size of the largest earthquakes, a phenomenon known as **saturation**.

As the dimensions of the rupture grow with the size of the earthquake, the additional energy released does not continue to cause the growth of amplitudes at relatively short period but rather generates radiation at longer and longer periods, which is not detected by the seismographs from which ML, Ms and *m*b values are calculated.

Seismic moment has the advantage that **it does not saturate** and therefore it is really the only suitable measure for the largest earthquakes.

The **seismic moment M0** of an earthquake is given by

$$M_0 = \mu \cdot A \cdot U \qquad \textbf{Newton•m or dyne•cm}$$

Where **m** is the shear modulus of the material along the fault, **A** is the area of the fault rupture (L x W) and **U** is the average amount of slip on the fault. The seismic moment is named for its units of force times length and may be considered a **measure of the work done in rupturing the fault and moving the surrounding volume of the Earth crust**. It is generally not calculated from field measurements of U and A, but it is rather **determined from seismograms**. This can be done either from Fourier amplitude spectra or obtained from the Centroid Moment Tensor solution (CMT). Since 1977 Harvard University has routinely calculated CMT moments and fault plane solutions for earthquakes of magnitude 5.5 and greater.

In order to provide moment values in a format that is more easily interpreted, Hanks & Kanamori (1979) defined a moment magnitude scale, represented by M_w

$$M_w = 2/3 \cdot \log(Mo) - 10.73 \quad \textbf{(Mo in dyne•cm)}$$

M_L Local magnitude (Richter 1935)

log. of max amplitude (micron) of a seismogram recorded by a Wood-Anderson seismograph at 100 Km from the epicenter. For different seismographs and distance appropriate calibrations are used.

M_L= log A - log A° (log A° calibration factor) (wave period 0.1-1 sec)

mb Body waves magnitude

m_b= log(A/T) + Q(Δ°,h) (wave period 1-5.0 sec)

A/T ratio of max. amplitude and period calculated on body waves;
Q(D°,h,) calibration factor depending on distance D° and depth h of the earthquake.

MS Surface waves magnitude

calculated as a mean of the recordings of several seismographs generally located at large distances from the epicenter (thousands of km).

M_S= log(A/T) + 1.66 log (Δ°) + 3.3 + Ci (wave period ~ 20.0 sec)

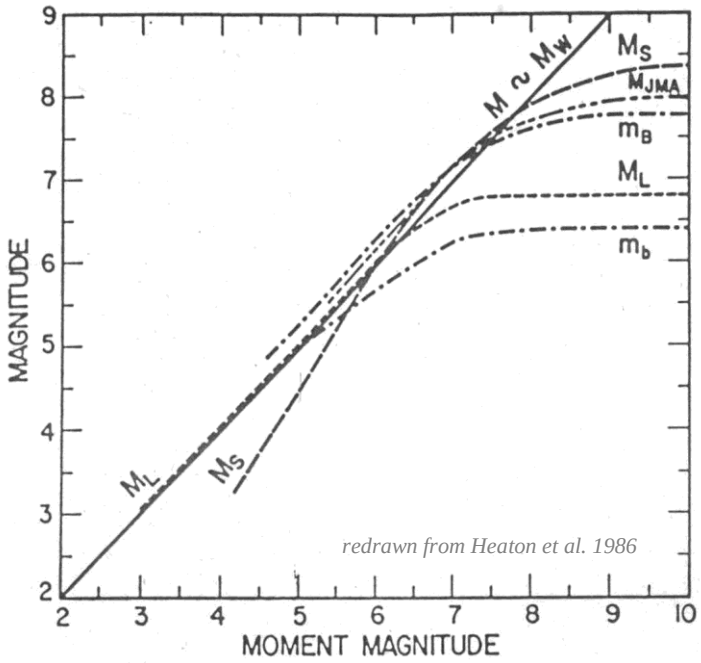
A/T ratio of max. amplitude and period calculated on surface waves;
D° epicentral distance in degrees; Ci calibr. station coefficient.

Mw Moment magnitude

the only type of magnitude not affected by saturation problems; calculated on the basis of the seismic moment **Mo** derived from the Fourier spectra of the seismometric recordings

$M_W = 2/3\log(M_o) - 10.73$

Relationship between moment magnitude and various magnitude scales



- M_W moment magnitude
- M_S surface magnitude
- MJMA Japan Met. Ag. mag.
- m_B long period body-wave mag.
- M_L local (Richter) mag.
- m_b short period body-wave mag

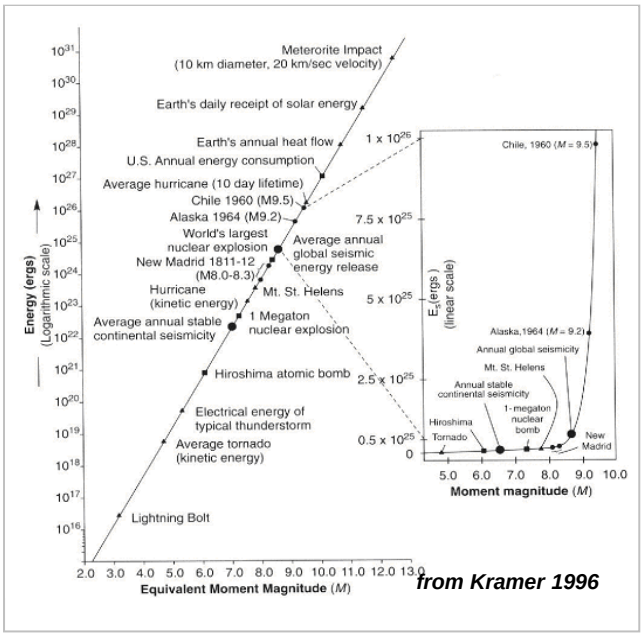
Magnitude and energy

Remembering that the energy of an earthquake is proportional to $\mathbf{A^2}$ and that the magnitude is proportional to the logarithm of **A**, empirical relationships (Gutenberg and Richter) can be

established, through a logarithmic scale, between magnitude and energy released at the focus

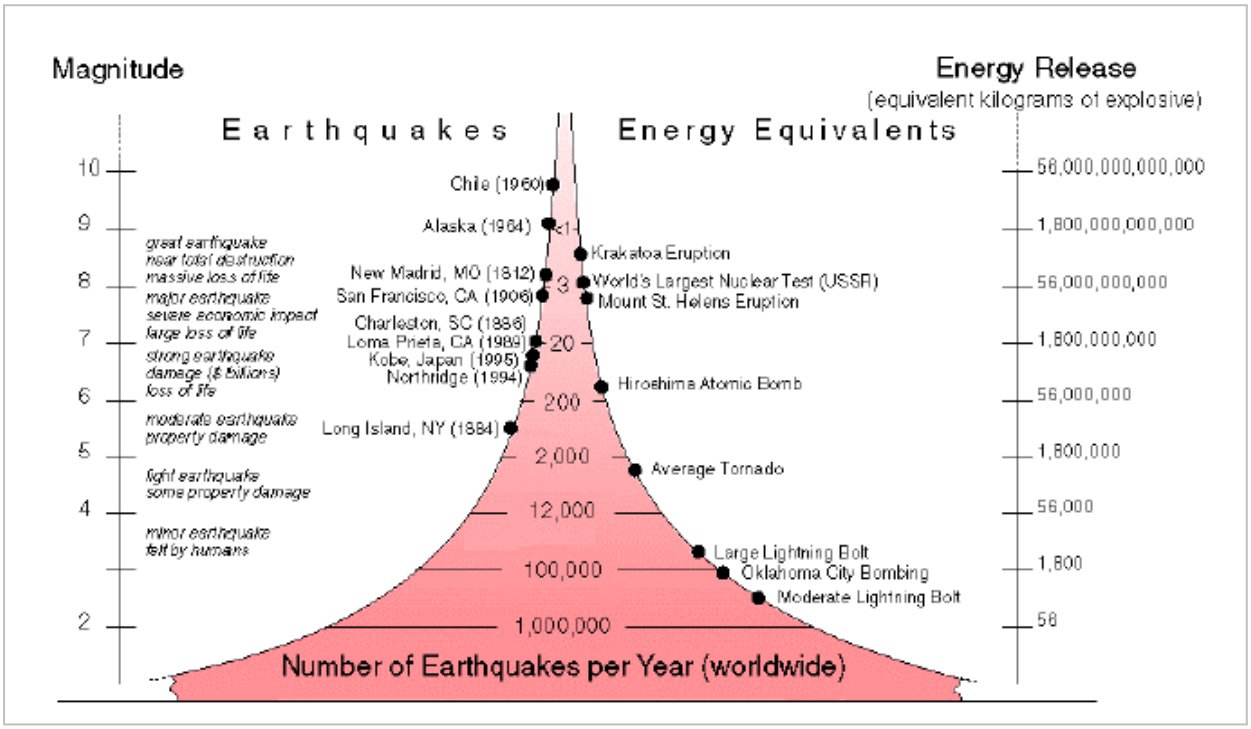
log(E)= 1.5Ms + 11.8 (erg)

For each unit of M the amplitude of the ground motion increases by a factor of 10 and the energy by a factor of $10^{1.5} \approx 32$

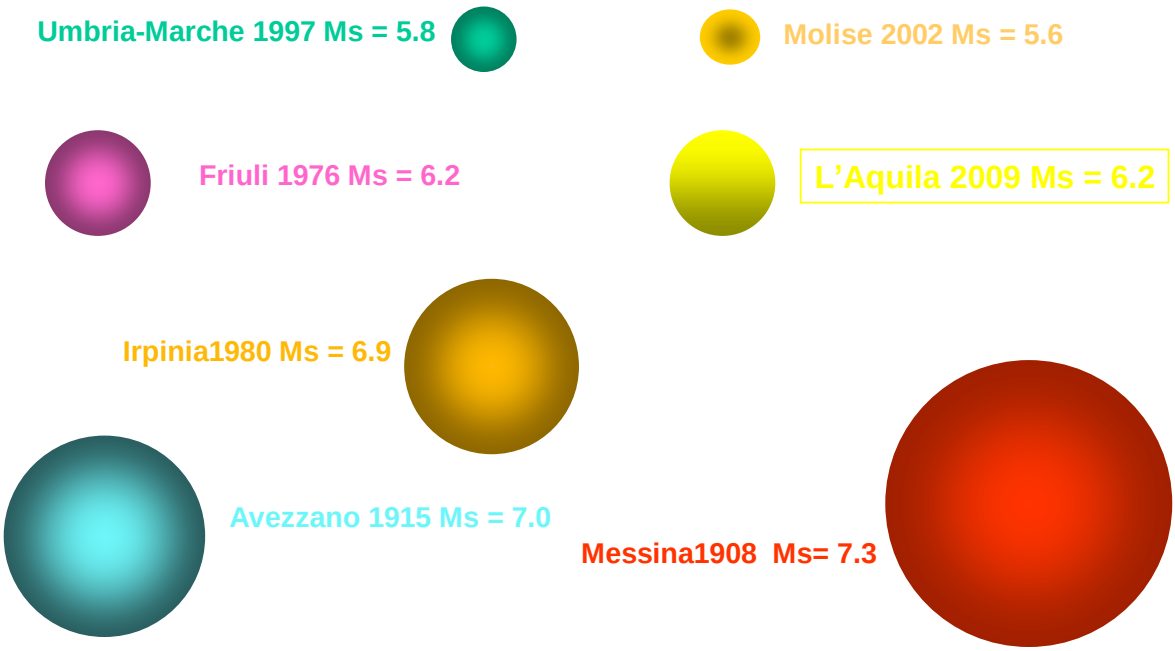


from Kramer 1996

Magnitude M_w	Energy released at the focus (x10^{20} erg)	Equivalent tons of explosive
4	0.006	56
5	0.19	1771
6	6	56,000
7	190	1,771,000
8	6000	56,000,000
9	190000	1,771,000,000

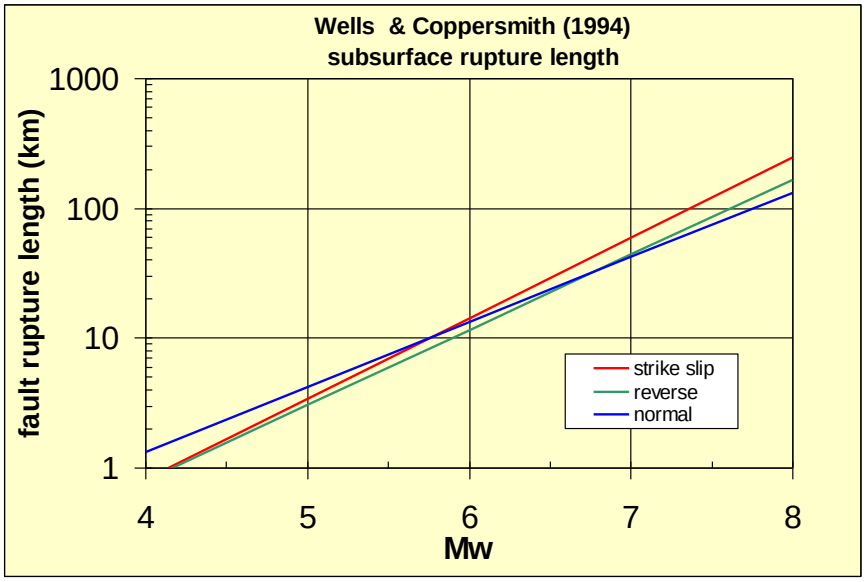


Magnitudo e energie a confronto per i maggiori terremoti italiani



Magnitude and fault rupture length

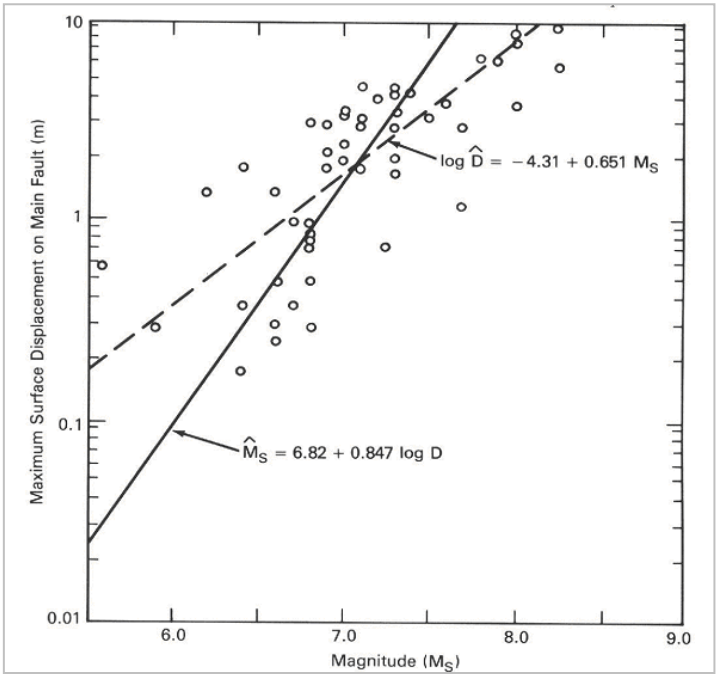
Magnitude is also proportional to the fault rupture length.



Many studies have produced empirical regressions between dimensions of the fault rupture, or the slip, and the earthquake magnitude, most notably the study of Wells & Coppersmith (1994). Such empirical equations are obtained by performing regression of rupture dimensions or slip on magnitude or vice versa.

M=5.08 + 1.16 log(srl)
Wells & Coppersmith (1994)
surface rupture length

M= 4.38 + 1.49 log(ssrl)
Wells & Coppersmith (1994)
sub-surface rupture length



Slip on the fault surface as a function of M

SUMATRA 26/12/04
M0= 3.57x 1029 dyne·cm Mw =9 Ms=8.6
Energy ~ 2x1025 erg ~ 32,000 Hiroshima bombs
Fault length ~ 700 km Max slip on fault ~ 25 m

Macroseismic Intensity

The concept of macroseismic intensity as a quantitative measure of the earthquake effects was firstly introduced by the Italian seismologist Giuseppe Mercalli in 1902.

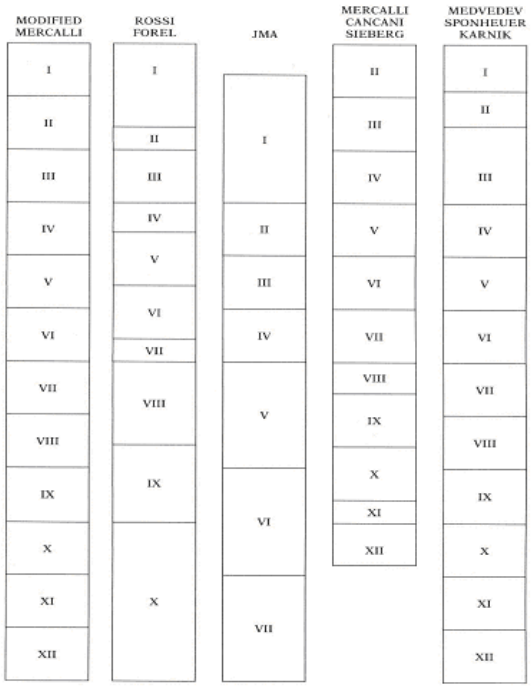
Macroseismic intensity has even nowadays a great importance in Earthquake Engineering for two main reasons:

- **It is the most rapid tool to perform a survey of the area affected by an earthquake (rescue organiz., damage assessment, monetary losses)**
- **It is the only way to evaluate the intensity of the historical earthquakes an compile seismic catalogues**

The macroseimic intensity scales are:

- **Empirical scales measuring the earthquakes effects on people and structures**
- **There are several dozen of these but only few are still use**
- **There are substantial differences in the assignments made by independent investigators studying the same earthquake**

Abbr.	Authors	Year (issue, modif.)	Characteristics
RF	De Rossi Forel	1883	X Degrees - no more used
MM	Modified Mercalli	1902, 1931, 1956 (Richter)	XII Degrees - U.S.A.
JMA	Japan Metereological Agency	1949	VII Degrees - Japan
MCS	**Mercalli Cancani Sieberg**	**1912, 1931**	**XII Degrees - no reference to building type - Italy**
MSK	**Medvedev Sponheuer Karnik**	**1964, 1981**	**XII Degrees - 3 building types (A,B,C) - Europe-USA**
EMS	**European Macroseismic Scale**	**1998**	**XII Deg. - 6 bld. types (A,B,C,D,E,F) - Europe**



Comparison of intensity scales (Reiter, 1990)

from Bommer, 2001a

Macroseismic Intensity is evaluated either by direct field observations or by questionnaires sent to the affected areas (the latter only for lower intensity values). When several observations are available, to take the arithmetic ***mean*** value is meaningless, because of the non-linear and discrete nature of the intensity scales. The value assigned is normally the ***modal*** observation.

The main problem with assessment of intensity is the subjectivity of the evaluations and the difficulty of covering large areas to determine the lower values. One further complication is that earthquakes are frequently followed by strong aftershocks and the damage observed in buildings will reflect the cumulative effect of all of the events.

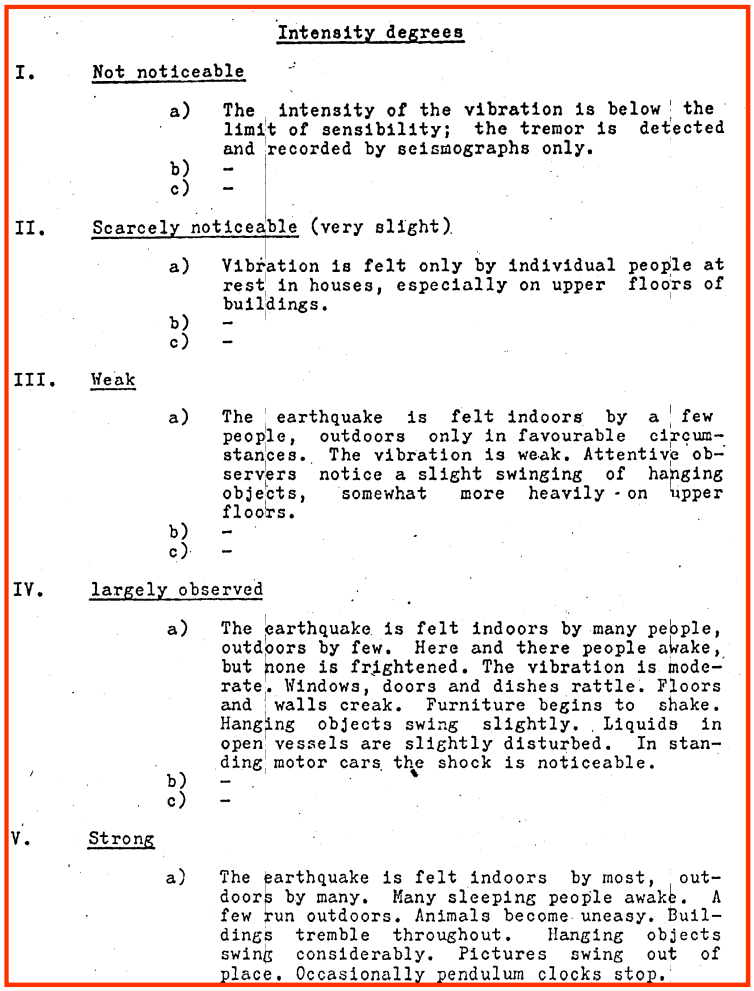
Intensity it is usually represented by Roman numerals and in fact it is meaningless to write a value of intensity as a decimal value because it is not a continuous variable. Intensity between VIII and IX may legitimately be represented as VIII-IX, VIII+ or IX-, but to write 8.5 is incorrect.

The scales are neither continuous nor linear. The variation from degree to degree is not gradual, each increase in one degree representing a jump in the level of shaking. Furthermore, the jumps between different degrees are not equal: the increase in the level of ground shaking from IV to V is not the same as the increase from VII to VIII.

Intensity scales

Particolari		gradi
Avvertito	rari, in quiete, ai piani superiori	2
	da pochi un casa	3
	numerosi nelle case, rari all'aperto	4
	da tutti in casa e all'aperto	5
Dormienti	rari	4
risvegliati	molti	5
Fuga	rari	5
	molti	6
Tintinnare di finestre, scricchiolare di porte, ecc.		4
Oscillazione di oggetti sospesi		5
Rintocchi	di orologi	5
di campane	piccole	6
	grandi	7
Oggetti si	rari	5
rovesciano	molti	6
Caduta di tegole e	poche	6
pietre di camino	molte	7
Edifici in pietre normali		
Danni	leggeri, rari	6
	moderati, molti	7
Distruzioni	1/4 di tutti gli edifici	8
	1/2 di tutti gli edifici	9
	3/4 di tutti gli edifici	10
Crolli	rari	8
	più di un 1/4 di tutti gli edifici	9
	più di un 1/2 di tutti gli edifici	10
	tutti gli edifici	11
Crollo di qualsiasi edificio di tutti i tipi dalle fondamenta		12

Mercalli Cancani Sieberg MCS-1931



Intensity degrees

I. Not noticeable

a) The intensity of the vibration is below the limit of sensibility; the tremor is detected and recorded by seismographs only.
b) –
c) –

II. Scarcely noticeable (very slight)

a) Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.
b) –
c) –

III. Weak

a) The earthquake is felt indoors by a few people, outdoors only in favourable circumstances. The vibration is weak. Attentive observers notice a slight swinging of hanging objects, somewhat more heavily on upper floors.
b) –
c) –

IV. largely observed

a) The earthquake is felt indoors by many people, outdoors by few. Here and there people awake, but none is frightened. The vibration is moderate. Windows, doors and dishes rattle. Floors and walls creak. Furniture begins to shake. Hanging objects swing slightly. Liquids in open vessels are slightly disturbed. In standing motor cars the shock is noticeable.
b) –
c) –

V. Strong

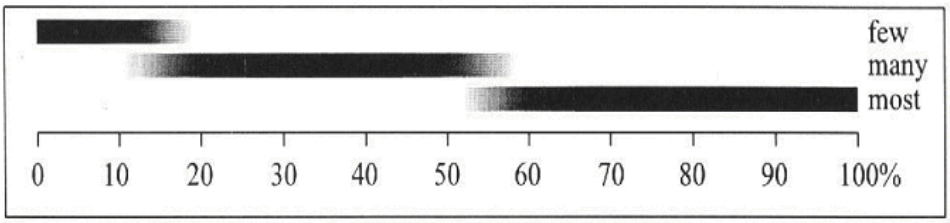
a) The earthquake is felt indoors by most, outdoors by many. Many sleeping people awake. A few run outdoors. Animals become uneasy. Buildings tremble throughout. Hanging objects swing considerably. Pictures swing out of place. Occasionally pendulum clocks stop.

Medvedev
Sponheuer
Karnik

MSK-81

European Macroseismic Scale EMS (Grunthal, 1998)

EMS intensity	Definition	Description of typical observed effects (abstracted)
I	**Not felt**	Not felt.
II	**Scarcely felt**	Felt only by very few individual people at rest in houses.
III	**Weak**	Felt indoors by a few people. People at rest feel a swaying or light trembling.
IV	**Largely observed**	Felt indoors by many people, outdoors by very few. A few people are awakened. Windows, doors and dishes rattle.
V	**Strong**	Felt indoors by most, outdoors by few. Many sleeping people awake. A few are frightened. Buildings tremble throughout. Hanging objects swing considerably. Small objects are shifted. Doors and windows swing open or shut.
VI damage begin	**Slightly damaging**	Many people are frightened and run outdoors. Some objects fall. Many houses suffer slight non-structural damage like hair-line cracks and fall of small pieces of plaster.
VII	**Damaging**	Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many well built ordinary buildings suffer moderate damage: small cracks in walls, fall of plaster, parts of chimneys fall down; older buildings may show large cracks in walls and failure of fill-in walls.
VIII collapse begin	**Heavily damaging**	Many people find it difficult to stand. Many houses have large cracks in walls. A few well built ordinary buildings show serious failure of walls, while weak older structures may collapse.
IX	**Destructive**	General panic. Many weak constructions collapse. Even well built ordinary buildings show very heavy damage: serious failure of walls and partial structural failure.
X	**Very destructive**	Many ordinary well built buildings collapse.
XI	**Devastating**	Most ordinary well built buildings collapse, even some with good earthquake resistant design are destroyed.
XII	**Completely devastating**	Almost all buildings are destroyed.



ARRANGEMENT OF THE SCALE

a) Effects on humans.

b) Effects on objects and nature,.

c) Damage to buildings

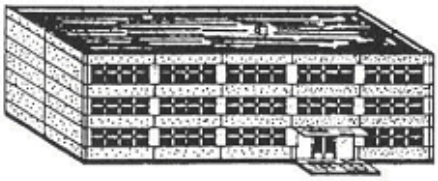
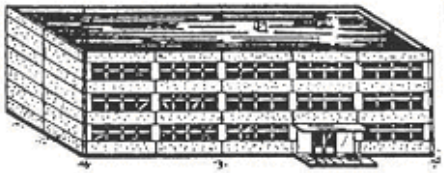
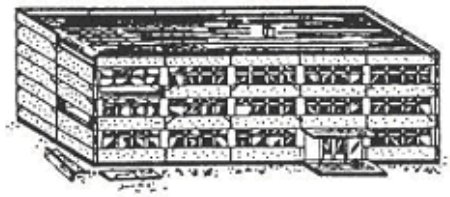
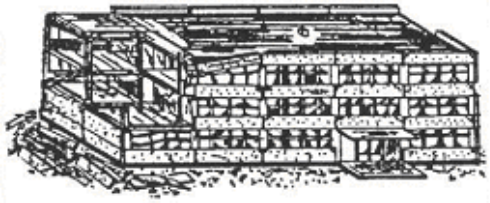
Classifications used in the European Macroseismic Scale (EMS)

Differentiation of structures (buildings) into vulnerability classes (Vulnerability Table)

	Type of Structure	Vulnerability Class A B C D E F
MASONRY	rubble stone, fieldstone	○
	adobe (earth brick)	○—
	simple stone	···○
	massive stone	—○···
	unreinforced, with manufactured stone units	···○···
	unreinforced, with RC floors	—○···
	reinforced or confined	···○—
REINFORCED CONCRETE (RC)	frame without earthquake-resistant design (ERD)	·····○···
	frame with moderate level of ERD	·····○—
	frame with high level of ERD	·····○—
	walls without ERD	···○—
	walls with moderate level of ERD	···○—
	walls with high level of ERD	···○—
STEEL	steel structures	·····○—
WOOD	timber structures	·····○—

○ most likely vulnerability class; — probable range;
·····range of less probable, exceptional cases

Classification of damage to masonry buildings	
	Grade 1: Negligible to slight damage **(no structural damage,** **slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
	Grade 2: Moderate damage **(slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	Grade 3: Substantial to heavy damage **(moderate structural damage,** **heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	Grade 4: Very heavy damage **(heavy structural damage,** **very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	Grade 5: Destruction **(very heavy structural damage)** Total or near total collapse.

Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	Grade 5: Destruction **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

VI. Slightly damaging

a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.
b) Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.
c) Damage of grade 1 is sustained by many buildings of vulnerability class A and B; a few of class A and B suffer damage of grade 2; a few of class C suffer damage of grade 1.

VII. Damaging

a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.
b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
c) Many buildings of vulnerability class A suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class B suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class C sustain damage of grade 2.
A few buildings of vulnerability class D sustain damage of grade 1.

VIII. Heavily damaging

a) Many people find it difficult to stand, even outdoors.
b) Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.
c) Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class D sustain damage of grade 2.

IX. Destructive

a) General panic. People may be forcibly thrown to the ground.
b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.
c) Many buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class C suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class D suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class E sustain damage of grade 2.

X. Very destructive

c) Most buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B sustain damage of grade 5.
Many buildings of vulnerability class C suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class D suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class E suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class F sustain damage of grade 2.

XI. Devastating

c) Most buildings of vulnerability class B sustain damage of grade 5.
Most buildings of vulnerability class C suffer damage of grade 4; many of grade 5.
Many buildings of vulnerability class D suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class E suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class F suffer damage of grade 2; a few of grade 3.

XII. Completely devastating

c) All buildings of vulnerability class A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability class D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
		1	2	3	4	5
Field stone masonry (in very weak mortar) **A**	**Campania-Basilicata, Italy 1980 / Balvano**					●

Comment:

The floor slabs have failed and so have most of the walls. This is very heavy structural damage and damage grade 5.

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
		1	2	3	4	5
Unreinforced masonry **B**	**Friuli, Italy 1976 / Gemona (Udine)**			●		

Comment:

There are large diagonal cracks in most walls, but they are not so severe and the walls have not failed. In this case the damage is grade 3.

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
		1	2	3	4	5
RC frame **C**	**Mexico City 1985**				●	

Comment:

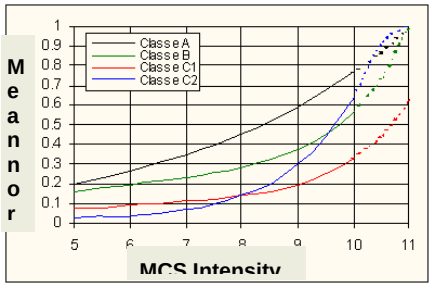
This building has suffered partial collapse of the upper part. Although single upper storeys have failed, no part of the building has collapsed completely to ground level, so the damage is only grade 4.

TYPE OF STRUCTURE	EARTHQUAKE / SITE	GRADE OF DAMAGE				
		1	2	3	4	5
RC walls **D**	**Great Hanshin, Japan 1995 / Kobe**			●		

Comment:

This building has suffered moderate structural damage over its full height. The cracks are concentrated in the weak short column elements of the outer facade. The integrity of the whole building has not been impaired. The damage grade is assessed as 3.

Shortcomings in the use of intensity in the Engineering practice



Intensity is widely used by Engineers in damage and loss assessment by means of **Damage Probability Matrices (DPM)** correlating the probability of a given level of damage, for a given building vulnerability class, to the macroseismic intensity, considered as **representative of the ground motion severity**. This because intensity data are generally more abundant than strong ground motion recordings in the sites where damage surveys are available.

Damage probability matrix for building vulnerability class A

Intensity	Damage Level					
	0	1	2	3	4	5
VI	0,188	0,373	0,296	0,117	0,023	0,002
VII	0,064	0,234	0,344	0,252	0,092	0,014
VIII	0,002	0,020	0,108	0,287	0,381	0,202
IX	0,0	0,001	0,017	0,111	0,372	0,498
X	0,0	0,0	0,002	0,030	0,234	0,734

The employment of the intensity in the DPM as representative of the ground motion severity has however several drawbacks:

- it is not a physical measurable quantity and its assessment is quite subjective;
- there are several evaluation scales (MSK, MCS….) and the conversion among them has never been precisely assessed;
- the scale is neither continuous nor linear and you can play only with discrete and limited values (in engineering practice often only VII, VIII, IX);
- it's impossible to separate the site amplification effects;
- intensity is, by definition, strictly correlated to building damage (perform regressions between damage and intensity is statistically meaningless)

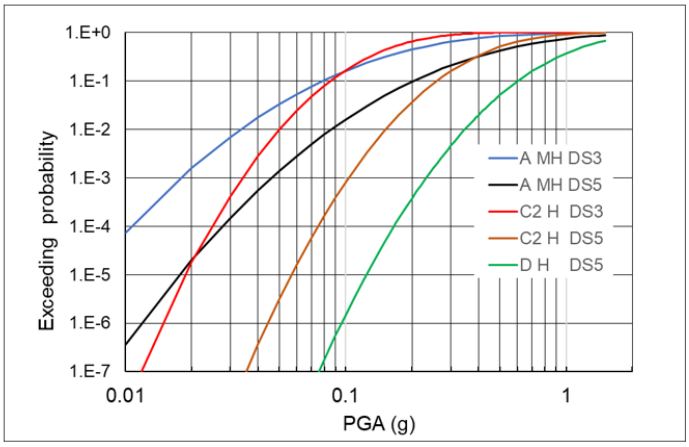
from Bramerini et al. 1995, Sabetta et al. 1998, Lucantoni et al. 2001.

Fragility curves

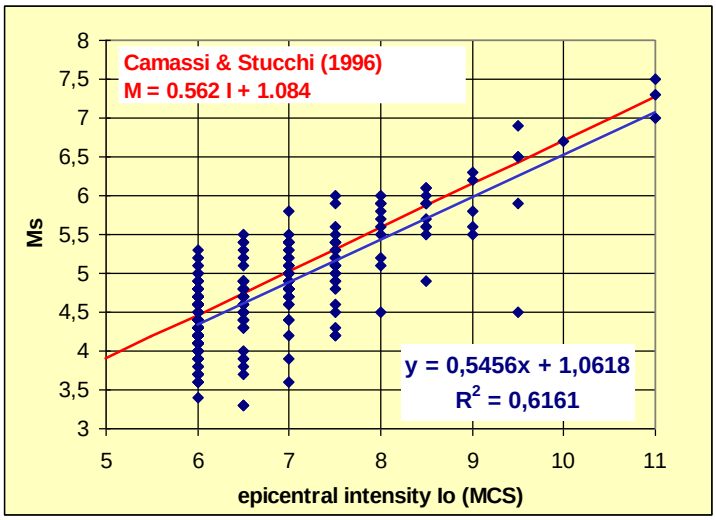
The fragility curves represent a good alternative to Damage Probability Matrices for damage and loss assessment.

They give the probability of reaching or exceeding a given damage state (DS), for a given building typology as a function of a ground motion parameter as Peak Ground Acceleration (PGA).

They are generally described by a cumulative lognormal distribution. The DS are those of the European Macroseismic Scale EMS-98



Magnitude – Intensity correlations



Empirical regression derived from the Italian seismic catalogue NT4.1 (2500 earthquakes from 1000 to 1992). Data are relative to 274 events, with I ≥ VI and shallow focal depth (10-30 km),

Instrumental earthquake recordings, and therefore **magnitude data, are available only since the beginning of the last century.**

Compared with the time-scale of the geological processes underlying earthquake generation, this is a very short period of observation.

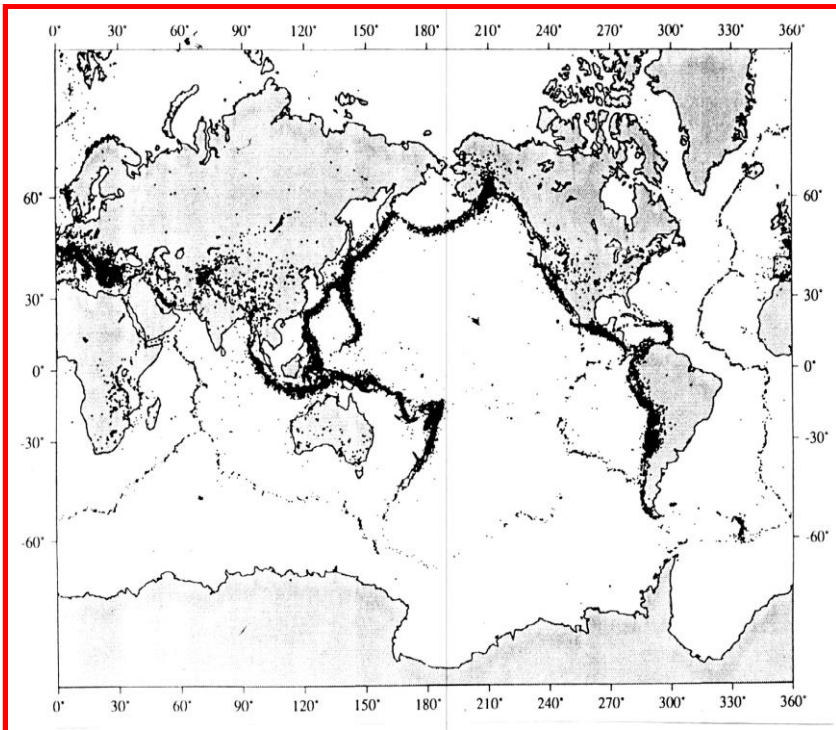
All the **information relative to historical earthquakes** (covering a period of 500-2000 years, variable according to the history of different countries) is **available in terms of macroseismic intensity** derived from historical reports an documents.

As we will see later, the majority of the ground motion predictive models used in seismic hazard assessment, require the earthquake magnitude as input parameter.

Therefore, to avoid to loose historical data, **is very important to implement empirical correlations between magnitude and epicentral intensity.**

These correlations are strongly dependent on the scales adopted, on earthquake focal depth and on the country where the data are taken from.

World seismicity

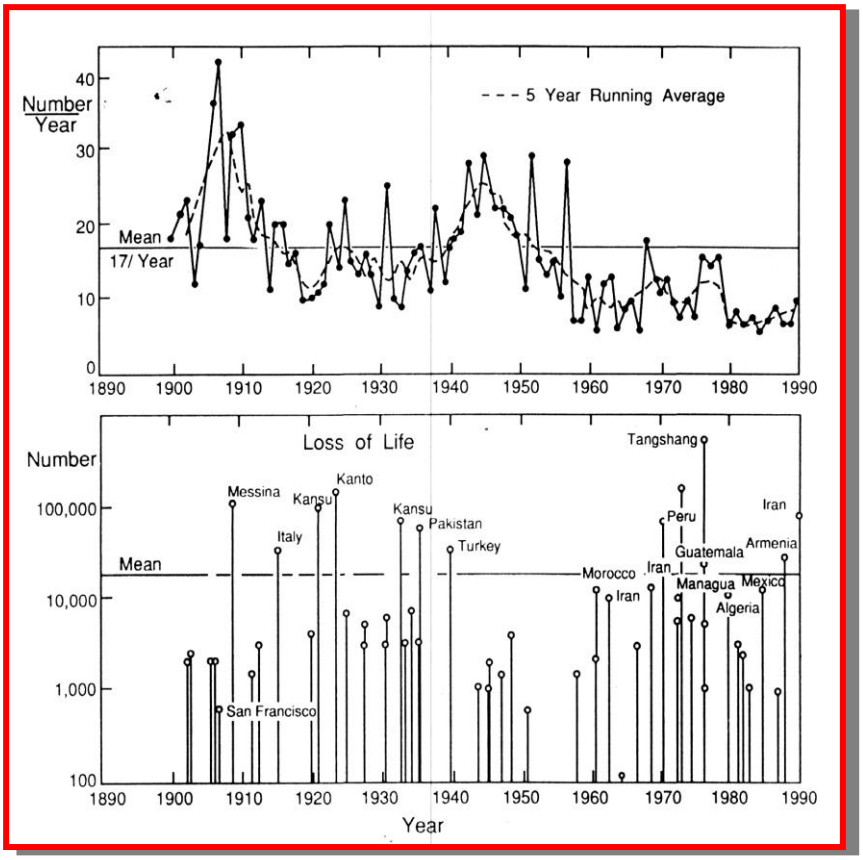


Distribution of earthquakes determined by the global networks for the years 1970 to 1990

from Lay and Wallace (1995)

Worldwide Earthquakes per Year

Magnitude M_S	Average Number Above M_S
8	2
7	20
6	100
5	3000
4	15,000
3	More than 100,000



Annual number of worldwide earthquakes above magnitude 7 in the last century

Induced fatalities of worldwide earthquakes in the last century

Some of the most damaging events of the last century

San Francisco-USA 1906
Ms = 7.8
Io = IX MM
750 victims

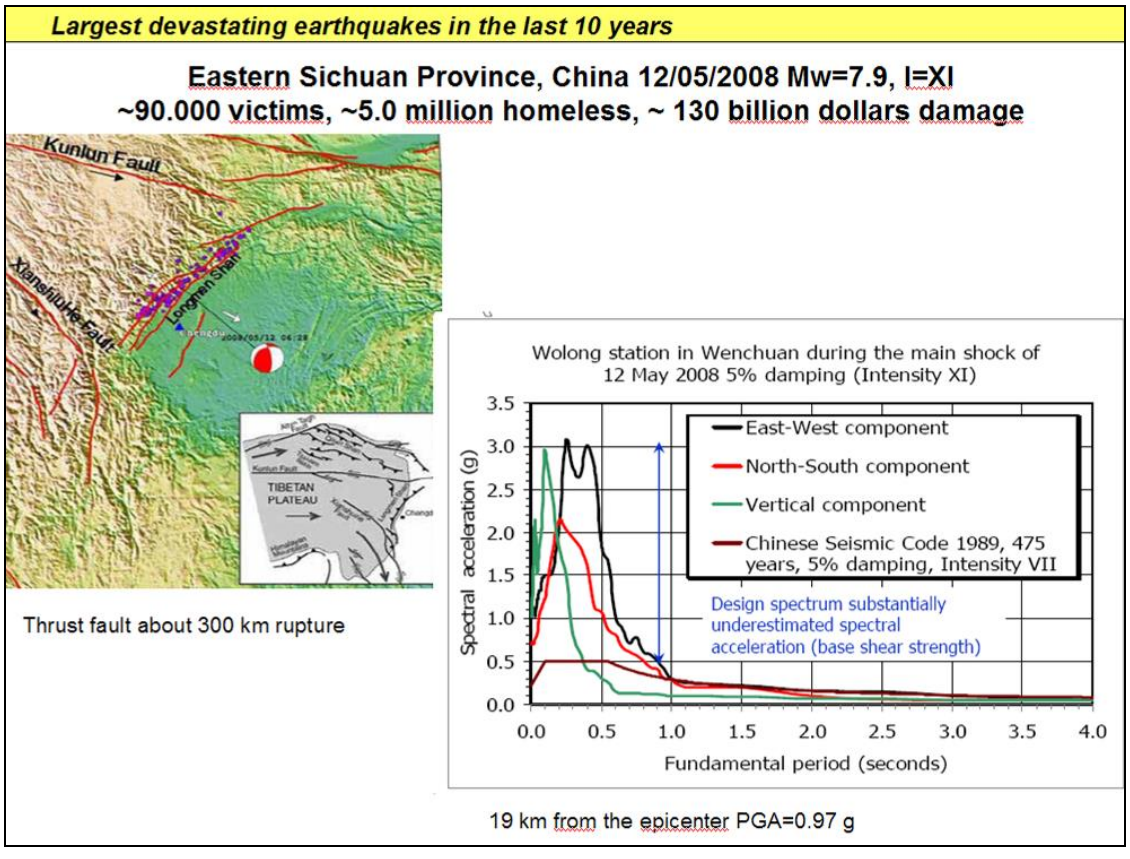
Messina - Italy, 1908
Ms = 7.2
Io = XI MCS
86.000 victims

Mexico City, 1985
Ms = 8.1
9.500 victims

Kobe – Japan, 1995
Ms = 7.2
5,500 victims
230,000 homeless
70 billions dollars damage

Turkey, Izmit 1999, Ms=7.8, Mw=7.4 about 17,000 victims, about 20,000 missing

Largest devastating earthquakes and tsunami in the last 10 years

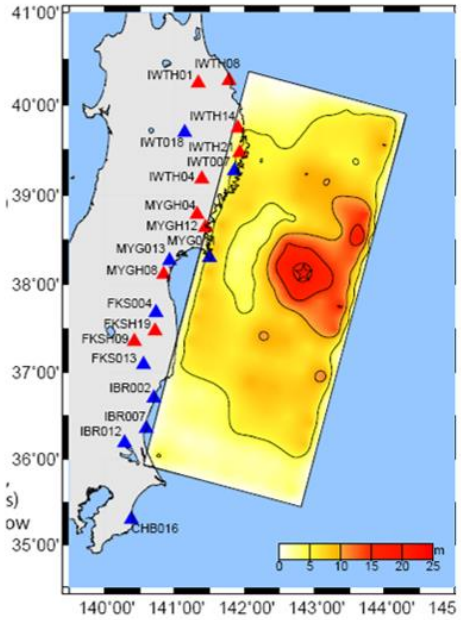


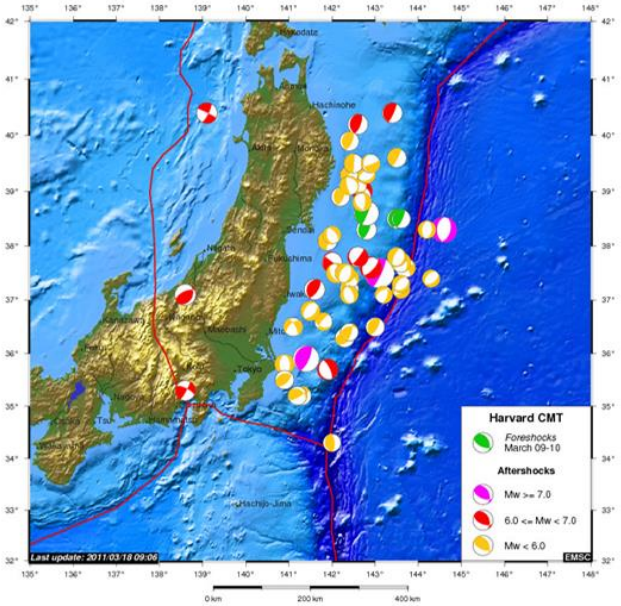
Largest devastating earthquakes in the last 10 years

Port au Prince - Haiti 12/01/2010 Mw=7.0, I=X
~200.000 victims, ~1.5 million homeless

Largest devastating earthquakes and tsunami in the last 10 years

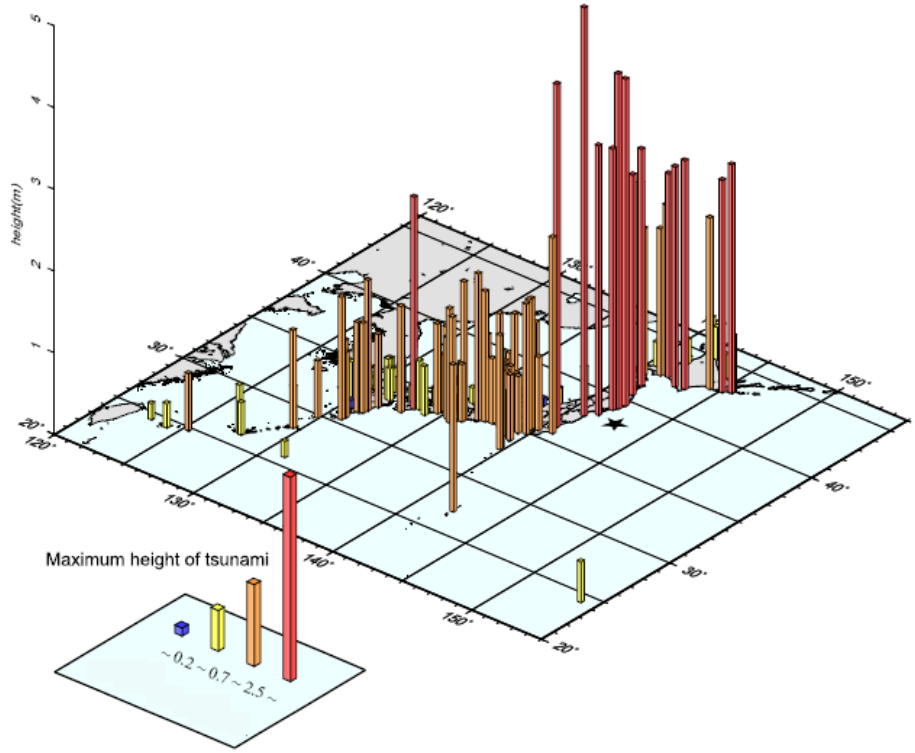
East coast Honshu Japan 11/03/2011 Mw=9
20-30.000 victims ? (TSUNAMI) 150 billion dollars damage?
the largest earthquake ever recorded in Japan, among the 5 largest earthquakes recorded worlwide





Largest devastating earthquakes and tsunami in the last 10 years

East coast Honshu Japan 11/03/2011 Mw=9

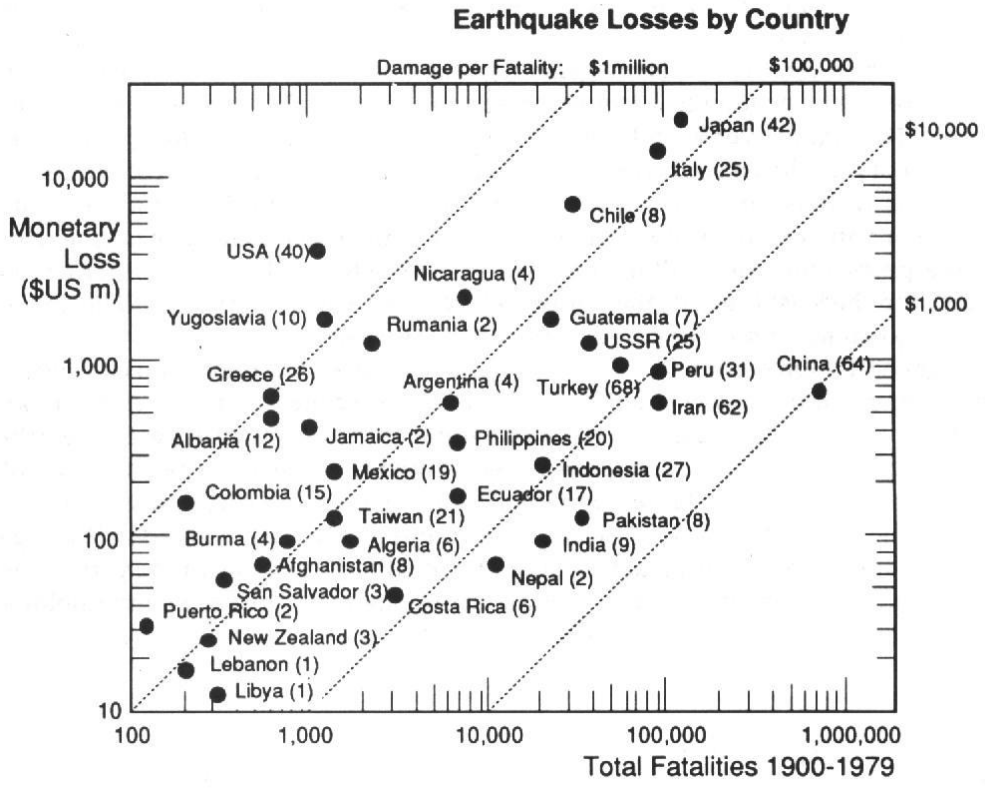


Observed Tsunami (time and height)

World greatest earthquakes (in terms of victims) during the last 30 years *of XX century*

Date	Region	Victims	Ms
1970.05.31	Peru	66,000	7.8
1971.02.09	California, S.Fernando	65	6.5
1972.12.23	Nicaragua, Managua	5,000	6.2
1976.02.04	Guatemala	22,000	7.9
1976.05.06	Italy, Friuli	965	6.5
1976.07.27	Cina, Tangshan	250,000	7.6
1977.03.04	Romania, Vrancea	2,000	7.2
1980.10.10	Algeria, El Asnam	3,500	7.7
1980.11.23	Italy, Irpinia	2,914	6.9
1981.06.11	Southern Iran	3,000	6.9
1982.12.13	Yemen	2,800	6.0
1985.09.19	Mexico, Michoacan	9,500	8.1
1988.12.07	Turkey	25,000	7.0
1989.10.17	California, Loma Prieta	62	7.1
1990.06.20	Iran	50,000	7.7
1994.01.17	California, Northridge	57	6.7
1995.01.17	Japan, Kobe	5,466	7.2
1999.08.17	Turkey, Izmit	17,000	7.8

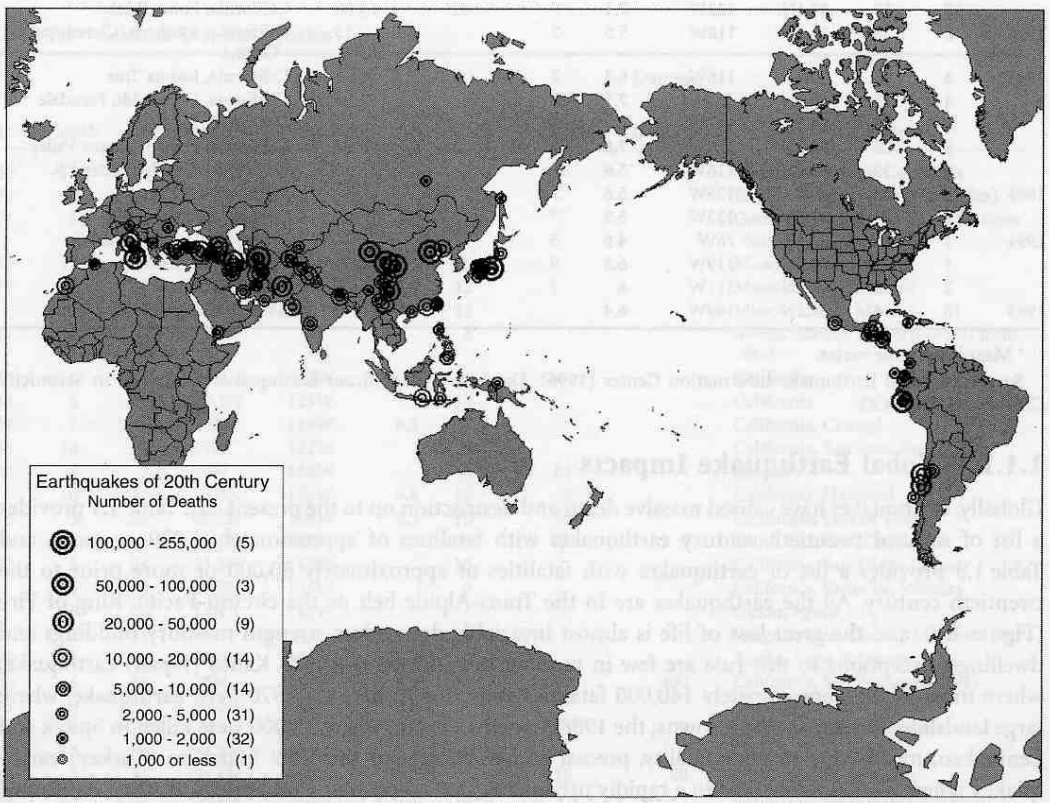
Earthquakes losses and Economy



Fatalities and economic losses in earthquakes by country; the numbers in parentheses are the numbers of earthquakes per country (Coburn & Spence, 1992).

Economic losses due to earthquakes from 1972-1990 (Coburn & Spence, 1992)

Country	Earthquake	Year	Loss ($bn)	GNP that year ($bn)	Loss (%GNP)
Nicaragua	Managua	1972	2.0	5.0	40.0
Guatemala	Guatemala City	1976	1.1	6.1	18.0
China	Tangshang	1976	6.0	400.0	1.5
Romania	Bucharest	1977	0.8	26.7	3.0
Yugoslavia	Montenegro	1979	2.2	22.0	10.0
Italy	Campania	1980	45.0	661.8	6.8
Mexico	Mexico City	1985	5.0	166.7	3.0
Greece	Kalamata	1986	0.8	40.0	2.0
El Salvador	San Salvador	1986	1.5	4.8	31.0
USSR	Armenia	1988	17.0	566.7	3.0
USA	Loma Prieta	1989	8.0	4,705.8	0.2
Iran	Manjil	1990	7.2	100.0	7.2
Philippines	Luzon	1990	1.5	55.1	2.7



Selected earthquakes since 1900 (fatalities greater than 1000).

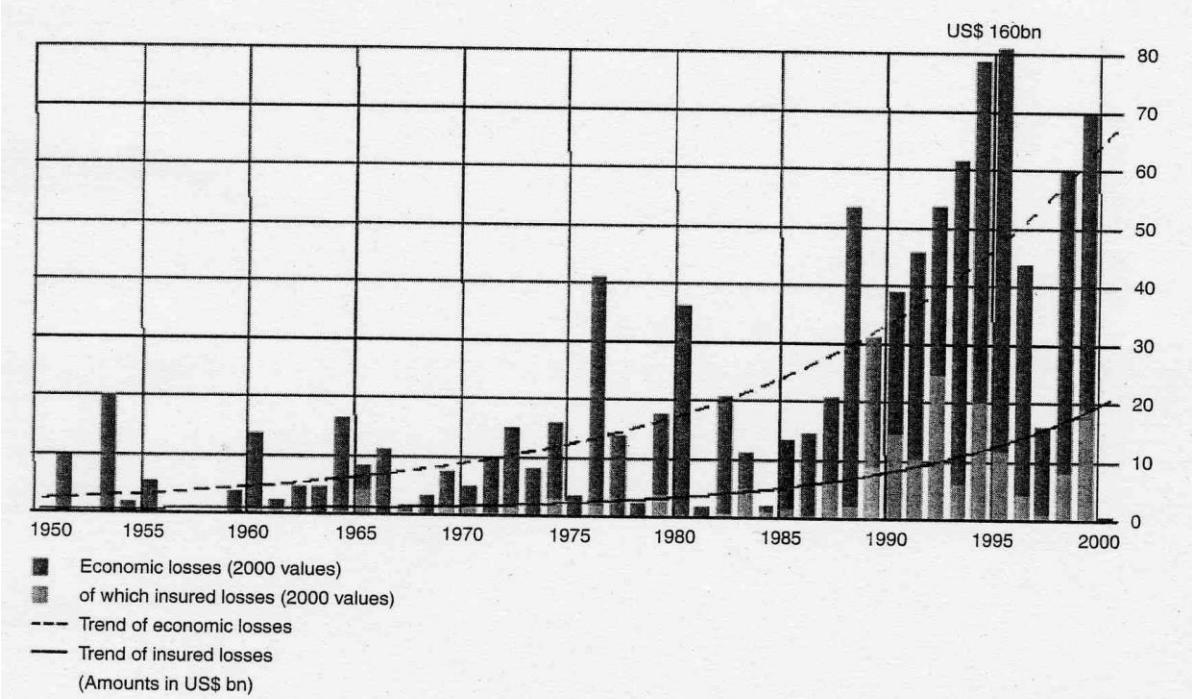
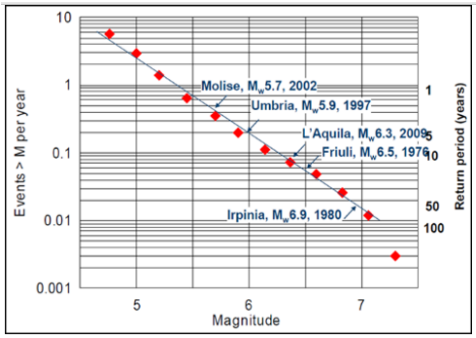
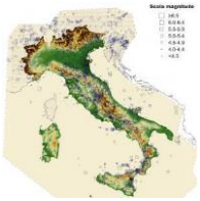


FIGURE 1.3 Trend of worldwide economic and insured losses. (From Munich Reinsurance.)

Italian seismicity



Le dimensioni del problema sismico in Italia



- a partire dall'anno 1000, secondo il Catalogo Parametrico dei Terremoti Italiani CPTI15, si sono verificati **4.860** eventi **220** dei quali di forte intensità **(>= VIII grado scala Mercalli) un terremoto distruttivo in media ogni 4 anni**
- negli ultimi **54** anni i terremoti hanno causato danni per oltre **150** miliardi di Euro. Una spesa di **circa 3 miliardi di euro ogni anno** sostenuta dal Governo
- negli ultimi **120 anni** i terremoti hanno causato più di **120 mila vittime** (delle quali 80000 dovute al solo terremoto di Messina del 1908) e distrutto una parte consistente del patrimonio storico, artistico e culturale il cui valore non è quantificabile
- il rapporto tra i **danni prodotti dai terremoti in Italia** e l'**energia** associata agli stessi è **molto più alto rispetto a quello di altri paesi ad elevata sismicità** quali la California o il Giappone
- il motivo di queste forti differenze dipende dall'**elevato livello di vulnerabilità del patrimonio edilizio italiano**. Ciò è dovuto alla presenza di un gran numero di edifici storici o di antica costruzione, al degrado di estesi quartieri nelle grandi aree metropolitane e all'edilizia illegale particolarmente diffusa nel centro-sud, proprio dove la pericolosità è maggiore.

Terremoti in Italia: dati storici

(Io≥VII) negli ultimi 54 ani

Earthquake	Date	Mw	Io MCS	Victims	Homeless	Source	Damage M€
Belice	15/01/1968	6.5	X	290	100,000	***	9,179
Tuscania	06/02/1971	5.2	VI-VII	20	4,000	*	*1,807*
Parmense	15/07/1971	5.7	VIII	1	1,000	*	*704*
Ancona	14/06/1972	5.5	VIII	0	30,000	*	*7,112*
Friuli	06/05/1976	6.5	X	978	200,000	*	18,540
Valnerina	19/09/1979	5.8	VIII-IX	5	25,000	*	*6,283*
Irpinia	23/11/1980	6.8	X	2,914	280,000	*	52,026
Appennino abruzzese	07/05/1984	5.8	VIII	0	6,000	*	*2,381*
Sicilia sud-orientale	13/12/1990	5.4	VII	12	15,000	*	*4,439*
Umbria-Marche	26/09/1997	5.7	VIII	11	38,000	***	13,463
Appennino Lucano	09/09/1998	5.5	VII	1	650	**	*525*
Molise	31/10/2002	5.7	VII-VIII	30	3,000	**	1,400
Salò	24/11/2004	5.0	VII-VIII	0	2,000	**	*1,128*
L'Aquila	06/04/2009	6.3	IX-X	309	67,460	****	17,458
Emilia	29/05/2012	6.0	VII-VIII	17	16,520	**	8,171
Amatrice	24/08/2016	6.2	X	299	31,760	****	13,163
			TOTAL	**4,887**	**820,390**		**157,778**
			per year	**92**	**15,479**		**2,977**

Catalog CFTI5med	*
Web	**
Specific study	***
Civil protection	****

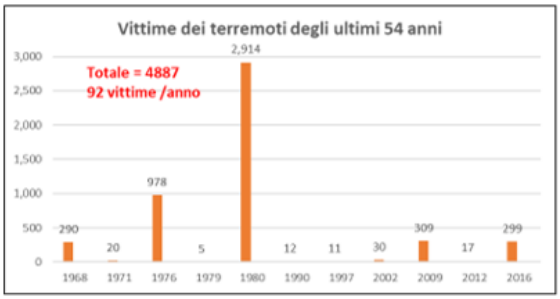
I dati sui senzatetto e sui danni sono affidabili solo per gli ultimi 50 anni

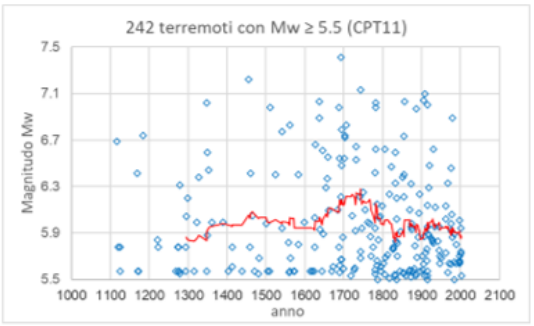
Le vittime per anno salgono a 994 se si contano dall'inizio del XX secolo (Messina 1908 e Avezzano 1915 sommano 113.000 vittime il 94% del totale)
Il valore più attendibile è probabilmente quello riferito all'intero catalogo che dà **407 vittime/anno**

(Io≥X, Mw ≥6.6) negli ultimi 853 anni

Year	Earthquake	Io	Mw	Victims
1169	Sicilia orientale	X	6.4	15,000
1328	Norcia	X	6.4	2,000
1349	Lazio meridionale-Molise	X	6.6	2,500
1456	Molise	XI	7.2	25,000
1461	Aquilano	X	6.4	150
1542	Siracusano	X	6.8	200
1561	Valle di Diano	X	6.8	584
1627	Gargano	X	6.7	5,000
1638	Crotonese/Calabria	X	6.9	30,000
1659	Calabria centrale	X	6.6	2,035
1688	Sannio	XI	7.0	10,000
1693	Sicilia orientale	XI	7.4	54,000
1694	Irpinia-Basilicata	X	6.8	4,820
1695	Asolano	X	6.5	150
1702	Beneventano-Irpinia	X	6.5	400
1703	Aquilano	XI	6.7	9,670
1706	Maiella	X-XI	6.8	2,400
1732	Irpinia	X-XI	6.6	1,940
1781	Appennino marchigiano	X	6.4	300
1783	Calabria	XI	6.6	35,170
1805	Molise	X	6.6	5,573
1832	Crotonese	X	6.6	234
1851	Basilicata	X	6.4	1,000
1854	Cosentino	X	6.2	500
1857	Basilicata	XI	7.0	19,000
1908	Calabria-Messina	XI	7.1	80,000
1915	Avezzano	XI	7.0	33,000
1919	Mugello	X	6.3	100
1920	Garfagnana	X	6.5	171
1930	Irpinia	X	6.6	1,404
1968	Valle del Belice	X	6.3	290
1976	Friuli	X	6.5	978
1980	Irpinia-Basilicata	X	6.9	2,735
2009	L'Aquila	X	6.3	309
2016	Amatrice	X	6.2	299
			TOTAL	**346,912**
			Per year	**407**

Costo dei terremoti in Italia

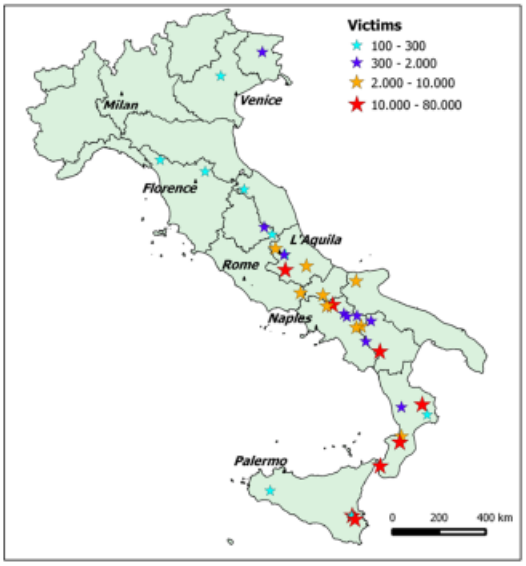




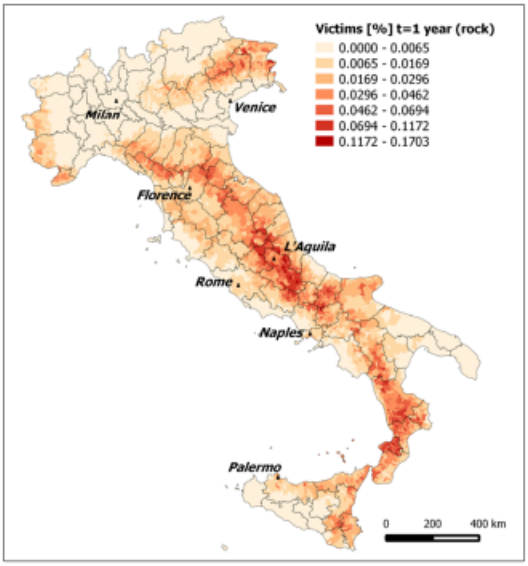
Il valore più attendibile è probabilmente quello riferito ai terremoti distruttivi dell'intero catalogo (CFTI5Med-Guidoboni et al. 2019), che media sulle variazioni di breve periodo e fornisce una stima di circa**407 vittime/anno**

La spesa globale in 54 anni (1968-2022) è di circa 158 miliardi di euro, per un valore di circa **3 miliardi di euro** spesi, in media, **ogni anno dal Governo italiano** solo per il costo dei danni diretti causati dai terremoti.

Mappe di rischio sismico in termini di vittime

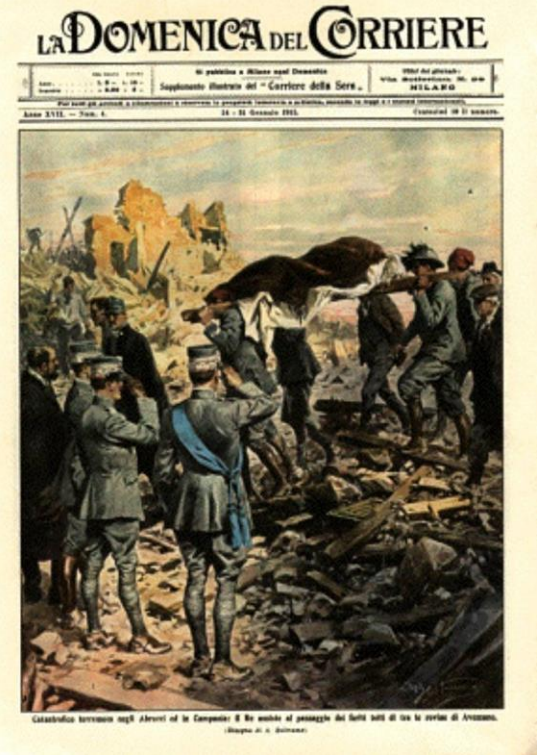


Numero di vittime relative a terremoti degli ultimi 853 anni con intensità ≥ X grado della scala MCS



Percentuale media annua del numero di vittime atteso nei comuni italiani

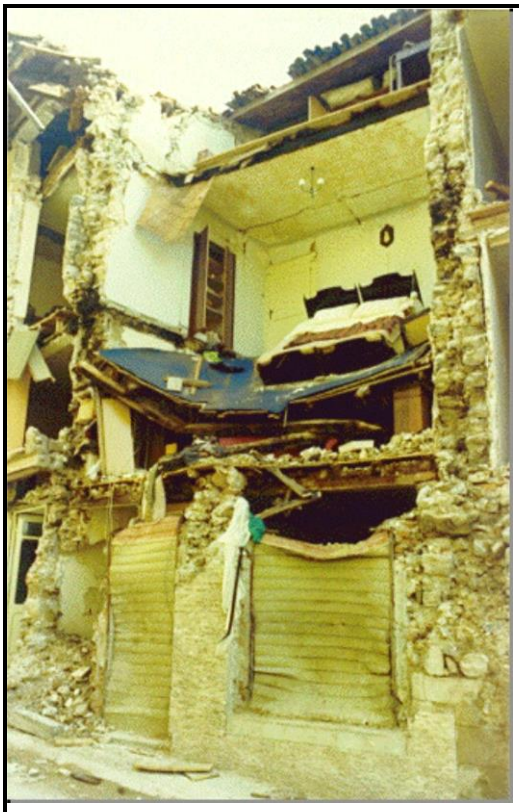
50



Cover of a famous Italian magazine of January 14 1915

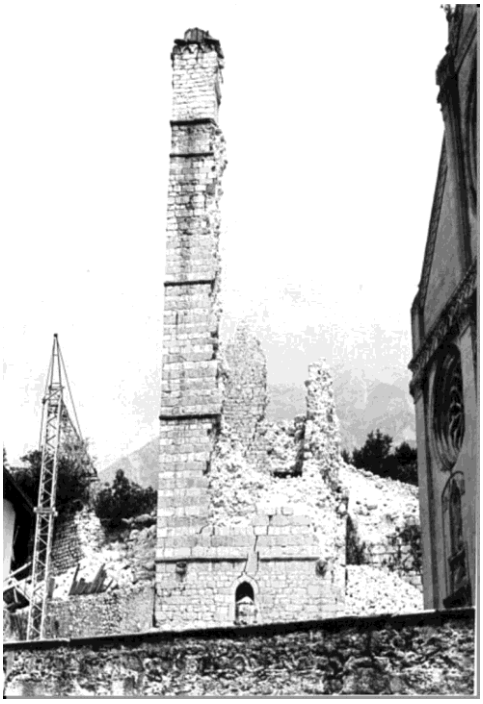
Fucino - Avezzano, 1915
Ms = 7.0
Io = XI MCS
32,610 victims

Avezzano : collapsed Cathedral



Gemona: collapsed field stone masonry

Friuli, 1976
Ms = 6.5
Io = IX-X MCS
965 victims



Gemona : Cathedral bell tower

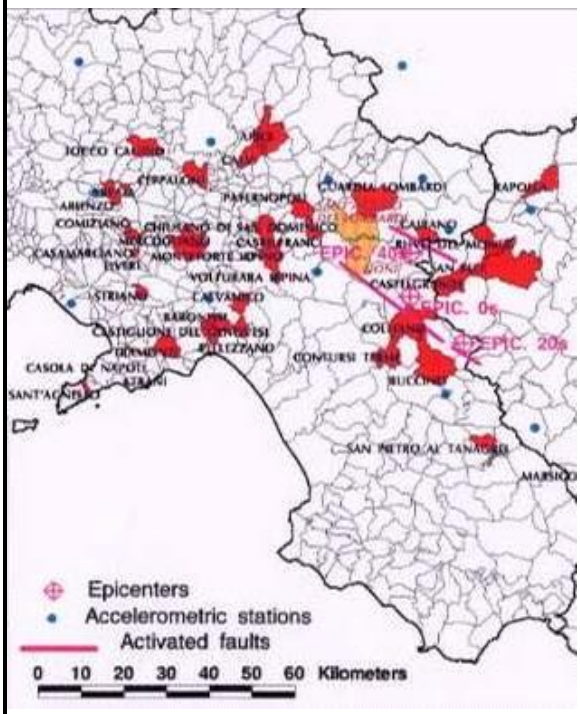
Irpinia, 1980
Ms = 6.9
Io = IX-X MCS
2,914 victims

village of Balvano after the earthquake

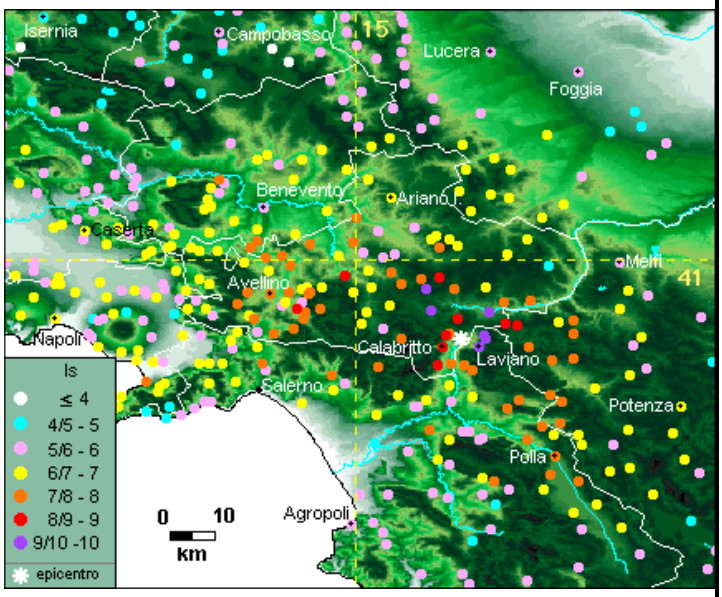
village of Balvano today

Irpinia 23-Nov-1980

Victims	Injured	Collapsed dwellings	Damaged dwellings	Homeless	Damaged municipal.
2735	8850	27627	470729	300000	639



Epicenters, faults, and damage surveys



Intensity (MCS) distribution

Umbria-Marche 1997
Ms = 5.9
Io = VIII-IX MCS
11 victims

Partially retrofitted building in Sellano

Masonry building damaged in Cesi

Lessons learned from the Umbria Marche Earthquake contributed to a substantial improvement of the Italian Civil Defence organization regarding in particular:

- ***emergency management***
- ***seismic risk reduction policies***

Molise 2002
Ms = 5.6
Io = VII-VIII MCS
30 vittime
12000 senza tetto

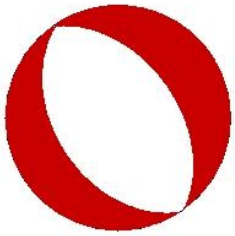
Recenti terremoti italiani

Terremoto de L'Aquila del 6 aprile 2009

Date 04/06/09 Region CENTRAL ITALY Ml 6.2 Mw 6.3
Centroid Location:
Or. Time 1:32:47.2 Lat. 42.32 N Long. 13.32 E Dep 12. fixed

Best Double Couple M0: 3.7*10**25
P1 str: 147 dip: 43 slip: -88
P2 324 47 -92

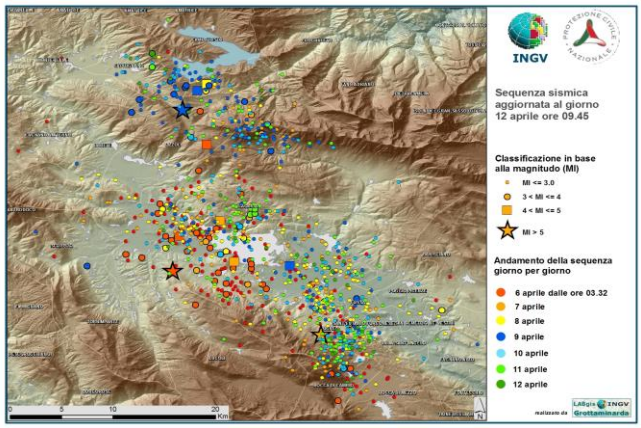
040609A



Moment Tensor (10**25 dyn-cm)
mrr: -3.75 mtt: 1.22 mff: 2.53
mrt: 0.23 mrf: -0.16 mtf: -1.71

Principal Axes
T val: 3.72 plg: 2 az: 55
N 0.05 1 325
P -3.76 88 200

DATA USED: MEDNET
AUTHOR: INGVBO

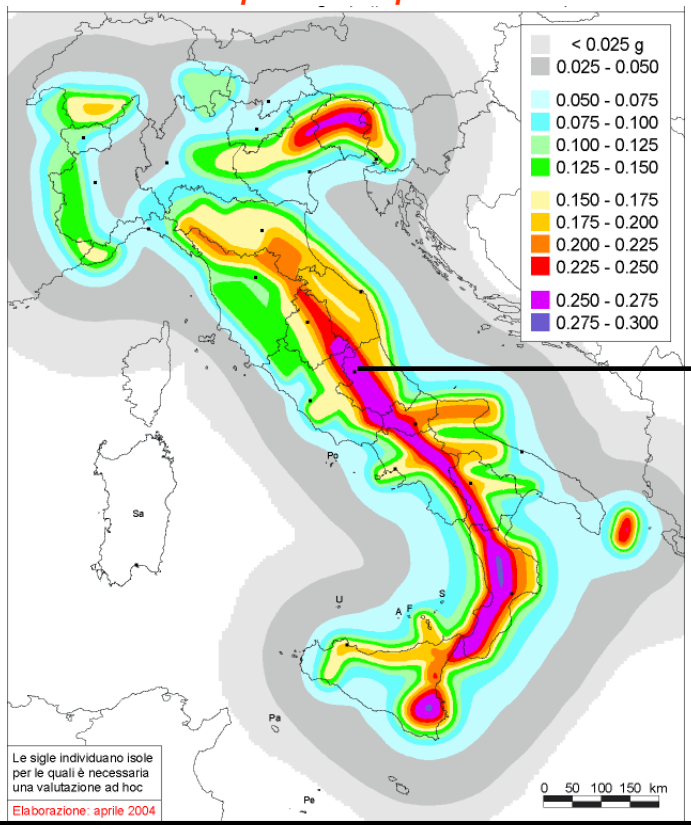


L'Aquila 6 aprile 2009

L'evento di **Mw=6.3 e profondità 9 km**, si è verificato alle ore 03:33 locali a circa 5 km a sud-est della città dell'Aquila su di una faglia normale con orientamento NW-SE ed immersione di circa 45° verso SW.

Questo terremoto ha generato, considerando anche le numerose repliche, la più grande e completa mole di dati sperimentali mai ottenuta in Italia per un singolo evento (registrazioni accelerometriche e sismometriche a larga-banda, interferometria, GPS, rilievi macrosimici e di danno, etc.)

Terremoto de L'Aquila del 6 aprile 2009



Mappa di pericolosità in PGA per Tr= 475 anni (INGV 2004) pubblicata sulla Gazzetta Ufficiale n. 147 del 11/05/06

L'Aquila classificata in zona 2 dal 07/02/1915
PGA = 0.26 g (475 anni)
Popolazione = 66.813
Abitaz. classe A = 21%
Abitaz. classe B = 11.2%
Abitaz. classe C = 67.8%

Indice di rischio sismico =0.26
(media Italia = 0.11)
1081° posto su 8100 comuni italiani

Terremoto de L'Aquila

The earthquake affected globally a territory of about 2,400 km^2 with a population of 140,000 causing severe loss of lives (**308 victims and 1,600 injured**) and damage (about **23,000 unusable buildings**).

Terremoto de L'Aquila del 6 aprile 2009

A great part of the artistic and cultural heritage has also been damaged (churches as "Chiesa delle Anime Sante" and "Basilica di Collemaggio", Town Hall, National Museum, etc.)

F. Sabetta 5. 59

Onna 21 aprile

L'intensità assegnata a Onna è del X grado e la distruzione molto significativa (foto qui sotto)

Alcuni case recenti e ben costruite non hanno quasi subito danni (foto a lato)

Hotel Duca degli Abruzzi

Prima e dopo

L'Aquila Via Roma
5 giugno

Interno

Esterno

Terremoto Emilia del maggio 2012

Evento sismico del 20 maggio

www.protezionecivile.gov.it

Ore 4.04: evento sismico di magnitudo (Ml) **5.9**

Ore 4.30: convocazione del Comitato Operativo
(rimarrà attivo fino al 23 maggio)

Prime 48 ore

Popolazione assistita: 5.300

Forze in campo: 3.900 uomini

- volontari: 1.200
- VVF: 700
- altre strutture operative: 2.000

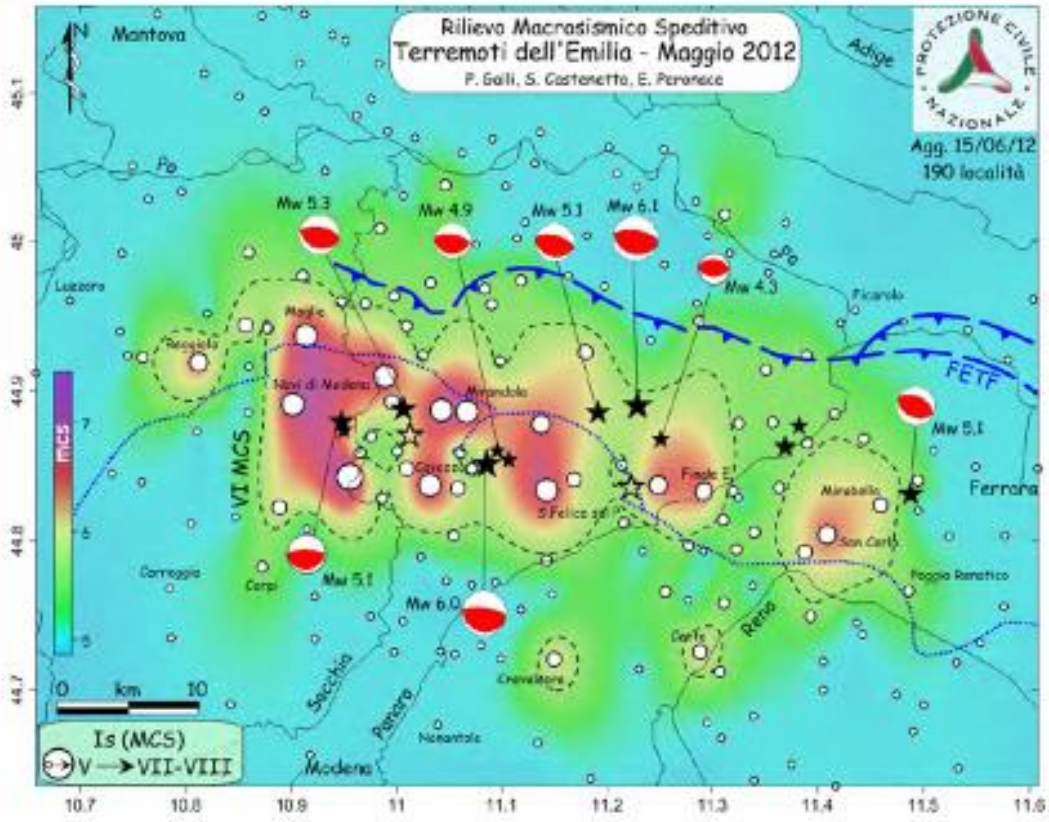
Il Consiglio dei Ministri dichiara, con decreto del 21 maggio, l'**eccezionale rischio di compromissione degli interessi primari** a causa dell'evento sismico ai sensi della L. 286/2002.

Il **22 maggio** il Consiglio dei Ministri delibera lo **stato di emergenza** per i territori delle province di Ferrara, Modena, Mantova e Bologna fissandone la durata a 60 giorni.

Il **coordinamento** degli interventi è affidato al **Capo del Dipartimento** della Protezione Civile.

OCDPC n. 1 *primi interventi urgenti di protezione civile per il soccorso, l'assistenza alla popolazione e gli interventi provvisionali strettamente necessari per le popolazioni colpite dal terremoto.*

Terremoto Emilia del maggio 2012



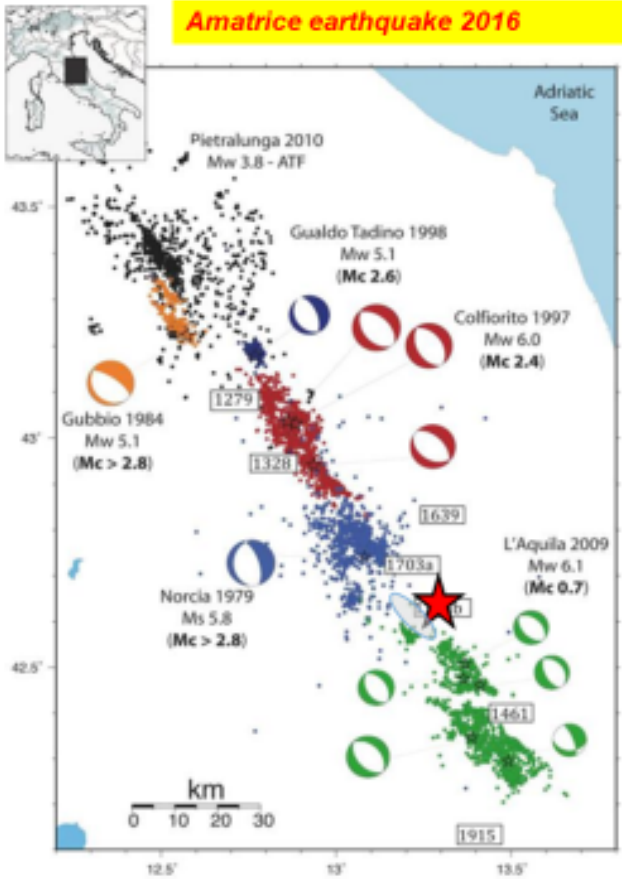
Terremoto Emilia del maggio 2012

Crollo del coronamento delle ceramiche Sant'Agostino alla periferia dell'omonimo

Fig. 6 – Finale Emilia, crollo della torre civica e del timpano del duomo ripresi la mattina del 20 Maggio 2012. La torre è successivamente crollata interamente nel corso della sequenza.

Fig. 9 – San Carlo. Cedimento differenziale di un edificio misto in c.a. e muratura per liquefazione con sviluppo di lesioni di livello 3. A destra, poco lontano, evidenze di liquefazione di sabbie

Amatrice earthquake 2016



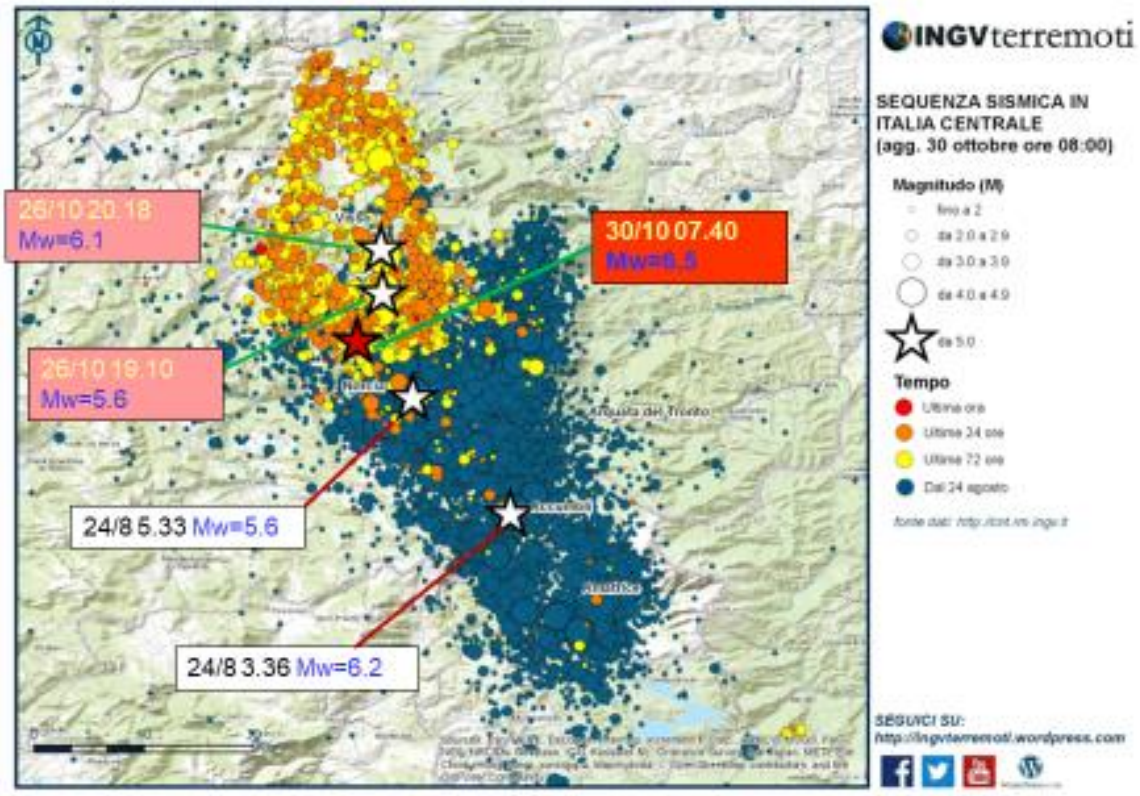
On August 24, 2016, at 03:36 (local time) a ML 6.0 earthquake (Mw 6.2) struck an extensive portion of the Central Apennines between the towns of Norcia and Amatrice.

The epicenter was located near the town of Accumoli. The area was struck by several earthquakes in historical times (1627, 1639, 1672, 1703;)

The seismogenic structure is oriented NNW-SSE and extends about 25-30 km between the towns of Norcia and Amatrice with a width of about 10-12 km and a depth of 10-12 km.

Amatrice-Norcia earthquake 2016

Distribuzione degli epicentri dal 24 agosto al 30 ottobre



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Amatrice-Norcia earthquake 2016

24th August 2016 3.36 a.m.- Earthquake Mw 6.2
297 victims, 386 injured, 4800 homeless

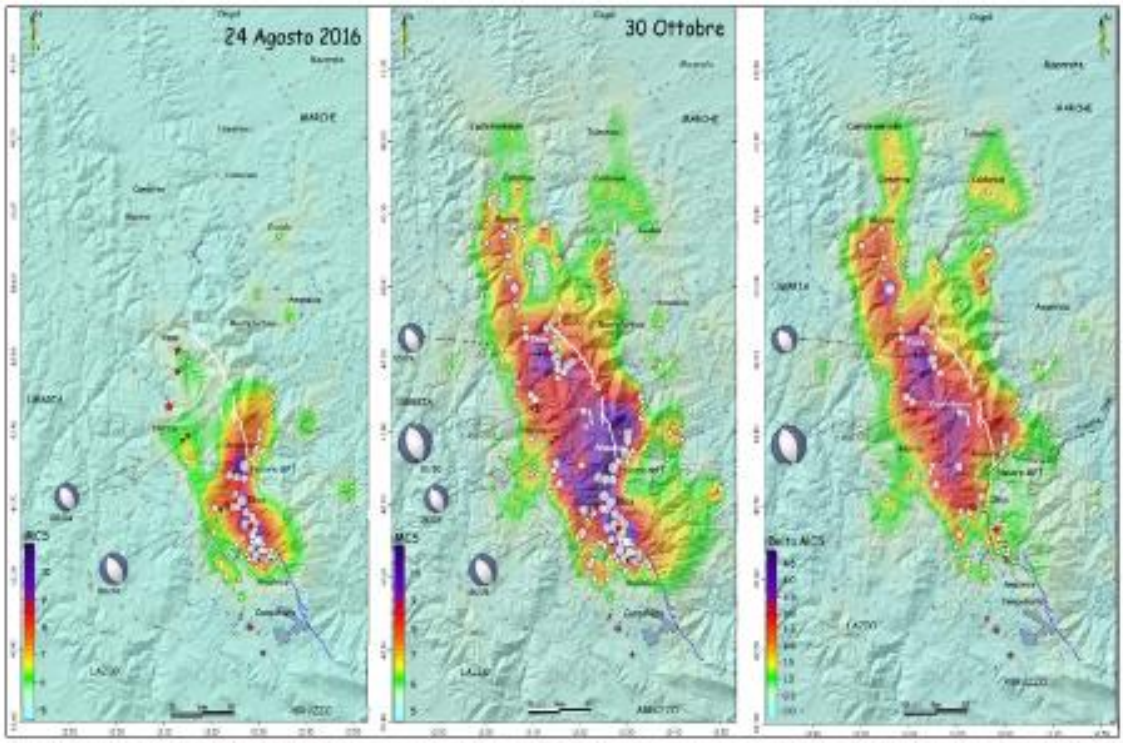
- 4.30: Operational Committee of Civil Protection meeting and DPC teams departure
- 6.00: Activation of all the operative teams (SAR) of the National Civil Prot Service
- August 25: Government approves Emergency state in the 4 affected Regions with a duration of 180 days
- Agust 28: Organisation of the Direction of Command and Control in Rieti (60 km from epicenter)
- August 30: Designation of the Special Government Commissioner for the reconstruction
- October 17: Governmental decree for the reconstruction assigning an initial budget of 200 Million Euro for the year 2016. The reconstruction will be managed by "Special Offices for the Reconstruction" established in each of the 4 Regions struck by the earthquake and coordinated by the Special Governement Commissioner. Each private citizen is allowed to have 100% of refund of the expenses for rehabilit/reconstr of his house provided a technical expertise testifying the damage caused by the 2016 earthquake. Reconstruction companies must be registered to a «white list» (antimafia)

26th October 2016 8.18 p.m.- Earthquake Mw 6.1
no victims, 4 injured, 4000 homeless

- October 27: Government extend Emergency state to the new affected areas with a further initial budget of 40 Million Euro

30th October 2016 7.40 a.m.- Earthquake Mw 6.5
no victims, 20 injured, 15000 homeless

Amatrice-Norcia earthquake 2016



Distribuzione dell'intensità macrosismica dopo i terremoti del 24.8.2016 (sinistra), del 30.10. 2016 (centro) e differenza tra i valori assegnati (destra) (Galli et al., 2016).

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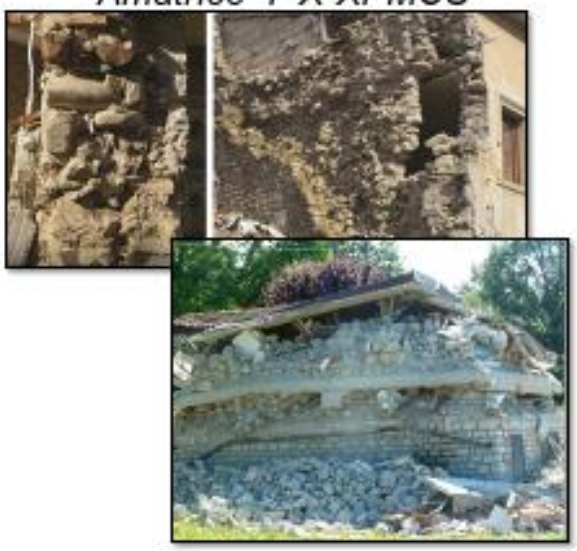
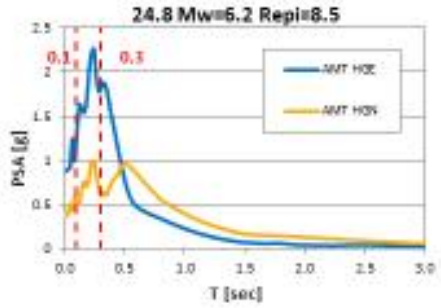
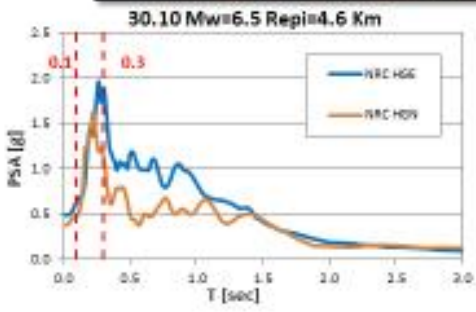
Amatrice I=X-XI MCS



Norcia I=VII-VIII MCS





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Amatrice earthquake 2016

Fire Brigades S.A.R.
Amatrice 25 August 2016

Amatrice earthquake 2016

Comune di Amatrice, casa a due piani in muratura con cordoli in c.a. alla periferia nord della frazione San Lorenzo e Flaviano SP 20, prima e dopo il IX-X° della scala Mercalli rilevato in tale area.

BEFORE

AFTER

In questo punto è stato recuperato un ragazzo che dormiva al primo piano che, grazie alla presenza di un grosso armadio che gli ha fatto da scudo dal tetto collassato, si è salvato.

Amatrice earthquake 2016

Progressive destruction of downtown Amatrice looking west along Corso Umberto I. (a) Before the earthquake (Google earth image). (b) After the24 August event (Is 10–11 MCS). (c) After the 30 October event (Is 11 MCS); note the collapse of the still-standing red, five-story R.C. building (happened during the 26 October earthquake) and the amazing strength of the medieval civic tower that lost only its canopy.

Galli et al. Tectonics 2017