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Considerations on the assessment of macroseismic intensity

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Abstract
Following a brief overview on the main characteristics of MCS (1930; the most employed in Italy), MSK (1981) and EMS (1992) macroseismic scales, considerations on their validity to underline the severity of damage on buildings are reported and discussed. Observations carried out on damage related to recent Italian earthquakes show that the seismic behaviour of buildings does not fit that provided by the scales, particularly with regard to the relationship «vulnerability class vs. building type».

Key words *earthquakes – macroseismic intensity scales*

1. Introduction

It is well known that the assignment of macroseismic intensity involves several issues, essentially dealing with the difficulty of defining the effects of earthquakes in simple and synthetic patterns, as those proposed by the macroseismic scales. It is also known that the extent of effects may depend not only on the seismic shaking, but also on a great number of factors which amplify or reduce them.

In Italy, the most employed macroseismic scale is the Mercalli-Cancani-Sieberg (MCS), used since the beginning of the century. The Medvedev-Sponheuer-Karnik (MSK) scale was only defined in 1964 and modified in 1981. This scale is generally employed in European countries.

In consideration of the various problems involved in the practical application of both scales and of the recent presentation of the European Macroseismic Scale (EMS) by the European Seismological Commission (Grünthal, 1993), it seems useful to examine the problem of the assessment of macroseismic intensity, especially in view of possible future use of the EMS scale.

2. Main scale characteristics

As far as the lower degrees ($\leq$ V degree), based on effects on man, are concerned, all three scales (MCS, MSK and EMS) are practically identical. Thus comparison is significant only for higher degrees and particularly with regard to damage to buildings.

At the moment, the MCS scale seems to be generally inadequate for two main reasons:

1) it is based on generical and mainly qualitative descriptions of the effects; this may lead to nonhomogeneous use;

2) the scale is well geared to study «old» earthquakes (those which occurred earlier than the last 50 years), for it does not consider the specific vulnerability of more recent building types.

Therefore the MCS scale better fits the study of «old» earthquakes: for such events it is almost impossible to identify the precise building type and detailed descriptions of damage are often lacking. It should also be stressed that the application of the MCS scale to these

earthquakes may provide intensity values higher than those provided by the other scales. This is due to the fact that past earthquakes more frequently involved towns with very vulnerable buildings, on account of poor maintenance, workmanship, quality of materials or other reasons.

The MSK scale is notoriously different from the MCS one, since it introduces various types of differentiations:

– three vulnerability classes; these are directly linked to three types of structure (buildings) briefly defined as follows: buildings made of fieldstone (type A), of bricks or hewn stone blocks (type B) and of precast concrete skeleton (type C);

– five degrees of damage;

– a key for using quantitative adjectives («many» corresponds to 10-50%, «single, few» to ≤ 10%, etc.).

Observations carried out during recent Italian earthquakes show that the seismic behaviour of buildings does not correspond to the MSK scale.

An instance of this drawback is shown by a document (Regione Basilicata, 1981) produced by the Genio Civile of Potenza, on the Irpinia 1980 earthquake. It assesses damage to public buildings (schools, town halls, hospitals, etc.) in 41 municipalities of Basilicata and Campania. The document points out that serious damage and destruction were significantly greater in buildings with reinforced concrete structures as compared with bricks and also with tufa or tuff blocks (such blocks are generally made of easily cuttable porous stone).

Table I shows the percentage of damage, as reported by the original document. Damage degree is classified according to:

– four structure types (fieldstone, tufa or tuff blocks, bricks and reinforced concrete);

– four intensity classes (degrees VI-VII, VII-VIII, VIII-IX and X of a not-so-well defined «Mercalli» scale;

– three levels of damage (undamaged or slightly damaged, heavily damaged and destroyed).

It can be noticed that:

– there is a higher percentage of damage for all classes of intensity in fieldstone buildings, which definitely seem to be the least resistant;

– brick buildings and, to a lesser degree, those made of tufa or tuff blocks sustained limited damage for high-intensity classes (VIII-IX and X degree);

– buildings in reinforced concrete sustained relatively serious damage for high-intensity classes (VIII-IX and X degree), while for lower intensity classes (VI-VII and VII-VIII degree) they clearly appear less damaged.

As for reinforced concrete buildings then, the situation seems to point out, in disagreement with the MSK scale, that vulnerability is definitely greater than in buildings made of bricks and tufa or tuff blocks and there is an irregular increase in damage correlated to the increase in shaking.

On the other hand, works by Braga *et al.* (1982) and Dolce and Liberatore (1984) on building damage due to the 1980 Irpinia earthquake, considered that «...attempts to classify areas struck by earthquake made by employing these directives (of MSK) lead to non-univocal solutions; this is essentially due to the generical descriptions of the scale and to the inconsistency between scale operational definition and reality...».

The case of the effects of the Tuscania February 6, 1971 earthquake (Bartolucci *et al.*, 1972) is different. Town damage shows a great divergence, greater than that pointed out by the MSK scale, between damage to buildings in masonry in the older, central part of the town and buildings with reinforced concrete structure in the town outskirts. The very serious damage to the first group, with many destroyed and many entirely collapsed buildings, corresponds to a nearly complete lack of damage in the second group.

Irregularities in the application of the MSK scale were noted in the assessment of damage caused by the 1976 Friuli earthquake. As it can be checked later on, if the MSK-81 scale is applied to data collected by the CNEN-ENEL Commission (1976a,b) related to the damage sustained by eight severely hit municipalities, assessment of intensity may sometimes differ according to the building type.

The EMS scale (1992) differs from the

Table I. The Irpinia earthquake of November 23, 1980; percentages of damage to public buildings in 41 municipalities of Basilicata and Campania (Anonymous, 1981).

Intensity classes (Mercalli scale)	Structure types	Public buildings		
		Undamaged or slightly damaged	Heavily damaged	Destroyed
VI-VII degree	Fieldstone	77.0	22.3	0.7
	Tufa or tuff	71.5	27.5	1.0
	Bricks	92.8	6.5	0.7
	Reinforced concrete	96.4	3.6	0.0
VII-VIII degree	Fieldstone	44.0	45.5	10.5
	Tufa or tuff	54.3	41.1	4.6
	Bricks	88.6	10.2	1.2
	Reinforced concrete	91.3	8.4	0.3
VIII-IX degree	Fieldstone	29.5	37.8	32.7
	Tufa or tuff	68.6	25.3	6.1
	Bricks	82.0	16.0	2.0
	Reinforced concrete	50.3	31.9	17.8
X degree	Fieldstone	20.1	26.0	53.9
	Tufa or tuff	49.6	43.5	6.0
	Bricks	85.6	11.8	2.6
	Reinforced concrete	39.4	35.4	25.3

MSK-81 especially because it provides six vulnerability classes (A, B, C, D, E and F). The first three correspond well with A, B, and C of the MSK-81. The last three (D, E, F) concern buildings constructed following antiseismic design. Specifications on degree of damage and definition of quantity are practically identical to those of the MSK-81. The EMS further provides a range in each vulnerability class, which takes into account the state of preservation of buildings, the quality of workmanship, and so on.

3. Intensity assessment

CNEN-ENEL Commission (1976a,b) data represent an opportunity to estimate macroseismic intensity applying both the scales generally used (MCS and MSK-81) and the European Scale (EMS) which has recently been proposed and is to be considered on trial. Data were collected in eight municipalities: Buia, Gemona del Friuli, Forgaria nel Friuli, Osoppo, Trasaghis, Maiano, Tarcento and San Daniele del Friuli. Data collection was carried out in June 1976: first of all data on the buildings of each municipality were collected from the respective Technical Offices; later, visits on site were made in order to examine damage and to classify buildings according to type. The limited time available did not allow for in-depth analysis: rubble was being cleared and demolition of destroyed or unsafe buildings was in progress; however data give a significant picture of the damage produced by earthquakes.

Table II displays data for each municipality; ordinary buildings are divided into three types (G1, G2, G3) which correspond quite closely

Table II. The Friuli earthquake of May 6, 1976; percentages of damage to ordinary buildings in heavily damaged municipalities (CNEN-ENEL, 1976a,b).

Municipality	Ordinary buildings						Intensity degrees		
	Type	Number	Undamaged	Slightly damaged	Heavily damaged	Collapsed or to be demolished	MCS	MSK-81	EMS
Buia	G1	1000	0 (0%)	50 (5%)	50 (5%)	900 (90%)		(IX-X)	(IX-X)
	G2	1250	250 (20%)	450 (36%)	250 (20%)	300 (24%)		(IX)	(X)
	G3	10	0 (0%)	5 (50%)	4 (40%)	1 (10%)			
	Tot.	2260	250 (11%)	505 (22%)	304 (14%)	1201 (53%)	IX-X	IX	IX-X
Gemona del Friuli	G1	2300	0 (0%)	50 (2%)	350 (15%)	1900 (83%)		(IX-X)	(IX-X)
	G2	700	0 (0%)	200 (28%)	300 (43%)	200 (29%)		(IX)	(X)
	G3	30	4 (13%)	15 (50%)	3 (10%)	8 (27%)		(IX-X)	(IX-X)
	Tot.	3030	4 (0%)	265 (9%)	653 (21%)	2108 (70%)	X	IX	IX-X
Forgaria nel Friuli	G1	1000	0 (0%)	50 (5%)	150 (15%)	800 (80%)		(IX-X)	(IX-X)
	G2	300	50 (16%)	50 (17%)	150 (50%)	50 (17%)		(VIII-IX)	(IX-X)
	G3	10	5 (50%)	5 (50%)	0 (0%)	0 (0%)			
	Tot.	1310	55 (4%)	105 (8%)	300 (23%)	850 (65%)	X	IX	IX-X
Osoppo	G1	750	50 (7%)	50 (7%)	100 (15%)	550 (73%)		(IX)	(IX)
	G2	300	50 (17%)	100 (33%)	100 (33%)	50 (17%)		(VIII-IX)	(IX-X)
	G3	10	8 (80%)	2 (20%)	0 (0%)	0 (0%)			
	Tot.	1060	108 (10%)	152 (14%)	200 (19%)	600 (57%)	IX-X	IX	IX
Trasaghis	G1	600	0 (0%)	0 (0%)	250 (42%)	350 (58%)		(VIII-IX)	(VIII-IX)
	G2	450	50 (11%)	150 (33%)	100 (23%)	150 (33%)		(IX)	(X)
	G3	0	0 (0%)	0 (0%)	0 (0%)	0 (0%)			
	Tot.	1050	50 (5%)	150 (14%)	350 (33%)	500 (48%)	IX-X	IX	IX
Maiano	G1	600	50 (8%)	100 (17%)	150 (25%)	300 (50%)		(VIII-IX)	(VIII-IX)
	G2	950	150 (16%)	300 (32%)	250 (26%)	250 (26%)		(IX)	(X)
	G3	20	12 (60%)	4 (20%)	0 (0%)	4 (20%)		(X)	(X)
	Tot.	1570	212 (14%)	404 (26%)	400 (25%)	554 (35%)	IX	IX	IX-X
Tarcento	G1	3150	500 (17%)	800 (25%)	1050 (33%)	800 (25%)		(VIII)	(VIII)
	G2	500	150 (30%)	50 (10%)	200 (40%)	100 (20%)		(IX)	(X)
	G3	20	5 (25%)	15 (75%)	0 (0%)	0 (0%)		(VIII-IX)	(VIII-IX)
	Tot.	3670	655 (18%)	865 (24%)	1250 (34%)	900 (24%)	VIII-IX	VIII-IX	IX
San Daniele del Friuli	G1	1600	800 (50%)	550 (35%)	150 (9%)	100 (6%)		(VII)	(VII)
	G2	550	250 (45%)	200 (37%)	100 (18%)	0 (0%)		(VII-VIII)	(VIII-IX)
	G3	150	90 (60%)	60 (40%)	0 (0%)	0 (0%)		(VII-VIII)	(VII-VIII)
	Tot.	2300	1140 (50%)	810 (35%)	250 (11%)	100 (4%)	VII	VII	VII-VIII

to those provided by the MSK-81 (A, B, C); in particular:

– G1 corresponds to «either old, or repaired or recently built houses, with structure in fieldstone, no particular building technique employed and wooden floors»;

– G2 corresponds to «mixed buildings in reinforced concrete and bearing walls in bricks, or prefabricated blocks, with foundations on plinths, or buildings with continuous walls built in concrete and tile lintol floors»;

– G3 corresponds to «buildings in reinforced concrete with skeleton structure».

Buildings in each municipality were divided, according to the damage they had suffered, into the four following groups:

– undamaged;
– slightly damaged (recoverable);
– heavily damaged (partially recoverable);
– collapsed or to be demolished.

Work was organized as follows in order to assess the value of intensity according to the three macroseismic scales being examined:

A) MCS scale; in order to compare it to the other two scales it was applied according to the MSK-81 specifications referring to degree of damage and definition of quantity.

B) MSK-81 scale; it was applied:

– assuming a correspondence between the three types of buildings (G1, G2, and G3) indicated by CNEN-ENEL (1976a,b) and the «A, B, C» categories, provided by the MSK-81;

– the three groups of damage indicated by CNEN-ENEL were placed within the five degrees provided by the scale; although descriptions of the groups of damage are extremely brief in the CNEN-ENEL reports, it appears clear that the «slightly damaged» buildings correspond to degrees 1 and in particular 2 of the MSK-81, the «heavily damaged» ones to degree 3, while the «collapsed or to be demolished» ones to degrees 4 and 5.

C) EMS scale; it was applied with the same procedure of the MSK one, since CNEN-ENEL Commission data do not provide information on the vulnerability ranges required by this scale. It should be stressed however that buildings of the G2 type (bearing structure in bricks or concrete blocks, but floors in reinforced concrete) in the MSK-81 scale correspond to the «B» category, while corresponding to «C» in the EMS scale.

It should be underlined that the whole municipality of Trasaghis, except for the hamlet of Peonis, is classified as belonging to the 2nd seismic category since 1935; but this fact seems to be negligible since Trasaghis is a small mountain town and in the last few decades had only a few new buildings, so that there appear to be none in reinforced concrete.

4. Discussion

Table II details an estimate of the intensity values obtained employing the three macroseismic scales; values for each building type are indicated in brackets. An examination of the table shows:

a) A major presence of buildings with a fieldstone structure (type G1): in five municipalities (Gemona del Friuli, Forgaria nel Friuli, Osoppo, Tarcento and San Daniele del Friuli) they are more than 70%, in one municipality (Trasaghis) more than 50% and in two (Buia and Maiano) about 40%; in the latest two municipalities buildings of G2 type are the greatest part. On the other hand there are very few (generally 1% or less) buildings in reinforced concrete (type G3) except for the municipality of San Daniele del Friuli, where they are about 6-7%.

b) Great differences, sometimes more than one degree, in the MSK-81 values for single building types. Still greater are the differences in the EMS values, as much as two degrees. Not much can be said about the seismic behaviour of buildings in reinforced concrete, since as already mentioned they represent a very low percentage. Only some anomalous percentages of damage can be noted, as in the case of Maiano and Tarcento: the first municipality does not show any «heavily damaged» buildings, while there is a high percentage (20%) of «collapsed or to be demolished» and «slightly damaged» buildings; the second one, instead, appears to have an extremely high percentage (75%) of «slightly damaged» buildings and none in the other classes of damage.

c) Varying differences between the MCS

and MSK-81 values in the various municipalities; in particular, the MCS values are higher than the MSK-81 ones in five cases and identical in three cases. It should be stressed that the five cases are related to the higher values (X and IX-X MCS degree), while the three cases are related to the lower ones (IX, VIII-IX and VII MCS degree).

d) The perfect coincidence of the MSK-81 and EMS values for building types G1 and G3 and the clear difference of one degree for category G2; as already mentioned, this is due to the fact that buildings of the G2 type (bearing structure in bricks or concrete blocks, but floors in reinforced concrete) in the MSK-81 scale correspond to the «B» category, but correspond to «C» in the EMS one. Consequently final values obtained with the EMS scale are generally about half a degree higher than those obtained with the MSK-81 one.

Generally speaking, comparing the intensity estimates obtained with the three analysed scales and considering the various building types in each municipality from the point of view of G1, G2 and G3 categories, no particular correlation or behaviour was noticed. This is probably due to the different vulnerability that buildings of the same category may have in the various municipalities. For instance, it might have been expected that in municipalities with a high presence (higher than 70%) of «G1» type buildings, MCS values would be higher than MSK-81 ones. In practice this was the case, but only in three out of five cases.

5. Conclusions

The intensity estimates provided by the three scales (MCS, MSK and EMS) according to CNEN-ENEL Commission data generally point out irregularities in damage distribution among different building types in comparison to the expectations of the scales themselves. This behaviour was also observed studying 1971 (Tuscania) and 1980 (Irpinia) earthquakes. In the eight cases under consideration the intensity estimates show a overall good agreement: in 5 cases, in fact, differences are within half a degree range and in the other 3 cases are within ranges of one, one-and-a-half and two degrees, respectively. The larger ranges are probably due to the different vulnerability which may characterize the same typology on account of bad state of preservation, lack of upkeep, use of poor quality materials, poor workmanship and other reasons. These possible variations in vulnerability, as already indicated, seem to have been taken into consideration in the EMS scale; in fact it provides a greater number of building types and vulnerability classes and particular ranges of vulnerability in consideration of the state of preservation, the quality of work and so on.

As a consequence of such detailed specifications on building types and vulnerability classes, the EMS scale looks especially geared for the study of future earthquakes.

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