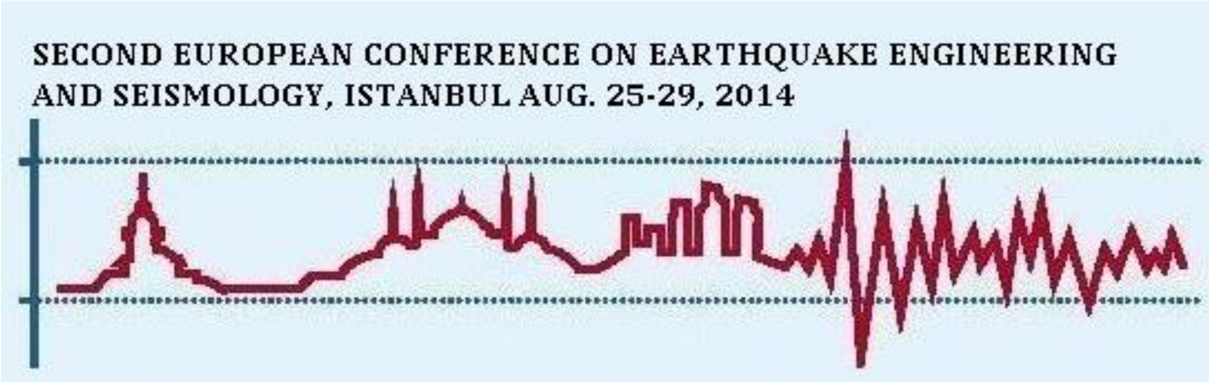

THE INTERNATIONAL MACROSEISMIC SCALE - EXTENDING EMS-98 FOR GLOBAL APPLICATION

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ABSTRACT

The global risk modelling work of GEM (the Global Earthquake Model) has demonstrated the need for a single internationally valid macroseismic scale to permit consistent intensity assignments in any earthquake-affected country. EMS-98 is a widely used macroseismic scale and its structure makes it very appropriate as the basis for a globally applicable scale. Work is in progress, supported by GEM, to modify the scale for intensities greater than VI in order to develop a new version to be known as the International Macroseismic Scale (IMS-14), which will be internally consistent with EMS-98. The programme of work undertaken to date includes a review of international experience with the application of EMS-98 in the last 15 years to identify aspects which can be improved; an examination of the dominant building typologies in 6 separate global regions, to identify those typologies to which the revised scale should be applicable; an assessment of the relative vulnerabilities of the dominant building typologies in each region; an examination of the probable failure modes of different building typologies; and a review of the process of assignment of vulnerability classes to building typologies in different regions. This paper presents the preliminary results of this work, and a set of recommendations for the adaptation of EMS-98. The need for further work to extend and validate the proposed IMS-14 is also discussed.

INTRODUCTION

The European Macroseismic Scale, 1998 (EMS-98, Grünthal et al. 1998) is a widely used macroseismic scale and its structure makes it very appropriate as the basis for a globally applicable scale. Indeed, although it was devised initially primarily for use in Europe, there is already much experience in its use in other parts of the world. Within the programme of GEM, a project is in progress to modify the current version of EMS-98, for intensity levels greater than VI, to make the scale more specifically internationally applicable. The scale will be known as the International Macroseismic Scale, and is expected to be published in 2015 for a preliminary review period. The expected benefits for global intensity assignments and risk assessment are to: improve the robustness of intensity assignments outside Europe; provide a standard scale for international use; reduce the need for inter-scale conversions; and enable better correlations to be made between macroseismic intensity and other measures of shaking intensity.

The following principal amendments to EMS-98 are proposed:

1. Division into two parts: Core Scale (plus Guidelines) and Building Guide.
2. The Core Scale will be the existing EMS-98 booklet, but with some revisions. These may include: revised damage descriptions and illustrations; a revised vulnerability table; some editing and updating of the Guidelines and Background Material; and an addition of some principles of web-based intensity assignment procedures.

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3. The Building Guide (web-based) will contain an inventory of principal worldwide building types; description of the vulnerability issues for each typology; photographic illustrations of examples of the principal building types and common failure modes. It will be a dynamic document with scope for continuous development.

The programme of work undertaken to date includes:

- A review of international experience with the application of EMS-98 in the last 15 years to identify aspects which can be improved.
- An examination of the dominant building typologies in 6 separate global regions, to identify those typologies to which the revised scale should be applicable.
- A preliminary assessment of the relative vulnerabilities of the dominant building typologies in each region.
- An examination of the probable failure modes of different building typologies.

Some preliminary work towards drafting the proposed IMS-14 has been carried out by the authors. This work will first be reviewed by Working Group informally supported by ESC and IASPEI. The draft will be reviewed by an international Expert Review Panel before publication.

The key principles of the proposed revision are as follows:

- Macroseismic intensity is, as in EMS-98, considered as “a classification of the severity of ground shaking on the observed effects in a limited area”.
- The internal consistency with EMS-98 must be preserved.
- The scale must remain robust and simple to use.

It is not intended to equate intensities to recorded ground motion parameters as a part of the scale.

In this paper, the review of EMS-98 field experiences is briefly summarised, leading to identification of aspects in which the EMS-98 scale should be modified in order for it to be more suitable for application internationally.

The paper then presents work to identify dominant building typologies across the earthquake zones globally, in 6 global regions; to provide broad definitions of different typologies, and to classify them in terms of vulnerability classes, and to describe and illustrate the types of damage found at each of 5 separate damage grades. Finally, the paper details the further work and validation needed to produce an update to the EMS-98 that will allow more convenient application of the scale outside Europe.

REVIEW OF EXPERIENCE WITH EMS-98

A review of field experience using EMS-98 was conducted to identify areas in which the scale should be developed to make it more suitable for international application. EMS-98 users in different countries, both inside and outside Europe, completed an online questionnaire. The questions covered two main areas:

- Key features of EMS-98 study: structure types encountered, vulnerability classes, damage grades, range of intensities.
- Problems encountered: absence of structure types, insufficient range of vulnerabilities for a structure type, difficulties in making intensity assignments.

The number of responses collected was 20, a good response given the highly specialised nature of the enquiry. Responses covered three main areas:

- Damage descriptions.
- Structure type definitions and inclusion of building types not currently represented in EMS-98.
- Vulnerability class definitions, ranges and additional vulnerability classes.

Modifications proposed in the EMS-98 damage descriptions included:

- Improvement and extension of damage descriptions, diagrams and Appendix of damage photographs.
- Extending damage descriptions to give guidance on internal as well as external damage indicators.
- Guidance on using damage to non-structural elements can be used to make damage assignments.
- Addressing the difficulties encountered in distinguishing between lower damage grades.
- Guidance on distinguishing damage not caused by earthquake ground shaking.

Modifications proposed in the EMS-98 structure type definitions included:
- Guidelines on identification of structural type.
- A review of earthquake resistant design (ERD) definitions for RC buildings.
- Inclusion of some building types not currently represented in EMS-98.

Modifications proposed in the EMS-98 vulnerability class definitions and ranges included:
- Improved description of suitable methods for assigning a vulnerability level to a building.
- More guidance in distinguishing buildings in higher vulnerability classes (Classes A and B).
- The need to extend the ranges of possible vulnerability class for construction types in some countries.
- The need for an additional vulnerability class (A*) for building types with greater vulnerability than vulnerability class A found in some countries.

Many of these suggested improvements have been incorporated in the work described in this paper. The full analysis of questionnaire responses can be found in Foulser-Piggott and Spence (2013).

REGIONAL ASSESSMENT OF PREDOMINANT BUILDING TYPOLOGIES

In order to make intensity assignments worldwide, structural types and vulnerabilities included in the scale must be representative of worldwide building types. This section describes the definition of a set of 6 zones, within which the predominant building types are similar.

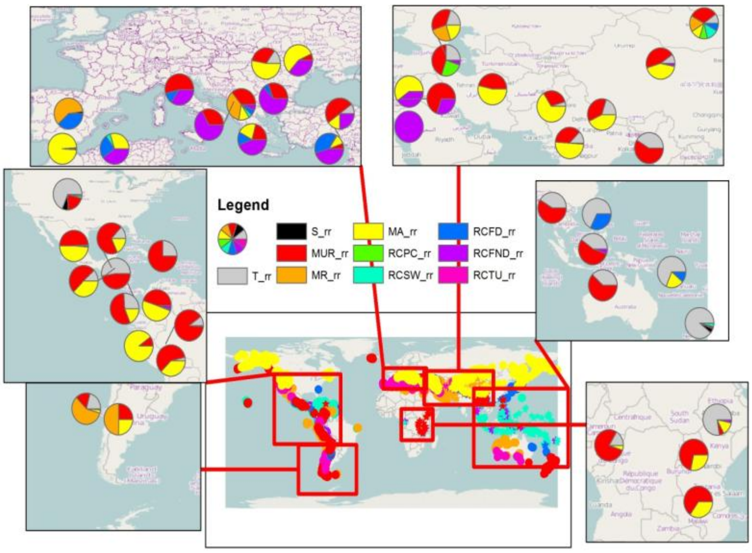


Figure 1. Rural residential building typology distributions for seismically active countries with actual building data.

These zones were subsequently used to summarise and synthesise building stock information from other sources and develop a classification of structural types, typical vulnerabilities, and vulnerability modifiers. The zonation adopted is based primarily on climate (considered to be the main determinant of residential building typology outside city centres), but also takes into account socio-economic status (Human Development Index, HDI) and seismicity. The method adopted is explained in detail in Foulser-Piggott and Spence (2013a). Figure 1 shows the 6 zones and the resulting rural building typology distributions. Within each zone it has been found that in approximately 80% of all countries the predominant building types are the same as shown in Table 1.

Table 1. Proposed IMS regions and corresponding predominant building types

(MUR=unreinforced masonry, MA=mud or adobe masonry, MR=reinforced masonry, RCFND= rc frame, non-ductile)

Zone	Region	Characteristics	Within region differences
1	North and Central America and Caribbean	Mainly MUR and timber as well as some MA (see note).	USA somewhat similar to zone 6. Countries with low HDI have large proportion of MA.
2	South America	Masonry dominates, particularly MR	
3	Western Europe and North Africa	RCFND and MUR are the dominant typologies.	Countries with low HDI have large proportion of MA.
4	Sub-Saharan Africa	High proportion of MUR and MA also common	The predominance of timber in the East of Africa.
5	Eastern Europe and India	Combination of MUR and MA and few other materials.	The Russian building stock which is included here is very diverse. However, it is placed in this region as the distribution of buildings is likely to be similar to the former states of USSR in this region.
6	Australasia and New Zealand	Timber dominates	There is a difference in secondary building type - between MUR in the West of the region and RCFD in the East.

REVIEW OF BUILDING TYPOLOGY DESCRIPTIONS AND VULNERABILITY CLASSES IN EMS-98

The Vulnerability Table of EMS-98 is central to the use of EMS-98 for intensity assignment, and differentiates EMS-98 from other macroseismic intensity scales. Through this table, the apparent structural typology of a building or group of buildings encountered in a macroseismic survey is assigned a vulnerability class (A to F), and according to the damage level observed in these buildings, an intensity assignment can then be made using the damage criteria associated with each level of intensity. This process is central to the intended use of EMS-98, and it is essential that it should be retained as a part of the proposed IMS- enhancement of the scale. However, there are a number of features of this Vulnerability Table which need to be reviewed, and some amendments are proposed here, as described below..

The present EMS-98 differentiates 15 separate structural typologies: 7 masonry typologies, 6 reinforced concrete typologies, and one each for steel and timber. Each of these structure types can be associated with an expected and a range of vulnerability classes, as shown in the Vulnerability Table. The Guidelines discuss the general scope of each structure type and also indicate features of each structure type which that could give rise to a higher or lower than expected vulnerability.

There is a danger that introducing further structure types to fit the building stock found worldwide could greatly extend the list of structure types, making the Vulnerability Table unwieldy. It may be preferable, rather, to reduce the number of separate structure types identified in the Vulnerability Table, and make more extensive use of the structure type definitions and guidance notes to enable a wider range of variations within each structure type. This is the approach proposed here.

Specifically, it is worth reconsidering the need for 7 separate masonry classes. Masonry is still very widely used in most parts of the world, and the vulnerability of masonry buildings varies widely. Yet it may be possible to adequately classify virtually all masonry as belonging to one of three classes, as discussed below. Further, in the proposed IMS-14 Vulnerability Table the 6 reinforced concrete classes are defined by two basic types (RC frame and RC walls), and by three levels of earthquake resistant design. Here too, a simplification of the Vulnerability Table into fewer separate classes with more detailed and local guidance about assigning vulnerability classes is suggested, rather than a complex elaboration of the vulnerability table. In the EMS-98 vulnerability table, there is no precise definition of what is and is not included within each structure type definition. Discussion of this is found in the Guidelines, but these do no amount to formal definitions. It is suggested therefore that the Vulnerability Table should, in IMS-14, be accompanied by a table of definitions of the scope of each structure type, with some notes on the variations likely to be found. The Guidelines can then be used to amplify this information.

Two separate approaches were taken to develop the revised Vulnerability Table. The first method is qualitative and started by reviewing the available literature on worldwide structure types and their vulnerabilities to produce a classification of structures and their vulnerabilities. The second method, which is more quantitative, used data on expected building vulnerability of the key building typologies in more than 35 different countries assembled by Cambridge Architectural Research (CAR) in the GEVES (Global Earthquake Vulnerability Estimation System) project (Spence et al 2007). The two approaches are detailed in Foulser-Piggott and Spence (2013a). The results of the two methods were compared and combined to produce the revised Vulnerability Table.

Draft Vulnerability Table

The result of the review described above is a draft proposal for the Vulnerability Table (*Differentiation of structures (buildings) into vulnerability classes)*. The same format and symbology as EMS-98 is used in Table 2, where:

- **O** = most likely vulnerability class
- **I** = max and min of probable range of vulnerability class

Table 2. Vulnerability Table

Type of structure		Vulnerability Class					
		A	B	C	D	E	F
Masonry (M)	Weak	O	I				
	URM	I	O	I			
	Structural		I	O	I		
Reinforced Concrete (RC)	Frame		I	O		I	
	Wall			I	O	I	
Steel (S)	Frame		I	O		I	
Timber (T)	Frame		I		O	I	

Definitions of structure types

The definitions given in Table 3 are derived from consideration of structural classification systems proposed in recent studies (Jaiswal et al, 2008, Spence et al, 2007, FEMA 2002, Brzev et al 2011) as well as the descriptions given in the EMS-98 Guidelines.

VULNERABILITY MODIFIERS

Vulnerability modifiers are required in IMS-14 to enable shifts for each building typology from the most likely vulnerability class to the vulnerability class appropriate in the location of the intensity survey, and taking account of special features of the buildings observed. EMS-98 identifies the following features as possibly contributing to vulnerability modification:

- Plan or vertical irregularity, including weak ground floor (soft storey), and modifications.
- Poor condition (including previous earthquake damage).
- Poor quality of construction.
- Position in block (middle, end, corner).
- Strengthening after construction.
- Earthquake resistant design level (dealt with partly, for RC only by the level of ERD defining the typology).

Table 3. Structure type definitions

Type	Sub-type	Description	Principal variants included
M1	**Weak**	Load-bearing walls of weak masonry, either earthen (adobe or rammed earth), or rubble stone in lime or mud mortar; roof of timber poles or joists, covered with earth or metal sheet; generally single storey.	Thick rubble stone masonry walls in older buildings in rural Europe, Turkey; adobe block construction in South America; *bahareque* buildings of rural South America with mud and timber lacing; rammed earth walling in some parts of rural Europe, South America.
M2	**Unreinforced**	Load-bearing walls of unit masonry, brick, concrete block or stone, laid in courses with mortar of cement or lime; floors either of reinforced concrete or timber joists supporting timber boards; roofs generally pitched and covered with tiles or metal roof sheet, occasionally reinforced concrete; generally up to 3 storeys, sometimes up to 6 stories.	Typical European residential building construction from 18th century onwards, many historical structures; individual buildings and long terraces; older commercial and industrial structures; retrofitted structures using steel ties (USA); cavity wall construction (parts of Europe, since 1930's).
M3	**Structural**	Load-bearing walls of reinforced or confined masonry; floors either of reinforced concrete or timber joists supporting timber boards; roofs generally pitched and covered with tiles or metal roof sheet, occasionally reinforced concrete; generally up to 3 stories.	Reinforced masonry (Europe, USA) with vertical and horizontal reinforcing bars within the masonry; confined masonry (Mexico, South America) with small reinforced concrete members framing and confining masonry load-bearing walls.
RC1	**Frame**	Loads carried by reinforced concrete moment-resisting frame consisting of beams and columns; infill walls of masonry or other materials; floors and roof generally of reinforced concrete, sometimes precast; single to multi-storey.	Frames with a variety of infill, frames with in-situ walls for lifts and stairs only; flat slab construction; precast frames; ductile or non-ductile detailing; pre-code, early code, modern code; low-rise, mid-rise and high-rise.
RC2	**Wall**	Loads carried by reinforced concrete bearing-wall, or by an infilled reinforced concrete frame with additional regularly-spaced reinforced concrete walls, floors and roofs generally of reinforced concrete, sometimes precast; single to multi-storey.	Perimeter concrete bearing-wall system, using in-situ concrete; in-situ concrete frame with regularly-spaced walls in each direction to carry lateral loads; precast concrete panel wall system (esp. former USSR).
S	**Steel Frame**	Loads carried by steel frame, either moment-resisting or braced, with infill walls of a variety of materials, floors and roofs of timber joists and panels, reinforced concrete or metal deck on steel beams, single to multi-storey.	Moment-resisting frame; concentrically braced or eccentrically braced frame; steel frame infilled with masonry or reinforced concrete or lightweight panels; steel frame encased in reinforced concrete; pre-code, early code, modern code; low-rise, mid-rise and high-rise; lightweight steel frame, low-rise.
T	**Timber Frame**	Loads carried by a timber frame, either with closely spaced stud walls with timber cladding or brick veneer; or more widely spaced post and beam construction with masonry or other infill; floors and roofs of timber joist construction, roofs normally pitched with covering of tiles or metal sheets; single up to 3 stories.	Timber stud-wall construction; post and beam construction; heavy timber construction with infill masonry (*himis* Turkey, *Dhajji Dewari*, India), traditional Japanese timber frame construction.

Several studies are available which have suggested vulnerability modifiers for some of these features, using different datasets and different scales. Giovinazzi and Lagomarsino (2004) define a Typology Vulnerability Index V_I applicable to each of the EMS-98 vulnerability classes (A to F), together with a formula enabling the expected level of damage to be estimated, according the EMS-98 definitions at each level of intensity. They also propose modification factors for V_I to apply to a range of features, including all those above, for masonry and each separate ERD level of RC. The height of the building is also considered to require a modifier, with low-rise buildings (1 to 3 stories) behaving better than average, and high rise buildings (8 or more stories for RC) worse than average. These modifiers are additive for buildings possessing more than one feature. Michel and Sira, (2012), have proposed vulnerability modifiers, expressed as ratios of one vulnerability class for a range of features, for RC and masonry buildings. These are also additive. They have made use of the Giovanazzi and Lagomarsino, (2004) modifiers but with some alterations. Spence and Foulser-Piggott (2013), have proposed vulnerability curves to define collapse rates for EMS-98 Vulnerability Classes A to E in terms of two parameters α, and I_0. Modifiers to parameter I_0 are proposed to account for height, quality of construction, and earthquake-resistant configuration, as well as a modifier to apply to buildings in any particular country group (four groups, all seismic countries classified as belonging to one of these four). These modifiers are additive. They are principally defined from an analysis of the building damage data collected in the CEQID database (www.ceqid.org), but information from other studies is used.

In the SAVE project, Zuccaro et al. (2002) use damage data from 8 Italian earthquakes to analyse the effect of vulnerability on aggregated damage level. Difference in vulnerability is measured by a synthetic parameter of damage (SPD), across EMS-98 intensity levels V to VIII.

These studies propose modifiers for each of the 6 key factors identified above and also include other factors, such as the height of the building, foundation conditions, spacing of buildings etc. Analysis of all the data available has led to an assessment of the likely modifiers to be used for each of the 6 vulnerability classes A to F, resulting from 7 primary features and 14 secondary features, as shown in Table 4. Each modifier is expressed as a ratio of one vulnerability class shift. Some of the modifiers apply to masonry buildings only. Country modifiers relate to Country groups 3 and 4 of four groups. as shown in Figure 2 and defined as follows:
Group 1. Countries with high seismicity and awareness: high levels of seismic design and construction expected.
Group 2. Lower seismicity, but generally good levels of design and construction
Group 3. High seismicity, but lower awareness and poor quality of much construction
Group 4. Seismicity mixed but very poor level of seismic awareness and generally unreliable quality of construction.

Figure 2. Proposed IMS country groups 3 and 4

One important feature which will affect vulnerability is the level of earthquake-resistant design (ERD). In EMS-98 a distinction between no ERD, moderate ERD and high ERD is used to identify the vulnerability class for RC structures. However, in the last 20 years, particularly with the widespread application of a new generation of codes (within Europe based on EC8), there has been both regional variation in the earthquake loading and significant differences in the degree of application of codes, and the ERD level can often not be easily determined for a group of RC buildings. Moreover ERD is nowadays also widely adopted for masonry, timber and steel frame as well as for RC buildings. All of these differences are increased when the current global building stock is to be considered. A new way to identify the likely influence on vulnerability class of the level of earthquake-resistant design is needed which can take account of the design code applicable at the time of the buildings construction, and the probability that this code has been implemented; and which can be applied to all building typologies. Defining these vulnerability modifiers will be the subject of further studies.

Table 4 Proposed vulnerability modifiers for building characteristics at each vulnerability class

Primary feature	Secondary feature	Class A	Class B	Class C	Class D	Class E	Class F
Plan or vertical irregularity	open ground floor	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
	other vertical irregularity	-0.25	-0.25	-0.25	-0.13	0.00	0.00
	horizontal irregularity	-0.25	-0.25	-0.25	-0.13	0	0
Poor condition (including previous earthquake damage)	Poor condition (including previous earthquake damage)	-0.25	-0.25	-0.25	-0.125	0	0
Quality of construction	Country group 3	-0.9	-0.2	-0.7	-0.6	-0.6	0.0
	Country group 4	-1.5	-0.4	-1.2	-1.0	-1.1	0.0
Position in the block (masonry only)	Middle of terrace/block	0.1	0.0	0.0			
	End or corner of terrace/block	-0.3	-0.2	-0.2			
Strengthening after construction (masonry)	Metal tie-rods present	0.4	0.5	0.5			
Height of buildings	Low-rise (1-3 floors)	0.0	0.0	0.3	0.3		
	High-rise (8 or more floors)	0.0	0.0	-0.2	-0.2		
Influence of horizontal structure (masonry only)	Rigid	1.6	1.1				
	Flexible			-1.1			

PROPOSED DAMAGE GRADE DIAGNOSTICS

The aims of this work were to:

- Propose ways in which the damage grade diagnostics given in the scale should be modified for particular subclasses.
- Propose new damage grade diagnostics suitable for steel frame structures and timber structures.
- Propose illustrations of the damage grades to assist in understanding the damage grades proposed.

An important principle of the work was that diagnostics given in the EMS-98 for reinforced concrete and masonry structures should be retained to ensure continuity in the application of the scale.

In developing the damage grade diagnostics for steel and timber frame structures, reference has been made to the HAZUS damage grade descriptions (FEMA, 2003) and for timber structures to the discussion of the New Zealand version of MMI (Dowrick, 1996). Photographs of damaged buildings from historical earthquake engineering field studies have also been used to define damage levels. These descriptions should be carefully reviewed by an international review panel, to test and ensure their relevance to dominant building typologies found in each country for which IMS-14 is intended to be applied.

Masonry Structures

The CAR study proposes the three main sub-groups, with definitions and variants as shown in Table 3. Damage grade definition remain the same as in EMS-98. Preliminary proposals for illustrations of each damage grade for masonry structures are shown in Figure 3.

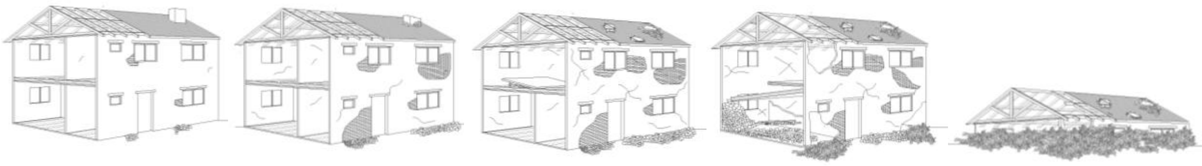
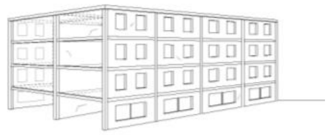
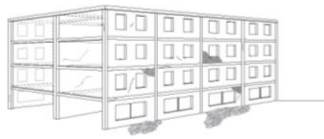
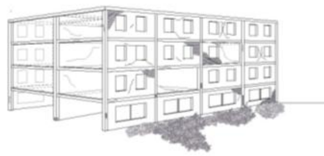
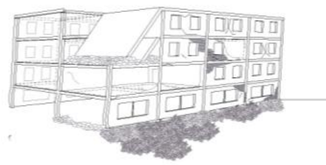
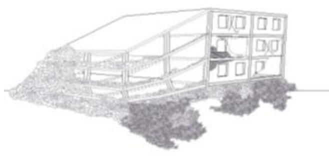


Figure 3. Illustration of the damage grade diagnostics for masonry structures

Reinforced concrete structures

The CAR study proposes the two main sub-groups shown, with definitions and variants as shown in Table 3. Damage grade definition, EMS-98 elaborations, and proposed variations for specific sub-types are shown in Table 5. Preliminary proposals for illustrations of each damage grade for RC structures are also shown.

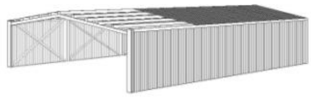
Table 5 EMS-98 damage grade diagnostics and proposed variants for reinforced concrete structures

	EMS-98 Definition	EMS-98 Elaboration	Proposed extension	Diagrams
Grade 1	Negligible to slight damage (no structural damage, slight non-structural damage	Fine cracks in plaster over frame members or 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	Cracks in columns and beams of frames and on shear wall surfaces. (Shear wall structures)	
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 concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.	Distress or movement at connections of precast frame connections. Cracks may appear at tops of walls near panel intersections (Precast concrete structures)	
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.	Most concrete shear walls have large, through-the-wall diagonal cracks. Most infill walls exhibit large cracks with bricks that have been dislodged or have fallen.(Shear wall structures) Some critical precast frame connections may have failed (precast concrete structures).	
Grade 5	Destruction (very heavy structural damage)	Collapse of ground floor or parts (e.g. wings) of buildings.		

Steel frame structures

The CAR study proposes a single steel frame class, with definitions and variants as shown in Table 3. Proposed general diagnostics and specific variations for specific sub-types are shown in Table 6. Preliminary proposals for illustrations of each damage grade for steel frame structures are also shown.

Table 6. Proposed IMS-14 damage grade diagnostics and proposed variants for steel frame structures

	EMS-98 Definition	Proposed IMS-14 Elaboration	Proposed modifications for sub-classes	Diagrams
Grade 1	Negligible to slight damage (no structural damage, slight non-structural damage	Fine cracks in plaster over frame members or at the base. Fine cracks in partitions and infills		
Grade 2	Moderate damage (slight structural damage, moderate non-structural damage	Few cases of failure or distress of frame members, bracing members or structural connections in a few cases; Cracks in partition and infill walls; failure of brittle cladding and plaster	In light steel frame structures a few rod braces may have yielded. (Light-steel frame structures)	
Grade 3	Substantial to heavy damage (moderate structural damage, heavy non-structural damage	Visible leaning of building or individual storey; some broken or buckled members in roof trusses; some distortion of columns or damage at connections; failure of some bracing members; Large cracks in partition and infill walls, failure of individual infill panels	Many braces have yielded (Light-steel frame structures). Masonry infilled frames may exhibit crushing of masonry around beam-column connections.(Masonry infilled frame structures)	
Grade 4	Very heavy damage (heavy structural damage, very heavy non-structural damage)	Building or individual storey leaning heavily; many failed members and/or connections; roof members shifting on column support; major distortion of columns.	Most infill walls exhibit large cracks. Masonry infill may bulge out-of-plane and some masonry may be dislodged and fall (Masonry infilled frames)	
Grade 5	Destruction (very heavy structural damage)	Collapse or partial collapse of entire structure Large permanent lateral displacement		

Timber frame structures

The CAR study proposes a single class, with definitions and variants as shown in Table 3. Proposed damage grade diagnostics and s variations for specific sub-types are shown in Table 7. Preliminary proposals for illustrations of each damage grade for timber frame structures are also shown.

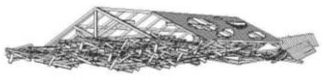
CONCLUSIONS

Studies have been presented leading to some proposed modifications of EMS-98 to make it more specifically applicable for global application, as IMS-14. The proposed modifications relate to the building damage aspects of the scale affecting only intensities VI and above. A basic principle is that the revised scale must be consistent with EMS-98, and remain robust and simple to use.

A review of international experiences with EMS-98 has been reported, leading to suggested modifications in damage descriptions, structure type definitions, and assignment of vulnerability classes.

A regional assessment of the predominant building types has identified 6 global regions within each of which particular building types dominate for the residential building stock.

Table 7. Proposed IMS-14 damage grade diagnostics and proposed variants for timber frame structures

	EMS-98 Definition	Proposed IMS-14 Elaboration (for lightweight timber structures)	Proposed modifications for subclasses	Diagrams
Grade 1	Negligible to slight damage (no structural damage, slight non-structural damage	No damage to structural frame. Few hairline cracks in internal walls or brick. Fall of small pieces of plaster.		
Grade 2	Moderate damage (slight structural damage, moderate non-structural damage	Little or no damage to structural frame. Small cracks in plaster or plasterboard edges; cracks in brick veneers; ; cracks of some masonry chimneys.		
Grade 3	Substantial to heavy damage (moderate structural damage, heavy non-structural damage	Some frame distortion visible. Veneers fail and expose frame. Large cracks in plaster or plasterboard edges. Roof tiles detach. Some chimneys fracture at roof line. Failure of individual non-structural elements (partitions, gable walls). Some shifting of unsecured foundations.	Small cracks or wood splitting at bolted connections (heavy timber frame structures).	
Grade 4	Very heavy damage (heavy structural damage, very heavy non-structural damage)	Serious frame distortion. Total failure of brick veneers. Toppling of most masonry chimneys. Houses not secured to foundations shifted off. Failure of some cripple walls	Partial collapse of soft-storey configurations (soft-storey structures). Slack or broken braces (braced timber frame structures).	
Grade 5	Destruction (very heavy structural damage)	Total or near total collapse of entire structure		

A proposed modification of the vulnerability table is presented, with a smaller number of major building typologies than are present in EMS-98, but with a wider range of possible variations. Precise definitions of the major structure types are given, including principal variants. A review of literature is used to propose vulnerability modifiers to help users of IMS-14 accurately assign vulnerability classes to building typologies found locally.

Revisions to the descriptions of the damage grades are presented to enable them to be used with a wider range of building types, and some new illustrations of these damage grades are presented.

These proposed modifications are provisional. They have benefitted from review by members of the IMS-14 Working Group, but have yet to be reviewed by the proposed IMS-14 External Review Panel or formally approved by the Working Group. Some further work to develop them is needed, for instance to define country groups and quantify appropriate vulnerability modifiers. The work is intended to take place in the next 12 months so that the new scale can be launched for a trial period starting in 2015.

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