INTERNATIONAL MACROSEISMIC SCALE (IMS-24) VULNERABILITY TABLE INCLUDING THE ASSIGNMENT OF VULNERABILITY CLASSES FOR ADDITIONAL BUILDING TYPES

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Abstract: *The differentiation of structures (buildings) into Vulnerability Classes (starting in EMS-92) can be regarded as one of the major decisions to provide the basis for a modern macroseismic scale, i.e., for reliable interpretation of earthquake damage as well as classification of the severity of shaking effects. Reviewing the rapid development in the field of Geographical Information Systems (GIS) and GeoData, the new elements of the EMS-92 have facilitated the use of the scale by insurers and decision-makers to derive damage prognosis or risk scenarios for different intensity measures. World-wide use results in new demands to cover whole building stocks and to replace engineered descriptions with more schematic (user-friendly and data-consistent) taxonomies for which in general comparable damage observations are neither existing nor available. The reasons can be seen in the lack of qualified staff capacities for reconnaissance work. As already mentioned in EMS-92, the Vulnerability Table is to some extent experimental and has to be refined in forthcoming editions of the scale in the light of experience and observations. For each building type, the Table shows the most likely Vulnerability Class and the probable range including exceptional (less probable) cases. The graphical symbols used have an often neglected but important statistical background. The main modifications of the Vulnerability Table from EMS-92 to EMS-98 and to IMS-24 are discussed reminding the dynamic character intended for its further international development. In addition, a generalized scheme for application is proposed depending on the quality of available information. The use of "quantities" (like "few", "many", "most") provides an additional statistical element enabling the link to vulnerability functions or corresponding indexes. Looking back to 25 years of EMS-98 experience, none of the observations request a fundamental change. Some of the lessons and insights into the vulnerability of building types and proposed improvements of their classification are summarized considering the findings of recent earthquakes. There are no serious limits to apply the Vulnerability Table – as one of the key elements of EMS-98 – at an international level. The EMS-98 is already referring to the most relevant structural types of buildings worldwide. It provides an open system for the implementation of other (or additional) structural types. Making use of this flexibility, an extended Vulnerability Table for IMS-24 is presented.*

1. Introduction

Empirical vulnerability assessment is connected with the outcome of macroseismic studies and the development of intensity scales. The concept of intensity itself has been adopted and modified over the course of the last century. The EMS-98 (Grünthal et al. 1998) - as its recent state - is one of a family of intensity scales taking Medvedev-Sponheuer-Karnik (MSK) scale as a starting point.

Jumping over the numerous versions of “modified” scales, it was the purpose of the Cahier du Centre Européen de Géodynamique et de Séismologie Volume 7 to present the update of the previous MSK scale and the 1st edition of the European Macroseismic Scale (EMS-92) by the Working Group on Macroseismic Scales of the European Seismological Commission (ESC), which was published in spring of 1993 (Grünthal et al., 1993).

This new scale was recommended by the XXIII General Assembly of the ESC in 1992 (Prague) to be used in parallel with existing scales for a period of three years, in order to gather experience under realistic conditions, especially on the more experimental parts of the scale: the vulnerability classes and engineered constructions. This testing phase was not restricted to Europe. Earthquakes whose engineering analysis of damage (mainly performed by the German Task Force for Earthquakes GTFE) used for the updating were: Roermond/The Netherlands 1992, Killari/India 1993, Northridge/USA 1994, Kobe/Japan 1995, Aegion/Greece 1995, Cariaco/Venezuela 1997 and Central Italy 1997/98. Several stronger earthquakes in Turkey were also included as representative case studies (Erzincan 1992, Dinar 1995 as well as - during the final phase of drafting - Adana/Ceyhan 1998). This led to a noticeable change in the previously quite optimistic evaluation of RC frame structures (Wenk et al., 1998).

One of the main intentions for the creation of the new scale was not to change the internal consistency of the original scheme. Other general aspects considered to be fundamental to the updating were the simplicity of the use and the robustness of the scale (i.e., minor differences in diagnostics should not make large differences in the assessed intensity). Further requirements are related to the engineering aspects. On one hand, the need to include new types of buildings, especially those including earthquake-resistant design (ERD) features, which are not covered by existing versions of the scale. On the other hand, the need to design a scale that meets the needs of civil engineers and other possible users. The specific needs were expressed in the discussion of the vulnerability or damage functions. In Figure B-1 (EMS-92, Annexe B Engineered Structures) the first set of “Relations between typical frequency distributions of damage grades for different intensity degrees (and definitions used in the EMS-92)” was presented. As a “quick attempt”, the curves exhibit some inconsistencies which might be explained by the missing model curves elsewhere. A better insight (at the time of EMS-92 elaboration) was provided by the surveys and results presented by Gülkan et al. (1992) and Spence et al. (1992). In Figure 4-1 of EMS-98, three model curves for different levels of intensity (low = slightly damaging, moderate = heavily damaging and high = very destructive) are distinguished.

In EMS-98 a prognosis is given that future applications or future needs might be the basis for further improvements of this new tool in the seismological and engineering practice. The final answer to this development cannot be given. It is the authors' point of view that “Shakemaps” and associated scenarios should go in line with a careful check and interpretation of the observed shaking effects, and in particular, of damage grades observed by the different types of structures.

2. Basic elements of empirical vulnerability assignment

2.1 Vulnerability of building types

The European Macroseismic Scale incorporates a compromise, in which a simple differentiation of the resistance of buildings to earthquake-generated shaking (i.e., vulnerability) has been employed in order to give a (intended) robust way of distinguishing the behavior in which buildings respond to earthquake shaking. The Vulnerability Table is an attempt to categorize (in a manageable and simple way) the seismic performance of structures, taking both building type or structural system and other vulnerability-affecting factors (e.g., quality of workmanship, state of disrepair, irregularities of shape, layout, design “defects”) into account. This is one of the main developments from previous scales which defined building classes solely by the type of construction (as an analogue of vulnerability).

With the EMS-92, it has been decided to move to classes directly representing vulnerability. Six classes of decreasing vulnerability (A to F) are proposed (see Table 2). The first three classes should be compatible with building categories in the MSK-64, representing the strength (or vulnerability) of the following basic structural types: adobe (earth brick) houses (vulnerability class VC A), brick masonry buildings (VC B) and reinforced concrete (RC) structures: The last one referring to RC without earthquake-resistant design (ERD).

It has been already accepted for the EMS-92 that engineered buildings can be used for intensity assignment only on the basis of ERD principles.

An essential step to overcome these problems was the introduction of the Vulnerability Table which provides the possibility to deal in one scheme with different kinds of buildings and the variety of their actual ranges of vulnerability. This Vulnerability Table, as an innovative part of the EMS, incorporates engineered and non-engineered buildings into a single frame. Classes D to F are intended to account for a decrease in vulnerability (approximately linear) as a result of an improved level of seismic design (ERD). Engineered structures with modern structural systems, not designed against lateral seismic loads, can still provide a certain level of earthquake- resistant which can be comparable to the level incorporated in engineered buildings with ERD. Structures designed against high levels of wind loading can be regarded as having inherent earthquake resistance.

The introduction of the vulnerability table was highly acknowledged, as well as the introduction of the new definitions of damage grades (see Wenk & Schwarz, 2024). New building types or those which are not covered by the present vulnerability table can be added in an appropriate way. Generally, the engineering aspects incorporated into the new scale were appreciated by the engineers. They were the subject of sessions at international conferences on earthquake engineering (Schwarz & Grünthal, 1994) and even of a Special Theme Session on the EMS-92 at the 11th World Conference on Earthquake Engineering in Acapulco in 1996 (Schwarz, 1996).

When assessing the vulnerability of an ordinary building in the field, the first step is to identify and evaluate the type of structure. This provides the basic ("most likely") vulnerability class. The most common building types in Europe are each represented by an entry in the Vulnerability Table indicating the "most likely class". Additionally, ranges on which a variation of the VC could be expected are given (i.e., "probable", "less probable and exceptional cases").

The Vulnerability Table provides the entries for most of the major building types encountered in Europe; the listing of types is necessarily simplified, and the editors recognized that the table is incomplete (Grünthal et al., 1998). According to the outcome of studies in Central Asia (Schwarz & Raschke, 1999) and Venezuela (Schwarz et al., 1998) a further sub-classification for adobe and wooden-type structures is recommended. Basic ideas on introducing new building types are given in Section 2.5 of the Guidelines and Background Material of the EMS-98.

2.2 Assignments

Table 1 gives an overview of possible combinations of symbols to identify the range of scatter and compares those building types included in the EMS-92 and EMS-98 (which are still open for IMS-24; see Table 3). The presence and the size of the different ranges of scatter describing individual building types depend on several factors. Nonetheless, the issues discussed in the following are also applicable to the (still to be determined) assignment of vulnerability classes of additional (or even new) building types (Schwarz, 2011). Particularly, it is relevant to note that such a scheme of classification is transferable to other natural hazard through the inclusion of the appropriate physical parameters are transferable to other natural hazards.

A non-existing range of scatter (No. 1 in Table 1) indicates very homogenous damage patterns (equal damage grades) of the individual damage cases under similar impact. Building types where the same damage levels can be observed for most damage cases have small ranges of scatter of (± 1) vulnerability class (No. 2 to 9 in Table 1). Variations in some cases to higher or lower damage grades can occur due to differences in the building construction. A larger range of scatter from ± 2 vulnerability classes stands usually for roughly classified building types (e.g. masonry in general). Consequently, within the EMS-98 some building types (e.g. adobe, wood) would benefit from a further sub-classification and require a more detailed consideration of the existing (regionally different) construction techniques. These wide ranges of scatter are also typical for building types with larger uncertainty in the building construction. Thus, according to the EMS-98 for example, reinforced concrete frame systems can have in the worst case a similar behavior to adobe building types.

Based on empirical data, it was explained in Schwarz & Maiwald (2007, 2012), how vulnerability classes can be assigned and how the concept can be transferred to other natural hazards. In this study, the proposed concept is extended to determine the ranges of scatter in the vulnerability classes of the individual building types; it is practically further refined on the basis of damage data gained from field surveys of recent earthquakes as well as tsunami events.

Table 1. Possible elements of vulnerability table (extracted from Table by Maiwald & Schwarz, 2017)

No.	**Ranges of scatter in Vulnerability Classes**					**Vulnerability table building type**		
	-2	**-1**	**0**	**1**	**2**	**EMS-92**	**EMS-98**	**IMS-24**
1			○			Masonry, rubble stone, fieldstone	Masonry, rubble stone, fieldstone	
2			○	┄┤		Masonry, adobe (earth brick)	-	
3			○	—┤		-	Masonry, adobe (earth brick)	
4		├┄	○			Masonry, simple stone	Masonry, simple stone	
5		├—	○			Masonry, unreinforced brick with RC floors RC with high level of ERD	-	
6		├┄	○	┄┤		Masonry, unreinforced brick/concrete blocks	Masonry, unreinforced, manufactured stone units	
7		├┄	○	—┤		-	Masonry, reinforced or confined RC walls (without ERD, with moderate level of ERD; with high level of ERD)	
8		├—	○	┄┤		Masonry, massive stone	Masonry, massive stone Masonry, with RC floors	
14	├┄	┄—	○			RC with minimum level of ERD RC with moderate level of ERD		
17		├┄	○	—	┄┤	reinforced brick (confined masonry)		
24	├—	—	○	┄┤		RC without ERD		
25	├┄	┄	○	—┤			RC frame without ERD	
26	├┄	—	○	—┤			RC frame (with moderate level of ERD; with high level of ERD) steel structures timber structures	
31	├┄	—	○	—	—┤	Wooden structures		

○ Most likely vulnerability class —— probable range ┄┄ less probable, exceptional cases.

3. Up-date of the Vulnerability Table for IMS-24

3.1 Review: From EMS-92 towards EMS-98

An overview of the main innovations introduced for the EMS-98 with respect to the testing version EMS-92 is given in Volume 15 of the Cahier du Centre Européen de Géodynamique et de Séismologie. Similar to the EMS-92, the EMS-98 printed version was edited by the chairman of the ESC Working Group G. Grünthal and the associated editors R.W. Musson, J. Schwarz and M. Stucchi. Sections 2 (Vulnerability) and 5 (Examples illustrating the classification of damage to buildings) which deal with the engineering aspects were mainly compiled by the authors and the research group of the Earthquake Damage Analysis Center (EDAC) in Weimar.

During the three-year testing phase, several earthquakes (e.g. Northridge/USA 1994, Kobe/Japan 1995, Aegion/Greece 1995) were undertaken with an engineering analysis of damage using reports or the data of field missions. In this regard, the main contributions were provided by the Engineering Group of the German Task Force for Earthquakes (GTFE). While studies of the structural pattern of these earthquakes were not finalized, other damaging events Dinar/Turkey 1995, Cariaco/Venezuela 1997 (Schwarz et al., 1998), Adana/Turkey 1998 (Wenk et al., 1998) and Central Italy 1997/98, provided further information and experience. They led finally, though with no complete agreement, to modifications of the Vulnerability Table. In particular, to the classification and differentiation of reinforced concrete (RC) structures as well as their level of ERD.

The classification of buildings with “anti-seismic” Design (ASD) mainly used by seismologists was replaced by the correct term of “Earthquake-Resistant Design ERD” enabling the direct link to the code development and here to the first drafting of Eurocode 8. (For avoiding misunderstanding, only “ERD” is used in the paper.)

The main modifications of the Vulnerability Table from EMS-92 to EMS-98 are given in Table 2. The ranges of the testing version (EMS-92) are shown with black fonts and symbols, while the changes introduced by the EMS-98 are indicated in red.

The whole process of establishing first the EMS-92 and finally the EMS-98 went on for almost ten years - including several breaks, which were essential for gathering further experiences. The given version of the EMS should represent a subsequent final stage of these activities in the scale’s updating. It was expected that future macroseismic practice would contribute to a deeper insight into the complex matters of assigning intensity. Some of the lessons and insights into the vulnerability of building types and the therefore adopted modifications within their classification can be summarized (without going into detail) as follows (Schwarz, 2011):

Adobe Structures

The behavior of adobe structures might be better than assumed; the differentiation of building types does not correspond to the variety of existing realizations. This is also true for unreinforced masonry structures with RC floors where simple rules concerning the stabilization of intersecting walls and arrangement of wall-connecting ring beams are efficient measures against the critical failure modes.

Brick Masonry Structures

It is distinguished between reinforced masonry and confined masonry for which a similar range of vulnerability classes could be assumed. The positive evaluation (D as most likely vulnerability class) was slightly reduced by excluding vulnerability class F and by limiting the range of probable (until E) and less probable classes (downwards until C).

Reinforced Concrete Structures

The timber and all RC structures with moderate or with high level of ERD experienced corrections to the probable ranges of vulnerability assignments, similar to brick masonry structures. Four types of RC structures are foreseen within the EMS-92: RC without and RC with a certain [minimum, moderate, high] level of ERD. In general, all RC types were ranked down by one class. The optimistic evaluation of the existing building stock and the final level of earthquake-resistant provision were confronted with a series of quite damaging earthquakes worldwide, where the quality and extent of damage indicate the need for a more realistic calibration.

With respect to RC structures, two major changes become evident:

(1) the rearrangement of the types concerning the level of Earthquake-Resistant Design (ERD);

(2) the differentiation of building types into RC wall and RC frame structures *.

* For both types the same most likely vulnerability class is given with clear differences concerning the still probable or less probable lower range. RC frame structures are now considered the building type with the largest scatter and uncertainty in response. In exceptional cases, Vulnerability Class B (moderate level of ERD) or even Vulnerability Class A (without ERD) might be appropriate. Only, by accepting this particularity, repeatedly recently observed damage situations can be interpreted consistently to the behavior of the other building types.

[Note. Over the last years or still decades, this situation has not changed significantly, remembering the damage analysis of the 1999 Izmit/Kocaeli (Turkey) earthquake (Schwarz et al., 2000) or February 2023 Kahramanmaraş (Turkey-Syria) earthquake sequence 2023 (Abrahamczyk et al., 2024).]

Vulnerability Class F type buildings

The vulnerability classes A-F (see Tables 2 and 3) are intended to represent approximately linear decreases in vulnerability as a result of an improved level of ERD. Note that no correlation with specialized engineering vulnerability functions is intended in the EMS, but this should be considered as an area of further development within the calibration of the scale (see 3.2).

In this context, it has to be postulated that none of the (existing) building types affected by the inertia forces of seismic shaking, could obtain vulnerability class F as the most likely one. Building with additional or special measures (e.g., the energy flow interrupting or controlled modifying) or devices (like base isolation, floating foundation etc.) are excluded from the evaluation. Due to the lack of data and the limited experience from observed global (full-scale) responses under earthquakes, especially those, reaching or exceeding the design level ground motion, separate consideration is recommended. With this respect, it has to be emphasized that special structures (as well as monumental buildings) have to be excluded from macroseismic interpretation and intensity assignments.

Vulnerability Classes for Buildings with Earthquake-Resistant Design

The limited damage observations for buildings with Earthquake-Resistant Design (ERD), and the guiding principle of current seismic design codes (i.e. reduced seismic force and allow inelastic deformations to absorb earthquake energy) make the assessment of the seismic vulnerability of this building type challenging. At both the European and international levels, attempts have been made to establish suitable terms for describing buildings with ERD, based on local and global conditions. Those terms are often influenced by the code development in the region of interest and local practices.

Due to the complexity of problems and the non-trivial task to decide upon the building type and its ERD, it was decided to give additional guidance to the new approach by a separate Annexe was compiled taking into account the comments and the reached state of discussion. Annexe B of the testing version (EMS-92) shows how the results of damage surveys could be incorporated into the scale. For this purpose, the damage functions have to be replaced by the EMS quantities (few, many, most) allowing the use of additional quantities (very few) for further refinement.

Furthermore, it can be shown that the damage probability functions of the five (+1) damage grades are of (slightly) different quality. They depend on the building type and its main horizontal resisting structural layout (walls, frames), as well as energy dissipating mechanism. In this direction, and recognizing the limited number of published statistical investigations of building types, it can be concluded that damage probability functions are in general of similar tendency (increase of damage with intensity) but different with respect to the shape, increase, decay or saturation. Future research work should help to improve the relation between vulnerability classes and types of buildings. The engineering aspects of the EMS-92 were, to some extent, experimental and tentative and should be refined after a testing period according to the feedback from and among the national specialists. As a result, the following fields are proposed for improvement and discussion:

(i) Classification of building types; the specification of most likely vulnerability classes and probable ranges, especially with regard to engineered structures; further subdivision of building types with respect to horizontal and vertical structural systems in certain areas;

(ii) Performance of buildings under different levels of earthquake shaking;

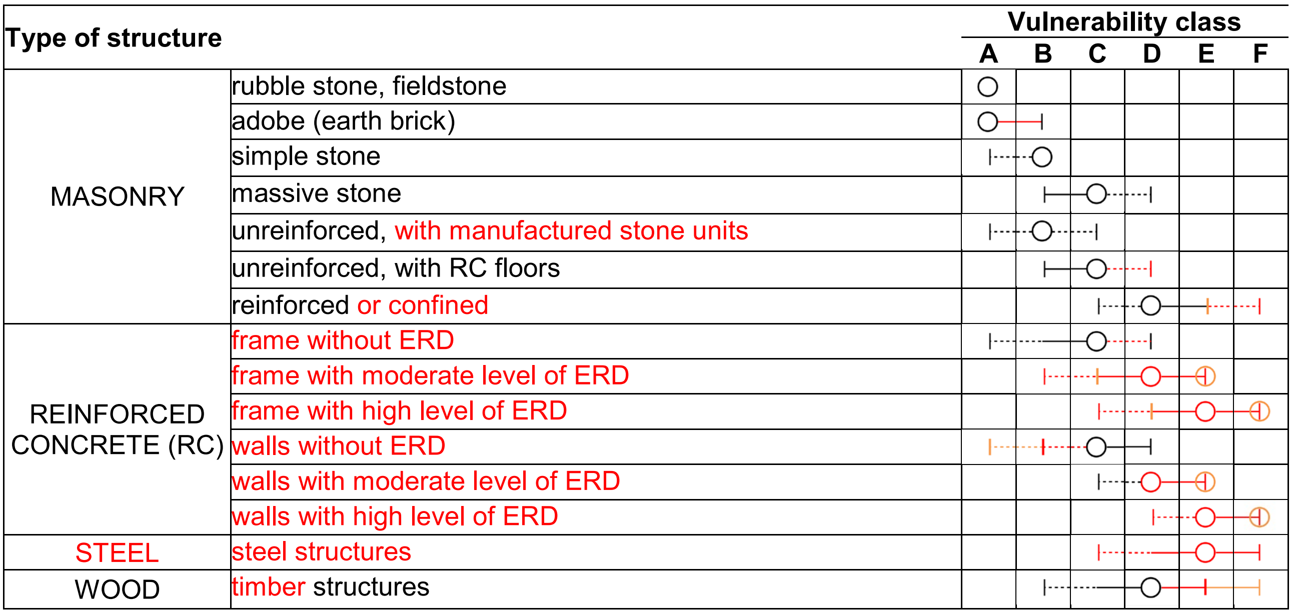
(iii) Evaluation of the level of earthquake resistance provided by seismic codes within European countries to define a code-consistent level of Earthquake-Resistant Design (ERD).

The feedback to the EMS-92 was remarkable. But in the sum of the responses, only a few comments were related to the Vulnerability Table and the list of building types. Therefore, some of the ambitious aims and approaches prepared by the Annexe B could not be reached.

Nevertheless, on the basis of a rather limited number and regionally concentrated data, a damage prognosis is given for structures with a certain level of earthquake-resistant design where the design input parameter should be the intensity. This approach reflects the code generation at the time of the Working Group “Macroseismic Scales” activities: hazard or zoning parameters are derived from correlations between intensity and effective and other design accelerations.

The typical approach was quasi-static in nature and the design level related to the base shear (with an equivalence indication to a design Intensity) was established, which was the basis of the EMS-98 classification.

Table 2. Differentiation of structures (buildings) into vulnerability classes (Vulnerability Table); Modifications of the Classification used in the European Macroseismic Scale from EMS-92 to EMS-98 (Schwarz, 2011).



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 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; ········ less probable, exceptional cases.

|┄○—| EMS-92; |┄○—| Modified in EMS-98; |┄○—| Re-arranged in EMS-98.

The establishment of this equivalence, although robust, poses challenges with changes in seismic code requirements (e.g. variation of assumed ductility, change in code philosophy) and an investigation on European and global scales is important (Haweyou et al., 2024).

Steel Structures

Steel structures, not included in the Table of EMS-92, are implemented without any further sub-classification. Results from the 1994 Northridge (California) earthquake and observation from the 1995 Kobe (Japan) earthquake are considered as well as publications from the observed failure mechanism during the 1985 Mexico earthquake, which were recognized during the reconstruction process that took place several years later.

Timber Structures

At and during the time of the ESC Working group activities to the Macroseismic Scales, the general understanding of timber structures was really underdeveloped. After the 1994 Northridge (CA) earthquake some published damage statistics indicated that previous vulnerability assignment and damage probability functions did not match the observed response characteristics (King & Rojahn, 1998).

From European earthquakes, no meaningful data could be provided. American construction techniques of wooden structures with gypsum planks are (until now) not typical for European earthquake regions. In particular and referring to Germany's mountainous areas, the widely used building type of timber frame structures with clay or brickwork filling techniques is not included within the scale.

Observations from the 1995 Kobe earthquake contribute to a series of experimental and analytical studies concerning the response of multi-story wooden structures. The link from these testing results into the empirical-based vulnerability classes is still not realized.

Timber and wood buildings have demonstrated low seismic vulnerability in earthquake-prone regions such as Slovenia and Chile, largely due to their lightweight construction, which reduces the impact of earthquake forces. The inherent flexibility and ductility of timber and wood structures also contribute to their inherent ERD, allowing them to better withstand ground shaking. However, certain factors, including foundation issues, inadequate wall-to-roof connections, and construction deficiencies, may increase vulnerability in specific cases.

3.2 Outlook: From EMS-98 to IMS-24

Introduction of additional building types

Meanwhile, the EMS-98 is used worldwide, and has been translated into other languages; adopted versions in French, Spanish, Chinese and Russian are available. As one of the global activities, it is now under discussion how to update the European Macroseismic Scale (EMS) so that after some calibration the attribute of an “International Macroseismic Scale” can be attested (Wald et al, 2024).

Besides these accompanying tendencies and initiatives, it is of general interest how additional structural building types should be introduced. In using the scale outside Europe, or in areas within Europe where a distinctive local building type is found, it may be necessary to deal with building types not covered by the Vulnerability Table as it stands. In the EMS-98, it is recommended that such a procedure should be best undertaken by a panel of experts in some controlled way (this can be secured if the editorial minds of the scale are not disregarded). Finally, statistical results of damage survey are the key to introduce new building types as well as for better correlating particular building types with the most likely or probable vulnerability classes.

Extension of the EMS-98 vulnerability table

Recent efforts to extend the vulnerability table can be seen in works by Schwarz et al. (2021) and Abrahamczyk et al., (2017; 2021), with reference to suggested vulnerability description in the World Housing Encyclopaedia (WHE, 2004). The presented tables show initial suggestions and provide basic ideas regarding the possible simplification or integration with the vulnerability table as it stands now as proposed for IMS-24 in Table 3.

[Note: Tables for masonry and RC type structures are reproduced in a companion paper by Schwarz & Abrahamczyk (2024) to discuss how WHE housing reports can be linked with EMS-98 (IMS-24).]

Table 3. Differentiation of structures (buildings) into vulnerability classes (Vulnerability Table); Modifications of the Classification proposed for the up-date of the European Macroseismic Scale EMS-98 (IMS-24)

Type of structure		**Abbr.**	**Vulnerability class**					
			A	**B**	**C**	**D**	**E**	**F**
MASONRY	rubble stone, fieldstone	M1	○					
	adobe (earth brick)	M2	○	—				
	simple stone	M3	┄	○				
	massive stone	M4		—	○	┄		
	unreinforced, with manufactured stone units	M5	┄	○	┄			
	unreinforced, with RC floors	M6		—	○	┄		
	reinforced or confined, with RC floors	M7			┄	○	—	
RC (Cast-in-situ)	frame without ERD	RC1-L	┄	┄—	○	┄		
	frame with moderate level of ERD	RC1-M		┄	┄—	○	—	
	frame with high level of ERD	RC1-H			┄	┄—	○	—
	walls without ERD	RC2-L		┄	○	—		
	walls with moderate level of ERD	RC2-M			┄	○	—	
	walls with high level of ERD	RC2-H				┄	○	—
	dual system without ERD	RC3-L		┄	○	┄		
	dual system with moderate level of ERD	RC3-M			┄	○	┄	
	dual system with high level of ERD	RC3-H				┄	○	┄
RC (Precast)	frame without ERD	RC4-L	—	—	○	┄		
	frame with moderate level of ERD	RC4-M		—	—	○	┄	
	walls or dual systems without ERD	RC5-L		—	○	┄		
	walls or dual systems with moderate level of ERD	RC5-M			—	○	—	
STEEL	frame without ERD	S-L			┄	○	—┄	┄
	frame with moderate or high level of ERD	S-M/H				┄	○	—
WOOD	frame or walls without ERD	W-L		┄	┄—	○	—	
	frame or walls with moderate or high level of ERD	W-M/H				┄	○	—

○ Most likely vulnerability class; —— probable range; ┄┄ less probable, exceptional cases.

Generalizations and assumptions which are implemented in Table 3 can be summarized as follows:

(1) *Reinforced and confined masonry*: Reports for the WHE (Abrahamczyk et al., 2017; 2021), in addition to numerically derived fragility functions, suggest that reinforced and confined masonry could be distinguished. Reinforced masonry building type appears to be slightly more vulnerable. This distinction, although backed with some observations/indications, may only be applicable to certain regions where confined masonry building type is typically used (e.g. Chile, Colombia) and less relevant for European buildings.

(2) *Dual system*: The combination of RC frame and walls systems into a dual system is a commonly used option and distinguish them from frame and walls existing types is possible. For consistency with the EMS-98 table, the term (low level of ERD) is suggested to not be used, following the assumption "RC structures without ERD and those RC structures of Type ERD-L are considered to belong to one building group in the Vulnerability Table" (Schwarz et al., 2015). – Also distinguishing the moderate and high levels of ERD is seen to be appropriate. For the vulnerability assignment of this building type, one should keep in mind that the interaction between the wall and frame systems increases the seismic demand in the beams on upper floors. In addition, having the seismic load resisted between the walls and frames allows slightly more deformation/inter-storey drifts in comparison to wall systems.

(3) *Precast concrete buildings*: This building type exhibits earthquake resistance due to its rigid box-type system, regular plan and elevation, continuous walls in both longitudinal and cross directions, and multiple panel connections. The floor and roof diaphragms are considered rigid, maintaining their integrity during seismic events. The lateral load path is complete, allowing for an effective transfer of inertial forces to the foundation. The wall proportions, foundation-wall connections, and wall-roof connections provide additional seismic resistance. However, some deficiencies have been observed in these buildings, such as poor or absent welded connections, corrosion of steel joints, and cracking in wall panel connection areas.

These deficiencies, if not addressed, may contribute to increased vulnerability during future seismic events. Despite these concerns, reinforced concrete precast systems generally perform better in earthquakes compared to other building types, due to their structural and architectural features that enhance seismic resistance.

It seems appropriate to distinguish RC precast building types by different levels of ERD. A high level of ERD might be assumed to be equivalent to a moderate level, hence the reduced energy dissipation ability and reduced redundancy in precast building types in comparison with cast-in-situ types. Some fragility functions indicate that dual and wall precast types could be considered together, with less difference in vulnerability in comparison to cast-in-situ dual and wall types.

In addition, numerically based comparisons by (Liao 2006: Taiwan) indicate that precast types for the same ERD level are slightly more vulnerable than cast-in-situ systems.

(4) *Flat slab type*: The large vulnerability range of flat slab building type makes it less suitable for intensity assignment. Dealing with this type as an inferior RC frame building type could be more appropriate.

(5) *Steel and wooden building*: Distinguishing steel and wooden building types seems appropriate with consideration of increased ductility for types with higher level of ERD. Wooden walls building type, since its limited adaptation, maybe considered within the timber frame types with slightly increased vulnerability.

(6) *Mixed type*: The vulnerability of mixed building types could vary significantly, and integrating it into a vulnerability table for intensity assignment is challenging. With the above comments in mind, a simplified vulnerability table is proposed, as shown in Table 3 (excluding this type).

Post-and-beam construction, commonly used in timber buildings, features a structural system where vertical posts and horizontal beams are connected to create a stable framework. This type of construction is prevalent in many countries, including Japan and Chile. In general, post-and-beam structures have certain inherent seismic-resistant properties due to the use of flexible connections and lightweight materials. However, seismic vulnerability can still exist in these structures depending on the quality of materials, workmanship, building code adherence, and maintenance.

In Japan, as described in WHE, single-family wooden houses primarily utilize a post-and-beam structural system. Lateral load resistance is provided by wooden shear walls with interior diagonal brace members or with plywood or manufactured wood panels.

Modern building codes address many structural and architectural features related to seismic resistance, but housing constructed according to pre-1980 building codes may still have higher vulnerability. Proper maintenance is crucial for ensuring long-term seismic resistance in these structures.

(7) *Abbreviations* in Table 3 refer to the compilation of the recent state of currently applied methods and EMS-related studies within the *Knowledge-Based Exposure Modelling Framework Depending on the Accuracy and Completeness of Available Data* (Schwarz et al., 2021) and the adaption of EMS-98 Vulnerability Table by Giovinazzi (2005).

The adapted damage model by Giovinazzi (2005) considers the range of scatter in the vulnerability classes of the building types defined in EMS-98 via so-called membership functions). Giovinazzi & Lagomarsino (2004) state:

Analogously to what done for quantity definition, EMS-98 table describes the different belonging of a typology to a vulnerability classes through linguistic terms: “most possible class”, “possible Class”, “unlikely class”. Even in this case, Fuzzy Set Theory can provide an useful contribution for the linguistic term interpretation. The different belonging of each typology to the vulnerability classes is represented in a fuzzy way, by discriminating the most likely class (c=1), the probable classes (c=0.6) and the exceptional cases (c=0.2). It is possible to define the membership function of each building type, as a linear combination of the vulnerability class membership functions, each one considered with its own degree of belongings.

On this basis, a Vulnerability Index (VCI) is introduced, and the results for structural types are presented in a tabular form. The representative (most plausible) value for the specific building is computed as the centroid of the membership function (see explanations and corrections of the VCI values as it has been identified by reconstructing the whole elaboration procedure by Schwarz et al., 2021). Table 3 can be extended by these indices to support a simplified use for risk studies (also in cases where information about the building stock is available in a statistically generalized or agglomerated form).

(8) *Vulnerability Table in IMS-24*: Table 3 has to be considered as a proposal and is still under discussion (among the members of IMS Working group; see Wald et al. (2024).

3.3 Decisions of IMS Working Group

Not at least, it has to be mentioned that the proposed Table of Vulnerability classes for an International Macroseismic Scale (IMS) is in line with the Decisions of IMS WG Meeting Potsdam 22nd and 23rd January 2015 (complied by Th. Wenk and submitted by Mail to the WG members G. Grünthal, R. M.W. Musson, J. Schwarz, R. Spence and R. Foulser-Piggott); in particular to:

- Decision No. 13: Steel types should be subdivided in two types in function of ERD similar as the existing RC frame and RC wall types. (* One option would be a separate type for mixed steel-masonry structures.)
- Decision No. 14: RC types are kept unchanged.
- Decision No. 15: Timber types should be developed consistent with the new steel types including non-frame structures.
- Decision No. 18: The masonry types are kept unchanged. (* One option would be a separate type for mixed masonry-concrete structures.)

As can be taken from the decisions, it has to be recognized that a large portion of existing buildings can be regarded as a “mixed type”, including several options of combination.

Further on, it was agreed that any up-dated Vulnerability Table should maintain the robustness of the Scale and its applicability in the field work, i.e. the general tendency should go in the direction of simplification to enable a manageable field work and handling of data collection in case of stronger earthquakes and densely populated areas.

4. Outlooking conclusions

It is the target of the paper to provide an entry in the history of the differentiation of structures (buildings) into vulnerability classes – shortly and widely used as “Vulnerability Table” - of the European Macroseismic Scale, the studies (field surveys) behind and the meanwhile activities and efforts for its up-date.

Comparable to the recent code development one of the main demands is related to the “ease of use”, another one might be directed to the required (or existing) qualification of the user. It has to be avoided that the use is possible by engineers, only.

It is the common understanding of the recently re-activated IMS Working Group to design a scale for the widest possible range of interested people, including the circle of seismologists who have only exceptionally been able to acquire a certain understanding of civil engineering.

An International Macroseismic Scale (Wald et al., 2024) has to provide simple tools for interpreting the observable damage of earthquakes in our built environment, including in the majority of highly vulnerable traditional building types, well as engineered structures with different levels of ERD as well as those where the expected level of ERD is far away from real construction practice.

Despite this, expectations are ongoing to use a modern scale or damage prognosis and risk scenarios, too. It is the authors viewpoint that for the risk studies other (more differentiated) Vulnerability Tables are requested. They might include story classes or other parameters of subdivision (see Schwarz et al., 2021; Schwarz & Abrahamczyk, 2024).

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