

HOW TO LINK WHE HOUSING REPORTS WITH EMS-98 (IMS-24) VULNERABILITY TABLE

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Abstract: *The European Macroseismic Scale 1998 (EMS-98) incorporates a compromise, in which a simple differentiation of the resistance of buildings to earthquake generated shaking (vulnerability) has been employed in order to give the demanded robust way of distinguishing the behavior in which buildings respond to earthquake. The Vulnerability Table is an attempt to categorize (in a simple way) the earthquake behavior of structures, taking building type, structural system, earthquake resistant design, and other vulnerability affecting factors (design “defects” etc.) into account. It was a major advance of modern scales that both qualitative and quantitative aspects of damage are introduced. The paper provides some requests to the reports; in particular, concerning the assignment of Vulnerability Classes and the re-check of the quality of information submitted. A critical review of existing housing reports is recommended to clarify the quality of earthquake observations and if derived from EMS-98 Vulnerability Table only, the background for the assignment of the most likely class and the probable ranges. The main target is to provide rules (guidelines) for the vulnerability rating consistent EMS-98 (IMS-24) assignments. On this basis, the paper suggests improvements as well as a general procedure for updating the existing WHE reports and for considering observed damage in a comparative way. The question of how many building types are really necessary in order to perform a macroseismic survey and to assign an EMS intensity is still under discussion. The answer might support the tendency to concentrate on the relevant (i.e., the quantitatively dominating) types and on those types which are indicating a small variation of Vulnerability Classes, only. Buildings of this reference type(s) could be identified by structural (primary) and non-structural (secondary) characteristics. Another aspect discussed is the relationship to the EMS-98 and the consistent handling of building types and vulnerability assignments. In summary it can be stated that the WHE database provides an excellent entry in the assessment of worldwide building stock; only a few of the reports assign unrealistically high or low vulnerability classes compared to the expected assignments and therefore should be revised. The establishment of the link between WHE housing reports, evaluated and assessed damage reports as well as regular amendments to existing reports will support the development of IMS-24.*

1 EMS-98 towards IMS-24

Internationally, various damage models exist to quantify the structural damage to the structure and the resulting losses due to seismic action. A remarkable step of robust simplification is seen in the concept of Vulnerability Classes as introduced by the European Macroseismic Scale (Grünthal et al.; 1992, 1998). The set of (a reduced number of) Vulnerability Classes makes the complexity of an existing building stock manageable.

One of the inherent advantages of the European Macroseismic Scale in its last version EMS-98 (Grünthal et al., 1998) is that for the diversity of building types and structural realizations, very stringent rules for their substitution in terms of vulnerability classes (VC) are given. EMS-98 provides a robust and simple method, which is directly linked with the damage (Schwarz, 2011). For each vulnerability class, a description of the probable quality (damage grades) and extent (quantity of their occurrence) in dependence on the level of shaking is given. The user decides the appropriate class by considering and evaluating the factors that affect vulnerability (like building configuration, material, regularity, particular aspects in the ground and elevation plan, quality of workmanship and maintenance) and upon the level of Earthquake Resistant Design (ERD) in the case of engineered structures. Therefore, the building typology for empirical (intensity-based) risk assessment is limited as to the assigned Vulnerability Classes (VC), ranging from A to F. Transition classes (e.g. BC) are explicitly allowed (Abrahamczyk et al., 2013).

The current state of exposure modelling is characterized not only by deficiencies in the availability and completeness of data. Further on, it has to be recognized that for some of the predominant building types the fragility functions are lacking (Schwarz et al., 2021).

Remarks on introducing new building types given by the EMS-98 might provide an orientation of how and by which procedure “missing types” or “missing functions” might be introduced. Before referencing these instructions, it should be emphasized that the guidelines of the EMS-98 are related to the assignment of appropriate Vulnerability Classes (see proposal for an up-date and IMS-24 by Schwarz et al., 2024)

In using the exposure modelling framework for 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. The overall aim is to compare the new building type with those already covered and attempt to establish equivalence. If it is considered that the type is as strong, but not stronger, than normal URM construction, for example, then one may classify the type as being basically of class B. If the type is such that, owing to innate ductility it never performs worse than brick buildings, but in some cases where construction is very good it performs significantly better, then one might deduce that the building type should be represented on the Vulnerability Table as a circle under B and a line extending to C but not to A; see Table 1.

The question is how such an equivalence should be established. Ideally, in an area where the new building type coexists with a building type already present in the Vulnerability Table, then the results of a damage survey could be used to establish an objective classification.

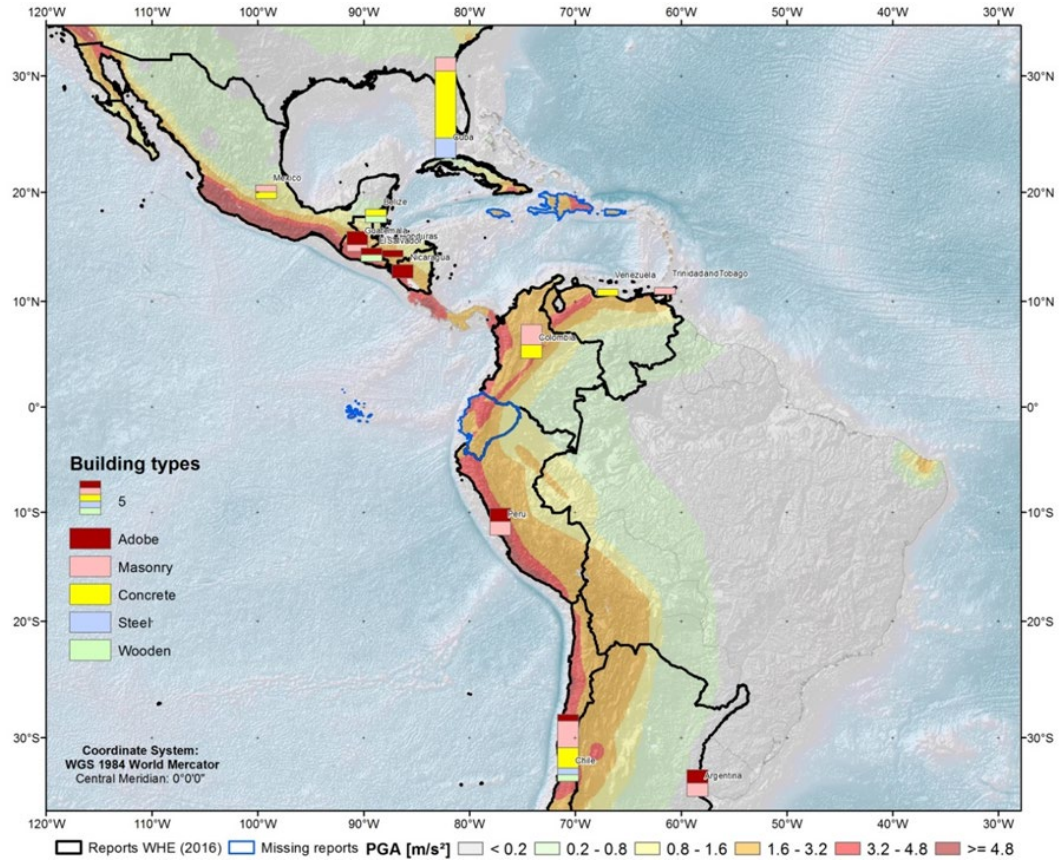
Failing this, one may be able to estimate an equivalence on theoretical grounds from a comparative view of ductility and strength, considering the horizontal elements as well as vertical ones and the links between.

A set of new structural types has been introduced with their probable ranges of Vulnerability Classes in Tables (see also Abrahamczyk et al., 2021).

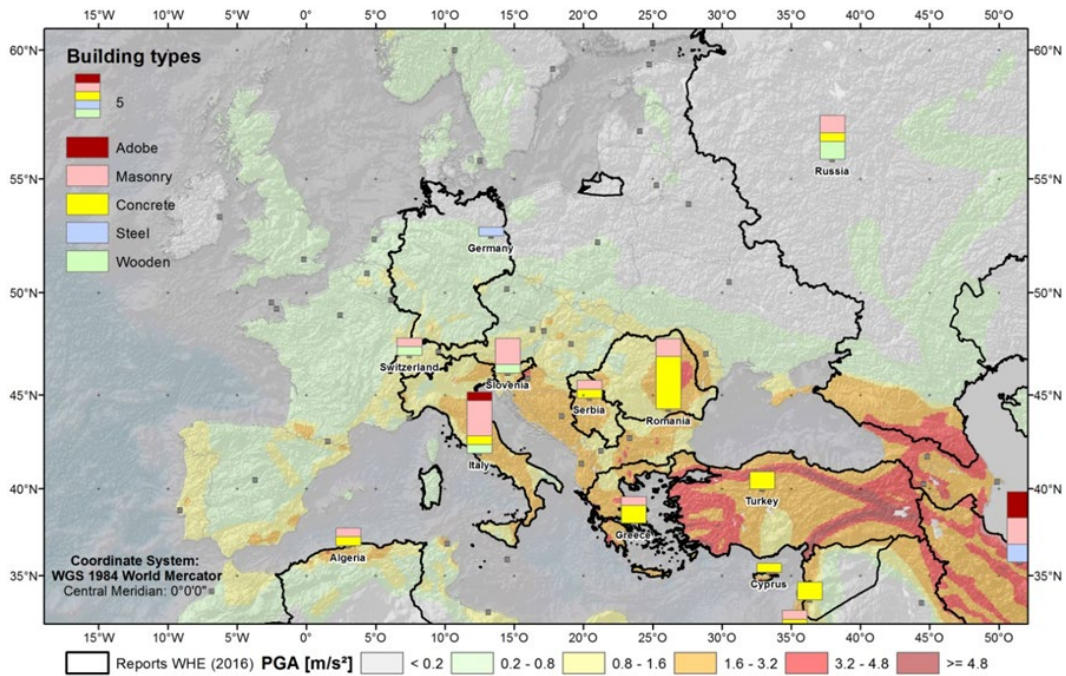
2 World Housing Encyclopedia

The World Housing Encyclopedia (WHE, 2004) was initiated as a database collecting information about typical building types worldwide and their major properties as well as their overall seismic vulnerability rating. The lower bound (i.e., the worst possible) and the upper bound (i.e., the best possible) performance have to be described by the authors as part of a predefined report template. At present, about 208 reports from more than 44 countries are included in the online database (see Figure 1).

The World Housing Encyclopedia (WHE) is a collection of resources related to housing construction practices in seismically active areas in the world. The mission is to share information related to different construction types and encourage the use of earthquake-resistant construction technologies worldwide.



a) Central America



b) Europe and Near East

Figure 1. Overview about existing WHE reports for main building types in a) Central America and b) Europe and Central Asia (taken from Abrahamczyk et al., 2017).

The WHE Report Database contains reports on housing construction types in seismically active countries. A closer look to worldwide regions of high seismic risk provides a first idea about prevalent building types in these areas and countries (WHE, 2004). Each housing report contains a detailed description of a specific housing type in a particular region (of a country), somehow recognizing the local resources of available material.

WHE can be regarded as the most comprehensive database covering the variation of structural systems for the majority of building typologies in earthquake-affected regions worldwide. Recent efforts of the WHE leadership have been concentrated on the identification and detailed description of prominent building typologies in various parts of the world that are still missing in the database.

Table 1. Overview of **masonry building** types and assigned vulnerability classes in WHE reports and comparison with EMS-98 vulnerability classes and 1st proposal for the IMS by Abrahamczyk et al. (2017)

Type of Structure	No. of reports	No. of stories	Vulnerability Class					
			A	B	C	D	E	F
EMS-98	rubble stone, fieldstone	*	○					
	adobe (earth brick)		○—					
	simple stone		○					
	massive stone			○—				
	unreinforced, with manufactured stone units		○					
	unreinforced, with RC floors			○—				
	reinforced or confined					○—		
IMS	Masonry (M) – Weak		○—					
	Masonry (M) – URM		○—					
	Masonry (M) – Structural			○—				
WHE	Unreinforced Masonry Buildings, Brick masonry	20	1 - 6	○				
	in lime/cement mortar	12	1 - 6	○				
	in mud/lime mortar	8	1 - 5	○				
	Stone Masonry House	15	1 - 7	○				
	Rubble stone without/with mud/lime/cement mortar	2	1 - 4	○				
	Dressed stone masonry (in lime/cement mortar)	13	1 - 7	○				
	Confined Masonry Building	11	1 - 6			○		
	Clay bricks, with concrete tie-columns and beams	6	1 - 6			○		
	Concrete blocks, tie-columns and beams	5	1 - 6			○		

Explanations:

- Most likely vulnerability class; — probable range; less probable range, exceptional cases.
- Vulnerability Table of the EMS-98.
- Vulnerability Table according to the 1st proposal of the IMS working group (Spence & Foulser-Pigott, 2014).
- Transformed Vulnerability ratings from different WHE reports acc. to the main type definition.
- Transformed Vulnerability ratings with distinction of the sub-types.
- * Damage reports related to different major earthquakes worldwide (Northridge/USA 1994, Kobe/Japan 1995, Aegion/Greece 1995, Dinar/Turkey 1996, Cariaco/Venezuela 1997, Central Italy 1997/1998).

The paper is intending to inform and initiate:

- a strategy for a frequent review of existing WHE housing reports based on the creation of a link to other EERI initiatives like EQ clearinghouse or other freely available resources;
- a guide for the vulnerability rating based on a comparative study with EMS-98 (Grünthal et al., 1998) in preparation of the development of an International Macroseismic Scale (Abrahamczyk et al., 2017; 2021, Schwarz et al., 2024) and the GEM building taxonomy (Gallagher et al., 2013).

On this basis, the paper suggests improvements as well as a general procedure for updating the various WHE reports. The purpose of this study is to assess the quality (reliability) of information provided in the WHE reports. Especially, the assignment of the vulnerability will be discussed, whereas the behavior of other building typologies will be taken into consideration.

According to the EMS-98 approach, which has been followed in the studies by Abrahamczyk et al. (2017, 2021) and Schwarz et al. (2015), the vulnerability class of an individual building typology generally depends on the observed earthquake damage for that typology relative to other similar typologies, and is presented as a range rather than a single value.

It is believed that the paper will be relevant to earthquake engineering professionals interested in seismic vulnerability of building typologies, and will support the exchange of experience and links between different international activities such as earthquake reconnaissance studies, EQ clearinghouses, etc. In addition, it will support the WHE leadership to proactively encourage authors to update their reports.

3 Basic elements of Vulnerability Table

3.1 Use of symbols

To indicate the vulnerability of construction methods (type of structure), the WHE uses a symbology that slightly differs from the one implemented by the EMS (see Table 2), nonetheless it can be considered as the first accompanying contribution to the preparation of the International Macroseismic Scale.

Table 2 gives examples for the description of vulnerability (most likely, probable and less probable ranges, exceptional cases) following the Assignment Procedures AssP in Table 3.

The following statements can be made:

- The elements are only used in full in the vulnerability table of the Core Scale and in the applications of EDAC (e.g., in some cases also when transferring the concept to other natural hazards); they stand for a comparative evaluation of earthquake damage in terms of construction methods (type ①).
- Some applications offer a simplification that appears permissible in view of the knowledge level (i.e., only what can actually be assigned should be assigned).
- With many applications and the approach in the run-up to the IMS, however, it can be assumed that there is a lack of understanding of the basics and intricacies of the EMS (connection between building type-vulnerability- damage grade and quantity of occurrence) and the intended use of the symbols.

Table 2. Examples for the description of vulnerability (following the Assignment Procedures of Table 3)

ID	Type of structure	AssP	Vulnerability Class							
			A ⁻	A	B	C	D	E	F	F ⁺
M	Confined	①			-----○-----					
		①			-----○-----					
RC	RC ERD	②					○			
		②			lb		ml	ub		
		③					○			
		④				±	ml	±		

Explanation for symbols used in Table 2:

classes: **ml**: most likely **ub**: upper bound **lb**: lower bound
 ranges: **r-p**: probable **r...lp(exc)**: less probable, exceptional cases

“A-“ and “F+“ (never used) might expected for buildings types or structural system which should be excluded by the intensity assignment (i.e., monumental buildings, tall and special structures, plants etc.)

The various "EMS symbols" should continue to be used in a targeted manner (in the sense of the "empirical values" gained from earthquakes, including the implied engineering judgement).

3.2 Assignment Procedures

The introduction of different assignment procedure (AssP) might indicate the quality of information and the inherent uncertainties as well as misleading judgements.

In minimum, four assignment procedure (AssP) ① to ④ should be distinguished (see Table 3). They might provide by the selected „indicative characteristics“ relevant criteria for a classification or evaluation of the information quality mirroring the request to be complementary and in line with the assignments within the EMS Vulnerability Table.

Assignment procedure ① follows the form within the Vulnerability Table of the EMS Core Scale. Elements for the classes and ranges are used completely to indicate the uncertainties of observed effects (now in terms of the probability of practical occurrence). The „indicative characteristics“ include the comparative consideration of the observed effects (damage grades) on the basis of different earthquakes and intensity levels.

Assignment procedure ④ refers to the most likely class, only. It would be the “lowest” level of information quality if the uncertainties are ignored or couldn’t be identified.

Reports in WHE follow assignment procedure ② and provide the most likely class (**ml**) and the classes for the upper and lower bounds (**ub**, **lb**), only; the ranges are for the uncertainty between/within are not described. This is correct and recommendable if no more information is available.

The numerical damage description or modelling (lognormal, β -distribution etc.) could be derived from the ranges and the symmetrical or non-symmetrical deviation from the most likely class. This is explained and studied by Maiwald & Schwarz (2017). The proposed methodology procedure can provide the entry to link fragility functions with empirical studies and assigned ranges of vulnerability classes, and vice versa.

Table 3. Assignment Procedures

AssP	Indicative characteristics	Elements				
		ml	lb	ub	r-p	r..lp
①	Non-symmetrical ranges; covering different probabilities or uncertainties over a range of VC (EMS-98).	●	●	●	●	●
②	Non-symmetrical ranges; equal (not defined) probability within the range of VC (WHE, close to EMS-98).	●	●	●		
③	Symmetrical ranges; equal (not defined) probability; only \pm one VC (i.e., equal probability) (Maqsood & Schwarz, 2008).	●	○	○		
④	Most likely VC is assigned, only appropriate in case of quite unique building type or by ignorance of uncertainties.	●				

Symbols:
 ● Used, part of the description
 ○ might be used

3.3 Improvements

During the WHE Committee Meeting July 24, 2014 Anchorage, Alaska (Meeting Notes by Marjorie Greene & Dominik Lang, Aug 14, 2014) it was discussed how WHE could take a relevant role in linking the reports with the ongoing initiative for an International Macroseismic Scale (Spence & Foulser-Pigott, 2014).

Some ideas and strategies could be agreed for improvement and update of WHE reports:

- (1) Give more information on the assigned vulnerability class(es) and ranges;
- (2) Improve the description of vulnerability classes, bring the information to *an even level*;
- (3) request authors to provide new information, not only with respect to the vulnerability class, but also for other items of the report
- (4) put a date when form was last modified.

Concerning (1), authors should be asked to indicate the quality of their data, particularly their confidence level in determining vulnerability, and to provide more information about the basis on which the vulnerability class was assigned.

Upcoming changes in the European Macroseismic Scale (towards IMS) should be recognized and should be incorporated. Additional guidance from EMS/IMS authors should be provided.

One of the fundamental critics are related to the link of the reports to observed damage and the relation of the indicative vulnerability of the described building type to the response of others in the same region, assuming a similar level of shaking. Not at least, it has to be pointed out, that the assigned vulnerability classes in the EMS-98 refer to the outcome of different earthquakes and field surveys, covering in best case different levels of shaking.

In general, vulnerability classes given by the WHE Reports refer to one building type but not to a comparative damage analysis of different types within the affected region. Therefore, information about the building type should be enriched by information concerning the statistical representativeness. In as much this demand is satisfied should be studied. It is recommended to introduce quality indicators. First attempts are given by GEM (Gallagher et al., 2013).

Concerning (2) to (4) and in line to the development of IMS, it was recommended to use “tagging colours” for the quality of reports.

Table 4. Proposal for the quality check of WHE Reports

„Tagging“ (Symbol, color)	Criteria for the quality check of reports and the vulnerability assignment			
	Several EQs or observed shaking effects/intensities [one EQ]	Comparison of structural system of building types	Representativeness of the structural type for the target region	Consistency check to previous assignments or other reports for the same type*
↑	✓	✓	✓	✓
↗	[✓]	✓	[✓]	✓
↘	[✓]	[✓]	[✓]	✓
→			✓	✓
→			[✓]	✓
↘			[✓]	

* **Note:** An engineered plausible and qualified description and evaluation should be supported by a (Wiki-compatible) review system.

3.4 Remarks on introducing new building types

The following brief guidelines give some indications to how new types can be added. This is unlikely to be a straightforward procedure and is best undertaken by a panel of experts in a controlled way.

Note that there is a basic requirement for a new building type to be one that is sufficiently common to be treated statistically in assessing intensity. Any sort of rural housing type is suitable; uncommon industrial buildings are not. The overall aim is to compare the new or additional building type with those already covered (and to maintain an equivalence in the observed or probably observable response for the assigned vulnerability classes). If it is considered that the type is as strong, but not stronger, than normal brick construction, for example, then one may classify the type as being basically of class B. If the type is such that, owing to innate ductility it never performs worse than brick buildings, but in some cases where construction is very good it performs significantly better, then one might deduce that the building type should be represented on the Vulnerability Table as a circle under B and a line extending to C but not to A.

The question is how such an equivalence should be established. Ideally, in an area where the new building type coexists with a building type already present in the Vulnerability Table, then the results of a damage survey could be used to establish an objective classification. For example, in a town, many brick buildings suffer damage of grade 2 but only a few of the new building type are so damaged. The intensity is assessed as 7, and the evidence indicates that the new building type is of class C.

If this is not possible because the new building type is the exclusive construction type in the area, it may be possible to assess intensities 6-8 from other diagnostics and then, by considering the proportion of damaged buildings, determine the correct vulnerability class.

Care needs to be taken with building types that could be considered as compound constructions. An example is given by wooden buildings with exterior brick cladding. In this case, if the cladding is not well-bonded to the structure it may be very weak and easily damaged, while the wooden frame remains ductile and unaffected. Such buildings may suffer non-structural damage quite easily while having high resistance to structural collapse. Buildings with special strengthening, as previously discussed, can also present cases that can be difficult to resolve in a simple way.

4 Transformation of vulnerability assignments into the EMS-98 classification scheme

Similar to the EMS-98, structural vulnerability is described by six classes ranging from high to very low vulnerability or from very poor to excellent seismic performance in the reports of the World Housing Encyclopedia (WHE, 2004). Each report more or less assigns an overall rating as well as an upper (worst) and a lower (best possible) bound (Schwarz et al., 2015).

Tables 5 and 6 represent the assigned overall seismic vulnerability ratings taken from the various WHE reports for masonry and R.C. buildings, respectively. These ratings are transformed into the original "Vulnerability Table" of the EMS-98 by determining the most likely vulnerability class as well as its probable and less probable ranges:

- The most likely vulnerability class is determined as the mean value of all assigned overall ratings.
- The probable range is determined as the mean of all assigned lower and upper bounds.
- The less probable range defines the lowest and uppermost assigned seismic vulnerability ratings.

The comparison of the assigned vulnerability class ranges according to the EMS-98 and the assigned vulnerability classes in the WHE reports show (Abrahamczyk et al, 2017):

- (1) In general, a scatter in the "most likely VC" assignments, and (more evident) for the probable and less probable ranges for similar structural types exists. (The reasons might be related to regional peculiarities and differences in the national seismic design codes);
- (2) Difficulties in the assignment of the vulnerability classes are "compensated" by using assignment procedures (AssP) ③ and ④ (see Tables 2 and 3).
- (3) Results from Tables 5 and 6 can't replace the EMS classification, they are indicative, but might be taken as a controlling scheme for (and before) inserting additional structural types within an IMS version.

Table 5. Overview of **R.C. building types** and assigned vulnerability classes in WHE reports transferred into EMS-98 vulnerability classes and ranges (Abrahamczyk et al., 2017)

Type of Structure	No. of reports	No. of stories	Vulnerability Class						
			A	B	C	D	E	F	
Moment Resisting Frame	Designed for gravity loads only, with URM infills	17	1 - 18						
	Story Class I	6	1 - 3						
	Story Class II	6	4 - 6						
	Story Class III	5	> 6						
	Designed for seismic effects, with URM infills	9	1 - 20						
	Story Class I	3	1 - 3						
	Story Class II	4	4 - 6						
	Story Class III	2	> 6						
	Dual system – frame with walls	4	4 - 30						
	EMS-98: frame without ERD	*							
EMS-98: frame with moderate level of ERD									
EMS-98: frame with high level of ERD									
Structural Wall	Moment frame with in-situ shear walls	7	1 - 35						
	Moment frame with precast shear wall	1	5 - 10						
	EMS-98: walls without ERD								
	EMS-98: walls with moderate level of ERD								
	EMS-98: walls with high level of ERD								
Precast	Large panel precast walls	3	2 - 9						
	Pre-stressed moment frame with walls	1	1 - 12						
	Moment frame	5	5 - 18						
	Shear wall structure with walls cast in-situ	4	1 - 18						

Legend:

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

— Vulnerability Table of the EMS-98

— Transformed vulnerability ratings from the different WHE reports without distinction of story classes

— Transformed vulnerability ratings with distinction of three story classes (SC)

Table 6. Overview of **Masonry** and assigned vulnerability classes in WHE reports transferred into EMS-98 vulnerability classes and ranges (Abrahamczyk et al., 2017)

Type of Structure	No. of reports	No. of stories	Vulnerability Class					
			A	B	C	D	E	F
Adobe ⁽¹⁾	24	1 - 7	·○——·····					
- adobe block walls	10	1 - 2	○—					
- mud walls	9	1 - 3	·○·····					
- mud walls with horizontal wood elements	2	1	·○—					
- rammed earth/pile construction	3	1 - 3	○					
EMS-98: rubble stone, fieldstone	-	-	○					
EMS-98: adobe (earth brick)	-	-	○—					
Stone masonry walls	18	1 - 7	·○·····					
- rubble stone without/with mud/lime/cement mortar	16	1 - 7	○·····					
- massive stone masonry (in lime/cement mortar)	2	1 - 4	·○—					
EMS-98: simple stone	-	-	······○					
EMS-98: massive stone	-	-	······○·····					
Unreinforced masonry walls (URM)	22	1 - 6	·○·····					
- in lime/cement mortar	13	1 - 6	·○·····					
- in mud/lime mortar	9	1 - 5	·○·····					
EMS-98: unreinforced, with manufactured stone units	-	-	······○·····					
EMS-98: unreinforced, with RC floors	-	-	······○·····					
Confined masonry building ⁽²⁾	13	1 - 6		······○·····				
Reinforced masonry ⁽²⁾	3	1 - 4	······○·····					
EMS-98: reinforced or confined	-	-		······○·····				

Legend:

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

— Vulnerability Table of the EMS-98

—— Transformed vulnerability ratings from the different WHE reports without distinction of story classes

— Transformed vulnerability ratings with distinction of up to three story classes (SC)

(1) The report from India on “Traditional rural house in Kutch region of India” was neglected, because of its disproportional high vulnerability assignment; i.e., vulnerability class E for less probable

(2) Brick and concrete block masonry are combined, because many reports cover both material types!

5 Outlook – Need for comparison of taxonomies

A correlation between the SERA building types and the EMS-98 building types is established, with a focus on types relevant to the exposure modelling of TURNkey testbeds (Schwarz et al., 2021). **Fehler! Verweisquelle konnte nicht gefunden werden.**7 shows the suggested correlation.

Table 7. Correlation between SERA and EMS-98 building types (Schwarz et al., 2021).

SERA building types (GEM taxonomy)					EMS-98		
MLLRS		LLRS		Height	SS	Abbr.	Type of Structure
L1	L2	L1	L2				
MUR	STRUB	LWAL	DNO	LR		M1	rubble stone, fieldstone
MUR	ADO	LWAL	DNO	LR		M2	adobe (earth brick)
ER	ETC	LWAL	DNO	LR			
MUR	ST	LWAL	DNO	LR;MR		M3	simple stone
MUR	STDRE	LWAL	DNO	LR;MR		M4	massive stone
MUR	CB	LWAL	DNO	LR		M5	unreinforced, with manufactured stone units
MUR	CL	LWAL	DNO	LR;MR		M6	unreinforced, with RC floors
MR		LWAL	DUCL	LR		M7-R ⁽¹⁾	reinforced
MCF		LWAL	DNO;DUCL	LR;MR		M7-C ⁽¹⁾	confined
CR		LFINF	DNO;DUCL	LR;MR;HR	SOS	RC1-L	frame without ERD
CR		LFM	DNO;DUCL	LR;MR;HR			
CR		LFINF	DUCM	LR;MR;HR	SOS	RC1-M	frame with moderate level of ERD
CR		LFM	DUCM	LR;MR;HR			
CR		LFINF	DUCH	LR;MR;HR	SOS	RC1-H	frame with high level of ERD
CR		LFM	DUCH	LR;MR;HR			
CR		LWAL	DNO;DUCL	LR;MR;HR		RC2-L	walls without ERD
CR		LWAL	DUCM	LR;MR;HR		RC2-M	walls with moderate level of ERD
CR		LWAL	DUCH	LR;MR;HR		RC2-H	walls with high level of ERD
CR		LDUAL	DNO;DUCL	LR;MR;HR	SOS	RC3-L ⁽²⁾	dual system without or with low level of ERD
CR		LDUAL	DUCM;DUCH	LR;MR;HR	SOS	RC3-M/H ⁽²⁾	dual system with moderate/ high level of ERD
CR	PC	LFM	DUCL;DUCM	LR;MR;HR		RC4 ⁽²⁾	precast frame
CR	PC	LPB	DNO	LR			
CR	PC	LWAL	DNO to DUCH	LR;MR;HR		RC5 ⁽²⁾	precast walls
CR	PC	LDUAL	DUCM	LR;MR;HR		RC6 ⁽²⁾	precast dual system
CR		LFLS	DNO			RC7 ⁽²⁾	flat slab
S		LFM	DNO;DUCL	LR;MR;HR			
S		LFINF	DNO;DUCL	LR;MR;HR		S-L ⁽¹⁾	frame without and low level of ERD
S		LFBR	DNO;DUCL	LR;MR;HR			
S	SL	LFM	DUCL	LR			
S		LFM	DUCM;DUCH	LR;MR;HR			
S		LFINF	DUCM;DUCH	LR;MR;HR		S-M/H ⁽¹⁾	frame with moderate/high level of ERD
S		LFBR	DUCM;DUCH	LR;MR;HR			
S	SL	LFM	DUCM	LR			
W	WHE	LFM	DUCL	LR		W1-L ⁽¹⁾	frame with low level of ERD
W	WHE	LFM	DUCM;DUCH	LR		W1-M/H ⁽¹⁾	frame with moderate/high level of ERD
W		LWAL	DNO to DUCH	LR;MR		W2 ⁽²⁾	walls
SRC				LR;MR		X1 ⁽²⁾	concrete, composite with steel section
W	S	LPB	DNO	LR		X2 ⁽²⁾	timber and steel, post and beam

Explanations:

MLLRS: Material of lateral load-resisting system LLRS: Lateral load-resisting system

SS: Soft-storey

ERD: Earthquake-resistant design

M: Masonry. RC: Reinforced concrete. S: Steel. W: Wood. MX: Mixed.

⁽¹⁾ Subclassified ⁽²⁾ Introduced.

Recent efforts of the WHE executive committee have been concentrated on the review of the existing WHE housing reports based on the creation of a link to other EERI initiatives like EQ clearinghouse (EERI, 1973) and other open access resources. Reports are checked for major discrepancies, missing information and inconsistencies, see criteria given in Table 4. In addition, the database is transformed into a WIKI (<https://cerem.ufp.pt/start>), whereas authors rights and possibility of changes within the original housing report have to be addressed. Now, amendments, comments and trackable changes are easily possible and WHE WIKI becomes a living tool; reports as well as relevant explanatory documents are linked and can be assessed, easily.

6 References

- Abrahamczyk, L.; Schwarz, J.; Langhammer, T.; Genes, M.C.; Bikce, M.; Kacin, S. and Gülkan, P. (2013). Seismic Risk Assessment and Mitigation in the Antakya-Maras Region (SERAMAR): Empirical Studies on the basis of EMS-98. *Earthquake Spectra*, Vol. 29 (3):683-704.
- Abrahamczyk, L., Lang, D.H., Schwarz, J. (2017). WHE-Reports as a complementary database towards the development of an International Macroseismic Scale. *Proceedings 16th World Conference on Earthquake Engineering*, Santiago, Chile, 2017, Paper-No. 3657.
- Abrahamczyk, L., Brzev, S., López Menjivar, M.A., Silva, V., Lang, D.H., Schwarz, J. (2021). WHE Housing Reports – A review with respect to past and current earthquake damage observation. *Proceedings 17th World Conference on Earthquake Engineering*, Sendai, Japan, Paper No. 1396.
- EERI (1973). *Learning From Earthquakes* [Internet], <http://www.learningfromearthquakes.org> [last access Jan. 2020].
- Grünthal, G., Musson, R.M.W., Schwarz, J., Stucchi, M. (1998). European Macroseismic Scale 1998. *Cahiers du Centre Européen de Géodynamique et de Séismologie*, Vol. 15, Luxembourg.
- Gallagher, H., Farmer, B., Mendoza, C., Lee, C., Dickson, H., Greene, M. (2013). *GEM Building Taxonomy v2.0: Evaluation and Testing Report, GEM Building Taxonomy Global Component*. Available from <http://www.nexus.globalquakemodel.org/gem-building-taxonomy/posts/report-on-evaluation-and-testing-of-the-gem-building-taxonomy-released/>
- Maiwald H., Schwarz J. (2017). Vulnerability assessment of Multi Hazard exposed building types - development of an EMS-98 based empirical-statistical methodology. *Proceedings 16th World Conference on Earthquake Engineering*, Santiago, Chile, 2017, Paper No. 2134.
- Maqsood, S.T., Schwarz, J. (2008). Analysis of building damage during the 8th October, 2005 Earthquake in Pakistan. *Seismological Research Letters*, 79 (2): 163-177.
- Schwarz, J. (2011). Empirical vulnerability assessment – a review of contributions to the damage description for the European Macroseismic Scale. *Proceedings of: Earthquake Engineering and Engineering Seismology: Past Achievements and Future Prospects*. Ankara, Turkey.
- Schwarz, J., Abrahamczyk, L., Hadidian, N., Haweyou, M., Kaufmann, C. (2021). Report on Knowledge-based exposure modelling framework depending on the accuracy and completeness of available data. Version 1.0, Deliverable D4.1. *TURNkey project*. H2020-SC5-2018. <https://drive.google.com/file/d/1AxOXQJjmoJq6mwAhix9BH-K9jfeNTP32/view>
- Schwarz, J., Abrahamczyk, L., Leipold, M., Wenk, T. (2015). Vulnerability assessment and damage description for R.C. frame structures following the EMS-98 principles. *Bulletin of Earthquake Engineering*, Vol. 13 (4): 1141-1159.
- Schwarz, J., Haweyou, M., Wenk, Th. (2024). IMS-24 Vulnerability Table and the assignment of Vulnerability Classes for additional building types. *Proceedings 18th World Conference on Earthquake Engineering, Milano*, Italy, 2024.
- Spence, R., Foulser-Piggott, R. (2014). The International Macroseismic scale – extending EMS-98 for global application. *Proceedings of the Second European Conference on Earthquake Engineering*. Istanbul (Turkey), 2014, Paper 835.
- WHE (2004). *World Housing Encyclopedia - a joint project by EERI and IAEE* [Internet]. <http://www.world-housing.net/>.