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WHE-REPORTS AS A COMPLEMENTARY DATABASE TOWARDS THE DEVELOPMENT OF AN INTERNATIONAL MACROSEISMIC SCALE

L. Abrahamczyk[(1)], D.H. Lang[(2)], J. Schwarz[(3)]

[(1)] *Researcher, GRK1462, Bauhaus-University Weimar, Germany, lars.abrahamczyk@uni-weimar.de*
[(2)] *Head of Department, Earthquake Hazard and Risk, NORSAR, Norway, dominik@norsar.no*
[(3)] *Head, Earthquake Damage Analysis Center, Bauhaus-University Weimar, Germany, schwarz@uni-weimar.de*

Abstract

Over the past few years the number of reports which are included in the World Housing Encyclopedia - WHE (http://db.world-housing.net/) has increased in a remarkable way. This development was not the least supported by international initiatives contributing to global earthquake (risk) reduction. The WHE can be regarded as the most comprehensive database covering the regional variation of structural systems for the majority of building typologies in earthquake-affected regions worldwide. Recent efforts have been concentrating on the identification and detailed description of prominent building typologies in various parts of the world that are still missing in the database. Further progress in filling up the database might be achieved by affiliating/collaborating with international Master courses and the elaboration of reports as part of the project work related to risk assessment in structural engineering, most probably by students preparing reports of typologies prevalent in their home countries (see http://www.uni-weimar.de/nhre).

The paper at hand informs about the current update of WHE reports in order to give a more harmonized assignment of the most likely vulnerability class (as well as their ranges) to the respective typologies. Authors are asked to indicate the quality of their data, particularly their confidence level in determining the vulnerability class and what type of information this assignment is based upon. This editorial qualification supports the direct link of the reports in transforming the European Macroseismic Scale (EMS-98) into an International Macroseismic Scale (IMS). Guidance is provided how the description of vulnerability classes can be better related to the EMS-98 principles while harmonizing the information provided. In addition to the vulnerability class, authors are requested to submit updates of the reports, especially immediately after the occurrence of larger earthquakes. Here, the quality (reliability) of the assignments could be indicated, accepting that the vulnerability of an individual building typology (reported) stands in a meaningful/sound relationship to the observed response and assigned vulnerability classes of other building typologies.

The paper summarizes regional variations of the overall building typology and tries to correlate general characteristics (e.g., age) with seismic vulnerability features (i.e., structural layout, elements, connections, floor and roof type etc.) to the expected “IMS vulnerability class” for each regional variant. Following the updated EMS Vulnerability Table, regional particularities are expressed in their most likely vulnerability class, along with the ranges of probable and less probable (i.e., exceptional) cases.

Keywords: World Housing Encyclopedia, Vulnerability assessment, EMS-98

1. Introduction

The description of the structural vulnerability of buildings and the resulting damage predictions for different impact levels are key elements of seismic risk studies, especially when an entire building stock is under assessment. Damage analyses of recent earthquakes generally contribute to a better understanding and interpretation of the response (performance) of structures, their damage mechanisms as well as damage patterns. Based on these observations, some guidance could be added to the EMS-98 how to interpret the damage of both structural and non-structural elements as well as the extent of damage and its distribution over the building. Further, the EMS-98 vulnerability definitions could be refined with respect to its further development into an International Macroseismic Scale (in the following named IMS).

Due to the limited number of available systematically surveyed empirical data of earthquake damages, the reports of the World Housing Encyclopedia are studied. The systematic assessment of the reports and the transformation of the vulnerability assignments into the EMS-98 vulnerability class scheme allow a comparative study as well as a probable extension of the European Macroseismic Scale whose development was paused after its most recent version published in 1998 (Grünthal et al., 1998).

2. EMS-98: Building types and vulnerability assignments

The European Macroseismic Scale 1998 (EMS-98) [1] incorporates a compromise, in which a simple differentiation of the resistance of buildings to earthquake shaking (vulnerability) was employed. The introduction of vulnerability classes provides a robust solution in describing the way different building typologies may respond to earthquake shaking. The Vulnerability Table is an attempt to categorize the seismic resistance of different structures in a manageable way, taking both building type and other factors (e.g. workmanship, regularity, state of preservation, level of earthquake-resistant design) into account. The most recent version of the scale (i.e., EMS-98) is a development from previous scales which used only the construction type as an analogue of (a descriptor for) vulnerability.

The EMS-98 explicitly allows the assignment of transition classes and the consideration of vulnerability-affecting factors. It is one of the inherent advantages of the EMS-98 that the ranges of the vulnerability can be used to indicate the scatter of existing realizations and – with rather simplified graphical elements – the probability of expectation.

Currently, the EMS-98 distinguishes four major building types according to the main structural/work materials: i.e., masonry, reinforced concrete (R.C.), steel, and timber, whereas for masonry and reinforced concrete several sub-types are already defined. In the case of R.C. structures, the EMS-98 considers different levels of earthquake-resistant design (ERD) for frame and wall systems. These levels assume that both the structural design and the construction processes of buildings located in seismically active regions follow the respective seismic code provisions, thereby considering the prescribed level of earthquake ground motion adjusted to the local site and soil conditions. The different design levels represent different levels of ground motion or base shear coefficient. Masonry, one of the main classes with respect to its prevalence in worldwide earthquake areas, includes sub-types for rather weak materials (i.e., adobe, rubble and simple stones) as well as massive and manufactured (i.e., rectangular) brick or block units. In addition, different floor types as well as wall reinforcements (i.e., internal wall reinforcement or confinement) are considered. So far timber and steel structures are not further distinguished.

In the framework of the EMS-98 the assignment of the most likely as well as the most probable vulnerability class incorporates a compromise. Thereby, a simple differentiation of the resistance of buildings to earthquake-generated shaking (vulnerability) was employed in order to give a robust way of differentiating the way in which buildings may respond to earthquake shaking. The Vulnerability Table is an attempt to categorize the strength of structures in a manageable way, taking both building type and other factors into account. According to this approach adobe buildings are the most vulnerable building types (i.e., vulnerability class A), while the more engineered building typologies with the highest level of ERD are considered as the least vulnerable typologies.

Damage observations and experiences gathered during the past 20 years have provided new data, which might lead to an update/modification or even introduction of new building typologies, i.e., sub-types. Keeping the robustness and simplicity of the EMS-98, the assignment of the vulnerability class for new or modified building types has to follow the original principles. This means that the most likely vulnerability classes of different building types located in an area with similar intensity have to be adjusted to each other. Higher damage grades have to be expected/observed for lower vulnerability classes and vice versa.

3. The World Housing Encyclopedia

The World Housing Encyclopedia [2] 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, 162 reports from 44 countries are included in the online database (state April 2016; see Fig. 1).

A closer look to worldwide regions of high seismic risk (like e.g., I. Central and South America) and Europe provides a first idea about prevalent building types in these areas and countries. Unfortunately, the WHE could not reach a status of completeness yet. Therefore, the available reports are just describing representative building types for the respective country. Information about the percentile distribution is not yet available. Nevertheless on the basis of the available information the most vulnerable areas/ countries can be identified.

Fig. 2 illustrates the already existing reports as well as described building types in Central America and Europe and Central Asia. It indicates that the building stock is still incompletely described for many countries. On the other hand, the figures highlight/illustrate which regions or countries should be prioritized in terms of preparing reports on so far missing building typologies. The building stock is not or only partially described for countries in Central and South America and the Caribbean. So far, there are no reports prepared for Ecuador, Jamaica and Haiti. Field surveys from the April 2016 Ecuador earthquake might contribute to fill the gap.

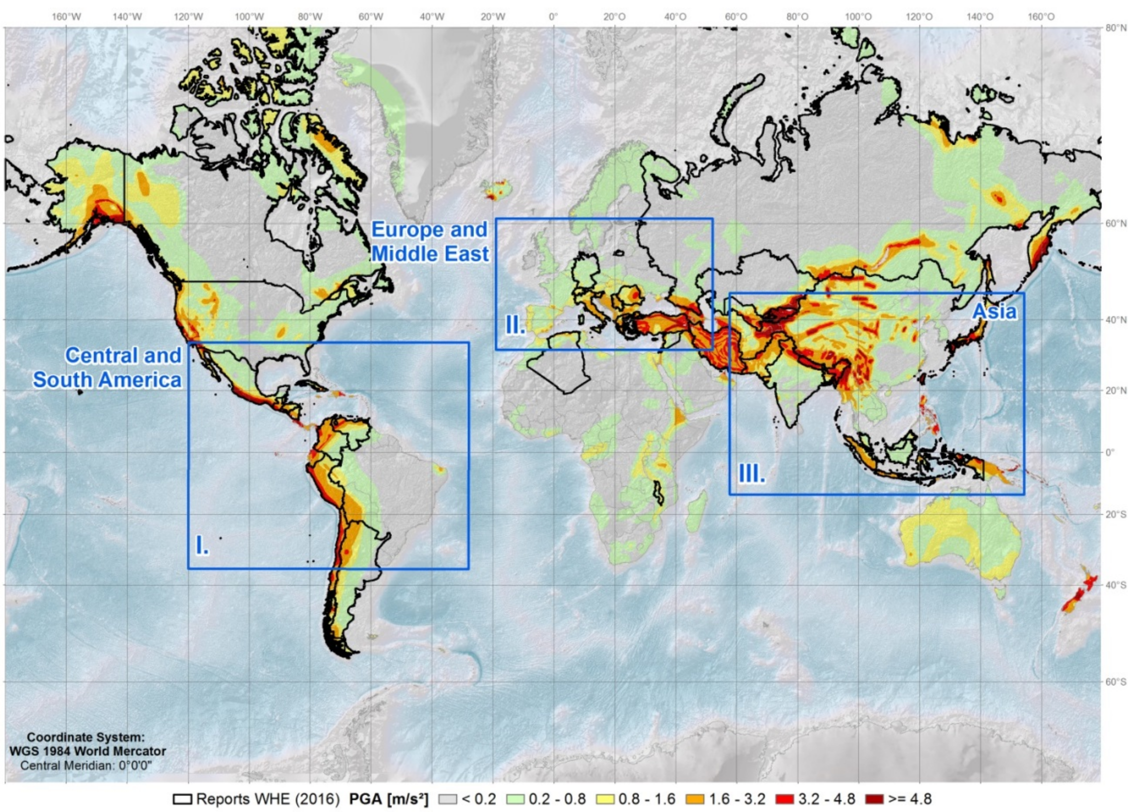
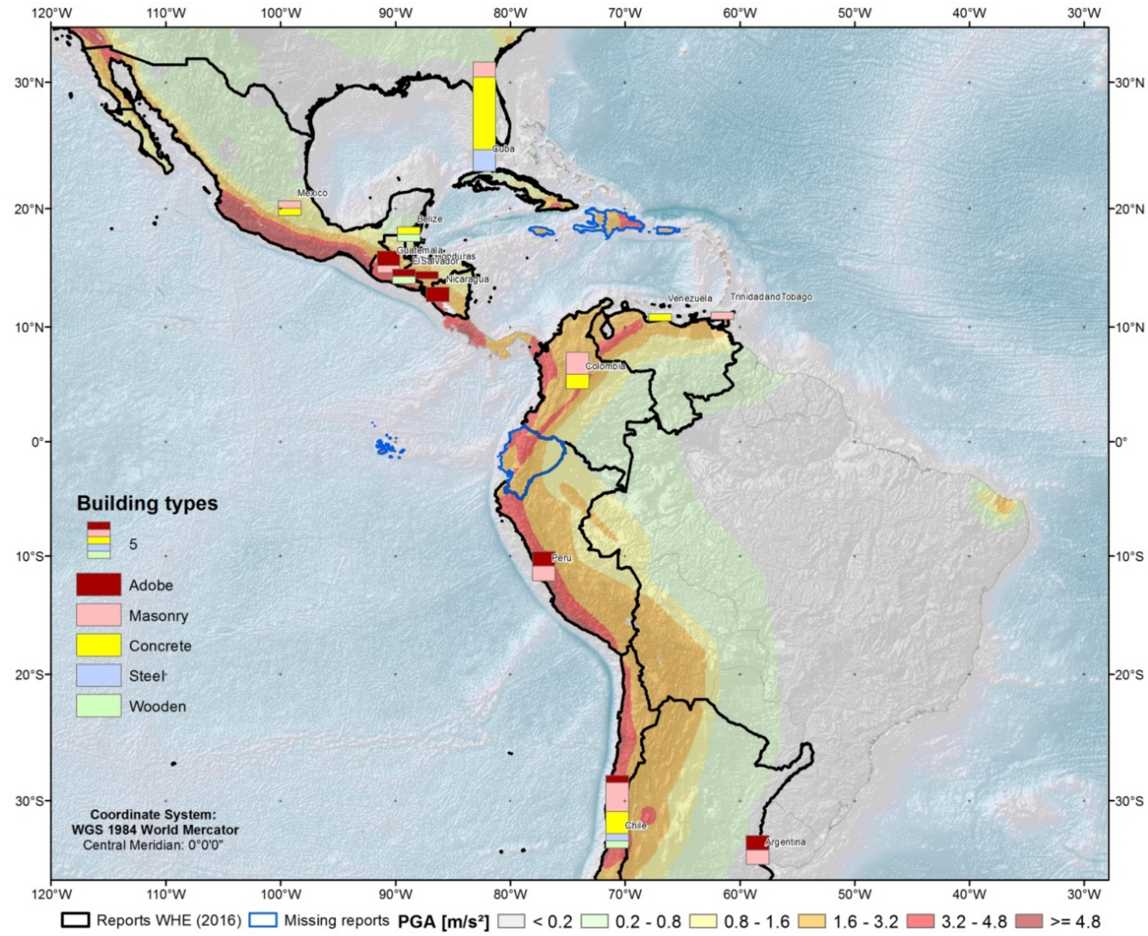
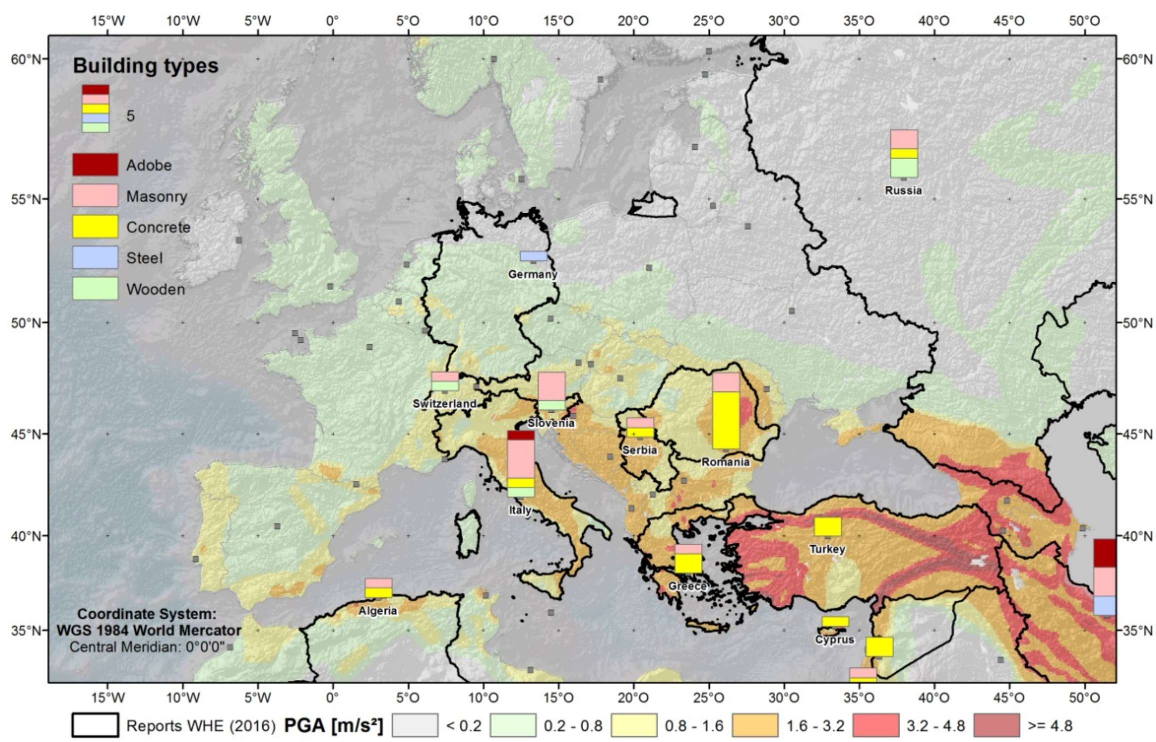


Fig. 1 – Comparison of available WHE reports and hazard-dominated areas (countries) according to GSHAP [3].



a)



b)

Fig. 2 – Overview about existing WHE reports for main building types in a) Central America and b) Europe and Central Asia.

Similar to the EMS-98, the WHE differentiates major building typologies with different sub-types. A comparative study of the WHE reports shows, that, similar to the EMS-98, four major building types are distinguished, i.e., R.C., masonry, steel, and timber. In addition, few reports are discussing other building types, like e.g. base-isolated structures which do not play a major role for a later intensity assignment. In fact, the WHE also defines pretty similar but also additional sub-types like the EMS-98 does for masonry and R.C. buildings.

In parts of the conducted comparative study the available information from the WHE online database (http://db.world-housing.net/) are systematically studied in order to summarize regional variations of the overall building typology and to correlate worldwide vulnerability assignments in the context of the "IMS vulnerability classes".

4. Vulnerability Classes for different building types – a comparative study

4.1 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 [4].

Tables 1 and 2 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 [5]:

- 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:

- a large scatter in the most likely assignment as well as in the probable and less probable ranges (the reasons might be related to regional peculiarities and differences in the national seismic design codes);
- moreover, difficulties in the assignment of the vulnerability classes and the generation of a refined classification scheme.

4.2 Reinforced Concrete (R.C.) building types

The comparison of the vulnerability classes assigned to reinforced-concrete structures leads to the following conclusions:

- The assigned vulnerability classes for "moment-resisting frames designed for gravity loads only" are always lower in comparison to the European approach (EMS-98).
- "Structural wall buildings" are better evaluated or comparable to the EMS-98 type "walls with moderate to high level of earthquake resistant design". The reason for this circumstance may lie in the fact that such buildings are usually designed for earthquake loads.
- The uncertainty in the less probable range of the vulnerability assignment is in most of the cases defined by single reports which might have to be re-evaluated and/or corrected.
  Example: In the case of building type *Moment resistant frame – designed for gravity loads only, with URM infills*, vulnerability class E was assigned in two cases, i.e., for irregular multi-story (5 to 10 stories) apartment buildings in India (WHE Report #19), and for 2-story R.C. buildings in Malaysia(WHE Report #44). In the first case (India), the assigned vulnerability class seems to be too optimistic, while the description of the buildings in Malaysia is emphasizing that "*the vertical load-resisting system is reinforced-concrete structural walls (with frames)*", hence presumably underestimating the building type's seismic performance.

- The assigned probable ranges of the vulnerability assignments show a quite stable/narrow band, which indicates a quite common international understanding/evaluation.
- The differentiation of 'Story Classes' is regarded as a progress for more sophisticated vulnerability assignments. In general, the probable and less probable ranges indicate the expected trend, but still need additional data to confirm their reliability before an international use might be recommended. [Note: Five reports only do not represent a sufficient number in order to provide a stable basis.]
- Surprisingly, the international assigned vulnerability classes for *"moment-resisting frames designed for gravity loads only"* with 4 to 6 stories are higher (i.e., more optimistic) than those for 1 to 3 stories.
- The WHE is introducing the building type *"Precast concrete"* which is so far not introduced in the EMS-98. Thus, the WHE reports could be a suitable basis for the introduction of an additional building type in an internationally updated version of the EMS-98.

Table 1 – Overview of **R.C. building types** and assigned vulnerability classes in WHE reports transferred into EMS-98 vulnerability classes and ranges [4, 6]

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 *1 (legend!!!)	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 *2 (legend!!!)	4	4 - 6						
	- Story Class III	2	> 6						
	Dual system – frame with shear wall	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 Concrete	Large panel precast walls	3	2 – 9						
	Pre-stressed moment frame with shear walls	1	5 – 18						
	Moment frame	5	1 - 12						
	Shear wall structure with walls cast in-situ	4	1 - 18						

<u>Legend:</u> see Table 2

Table 2 – Overview of **Masonry** and assigned vulnerability classes in WHE reports transferred into EMS-98 vulnerability classes and ranges [6]

Type of Structure	No. of reports	No. of stories	Vulnerability Class (VC) 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!

4.2 Masonry building types

The comparison of the vulnerability classes assigned to the whole group of masonry building types leads to the following conclusions:

- The exceptional cases for adobe structure have to be critically reviewed.
- A sub-classification of adobe building types may be necessary in order to consider vulnerability-affecting measures and/or regional peculiarities. Surprisingly, horizontal timber elements in mud walls do not lead to a better vulnerability compared to mud walls without any supporting elements/features.
- The classification of the building types *"Stone Masonry Walls, Simple Stone and Massive Stone"* requires some sort of training (especially for non-engineers or laymen users) in order to guarantee a common understanding and harmonized use. A clear distinction of structural and non-structural aspects and criteria for the assessment are recommended.
- Confined masonry is better evaluated (i.e., VC D) than reinforced masonry; a distinction of these typologies into separate classes should be introduced in the next generation of the EMS-98.

The differentiation of unreinforced masonry buildings with respect to the type of the flooring system (flexible or rigid) as provided by the EMS-98 cannot be addressed by the WHE reports so far. Unfortunately, there are not enough reports available addressing the floor type: In addition, the scatter is still huge and effected by several parameters (e.g. number of stories, wall density, floor type, etc.). The less probable and probable range of the vulnerability class would not show any difference to the type of *"Unreinforced Masonry Walls"*.

4.3 Steel and Timber building types

The comparison of the vulnerability classes (VC) assigned to steel and timber building types shows that:

- The number of reports is rather limited. Assignments for steel buildings according to the WHE indicate more vulnerable systems, i.e., the vulnerability classes are less optimistic than the range provided in the Vulnerability Table of the EMS-98. In the case of some timber building types the situation is vice versa.
- The introduction of subtypes for steel and timber structures might be necessary, but only on the basis of additional reports and experiences. The currently available number of reports is not sufficient to support the introduction of subtypes. In the case of timber structures, the differentiation of subtypes would lead to a reduction of the extremely high less probable range of the VC and could consider regional peculiarities.
- VC F was quite often assigned for the less probable range for timber building types. The reasons might be that such buildings are usually 1-story buildings which have a low vulnerability due to their light-weight construction. Therefore, a further subtype might be introduced which considers also the number of stories of timber structures.
- The uncertainty in the less probable range of the vulnerability assignment is in most of the cases caused by single reports which might have to be re-evaluated and/or corrected.

4.4 Number of necessary building types

The question of how many building types are really necessary in order to perform a macroseismic survey and to assign an EMS intensity is already under discussion [7]. The answer to this question 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 if the buildings of this type could be identified by structural and non-structural characteristics (i.e., unreinforced masonry structures). Also, from a series of subtypes included in the WHE, it can be noted that too many subtypes do not necessarily lead to an improvement if the assignment of the appropriate vulnerability classes itself is not easy in use.

Another aspect of importance is the relationship to the EMS-98 and the target of a consistent handling of buildings. Steel types should be subdivided into two types, i.e., as a function of ERD similar as it is done with existing RC frame and RC wall types. Separate types for mixed steel-masonry structures as well as mixed masonry-concrete structures are still missing.

5. Strategies for a systematic and prioritized vulnerability assessment

5.1 Comparative Studies for similar building types and the regional variation of their vulnerabilities

In Table 3 the most likely vulnerability assignments are compared for all building types according to the related WHE reports per country. Only countries are considered with more than two reports, i.e., prepared for countries of Central America, Europe and Central Asia. The comparison allows a consistency check of the vulnerability assignments and might allow the identification of regional peculiarities.

The systematic analysis shows that in most of the cases the vulnerability assignment of all reports is consistently done over all building types per country; some of the building types have to be redefined and adjusted (e.g., rubble stone masonry) in order to enable a common understanding of the types and their vulnerability. Beside the intention to increase the completeness of the international building types, the allocation of the most likely as well as probable vulnerability is a crucial and difficult task.

Table 3 – Comparison of the most likely vulnerability assignments for all building types

Country	Vulnerability Class					
	A	B	C	D	E	F
Latin America						
Argentina	**A-b**	**A-m**		CM	CM	
Chile	**A-b**	RM		RM	CM	**RC-FD** | **RC-W** | **S**
Colombia		**RC-Fg** | URM		**RC-W** | RM		
Cuba		CM $^{*)}$	**S** | **RC-P** | **RC-Fd** | **RC-P** | **S**		**RC-Fd**	
Guatemala	**A-b** | **A-r**			CM		
Peru	**A-mw**			**A-m** $^{*)}$ | CM		
Europe and Central Asia						
Greece	**SM-r**		**RC-Fd**		**RC-FD**	
India	**A-m** | **SM-r**	URM	URM | **RC-Fg**	**A-b** $^{*)}$ | **W**		**W**
Iran	**A-b** | **SM-r**	**A-m**	CM | **S**	**S**		
Italy	**SM-r**	**A-m** | **SM-r**	**RC-Fg**			
Kyrgyzstan	**A-m**	URM | **RC-P** $^{*)}$	CM | **RC-P**		**RC-P**	**W**
Pakistan	**A-b** | **SM-r** | **URM** $^{*)}$	**W**	**RC-Fd**			
Romania	**RC-Fg** $^{*)}$	URM	URM | **RC-Fg** $^{*)}$	**RC-Fd** | **RC-P**	**RC-W**	
Slovenia	**SM-r**		URM	CM	**W**	
Russia		URM	URM	**RC-P** | **W**	**W**	
Nepal	**SM-r**		URM | **RC-Fg**			

Legend:

A – adobe; b … block walls; r … rammed earth

m … mud walls; mw … mud walls with timber elements

SM – stone masonry; r … rubble stone

RM – reinforced masonry; CM – confined masonry; URM – unreinforced masonry

RC – reinforced concrete; Fg … frame designed for gravity loads only; Fd … frame designed for seismic effects

P … precast concrete; W … structural wall; FD … dual system

W – timber; S – steel

Some reports show a quite different “most likely vulnerability” (marked with a star *). Such reports should be critically analyzed, and might be revised and/or their background information has to be studied. Especially in cases when the assigned vulnerability was derived from damaging reports of past earthquake. The systematic analysis clearly shows that guidelines have to be introduced for the assignment of the most likely as well as the probable vulnerability classes on the basis of few parameters, whereas those related to the seismic resistant design becomes the highest priority

The international comparison leads to a huge scatter in the vulnerability assignments. Unfortunately, a regional dependency cannot be identified and further studies are necessary.

5.2 Comparative Studies for adjacent countries and the introduction of “regional building types”

It should not be the target to have several reports for the same building type from different neighboring countries if they are comparable concerning work material, structural system and if the seismic exposure is of similar quality (see Figures 1 and 2).

The EMS-98 and its development is a model-like example for a comparative building type evaluation taking the observations of different earthquakes for similar building types into consideration. One of the key elements of the EMS-98 is the Vulnerability Table for the different building types. This table proposes a consistent vulnerability assignment for the different materials as well as structural systems with respect to their seismic resistance and damaging response under seismic action. One class of higher vulnerability indicates one damage grade less for the same seismic action (i.e., intensity).

5.3 Missing reports (of still not covered areas and building types)

The systematic assessment of the WHE database and the use of Geographical Information Systems provide an overview about the reached state of the WHE database. Fig. 2 highlights the regions or countries which should be prioritized in terms of preparing reports on so far missing building types. It also indicates the missing information about the building stock distribution. In further sophistication seismically affected areas could be distinguished into rural and urban areas which allow a further specification/prioritization in terms of dominant building types. In general, the occurrence of damaging earthquakes will sharpen the view on the existing classical building types and those buildings which are growing in number and variety as a consequence of social unbalance – also known as informal construction.

For the purpose of a systematic evaluation and in order to reach completeness concerning the (probably) most affected regions, the right strategy for the further development and maintenance of international building type information system has to be decided which could be linked with the basic document of an updated Macroseismic Scale on the basis of the EMS-98. Key elements for this information system should be the hazard level (see Figures 1 and 2), the level of urbanization and the areal use (i.e., differentiation between rural and urban areas), as well as dominant building types.

5.4 Identification of dominating building types: Case Study Ecuador

As previously mentioned, no reports for Ecuador do exist. The recent 2016 Ecuador earthquake provides very valuable information about the behavior of typical building types in the affected area. But it also shows some crucial differences. The Mw 7.8 earthquake of April 16, 2016 occurred offshore of the north-west area of Ecuador at a depth of 20 km. The epicenter of the earthquake was located near the town Perdenales in the province of Manabi (N 0.353°, W 79.925°).

Table 4 – Building types and structural systems in the epicentral (central coastal) area of the April 2016 EQ

Type	Structural System	Infills	Usage	No. of Stories	%
Reinforced Concrete (R.C.)	**Flat slab**	**hollow blocks**	Residential – Commercial	**1 – 7**	**41 %**
		bricks	Residential – Commercial	2 – 3	20 %
	Frame columns-beams	hollow blocks	Residential – Commercial	-	-
		bricks	Residential – Commercial	1	7 %
Wood	u.c.(under consideration)	hollow blocks	Residential	1 – 2	13 %
	u.c.	bricks			2 %
Bamboo	u.c.	bricks	Residential	1	1 %
Mixed		all types	Residential – Commercial	2	16 %

From the earthquake's intensity (shake)map, which is based upon the EMS-98, it can be concluded that the seismic event was felt in 75 percent of Ecuador's area, where the highest intensity was observed in Perdenales with intensity I (EMS-98) = 9. The central coast of Ecuador and the cities Muisne, Manta, Portoviejo, Jama, Chone, and Guayaquil were more affected by the seismic event with intensities of 8, 7, and 6, respectively. In Quito, the capital of Ecuador, the event was felt with an intensity of 5 (EMS-98). The buildings generally responded well to the seismic action but there was one building which collapsed and two other which had severe damage. The main damage-enforcing factors are related to the informal construction type and the used (weak) materials. The Risk Management Secretary of Ecuador (SGR) was in charge of the assessment of the buildings which are still standing [10].

From the field survey (performed only a few days after the main shock) and the preliminary engineering analysis of building damage [10] it can be concluded that the predominant building type is a R.C. flat-slab system where the floor slabs are resting on a regularly distributed mesh of quite slender columns (see examples in Fig. 4). This type is realized in variations of the infills and the total number of stories. Several damage cases indicate the (well-known) high vulnerability of this (for horizontal action) unfavorable structural system and the impact of infill (out-off plane) failure. No doubt, that a report about this type would automatically cover a large portion of the existing building stock; the final vulnerability assignment can be related to the vulnerability of other building types by comparing the damage statistics at sites of equal intensity.

Fig. 4 – Multistory R.C. buildings with flat slabs that were damaged during the 2016 Ecuador earthquake

6. Conclusions

The comparative study of WHE reports with international damage surveys (e.g. [8, 9]) with respect to the EMS-98 building type classification scheme as well as vulnerability class definitions reveals quite common dominant building types as well as sub-types. While the main building types are defined by the material of the primary elements, sub-types are mainly defined by the vertical load-bearing members like frame, wall and/or level of earthquake resistant design (ERD). The consideration of horizontal load-bearing members as important elements for the integrity of structures (especially non-engineered and masonry building types) are currently not fully applied.

Finally it can be stated that the WHE provides an excellent entry in the assessment of worldwide building stock. The database provides valuable information about the typical building types in worldwide seismically active regions. Unfortunately, some of the given parameters are insufficiently described and need some further justifications (e.g. wall densities). Few of the reports assign unrealistic high or low vulnerability classes compared to the overall (most likely) assignments and therefore should be revised.

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